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Techno-Economic Assessment of Implementing Concentrated Solar Power Technology in the Palestinian Territories

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Abstract— This paper investigates - technically and economically - the possibility of implementing the concentrated solar power (CSP) technology in the Palestinian Territories (PT) to fulfill their escalating electricity demand. For this purpose, five PT sites, namely Jericho, Nablus, Hebron, Ramallah, and Gaza Strip, are selected to investigate their suitability for installing a 1 MW CSP plant with parabolic trough collectors. The obtained results show that all of the investigated sites – except for Gaza Strip - are appropriate candidates for implementing the proposed CSP plant. With a levelized cost of energy (LCOE) reaching 0.164 US$/kWh (without storage) and 0.153 US$/kWh (with 3 hours of storage) in addition to a simple payback period (SPP) - of applying the CSP plant – reaching 7.5 years (without storage) and 7.6 years (with 3 hours of storage), Ramallah proves to be the most suitable site for installing the proposed plant, followed by Hebron, Nablus and Jericho. On the contrary, Gaza Strip - with LCOE of 0.496 US$/kWh (without storage) and 0.468 US$/kWh (with 3 hours of storage) besides a SPP of 20 years (without storage) and 27 years (with 3 hours of storage) – demonstrate its infeasibility for employing the proposed CSP plant. These facts are also supported by the results of the following investigated meters: the net present value, the annual life cycle savings, and the benefit-cost ratio. The results of the sensitivity analysis disclose that the solar farm's cost and produced electricity tariff are the prevailing factors in defining the feasibility of applying the CSP technology in PT.

Keywords— The Palestinian Territories; Concentrated solar power; Parabolic trough collectors, Electricity generation; Techno-economic analysis; Sensitivity analysis.

1. INTRODUCTION

The world interest in alternative renewable energy sources (RES) has increased due to the rising in energy consumption, environmental issues, and also the predicted depletion of conventional energy sources. The concentrated solar power (CSP) is a technology that utilizes direct solar energy through concentrating mirrors to gather the sunlight as heat. This heat raises the temperature of the heat transfer fluid (HTF). A conventional thermal power block absorbs the heat from the HTF and drives a steam engine to generate electricity [1].

Palestinian Territories (PT) buy all its needs of fossil fuels, and imports about 90% of its electricity [2-4]. Electrical energy represents about 30% of the total energy consumption in the PT. Gaza power plant with 140 MW is the only conventional power station that exists in PT. With an annual growth of 7% in electricity consumption [2, 3], the generated electrical energy is insufficient to cover the demands of the local consumers.

Utilizing renewable energy (RE) for electricity generation is the driving force behind the Palestinian RE strategy. It aims to generate 240 GWh of electricity - representing about 10.0% of electrical energy demand - from RE by 2022 [5]. Bioenergy is utilized for cooking and heating in rural areas. Wind energy might be feasible in some locations but no sufficient data are available. Utilization of biogas is still under investigation in PT [6, 7]. The solar thermal applications in PT are mainly for water heating, in addition to crop and vegetable drying [6].

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On the other hand, PT is qualified for electricity generation using photovoltaic (PV) and CSP technology as the global solar radiation is around 5.46 kWh/m^2/day in addition to the high potential of beam solar radiation [4, 6].

Many researchers have investigated the possibility of employing CSP systems for electricity generation. A study for applying a 50 MWe CSP in a site in Romania with 1875 kWh/m^2 total direct normal incidence (DNI) was implemented [8]. A feasibility study of applying 50 MWe using parabolic trough CSP in Saudi Arabia was conducted. It indicated that the levelized cost of energy (LCOE) is 0.107 USD/kWh [9]. Applying parabolic trough CSP was investigated in Algeria. The total DNI was found to range from 2100 to 2700 kWh/m^2. The generated power ranged from 63 to 107 MWh [10, 11]. A feasibility study of applying a 30 MWe parabolic trough CSP in a site in Pakistan was performed. The total annual DNI is 2057.6 kWh/m^2 and the LCOE was found to be 0.15 USD/kWh [1]. The feasibility of installing a 1 MW parabolic trough CSP in Suez – having a total annual DNI of 2190 kWh/m^2 - was performed. The LCOE was 0.25 USD/kWh [12].

For the PT, studying the possibility of utilizing the CSP technology is not reported. Therefore, this paper investigates technically and economically the possibility of implementing a 1 MW CSP palnt – with parabolic trough collectors (PTC) - in five sites that cover all the PT (namely, Jericho, Hebron, Nablus, Ramallah, and Gaza Strip). PTC is utilized - in this study - because it is technologically matured and has a lot of successful stories [6].

2. RESEARCH METHODOLOGY

To perform the techno-economic analysis for implementing CSP plant in the PT, the following algorithm is followed: studying the geographical features of the PT; collecting detailed data about the potential sites; defining a criteria for selecting proper sites for implementing the CSP plant; and finally performing the techno-economic and feasibility analysis.

3. ASSESSMENT ANALYSIS

3.1. Technical Assessment

PT - with an estimated area of 6220 km^2 - are located between the Mediterranean Sea and the Jordan River (at 31°– 33° latitudes and 34°-36° longitudes) and they are divided geographically into the West Bank (which encompasses Jericho, Hebron, Nablus and Ramallah governorates) in addition to Gaza Strip.

3.1.1. The Land Cover, Use, and Slope

The land availability to build a large CSP plant is significant as 1 MW plant requires about 20000-25000 m^2 [16]. The exclusion criterion is used to choose a suitable site for installing CSP plants [17]. It dictates that the populated areas, ground structure, water sources, high land slope, dunes, protected areas, forests, mountains, agricultural areas are all to be excluded. Slope inclination is another factor that affects the feasibility of a CSP plant and its cost. PTCs require flat areas with 1-2% slope [13, 14].

After applying the exclusion criteria for built-up areas, heritage, and agriculture [4, 18-20], five sites - in the five PT governorates - were selected. They are shown in Table 1 with their land slope.

Table 1. The selected sites with location coordinates and slopes.

Governorate/site	Coordinates		Slope [%]
	Latitude	longitude	
Jericho/ Jericho	31° 44' 47.72"	35° 29' 13.43"	1.6
Hebron/ East Yata	31° 26' 22.26"	35° 06' 48.50"	2.0
Nablus/ Nablus	32° 12' 09.73"	35° 18' 54.83"	2.0
Ramallah/ South East Ramun	31° 55' 29.21"	35° 19' 08.01"	2.0
Gaza Strip/ Northeast Jarara	31° 22' 08.26"	34° 21' 53.21"	1.8

3.1.2. Solar Radiation Potential

The CSP technology requires a DNI ranging from 1900 to 2100 kWh/m^2/year to give attractive LCOE. Such DNI values are recorded in so-called Sun Belt areas that include the PT and located between latitudes 15° to 40° on both hemispheres [13]. To obtain DNI data, the satellite data are used [14]. They are based on a solar geographic information system (GIS), which is an estimating model with a high-resolution global database of DNI and meteorological data. It is computed and updated on a daily bases [15]. From the data, the annual average DNI potential for the PT is 2000 kWh/m^2, which indicates the feasibility of implementing CSP plants in the PT [14]. This is also evident from Table 2 that shows the DNI potential for each of the PT's selected sites.

Table 2. DNI potential for the selected sites.

Governorate/ site	DNI potential [kWh/m^2/year]
Jericho/ Jericho	2071
Hebron/ East Yata	2286
Nablus/ Nablus	2094
Ramallah/ South East Ramun	2187
Gaza Strip/ Northeast Jarara	2167

3.1.3. Water Availability

For wet cooling, the PTC CSP systems technology requires about 3 m^3 of water per 1 MWh, while for dry cooling it requires about 0.3 m^3 of water per 1 MWh [21]. Luckily, all the selected sites can afford this requirement based on data collected from the Ministry of Local Government and National Spatial Plan [4]. Furthermore, they are close to water resources and near water connection grids.

3.1.4. Transportation Grids

To reduce the investment costs, the suggested CSP plant is required to be close to transportation grids [17, 21]. Fortunately, all the suggested sites are located within the transportation grids.

3.1.5. Power Transmission Lines

To reduce the cost of the infrastructure, the CSP plant is recommended to be as close as possible to the transmission lines [21]. Since the power transmission lines extend to all regions of the PT due to their small area, all of the selected sites are located close to transmission lines.

3.1.6. Other Meteorological Conditions

Table 3 shows the average annual wind speed, temperature, and relative humidity for the chosen sites. The structure of PTC endures wind speeds of 33.3 to 36.1 m/s, which never occurred in PT as shown in Table 3. For wet cooling, the performance of the condensers grows with declining wet-bulb temperature. It is a function of ambient temperature and relative humidity. The ambient temperature and relative humidity of the selected regions are analyzed from 1994 to 2013 as shown in Table 3 [4]. They are acceptable and don't affect the performance of the CSP plant. Further analysis on this subject is available in [4].

Table 3. Average annual wind speed, temperature and relative humidity for the selected sites.

Governorate	Average annual wind speed [m/s]	Average annual ambient temperature [°C]	Average annual relative humidity [%]
Jericho	1.50	22.8	45.5
Hebron	2.40	17.0	68.0
Nablus	1.76	17.9	68.2
Ramallah	2.84	17.0	70.5
Gaza Strip	2.80	20.5	64.6

3.2. Economic Analysis

From the above discussion, all types of CSP technology can be implemented in the PT. However, PTC is used since it is commercially available and technically proven. To investigate the feasibility of implementing the PTC CSP plant in PT, a 1 MW plant is proposed. This is to evade the restriction in land availability for some sites like Gaza Strip. Table 4 demonstrates the specifications of the plant.

Table 4. Technical specifications for the PTC system plant.

Specification	Value
Capacity	1 MW
Capacity factor	36 % (no storage) 50 % (3 h of storage)
Annual electricity generation	3154 MWh (no storage) 4380 MWh (3 h of storage)
Destination of generated power	To grid

The levelized cost of energy (LCOE) is the most frequently utilized parameter for the feasibility analysis of CSP plants. It is remarkably influenced by the employed inputs and assumptions, and it is estimated as [22]:

$$LCOE_{csp} = \left[\frac{C_{csp}CRF + \xi C_{csp}}{AEG_{csp}}\right] \tag{1}$$

where , C_{csp} signifies the capital cost, ξ characterizes the annual repair and maintenance factor, ξC_{csp} represents the annual operation and maintenance (O&M) cost, AEG_{CSP} is the annual electricity generation by the CSP plant, which is estimated as following [4, 23]:

$$AEG_{csp} = (365 * 24)CF_{csp}P_{csp} \tag{2}$$

where P_{csp} characterizes the capacity of the plant, CF_{csp} characterizes the capacity factor while *CRF* - appearing in Eq. (1) - signifies the capital recovery factor, which is found as following:

$$CRF = \frac{d(1+d)^{t_{csp}}}{(1+d)^{t_{csp}} - 1} \tag{3}$$

where d is the interest rate and t_{csp} is the lifetime.

In order to estimate the numbers of years required for an investment to be paid back, simple payback period (SPP) is used and it is estimated as:

$$\mathrm{SPP} = \frac{\text{Capital Investment}}{\text{Net Income per year}} \tag{4}$$

The discount payback period (DPP) discounts each of the estimated cash flows and then determines the payback period from those discounted flows. It is estimated as:

$$\mathrm{DPP_{csp}} = \left[\frac{\ln(\mathrm{B_i} - \mathrm{C_i}) - \ln\{(\mathrm{B_i} - \mathrm{C_i}) - \mathrm{dC_{csp}}\}}{\ln(1+\mathrm{d})}\right] \tag{5}$$

where $\mathrm{B_i}$ signifies the annual benefit accumulated to the investor by selling the electricity generated by the plant , $\mathrm{C_i}$ (= $\xi \mathrm{C_{csp}}$) is the annual O&M cost of the CSP project. $\mathrm{B_i}$ can be assessed as:

$$\mathrm{B_i} = 8760\mathrm{CF_{csp}}\mathrm{P_{csp}}\mathrm{p_e} \tag{6}$$

where p_e is the purchase price of electricity generated by the plant.

Besides the payback period, the equity payback period indicator is used. It constitutes the period of time that takes a certain project to recoup its own initial investment (equity) out of the project cash flows generated. This makes it a better time indicator of the project merits than the SPP.

The net Benefit-Cost (B-C) ratio is the ratio of the net benefits to costs of the project. If (B-C) ratio is greater than one, then the project is viable. It is assessed using the following equation:

$$\left(\frac{\mathrm{B}}{\mathrm{C}}\right)_{\mathrm{csp}} = \left(\frac{1}{\mathrm{C_{csp}}}\right)\left[\sum_{\mathrm{i}}^{\mathrm{t_{csp}}}\left(\frac{(\mathrm{B_i} - \mathrm{C_i})}{(1+\mathrm{d})^{\mathrm{i}}}\right)\right] \tag{7}$$

The net present value (NPV) indicates if the projected earnings generated by an investment or a project exceed the anticipated costs or not. So generally, an investment with a positive NPV will be a profitable one, while an investment with a negative NPV will result in a net loss. The NPV is estimated as:

$$NPV_{csp} = \left[\sum_{i}^{t_{csp}} \left(\frac{(B_i - C_i)}{(1+d)^i}\right)\right] - C_{csp} \quad (8)$$

The capital cost of the PTC CSP system with and without storage is normally given in a range and this investigation is based on the most frequent price. The prices included in this investigation are normally based on a study implemented by the author [6] and other researches [24]. The income tax for RE projects in the PT is zero. The annual repair and maintenance cost is given from references [17, 25]. The size of the storage system is assumed for 3 hours. This is because the available area is limited in the PT and increasing the size of the storage system requires a further increase in the collector's area. Table 5 shows the input parameters for the economic analysis.

Table 5. Input parameters for economic analysis.

Parameters	Symbol	Value
The capital cost	C_{csp}	4500 $/kW (no-storage) 6000 $/kW (3 hours-storage)
Annual repair and maintenance cost as a fraction	ξ	0.02
Discount rate	D	0.10
Useful lifetime	T_{csp}	30 years
Capital recovery factor	CRF	0.1060
Produced electricity tariff	-	0.1750 $/kWh

To achieve a more professional and comprehensive financial analysis, RETScreen software is used [26]. Fig. 1 illustrates the NPV obtained by implementing the proposed 1 MW CSP plant based on PTC technology with and without storage in the selected PT sites. It shows that Ramallah has the best NPV while Jericho has the lowest one. Contrary to other sites, Gaza Strip shows a negative NPV indicating that implementing the CSP plant there will result in a net loss. Fig. 1 also illustrates that utilizing a storage system leads to a growth in the generated energy due to surplus energy, which in turns to improves the NPV.

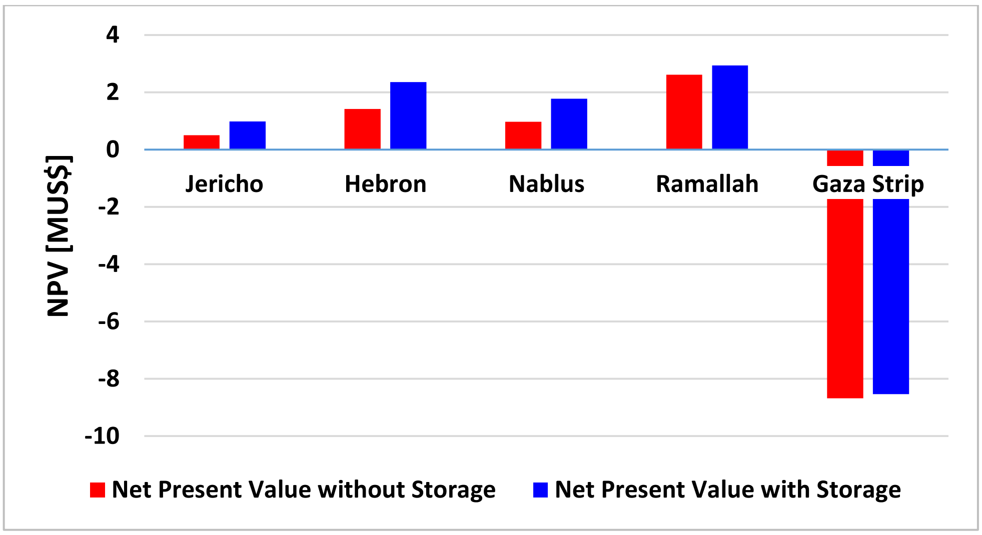

Fig. 1. The NPV of implementing the proposed 1 MW CSP plant in the selected sites.

Fig. 2 shows that the annual life cycle savings (ALCS) for Ramallah is the best while the wost is for the Jericho. Gaza Strip site is not feasible, because using a storage system there raises savings.

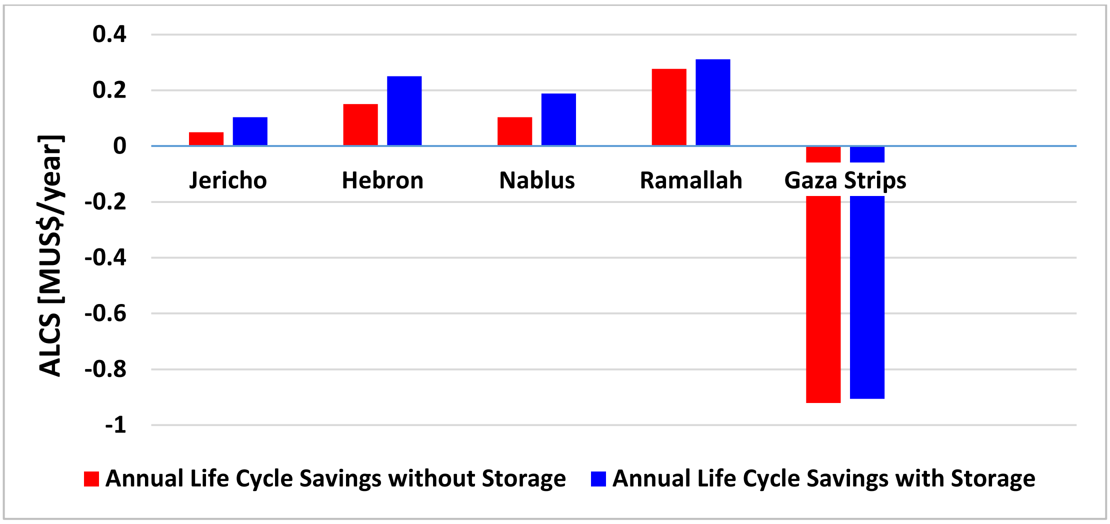

Fig. 2. Annual life cycle savings of implementing the proposed 1 MW CSP plant in the selected sites.

The results of the simple and equity payback periods are illustrated in Fig. 3. Ramallah is the best site and it is negatively affected if a storage system is utilized.

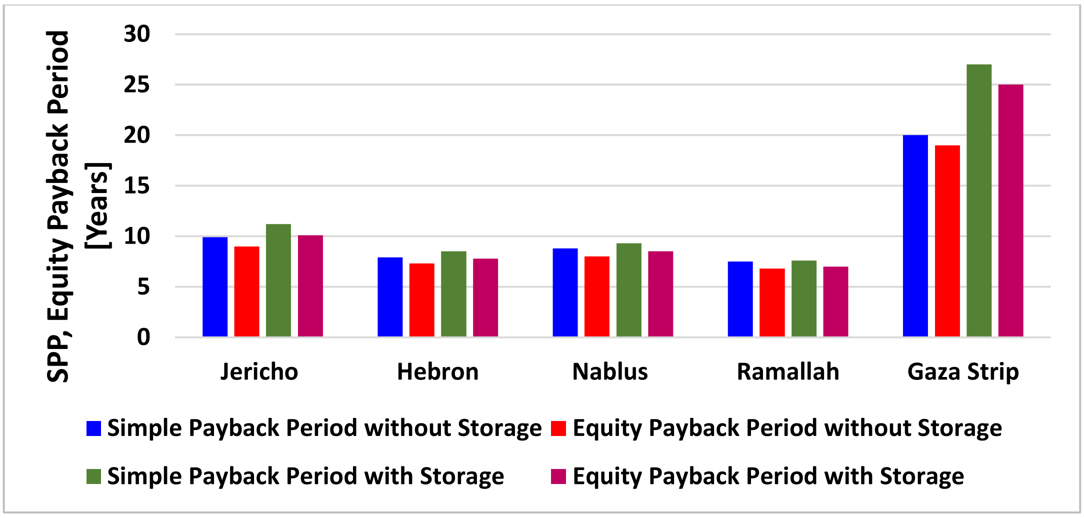

Fig. 3. Simple and equity payback periods of the proposed 1 MW CSP plant in the selected sites.

The (B-C) ratio is contrariwise relative to the investment cost, it declines as the initial cost rises. For this reason and as depicted in Fig. 4, the (B-C) ratio is reduced by introducing a storage. It is also noticed that for all of the investigated sites (except for Gaza Strip), the (B-C) ratio for the 1 MW CSP plant (with and without storage) is greater than one. This indicates the viability of implementing the proposed CSP plant in these sites.

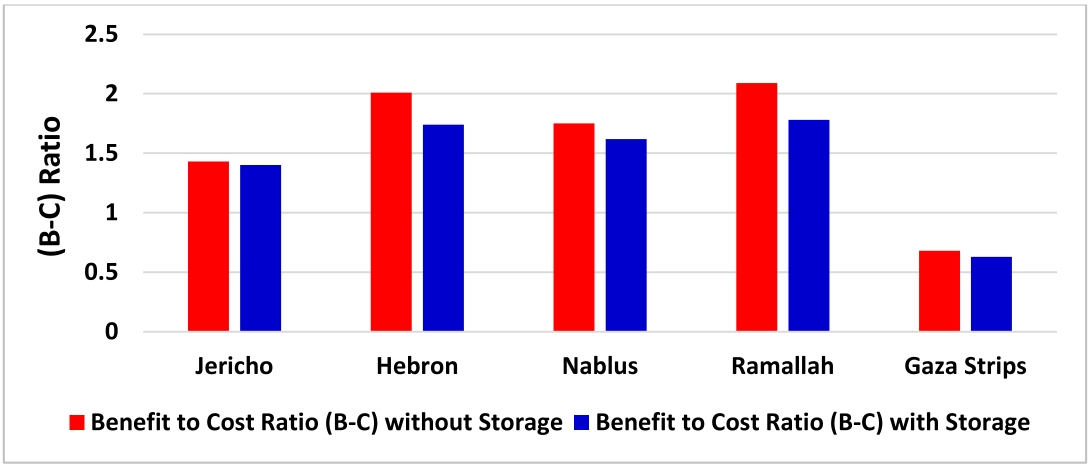

Fig. 4. The (B-C) ratio of the proposed 1 MW CSP plant in the selected sites.

Fig. 5 shows that the lowest values of LCOE are achieved in Ramallah, reaching 0.164 US$/kWh without storage and 0.153 US$/kWh with storage. These values are relatively very high, compared to the values obtained in a recent study conducted by one of this paper's authors, where he investigated the LCOE from a grid-connected PV system in Jericho [6]. The results of that study are depicted in Fig. 6. It shows that the LCOE ranges from 0.065 to 0.125 US$/kWh if the capital cost ranges from 1000 to 3000 US$.

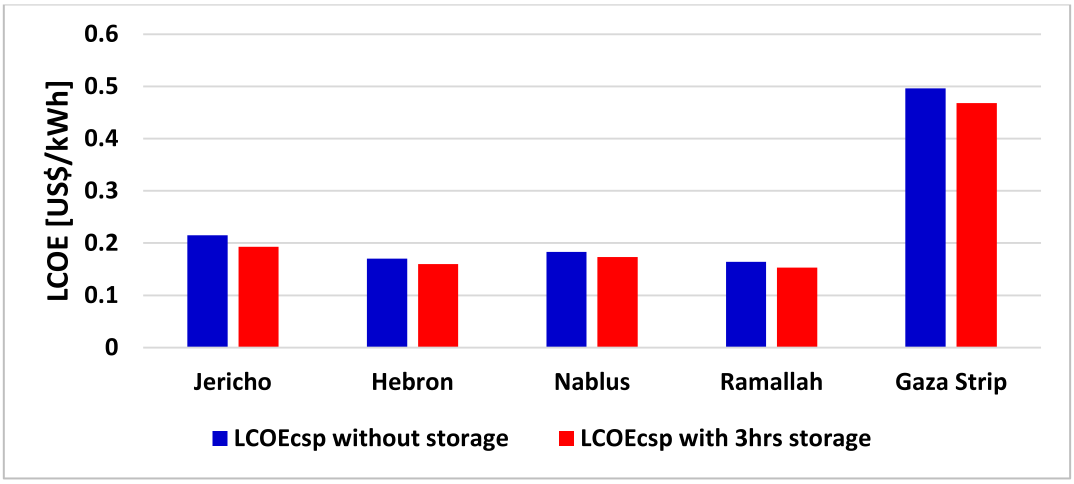

Fig. 5. LCOE generated by the proposed 1 MW CSP plant in the selected sites.

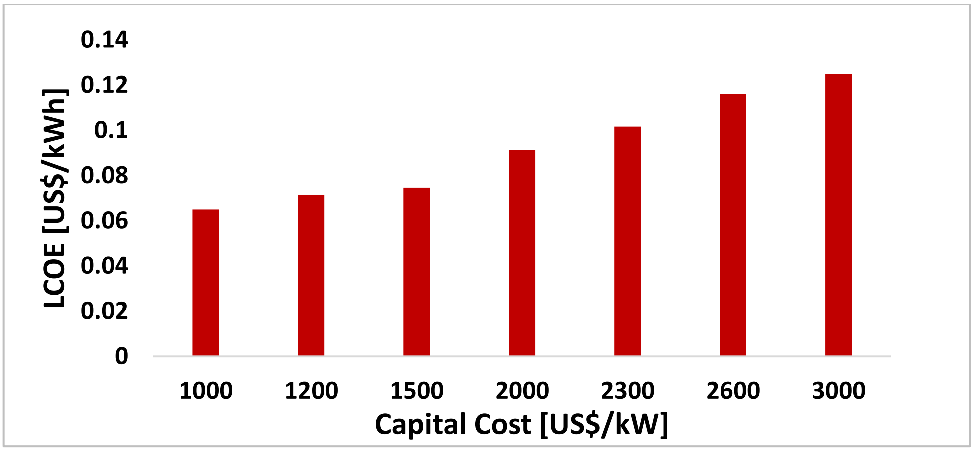

Fig. 6. LCOE generated from a PV system for a wide range of the system's capital cost [6].

4. SENSITIVITY ANALYSIS

The first scenario assumes that the cost of CSP plant is sponsored by the Government. This scenario is significant to study the consequence of the solar farm's cost on the feasibility of the project. Fig. 7 compares the NPV for the CSP plant (with governmental grant) with those of the base case (discussed in section 3.2). It reveals that all sites have a similar NPV. This means that the solar farm's cost considerably affects the financial parameters.

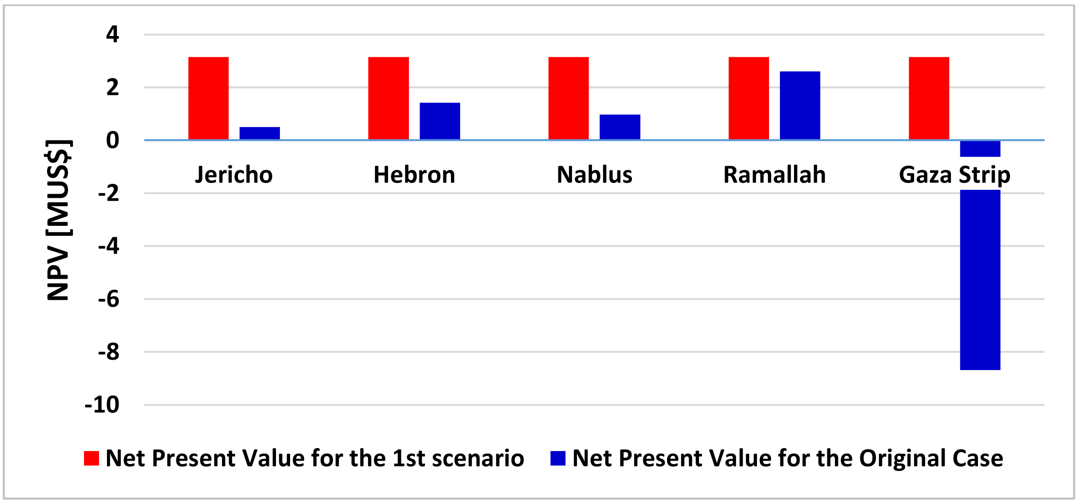

Fig. 7. The net present value for the proposed 1 MW CSP plant in the selected sites.

Similar remarks are noticed, from Fig. 8, which depicts the ALCS for the 1 MW CSP plant in the investigated sites.

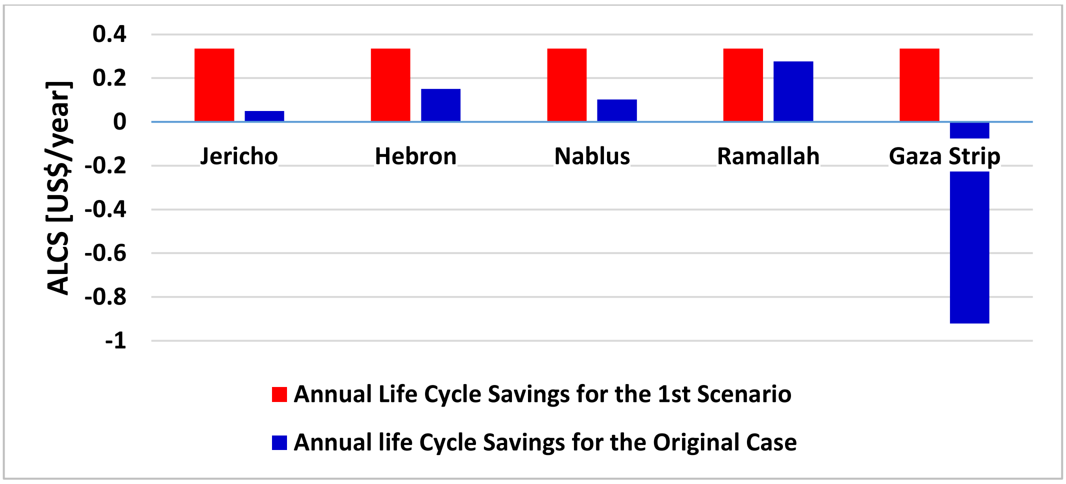

Fig. 8. Annual life cycle savings for the proposed 1 MW CSP plant in the selected sites.

The second scenario assumes that the produced electricity tariff has improved from 0.175 US$/kWh to 0.184 US$/kWh by presenting a 5% incentives on the selling price. This scenario is significant to study the effect of the electricity tariff on the feasibility of the project. Fig. 9 indicates that the NPV is increasing, compared to the base case, as the produced electricity tariff increases. This is also true for ALCS, exhibited in Fig. 10.

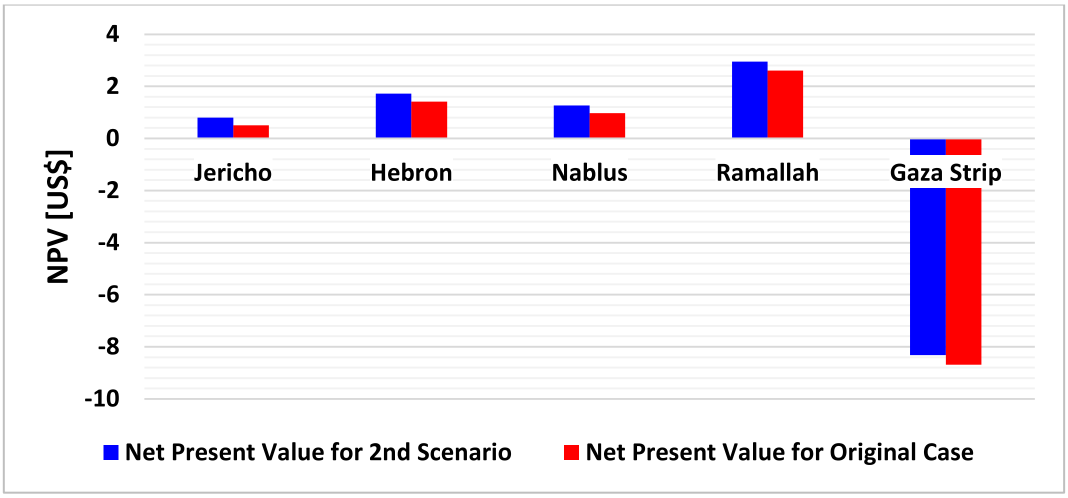

Fig. 9. NPV for the proposed 1 MW CSP plant in the selected sites.

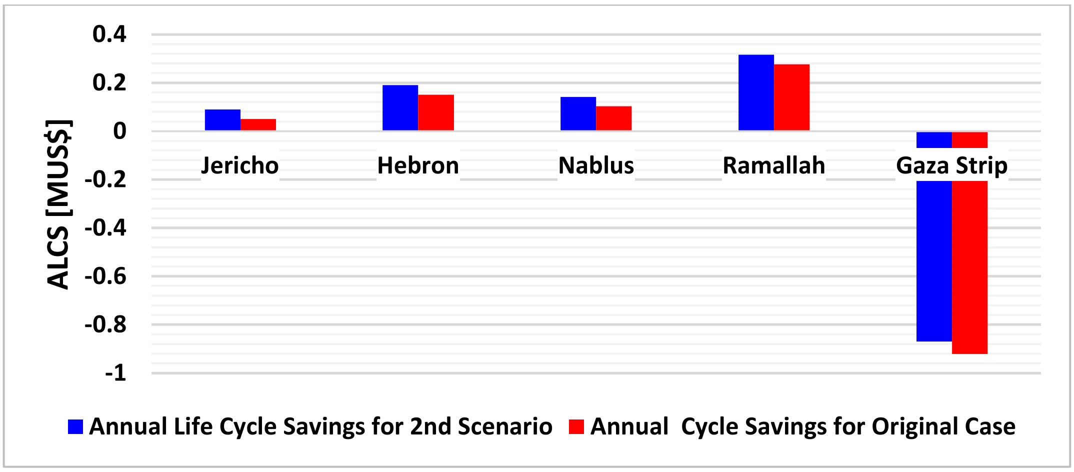

Fig. 10. Annual-life cycle savings for the proposed 1 MW CSP plant in the selected sites.

The rise in electricity tariff causes further savings and leads – eventually - to a decline in the payback periods - as illustrated in Fig. 11. The (B-C) ratio also improves gradually with growth in electricity tariff as illustrated in Fig. 12.

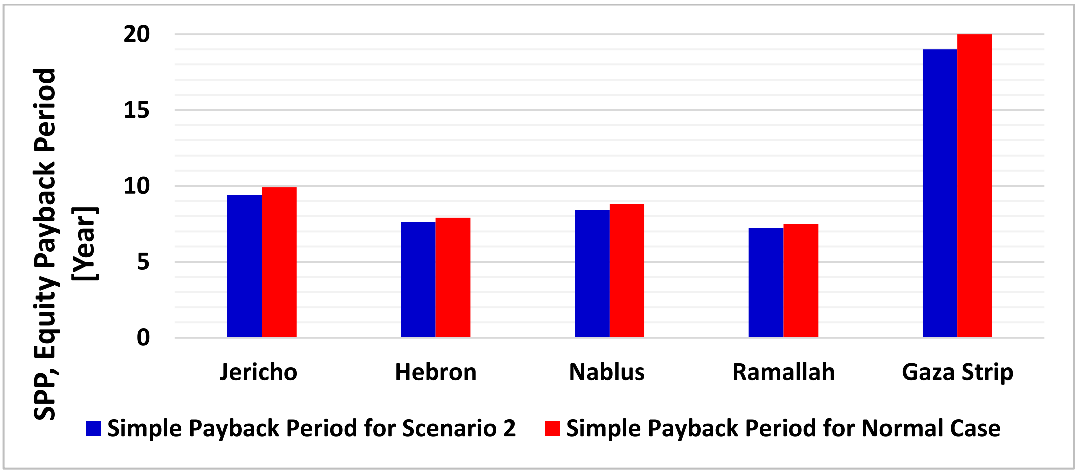

Fig. 11. SPP and equity payback period for the proposed 1 MW CSP plant in the selected sites.

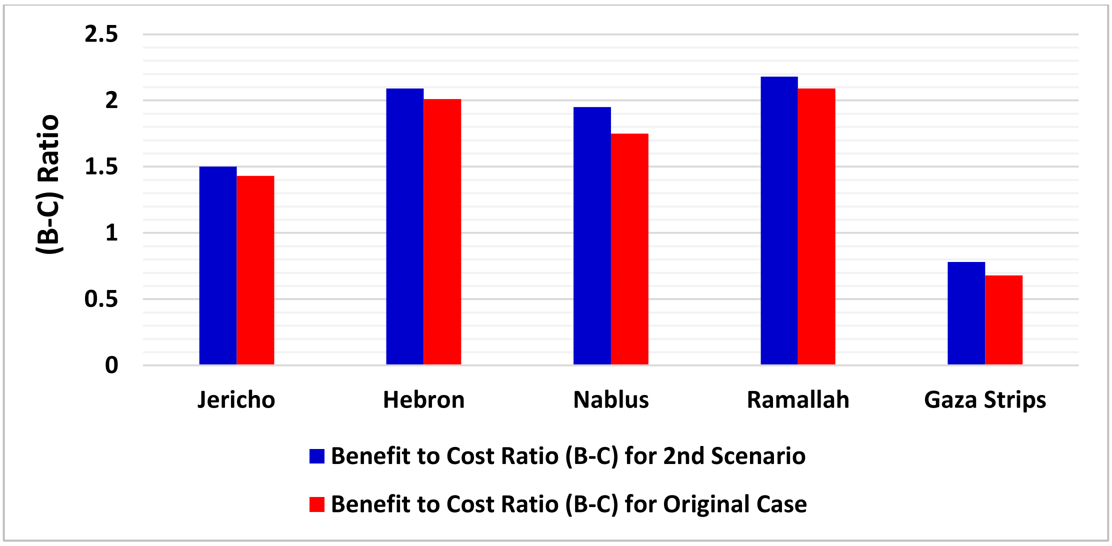

Fig. 12. The (B-C) ratio for the proposed 1 MW CSP plant in the selected sites.

5. CONCLUSIONS

The DNI potential in the PT, especially in the selected sites, was found to comply with the minimum required DNI. Moreover, all the sites have available unexploited lands, which brand them suitable for employing the proposed 1 MW PTC CSP plant.

The results of the techno-economic analysis – based on the economic indicators, namely SPP, equity payback period, NPV, ALCS, and (B-C) ratio - approved that all the investigated sites - excluding Gaza Strip – are suitable for applying the CSP technology.

Based on the LCOE - for the proposed plant with/without storage, Gaza Strip (among the investigated sites) had the highest LCOE whereas Ramallah had the lowest LCOE. This ranks Ramallah – among the investigated sites – the first in terms of its suitability for implementing the proposed plant, followed by Hebron, Nablus and Jericho. The employment of the CSP plant in Gaza Strip is not feasible.

The sensitivity analysis assured that the solar farm's cost and the produced electricity tariff were the prevailing factors in the feasibility study and that presenting storage to the CSP plant led to a variation in financial parameters.

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