Indirect Solar Desalination: Value Engineering and Cost Benefit Analysis

Grace Rachid, Mutasem El-Fadel, Mahmoud Al-Hindi, Ibrahim Jamali, Daniel Abdel Nour

***Abstract*—**This study examines the feasibility of indirect solar desalination in oil producing countries in the Middle East and North Africa (MENA) region. It relies on value engineering (VE) and cost-benefit with sensitivity analyses to identify optimal coupling configurations of desalination and solar energy technologies. A comparative return on investment was assessed as a function of water costs for varied plant capacities (25,000 to 75,000 m^3/day), project lifetimes (15 to 25 years), and discount rates (5 to 15%) taking into consideration water and energy subsidies, land cost as well as environmental externalities in the form of carbon credit related to greenhouse gas (GHG) emissions reduction. The results showed reverse osmosis (RO) coupled with photovoltaic technologies (PVs) as the most promising configuration, robust across different prices for Brent oil, discount rates, as well as different project lifetimes. Environmental externalities and subsidies analysis revealed that a 16% reduction in existing subsidy on water tariffs would ensure economic viability. Additionally, while land costs affect investment attractiveness, the viability of RO coupled with PV remains possible for a land purchase cost <\$ 80/m^2 or a lease rate <\$1/m^2/yr. Beyond those rates, further subsidy lifting is required.

***Keywords*—**Solar energy, desalination, value engineering, CBA, carbon credit, subsidies.

I. Introduction

DESALINATION of seawater and inland brackish groundwater is emerging as the main, and at times the only, potential long-term solution to face the challenge of water scarcity [1]. Despite technology advancement, desalination remains energy intensive process [2]-[6], with plants currently operated using fossil fuels, highlighting their un-sustainability and the need for the development of renewable energy sources [1], [7], [8]. Solar energy technologies, among other renewable energy sources, are emerging as a potential sustainable energy source for desalination through coupling with either concentrated solar power technologies (CSPs) or photovoltaic cells (PVs) [1], [9]-[11]. While the number of operational solar energy power plants has been increasing steadily, a limited number of solar powered desalination plants are currently in operation [12]-[16]. According to current literature, the most promising combinations for desalination are reportedly coupling a) PVs with Reverse Osmosis (RO) and Electro-dialysis (ED) systems or b) CSPs with Multi-stage Flash (MSF) and Multi-effect distillation (MED) systems [8], [12], [17], [18]. Conventional RO powered through the electric grid remains economically competitive in comparison to PV powered RO or CSP powered MED configurations with water produced at a cost nearly 2.5 times lower [18], [19]. However, environmental externalities associated with conventional electricity generation may offset the difference [20]. Potential environmental benefits associated with the use of renewable energy are catalyzing ongoing efforts to identify cost effective configurations that couple solar energy sources with desalination technologies [12], [19], [21], [22].

The Gulf countries (Kuwait, Saudi Arabia, Oman, United Arab Emirates, Qatar, Bahrain) continue to host the greatest installed desalination capacity due to water scarcity and abundant fossil fuels, followed by the Southern Mediterranean countries especially in oil producing countries (Algeria, Libya) [8], [23]. With the threat of a water deficit of 150 billion m^3/year in the Middle East and North Africa (MENA) region by 2050 of which 60 billion m^3/year are projected for the Gulf and 90 billion m^3/year for the Southern Mediterranean (including Egypt), the region is becoming increasingly dependent on desalination to supplement scarce water resources [5], [12], [24]. Capitalizing on its endowment with high solar radiation [25], [26], the region has attracted much interest towards coupling desalination with solar energy [5], [8], [9], [12], [17], [18], [25].

This study builds on ongoing efforts by examining the technical and financial aspects of solar driven desalination plants focusing on the feasibility of replacing gas turbine and fuel oil fired plants by CSP or PV plants in oil and gas producing countries in the Gulf Cooperation Council (GCC) and Southern Mediterranean. Water-energy subsidies, environmental externalities expressed as carbon credit related to Greenhouse Gas (GHG) emissions' reduction, and land cost are explored as economic enhancement schemes to allow for a less distorted assessment of the economic feasibility of indirect solar desalination as compared to conventional desalination.

II. Methodology

The methodology used for the economic assessment encompasses the elements of value engineering coupled with cost benefit sensitivity analyses while considering several economic enhancement factors as outlined in the analytical framework in Fig. 1.

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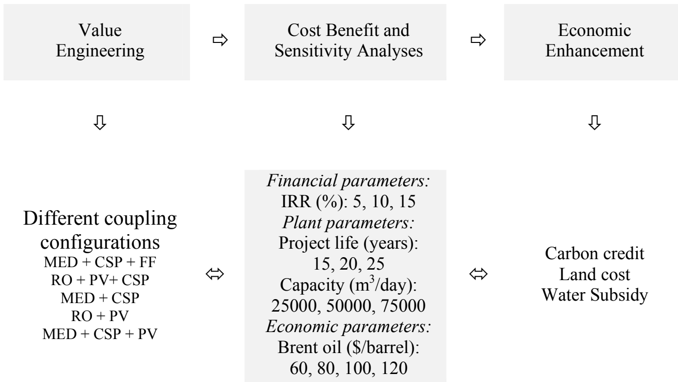

Fig. 1 Methodological Framework; MED: Multi-effect distillation; RO: Reverse Osmosis; CSP: Concentrated solar power; PV: Photovoltaic cells; FF: Fossil Fuel; IRR: Internal Rate of Return

A. Value Engineering

Value Engineering, is a systematic and functionality based approach that can reduce costs while maintaining or improving performance and quality requirements, undertaken here to identify optimal solar driven desalination plant configurations. The evaluation of configurations was based on the geographically varying solar irradiation in kWh/m^2 (which affects the amount of harvested solar power) and the total dissolved solids concentration in mg/l (which affects the energy requirements for the desalination plant). The economic evaluation assumed a combination of funding mechanisms encompassing equity and debt issuance. For a 25-year project lifetime, the public sector was assumed to finance using both equity and debt issuances in addition to offering the land needed for the solar field and desalination plant. For 15 and 20 years project lifetimes, it was assumed that the public and private sectors (developers and plant operators) would share financing of equity and debt, while the public sector would provide the land. The financial evaluation was based on discounted cash flow to calculate a desalinated water cost. By using a Net Present Value (NPV) analysis to assist in the selection of the preferred option(s) among Configurations A through E (see Table I), all cash flows are expressed in value at year (0) and inflation is discarded for all configurations.

TABLE I
CONFIGURATIONS OF SEAWATER DESALINATION POWERED BY SOLAR ENERGY

Configuration	Parameters
A	MED powered by parabolic troughs and secondary power through a fossil fuel fired cycle
B	RO with 67% / 33% ratio of needed energy collected by parabolic troughs to PVs
C	MED primary and secondary power by parabolic troughs
D	RO with 100% of required energy by PVs
E	MED powered by parabolic troughs and secondary power through PVs

The internal rate of return (IRR) and discount rate are based on assumptions respecting the guide to CBA of investment projects where interest rates and project life duration have been benchmarked in recently reported literature [23], [24], [27]-[31]. The total water cost (*TWC*) of solar desalination, expressed in terms of the capital, spare parts and supplies, operation and maintenance, secondary energy pumping, as well as indirect costs, is calculated by (1) in the Appendix [32]. The corresponding total financed capital cost (T_{FCC}) can be determined using (2) in the Appendix. While the land is assumed to be made available through the government or funding agency and hence not considered in the VE analysis, its corresponding cost was tested in the economic enhancement analysis as outlined below. Finally, cost calculations were conducted with annuity financing factors as determined using (3) and (4) in the Appendix [33].

B. Cost Benefit (CBA) and Sensitivity Analysis

The CBA was applied to two optimal configurations for solar-powered seawater desalination from the potential five configurations where positive factors or benefits and negative factors or costs were quantified. The base scenario consists of a 25 year planning horizon and 5% IRR which was considered as the net minimum acceptable rate of return on a new investment. Wider forecast scenarios were then examined by using a planning horizon of 20 and 15 years with 10% and 15% IRR and Brent Oil prices of $60, $80, $100 and $120 per barrel. The annual savings resulting from the investment in solar energy powered desalination plants were evaluated based on 2010 market values (See (5) in the Appendix). The NPV of the annual energy saved by shifting to solar powered desalination plants was then calculated by (6) in the Appendix. Capital costs for solar power (TCC), obtained using (7) in the Appendix, are subtracted from twice the annual savings in the considered configurations. This would yield overall benefits for oil and gas generating countries due to the fact that fuel oil, currently used for desalination, will be saved for other purposes or sold. Due to the declining trend in energy consumption, capital, operational and maintenance costs that are attributable to technological advancement, the attractiveness of shifting to solar powered desalination plants is further analyzed at the long term for the year 2020 using the same financial parameters.

C. Economic Enhancement Schemes

Similar to fossil fueled desalination, solar-powered desalination, albeit often presented as carbon-free, involves environmental externalities. Considering a life cycle analysis (LCA), greenhouse gases (GHGs) emitted during the extraction, processing, and disposal of associated manufacturing material can be used as a representative surrogate for these externalities [34], [35]. Water and electricity subsidies are common in the GCC countries in particular; hence, the shift from fossil fuel to solar-powered desalination is expected to be slow as solar energy prices need to be, at the least, on par with subsidized fuel generated electricity. In order to overcome this caveat and provide a realistic scenario for solar powered desalination, two schemes were examined (both including environmental externalities and land cost). The first scheme discussed in the economic enhancement analysis involves the progressive lifting of water/electricity subsidies as outlined in Table II with a 5% discount factor over a 25-year project lifetime, while operating Configuration D. Here, the income from reducing water subsidies combined with savings associated with environmental externalities can be estimated using (8) in the Appendix. The NPV of the income is then calculated in five stages for a project lifetime of 25 years by (9) in the Appendix. Concurrently, capital costs of the RO plant, photovoltaic installation, transformers, inverters and other variable costs are expressed via(10) in the Appendix. The deficit between capital costs and income NPV will continue to be subsidized by the government unless tariff charges are increased.

The second scheme consists of a modified Configuration A where the MED plant initially coupled with CSP only is now arranged in a co-generation mode with a power plant that shares solar heat from the CSP. The secondary energy, which was originally generated from fossil fuels, will now be generated from the steam turbine. The overall capacity of the co-generation power plant is 25MW (600,000 kWh/d) and operates all day (i.e. all 24 hours) to provide daily energy requirements for desalination, estimated at 312,500 kWh/d, and about 12MW worth of electricity to end users. The CSP field would collect the power plant heat requirements over 10 hours, and hence have a capacity of 60,000 kW/hr. Capital costs of the MED and CSP plants were calculated based on previously calculated TWCs as shown in (11) in the Appendix. Revenues from water tariffs were calculated previously in the first proposed enhancement scheme, whereas tariffs from electricity were calculated similarly using (12) in the Appendix. The deficit between the capital costs and income NPV can be recovered through subsidies or increased tariffs (electricity and/or water). On the other hand, the land area needed for the solar desalination plant was calculated by (13) in the Appendix for all configurations based on unit surface requirements for power generation (ha/MW) using PV panels or parabolic troughs [27], [30].

TABLE II
REDUCTION PLAN OF PUBLIC SUBSIDY AND DISCOUNT RATE MULTIPLIER

Years	Total Water ($/m^3)	Total Electricity ($/kWh)	$D_{RM(25)}$
1-5	0.6	0.09	4.33
6-10	0.7	0.1	3.39
11-15	0.8	0.11	2.66
16-20	0.9	0.12	2.08
21-25	1.0	0.13	1.63

III. RESULTS AND DISCUSSION

A. Value Engineering

Overall, the RO based solar desalination combinations (configurations B & D) resulted in a lower TWC when compared to MED based combinations (configurations A, C & E). All configurations resulted in lower TWCs in GCC countries in comparison to Southern Mediterranean countries irrespective of the project lifetime and / or the IRR reflecting the impact of the discount factor selection on TWC calculations. Further, combinations that are ranked better for public investment (25 years) are also ranked better for public/private investment (20 or 15 years), given that the same discount factor is used for GCC and Mediterranean countries. Fig. 2 illustrates the TWC for all plant capacities.

Configurations B and D yield similar TWC for all project durations and discount rates with a slight advantage for configuration D - which is highly plausible for public investment since the use of a smart grid is almost a certainty. Configurations A, C and E result in comparable TWC for various discount rates and project durations. Note that for configuration A, actual unit costs for the secondary power were used at market values and did not account for subsidies that are common in oil producing countries of the GCC and MENA regions. If subsidized electricity is considered then configuration A may be competitive with B and D. Accordingly, it may be concluded that configurations D (RO powered by photovoltaic and smart grid) and A (MED powered by parabolic troughs for primary and secondary energy through a fuel fired power cycle) are the most optimal configurations due to their relatively lower TWC.

In an effort to benchmark results**,** the estimated TWC of \$3/m³ (25,000 m^3/day MED plant) is comparable to the value reported in [5]; similarly, the TWC of \$2.21/m³ (25,000 m^3/day RO plant) is comparable to the value reported in[29] for similar size plants. However, these TWCs are higher than those reported for conventionally powered desalination plants \$3.00/m^3 versus \$ 0.52 – 1.95/m^3 for MED and \$ 2.21/m^3 versus \$ 0.48 – 1.62/m^3 for RO in [3], [8], [20]. This difference is primarily due to the transition costs to solar power inherent in the TWC of the indirect solar desalination configurations.

A. Cost Benefit and Sensitivity Analysis

Fig. 3 presents the corresponding NPV of oil/gas savings for the two optimal configurations A & D based on 2010 market values. Different scenarios for the price of Brent oil are examined to assess the sensitivity of the results. The cost of gasoil per kwh needed as secondary power for auxiliary operations was estimated at \$0.094, \$0.125, \$0.156 &\$0.188 for \$60, \$80, \$100&\$120 Brent barrel, respectively. The secondary power cost for auxiliary operations was calculated using (14) and (15) in the Appendix.

Subtracting capital costs from double the benefits demonstrates that investing in solar powered desalination plants in 2010 for configurations A and D is most attractive (positive difference) for public investment (25 years project lifetime and 5% discount factor and all Brent oil prices). The findings indicate that, for any given discount rate, the net present value for the investment is larger for GCC countries than it is for Mediterranean countries. This, in turn, is intuitive as the GCC countries are oil rich, while Mediterranean countries are not, and can therefore employ oil more heavily.

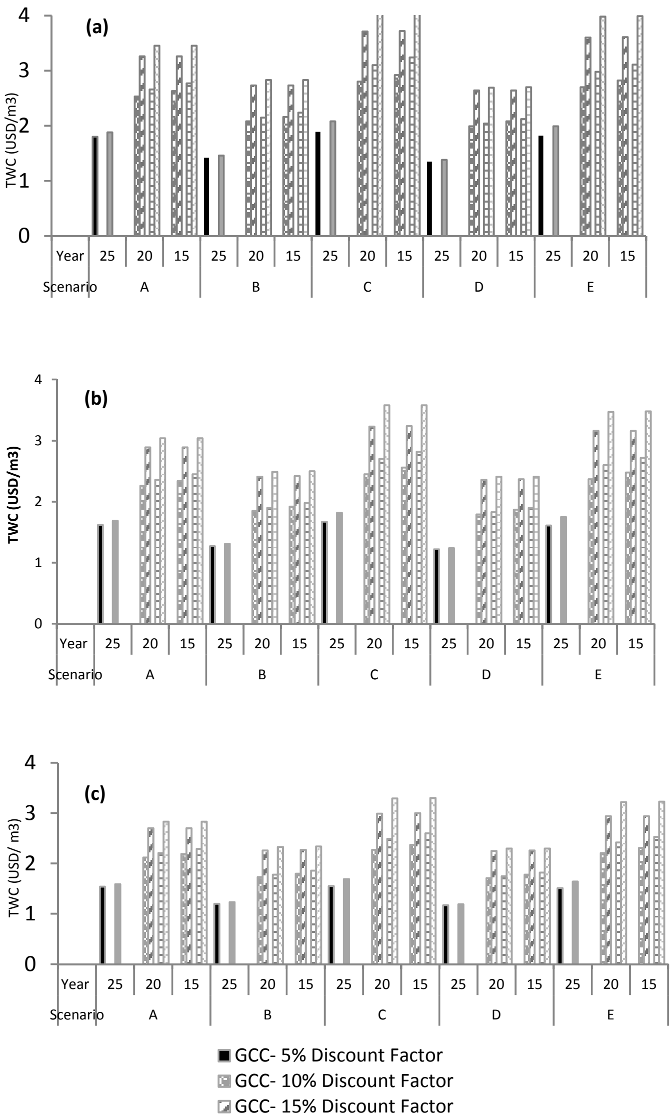

Fig. 2 Water Costs for configurations A through E for a Brent Oil price of 100$/barrel for plant capacities of (a) 25,000 m^3/day; (b) 50,000 m^3/day and (c) 75,000 m^3/day

Based on 2020 market values, the target solar capital costs for configuration A showed a drop of approximately 32% in comparison to 2010 values whereas a 33% drop was observed for configuration D for all project lifetime and IRR. With this energy consumption reduction, a 25% and 15% drop in annual benefits were observed in the year 2020 for configurations A and D respectively, with configuration A, which is more energy intensive, showing a higher drop. On the other hand, the overall decrease in annual benefits yielded a 33% NPV decrease for configuration A and a 15% decrease for configuration D. Subtracting the capital costs from double the benefits calculated for 2020 demonstrates that investing in solar powered desalination plants was most attractive (positive difference) for public investment (25 years project lifetime and 5% discount factor and all Brent oil prices). While both configurations A and D showed improvements in the CBA results by year 2020, configuration D is the most promising across all project lifetimes and discount rates.

B. Economic Enhancement Schemes

In the first economic enhancement scheme, income accruing from the reduction of water subsidies was calculated at \$73M while the benefits from offsetting carbon credits of averted GHG were estimated at \$4 million. Accordingly, the NPV of the collected income was then calculated for the project lifetime of 25 years as \$205 million. The capital costs of the RO plant, photovoltaic installation, transformers, inverters and other variable costs to be paid by the PPP were estimated at \$316 million (excluding the opportunity cost of land, estimated at \$391 million for a land unit cost of \$80/m^2 and \$550 million for a land cost of \$250/m^2). The deficit between the capital costs and income NPV is approximately \$111 million (excluding land cost) and \$186 million and \$345 million for the two proposed land unit costs. In order for the project to break even, the proposed water tariffs would be reduced by 16% while excluding land cost; but would be increased by 7% for a land unit cost of \$80/m2 over the first 5 years based on TWC calculated for configuration D (TWC = \$1.226/m^3) during the value engineering assessment.

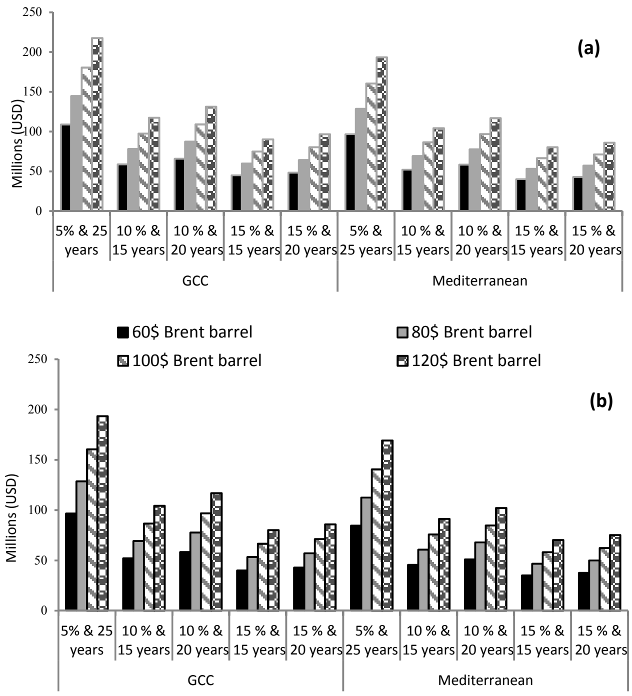

Fig. 3 Net present value of oil/gas savings or selling “saved” oil/gas in 2010 for (a) Configuration A and (b) Configuration D

In the second enhancement scheme, the capital costs of the MED, CSP and power plants were calculated with the environmental externality cost incurred by GHG emissions, which amounted to \$701M excluding land cost and \$821M for a land unit cost of \$80/m^2 and \$1.076M for a land cost of \$250/m^2. The income accruing to the Public sector-Private sector consortium from water and electricity tariffs as well as from the decline in GHG emissions was estimated at $73 million, $58million and $10 million, respectively. This amounts to $141 million with a total NPV of $383 million. The total electricity cost generated was calculated as $0.18/kWh. Clearly, electricity tariff rates are 50% cheaper than the actual production rates. This yields a considerable deficit between capital costs and income NPV estimated at $318M excluding land cost, $438M for a land cost of $\$80/m^2$ and $693M for a land cost of $\$250/m^2$. In order to breakeven, the proposed electricity tariff charges were kept as originally proposed and water tariff charges were increased by 13% while excluding land cost and 42% for a land unit cost of $\$80/m^2$ for the first 5 years based on TWC calculated for configuration A (TWC = $ $1.62/m^3$) during the value engineering assessment.

Currently published water and electricity tariff rates of the different utilities vary significantly among countries in the GCC region where the average actual water tariff is $\$1.03/m^3$ and the average electricity tariff is $0.03/kWh. These tariffs are already subsidized but the level of subsidies varies across countries. Accordingly, it is apparent that the proposed water costs in the first enhancement scheme is equal to the actual water cost in the GCC over the first five years of the project lifetime whereas the proposed water cost in the second enhancement scheme is 78% more expensive to cover for the highly subsidized electricity costs in the GCC. The balance to breakeven between water costs and electricity costs can be modified to suit specific utilities and countries requirements. The changes to water and electricity costs required for the projects to break even can be tailored to specificities of each country utilities' sector.

Table III summarizes the economics of optimal indirect solar desalination. It shows that the cost of indirect solar desalination through coupling CSPs with MED remains higher than conventional desalination under different environmental externalities and land cost considerations. The cost associated with different options will decrease if land for solar farms was offered. However, the analysis shows that coupling PVs with RO is competitive under all considerations except when land cost exceeds $\$80/m^2$.

IV. Conclusion

Value engineering and cost benefit analysis revealed a preference for RO seawater indirect solar desalination over MED for both GCC and Mediterranean countries. The estimated total water costs under different configurations of indirect solar desalination ranged between $1.17 and $\$3.3/m^3$ where RO desalination powered by PVs and smart grid (configuration D) and MED desalination powered by parabolic troughs (configuration A) were the most optimal configurations.

Environmental externalities and subsidies analysis revealed that configuration D could achieve a 16% reduction in subsidy ensuring economic attractiveness. Although accounting for land costs affects investment attractiveness, it remains viable at land cost of $ $40/m^2$ and at a lease rate of $\$1/m^2/yr$ for configuration D with corresponding 3-8% reduction in tariffs. Accordingly, indirect solar seawater desalination is a promising alternative for oil and gas producing GCC and Southern Mediterranean countries that can achieve double benefits by saving and selling the saved oil and gas.

TABLE III
SUMMARY OF ECONOMICS FOR WATER COST UNDER DIFFERENT CONSIDERATIONS IN GCC

Conditions			Configuration A: CSPs + MED	Configuration D: PVs + RO
Environmental externalities	Land Cost ($\$/m^2$)	Land Lease ($\$/m^2$/year)	Total WaterCost ($\$/m^3$)	
-	-	-	1.62	1.22
√	-	-	2.72	1.23
√	√ (80)	-	3.19	1.52
√	√ (250)	-	4.18	2.14
√	√ (40)	-	2.95	1.37
√	-	√ (1)	2.89	1.32
-	-	√ (1)	2.88	1.31

√: indicates the inclusion of environmental externalities or/and land cost. The number in () indicates land cost.

(Capacity: 50,000 m^3/day, Lifetime: 25 years, Discount Factor: 5%, Price:$100/barrel)

Appendix

TABLE IV
LIST OF EQUATIONS USED IN CALCULATIONS

Equations	***Eq. No.***
$TWC = D_{SDCC} + D_{SPCC} + D_{OMC} + S_{OMC(CSP)} + I_C + PV_{OMC}$ $D_{SDCC} = NYCR \div Y = (T_{FCC} \div D_{RM}) \div (DPC \times 365)$ $S_{OMC(CSP)} = S_{OMUC} \times E_d$ $S_{EPC} = S_{EPUC} \times U_{GC}$ $I_C = \frac{25\% T_{NCC}}{Y \times D_{RM}}$ $PV_{OMC} = 0.445\% \times PV_{CC} \times \frac{P}{Y}$	(1)
$T_{FCC} = T_{FE} + T_{FD} = \left(T_{NCC} \times {}^{E}/_{D} \times F\right) + (T_{NCC} \times (1 - {}^{E}/_{D}) \times F$ $T_{NCC} = T_{DCC} + T_{SCC} + T_{NTIC} + SGC$ $= (DPC \times t_{dcc}) + (t_{SCC} \times P) + T_{NTIC} + SGC + \left\{AGE \times {}^{AM_{CO2}}/_{10^6} \times D_{RM}\right\}$ $= (DPC \times t_{dcc}) + (t_{SCC} \times P) + T_{NTIC} + SGC + \left\{AGE \times {}^{LGE \times T_{DE} \times 356}/_{10^6} \times D_{RM}\right\}$ $P = T_{DE} \div t = DRC \times E_d \div t$ $T_{NTIC} = GTI + TTC = GTI + \left(\frac{P}{10} \times UTC\right)$	(2)
$A = E \times K = E \times \frac{IR \times (1 + IR)^n}{(1 - IR)^n - 1}$	(3)
$I_F = A \times n = E \times K \times n = E \times F$	(4)
$Y_s = T_{DE} \times U_{GC} \times 365 = DPC \times E_d \times 365$	(5)
$PV = \sum_{i=1}^{n} \frac{A_{CF}}{(1 + IRR)^i} = A_{CF} \times \sum_{i=1}^{n} \frac{1}{(1 + IRR)^i} = A_{CF} \times D_{RM}$	(6)
$TCC = T_{SCC} \times I_C + S_{OMC} + T_{NTIC}$	(7)
$A_{INC(W\&GHG)} = Y \times TWC = (DPC \times 365) \times TWC + AGE \times {}^{AM_{CO2}}/_{10^6}$ $= (DPC \times 365) \times TWC + AGE \times {}^{LGE \times T_{DE} \times 365}/_{10^6}$	(8)
$NPV = \sum_{i=1}^{n} \frac{A_{INC}}{(1 + IRR)^i} = A_{INC} \times \sum_{i=1}^{n} \frac{1}{(1 + IRR)^i} = A_{INC} \times D_{RM\,(\frac{5}{25})}$	(9)
$CC_{configuration\ D} = TWC_{Configuration\ D} \times Y \times D_{RM\ (25,5\%)}$	(10)
$CC_{Scenario\ A} = TWC_{Scenario\ A} \times Y \times D_{RM(25,5\%)}$	(11)
$A_{INC\ (electricity)} = Y_{SE} \times TEC = (SE \times 365) \times TEC$	(12)
$LR = LR_U \times P_{MW} = LR_U \times P \times 1 \times 100$	(13)
$G_{HC} = X \times a \div 24$	(14)
$U_{GC} = G_{HC} \div E_E = G_{HC} \div (435 \times 1000 \times 1hr)$	(15)

NOMENCLATURE

A	Annuity (equal cash flows) ($)
A_{CF}	Annual cash flow ($/year)
$A_{INC(electricity)}$	Annual Income from electricity end users ($/year)
$A_{INC(water\&GHG)}$	Annual Income from water end users and mitigated GHG ($/year)
AM_{CO2}	Annual mass of CO_2 to be mitigated (g CO_2/year)
$CC_{ConfigurationA}$	Capital costs to be paid by PPP (Scenario A) ($)
$CC_{ConfigurationD}$	Capital costs to be paid by PPP (Scenario D)($)
D_{TIC}	Desalination capital costs from transformers and inverters ($/m^3)
D_{OMC}	Desalination operation and maintenance costs ($/m^3)
DPC	Desalination plant capacity (m^3/d)
D_{SPCC}	Desalination spare parts and chemical costs ($/m^3)
D_{SDCC}	Direct solar desalination capital cost ($/m^3)
D_{RM}	Discount rate multiplier
$D_{RM(25)}$	Discount rate multiplier for 5 years increments over 25 years
$D_{RM\ (25\ years,\ 5\%)}$	Discount rate multiplier for 25 yrs& 5%
E	Initial Investment (equity / debt)
E_d	Desalination energy requirements (kWh/m^3)
E_E	Effective energy produced by a 435 MW plant (kWh)
E/D	Equity to Debt ratio (80/20 for 25 years and 75/25 for 20 and 15 years)
F	Financing Factor
G_{DC}	Gasoil daily cost ($/d)
G_{HC}	Gasoil hourly cost ($/h)
GTI	Grid Tie In Inverter, 600V and 36 MW
GW	Gigawatt
ha/MW	Hectare per megawatt
I_F	Initial Investment including financing($)
IR	Interest Rate
IRR	Internal rate of return (discount rate)
K	Summation Term
LR	Land Requirements (ha)
LR_U	Unit Land Requirements rate (ha/ MW)
NPV	Net present value ($)
NYCR	Net yearly cash receipt ($/year)
n	No. of years
PV_{CC}	Photovoltaics capital cost ($/kW)
PV_{OMC}	Photovoltaics operation & maintenance costs ($/m^3)
P_{MW}	Power Generated (MW)
P	Power generated (solar energy can be collected in a period t (kW)
S_{EPC}	Secondary energy pumping costs ($/m^3)
S_{EPUC}	Secondary energy for pumping requirements unit cost (kWh / m^3)
S_{OMC}	Solar operation and maintenance costs ($/m^3)
$S_{OMC(CSP)}$	Solar operation and maintenance costs for CSP based scenarios($/m^3)
S_{OMCY}	Annual solar operation and maintenance costs ($/year)
S_{OMUC}	Solar operation and maintenance unit costs ($/kWh)
SGC	Steam Generation Cost ($)
SE	Surplus of Energy (kWh/day)
SPT	Single Phase Transformer from 600V to 220V
t_{dcc}	Target desalination capital cost ($/m^3/d)
t_{scc}	Target solar capital cost ($/kW)
T	Ten hours for parabolic troughs and eight hours for photovoltaics
T_{DE}	Total daily energy needed (kWh/d)
T_{DCC}	Total desalination capital cost ($)
T_{FCC}	Total financed capital cost ($)
T_{FD}	Total financed debt ($
T_{FE}	Total financed equity ($)
T_{NCC}	Total net capital cost ($)
T_{NTIC}	Total net transformer & inverter capital cost ($)
T_{SCC}	Total solar capital cost ($)
TCC	Total Capital Costs (solar only) ($)
TEC	Total Electricity cost ($/kWh)
TTC	Total Transformer Cost ($)
TWC	Total water cost ($/m3)
$TWC_{Configuration\ A}$	Total water cost (Scenario A) ($/m^3)
$TWC_{Configuration\ D}$	Total water cost (Scenario D) ($/m^3)
U_{GC}	Used gasoil cost to generate 1kWh of auxiliary energy ($/kWh)
UTC	Unit Transformer Cost ($)
Y	Annual demand of desalinated water (m3/year)
Ys	Annual savings in avoiding burning fossil fuels ($)
YSE	Annual surplus energy (kWh/year)

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