Sustainable Energy Technologies and Assessments 31 (2019) 318–328

Contents lists available at ScienceDirect

Sustainable Energy Technologies and Assessments

journal homepage: www.elsevier.com/locate/seta

Assessment of solar energy potential in Gaza Strip-Palestine

Yasser Fathi Nassar[a], Samer Yassin Alsadi[b,*]

[a] Mechanical Engineering Department, Engineering and Technology Faculty, Sebha University, Brack, Libya
[b] Electrical Engineering Department, Faculty of Engineering and Technology, Palestine Technical University-Kadoorie, Tulkarm, Palestine

ARTICLE INFO

Keywords:
Palestine
Gaza Strip
Solar energy
Electricity crisis
(PV) solar system

ABSTRACT

Renewable energy sources and technologies have the potential to provide solutions to the energy problems. Solar energy can be an important part of the Palestinian's strategies not only to add a new capacity but also to increase energy security, addressing the environmental concerns. In this paper, efforts have been made to summarize the current status, availability, and future potential of solar energy options in Gaza Strip. Solar radiation data was provided by Meteoblue AG – Switzerland [www.meteoblue.com] as hourly time-series for 15 years from 2000 to 2015 for five cities in Gaza Strip, which are geographically presenting the entire Gaza Strip. Jabalia, Gaza, Deir-Albalah, Khan-Yunis, and Rafah. These data are used directly to evaluate the potential of solar energy in the three selected sites by means of the System Advisor Model (SAM) from National Renewable Energy Laboratory (NREL) software. The potential of solar energy in Palestine using Photovoltaic (PV) and concentrating (CS) solar systems have been discussed. The present study can be considered as a road-map to get out of the electricity crisis in the Gaza Strip and to end the suffering of Gazians. In this work, two scenarios are suggested, the first one is urgent, it stipulates to generate the demand load (552 GWh/year) by means of (PV) solar power systems. While the second scenario is leading to terminate the reliance on imported energy by producing all the energy needs locally via (PV) solar system. The study reached to determine the financial budget, the levelized cost of electricity (LCOE), and the technical parameters for both scenarios. The urgent action is building up a 555 MWp of (PV) solar system on the rooftop of Gaza Strip's buildings. This will cost about 800 million $US and the expected price of electricity will be ranged between ($US 0.07–0.11) per kWh, which is four times less than the present price ($US 0.29–0.46) per kWh. The solar energy can lay a strong foundation for an independent the Palestinian state, generate employment opportunities, alleviate poverty and provide a visionary approach to the dreams of Palestinian youths.

Introduction

The Gaza Strip is a narrow strip stretching along the southeast corner of the Mediterranean. It borders Egypt on the south-west as shown in Fig. 1. It is about 41 km long, the narrowest width is 6 km and the widest is 12 km wide, with a total area of 365 km^2. It lies on Longitude 34°26′ east and Latitude 31° 10′ north of the equator. According to the last census of the Palestinian Central Bureau of Statistics, at the first of April 2018, the population of Gaza Strip is 2.09 million. The average population density is 4986 people per square kilometres, while in the camps, the density can rise to as high as 100,000 people per square kilometres. The Gaza Strip is categorized as tropical region with a relatively hot summer and mild winter. As the population in Gaza Strip increases (annual population growth rate 2.7%), the consumption of water and energy will increase; leading to significant rise in unacceptable levels of air pollution, and the defect in water supply and energy sources will increase. Gaza Strip is currently suffering from shortage of electricity supply, especially, fossil fuel, which is considered the worst among the crises and problems that cause pain to people in Gaza Strip due to its direct effect on the economic and social life; leading to severe economic crisis that will result in a significant rise in the probability of an outbreak of warfare [1].

Although the electricity crisis in Gaza Strip since 2005, the practical efforts are still modest and does not go beyond some recommendations in scientific researches. Abu-Hafeetha (2009) studied the solar energy and its potential in the Palestinian territories. The Direct Normal Irradiance (DNI) ranges over the Gaza Strip approximately from 4.0 to 8.0 kWh/m^2/day winter to summer respectively. Similarly, Global Tilted Irradiance (GTI) could be as high as 7.6 kWh/m^2/day. The analysis has shown that solar energy share can reach 11.4% of total energy consumption for the year of 2020 just by implementing solar thermal systems; passive and active [2]. Naim (2010) discussed the potential of utilizing available abundant solar energy in Palestine using photovoltaic (PV) system. In his paper, he explained that the solar pumping

* Corresponding author.

https://doi.org/10.1016/j.seta.2018.12.010
Received 19 June 2018; Received in revised form 2 October 2018; Accepted 13 December 2018

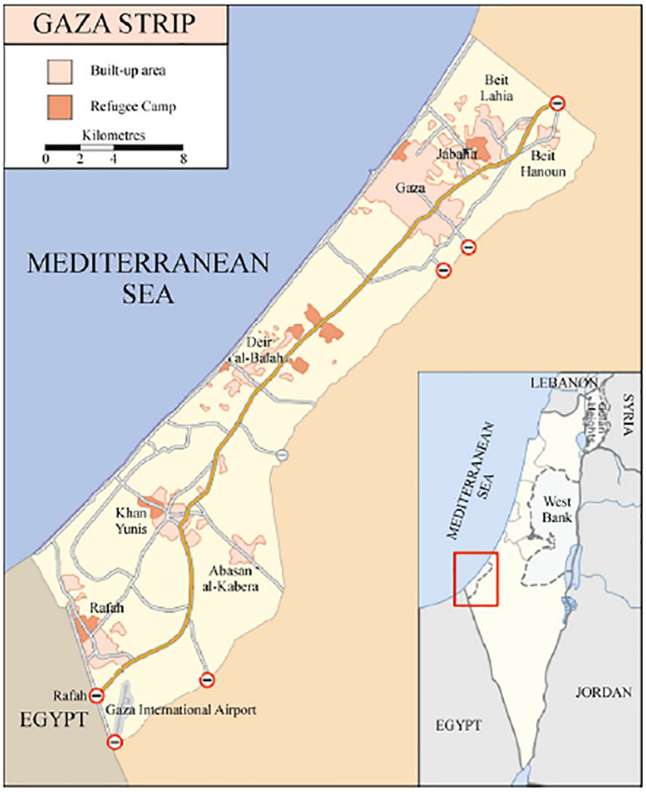

Fig. 1. Location and the cities of Gaza Strip-Palestine.
Source: https://www.ar.wikipedia.org/wiki/file:Gaza_Strip_map.png

technology is an important issue in providing solution to attain fresh water supply in the Palestinian remote and deprived areas. He also called for minimizing the dependence on the traditional energy resources, supplying the deprived areas with water and electricity and participating in the international environmental protection actions [3]. Aydi (2011) investigated the solar energy potential in Gaza Strip based on measurements of a complete year's data at a coastal location. The paper summarized the data for the years (1989–2002), which have been processed from the solar radiation survey. Typical meteorological year files based on the direct beam component, and the archived hourly data. The paper analysed data of 11 years. Results revealed that sufficient data probably now exist in order to enable one to identify the best places for locating solar power stations; in addition, extra years of data will be necessary before a sufficiently reliable data base will exist for the purpose of simulating solar- concentrator power plant performance and determining their economic benefit [4]. Hamed et al. (2013) discussed the challenges facing the Palestinian energy sector, and evaluated the renewable energy potential in meeting part of the energy demand. The study exhibited that the main renewable energy sources in Palestine are solar, wind biomass and geothermal. It was estimated that wind and solar energy sources have the potential to account for around 36% of electricity demand. Further, the conversion of agricultural waste into biodiesel can reduce diesel imports by 5%. Moreover, the conversion of animal waste into biogas has the potential to replace 1.6% of the imported liquefied petroleum gas and the use of geothermal energy for heating and cooling can reduce the cost of conventional energy used for these applications by 70% [5].

A review of renewable energy potential and analysis of the current energy sector situation in Palestine has been provided by Juaidi [6]. The study highlighted the main renewable energy source in Gaza Strip is the solar energy and the wind energy. Hence, a combination of wind and solar energy could stabilize the decentralized energy production in Gaza [7]. An analysis of a number of pilot projects being installed or are running for different renewable energy fields are indicative of their viability and potential in the context of the Palestinian territories is provided in [8]. Muhaisen focused on the electricity problem in the Gaza Strip, in terms of its causes and possible solutions. He recorded lack of information and outlines the problem and consequently recommends some actions and measures that may contribute in resolving it or at least mitigate possible severe effects [9]. Recently, the 2nd edition of the volume "urban energy transition" is lunched. This edition contains a chapter "Solar for Gaza-S4G". S4G is an energetic framework for renewable peace for Gaza. S4G sketched out a plane for Gaza and its wider region entirely based, and prospering on, renewable energy. It specified geographical, social, economic, technical, organizational, and political factors supporting the incorporation of renewable energy into various phases of relief, recovery, and regeneration [10].

The purpose of this study is to explore the areas in the Gaza Strip having a reasonable solar energy potential based on temporal and spatial analysis of meteorological parameters. The hope for a clean and independent energy supply by means of solar energy in Gaza should be the main essential focus of research in the next few years. The obstacles that arise in this respect are discussed here. Moreover, it will be focussed on the energy consumption, particularly electricity consumption in Gaza strip. The novelty of the present work lies behind, the usage of hourly time-series for 15 years from 2000 to 2015 for all cities of Gaza Strip. Using the SAM software for predicting the performance of renewable energy systems and analysing the financial feasibility of residential, commercial, and utility-scale grid-connected projects. A full project calculation from the budget needs, the (LCOE) and the land needed for all kinds of utility-scale electricity generation solar power system including the concentrated solar power. Most of the information documented in this research is recent and so far has not been published anywhere. Thus, the present study can be considered as a short and long term roadmap through the two scenarios that suggested by the study to develop the electricity industrial in the Gaza Strip in particular and in the whole Palestinian territories in general.

The importance of the research and the obtained results

The importance of the present study lies in the necessity of the stage in which the Gaza Strip is going through and looking for a radical solution to this crisis, especially the availability of donors and the sincere desire of all parties to end the suffering of the Gazans. Thereby, there is no doubt that a comprehensive economic, social and environmental study must be conducted to obtain results that could be a roadmap for the investment of solar energy in all the Palestinian territories. In this context, the figures set in this study are a summary of an economic and energetic study. The environmental impact of the electricity crisis in the Gaza Strip had been achieved early [11].

Energetic situation of Gaza Strip

The Palestinian Authority has been importing most of its electrical energy needs from neighbours mainly from Israel (66.6%), and Egypt (8.5%), the rest (24.9%) is domestic generation in the unique Palestinian power plant, which makes energy security an urgent need for Palestine's independence, as it illustrated in Fig. 2. The Gaza Strip has a single diesel-fired power plant at Nusseirat which was crippled in a July 2006 bombing. The total production capacity of the Gaza's electricity generation station 140 MW, the production is based on four gas turbines type "ABB GT10B2" where operates as a combined cycle with two steam turbines, thus the station is consisting of two generation units, each unit contains two gas turbines and one steam turbine. Currently, the gas turbines fired liquid fuel (diesel oil distillate No. 2). The fuel used in the plant is coming from Israel or in some times from Egypt and stored in two large tanks each with capacity of 10,000 cubic meters, where the average daily consumption of diesel oil about 800 cubic meters with full capacity, i.e. When filling fuel tanks full enough to run the plant for 30 days in the event of interruption of the fuel. At

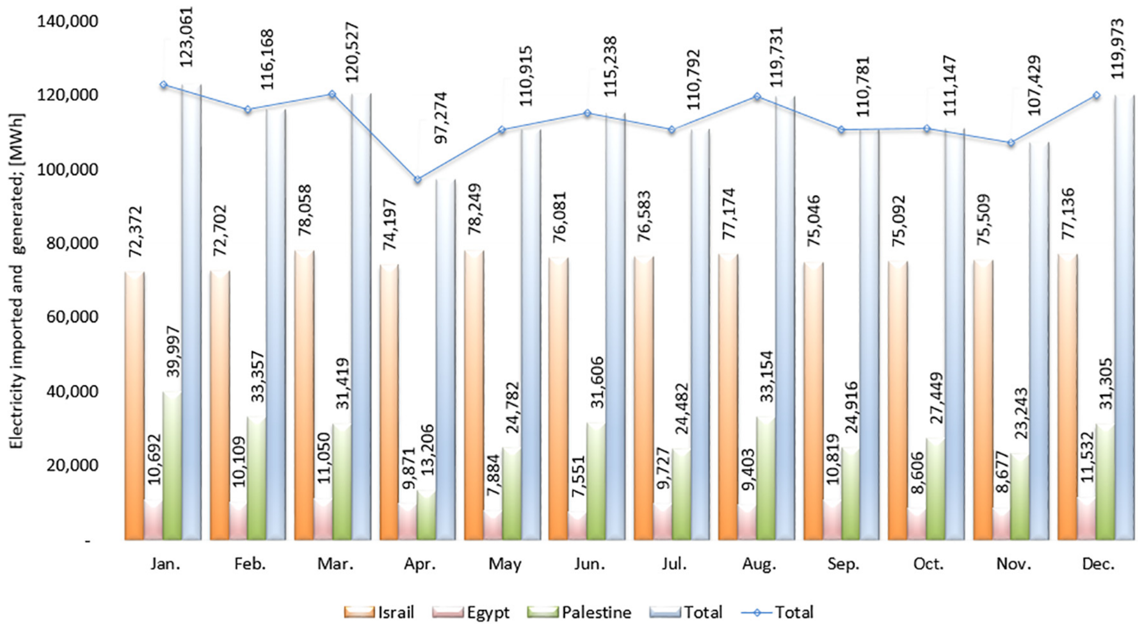

Fig. 2. Histogram of monthly imported electricity from Israeli electricity company and from Egypt, and locally generated by Palestine electric company, and the total available electricity. [Data sources: Palestinian Energy and Natural Resources Authority, 2017. Ramallah – Palestine]

the present time, it is producing a little more than 80 MW, with daily fuel consumption of 420,000 L. Due to the high cost of diesel, the plant is so expensive to operate – costing NIS 1.05–1.65 (US$ 0.29–0.46) per kWh – that it can typically be run only at half capacity. It has also suffered repeated damage during armed conflict affecting its fuel storage capacity. The best prospect is to convert the plant to run on natural gas, which would reduce its operating costs to at least a third of current levels. It should be noted that, the station can be also operating by natural gas instead of diesel oil. Construction of the gas line to supply the gas station from Israel at a cost of 18 million US$. Furthermore, the power plant needs to additional 7 million USD to put the station ready to work with gas so as to change the torches in the combustion chamber [12]. Further information about the energy infrastructure in Gaza Strip reported in the annual bulletin (June 2017) of the World Bank [13].

This dependence in electricity import has also increased electricity costs making Palestinians pay one of the highest electricity costs in the world (the electricity residential tariffs in Gaza Strip varying according to the consumption category 0.153–0.159 $/kWh). Imported quantity and prices and the breakdown of total final consumption of energy in 2017 is tabulated in Table 1 and depicted as bar of pie Fig. 3, respectively.

The major overarching problem for the Palestinian energy sector is the shortage in supply of conventional energy – particularly electricity and petroleum products – and the lack of an institutional infrastructure for generation and transmission. The monopoly of supply of conventional energy resources (electricity and petroleum products) by Israel leads to a situation of high energy insecurity. A total dependence on electricity imports has increased the electricity costs paid by Palestinians. Fig. 4 shows the drop in electricity power provided from both Israeli company and from Egyptian suppliers as well as the Palestinian company due to the lack of Diesel supplied by the Israeli side needed to rotate the power plant. On the other hand, the increase in energy demand due to the increase in the population, which made matters worse the shortage in energy is expected to reach 986 GWh in 2025, which equal to the available energy today (see Fig. 2).

Huge efforts are made and still required for the development of energy sector. There is an urgent need for research on energy demand/consumption, the implementation of R&D activities aimed at alleviating at least some of the energy problems and, above all, an efficient utilisation of renewable and local conventional energy resources. It is also envisaged by the Palestinian Energy and Natural Resources Authority that energy conservation should be at the core of energy planning with a view to reducing energy consumption. The prospects for employing solar energy technologies will now be discussed.

Solar energy potential and solar radiation characteristics

Palestine – especially Gaza Strip-has high solar energy potential. It has about 3000 sunshine hours per year and high annual average of solar radiation amounting to 3.67 kWh/m^2/day on horizontal surface and about 6.21 kWh/m^2/day on south facing tilted surface. The lowest solar energy average is in December; it amounts to 3.72 kWh/m^2/day. The solar radiation on tilted surface varies from 3.72 kWh/m^2/day in December in Jabalia to 7.54 kWh/m^2/day in June in Rafah. These figures are encouraging to exploit the solar energy for electricity generation. Fig. 5 shows the GeoModel long-term averages of solar resource: Global Horizontal Irradiation (GHI), Global Tilted Irradiation (GTI), Diffuse Horizontal Irradiation (DIF) and Direct Normal Irradiation (DNI) generated by Global Solar Atlas, the principal climate phenomena that determines solar power generation. Understanding solar resource

Table 1
Imported energy and average consumer prices in Gaza Strip by type of energy.

	Electricity	Gasoline	Diesel	Kerosene	LPG	Bitumen	Oils & Lubricants	Wood & Charcoal
Quantity	1,024,120 MWh	53,999 m^3	239,707 m^3	150 m^3	59,915 ton	748 ton	25 ton	427 ton
Price	0.56 NIS/kWh	5.75 NIS/L	5.09 NIS/L	5.79 NIS/L	61.0 NIS/12 kg	1.8 NIS/kg	10.0 NIS/kg	1.0 NIS/kg

1 USD = 3.588 NIS [Source: https://m.sa.investing.com/currencies/usd-ils at 27/04/2018].
[Source: Palestinian Central Bureau of Statistics, 2017, Ramallah – Palestine, and the prices are author collection at April 2018].

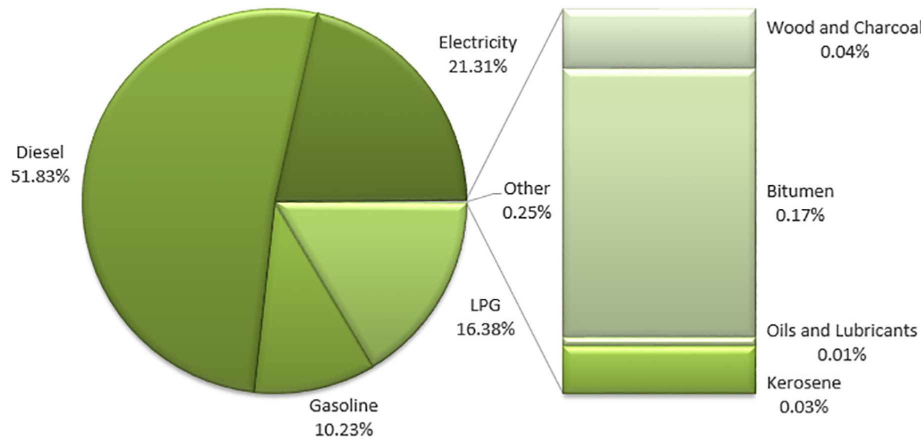

Fig. 3. Breakdown of final consumption of energy (17,301.61 TJ) in 2017 by source of energy for Gaza Strip.

is crucial for the development of solar energy applications. In particular, for the solar power sector, (PV) technologies typically require an analysis on (GHI) and (GTI). While, (CS) technologies, rely on DNI. Air temperature is also shown as it is the second most important climate variable determining the performance efficiency of solar power systems. This Global Solar Atlas, the most reliable sources of data currently available are used to generate the solar resource estimates provided, with the objective of supporting policy development of solar power project.

Preview Fig. 5 can be realized that the Strip can be divided into two regions, the coastal side and the inner region by which solar radiation is higher. Respecting to photovoltaic electricity output, it is obvious from the figure that, the highest values locate in the south and southern east of Rafah and the east of Khan-Yunis. However, this Atlas is good enough for the first stage of a solar energy project lifecycle: prospection and preliminary assessment. High-quality solar resource and meteorological data are needed also in the next stages: (i) project development; (ii) monitoring and asset management; and (iii) forecasting and operational management of solar power plants. In the stage of project development, site-specific hourly and/or sub-hourly time series and Typical Meteorological Year (TMY) data are required for the technical design, engineering, financing, risk assessment, and due-diligence. Such data is typically generated from at least 10 years or more of continuous climate records at sub-hourly time resolution. While, Fig. 6 illustrates the hourly (DNI) and (GTI) at January and July months for Rafah city in the south of the Gaza Strip. This city shows a high potential solar energy especially for (PV) solar application.

Solar energy projects in Gaza Strip

There has been a significant trend by the government, donor institutions and private institutions to support the provision of electricity through solar energy projects. One can say that most of the projects, which have been implemented in Gaza Strip, depends on foreign aids. Therefore, Gaza Strip witnessed the implementation of solar power systems in different sectors. One of the early project was done in 2013 under auspice of the Ministry of Health to supply the intensive care unit at Al-Naser children hospital with electrical power using solar panels. There is a similar application of solar panels in Jericho hospital at West Bank (Palestinian electricity regulatory council). In the same year, the ministry of education and higher education equipped several schools with solar system such as Ihsan Al-Aga girls secondary school and Bashir El-Rais girls secondary school followed by similar projects to date. Other bodies including ministry of agriculture, ministry of the

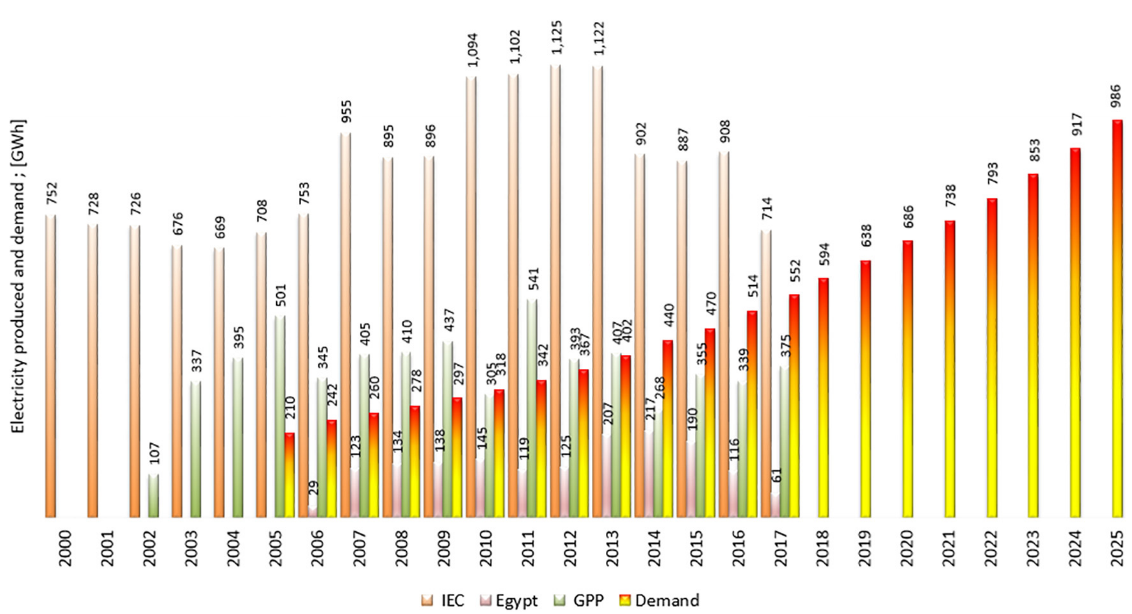

Fig. 4. Histogram of energy balance of Gaza Strip and the demand forecast. [Data source: Palestinian Energy Authority, electricity distribution company in the Gaza Strip, 2018]

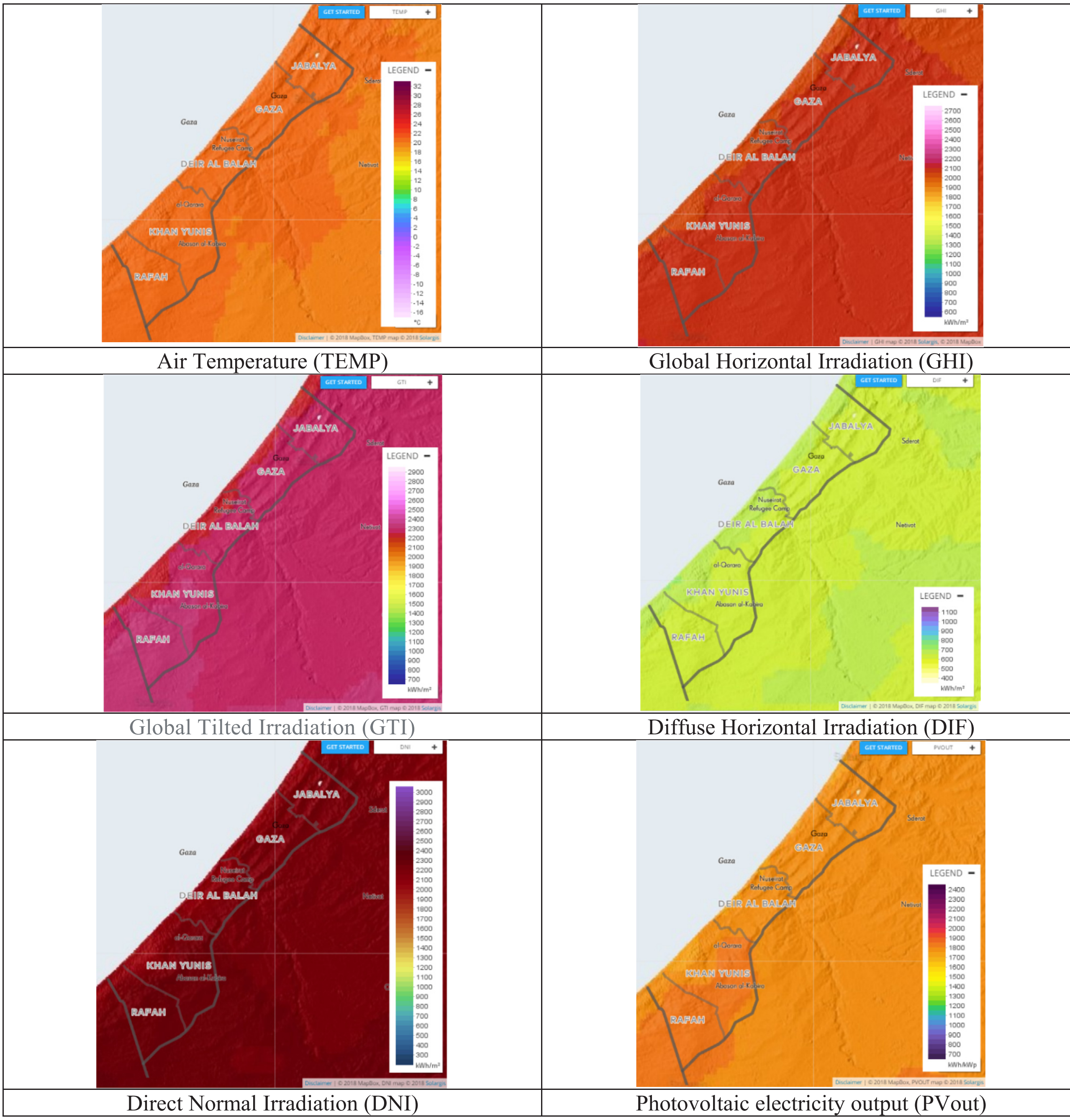

Fig. 5. Long-term averages of solar resource (GHI, DNI, GTI, DIF) and TEMP of Gaza Strip. [Source: http://globalsolaratlas.info/.]

interior, some local municipalities, some universities, some private companies and houses also adopt solar system to facilitate their electricity needs.

Gaza electricity distribution company (GEDCO) is planning to support citizens in Gaza Strip to install solar energy systems by paying the cost in instalment, which will be included in the monthly bill. By doing so, they follow the footprints of donor institutions that help citizens of Gaza Strip to install solar systems. The number of houses that benefited from the project is 450 homes [14].

The projects for electricity generation from (PV) solar systems in Gaza Strip which already established are 100 kWp with total cost of $440,000. Following the success of existing projects and prove their economy compared to other fossil fuel generators, many local institutional and private activities such as: schools, health clinics, solar water well and banks, have planned to install (PV) solar panels to meet the energy deficit. Some of these projects are listed below:

1. Project of lighting Wadi Gaza solar power capacity of 6 kW
2. lighting project of Ihsan Alagha School in Khan-Younis with capacity of 20 kW
3. At May 2013 (PV) solar project of 20 kW capacity to provide the intensive care unit in Al-Nasr children's hospital in Gaza Strip, (operating).
4. At autumn 2014 (PV) solar project of 4 kW to provide the intensive care unit in Al-Shafa hospital and planning to install another 30 kW (PV) solar panels to cover the needs of the maternity unit in the hospital [15].
5. At the end of 2017, and in the frame of the "Fundacion Promocion Social de la Cultura/" FPSC's projects "Promoting sustainable rural development in Gaza Strip in order to reduce its vulnerability and

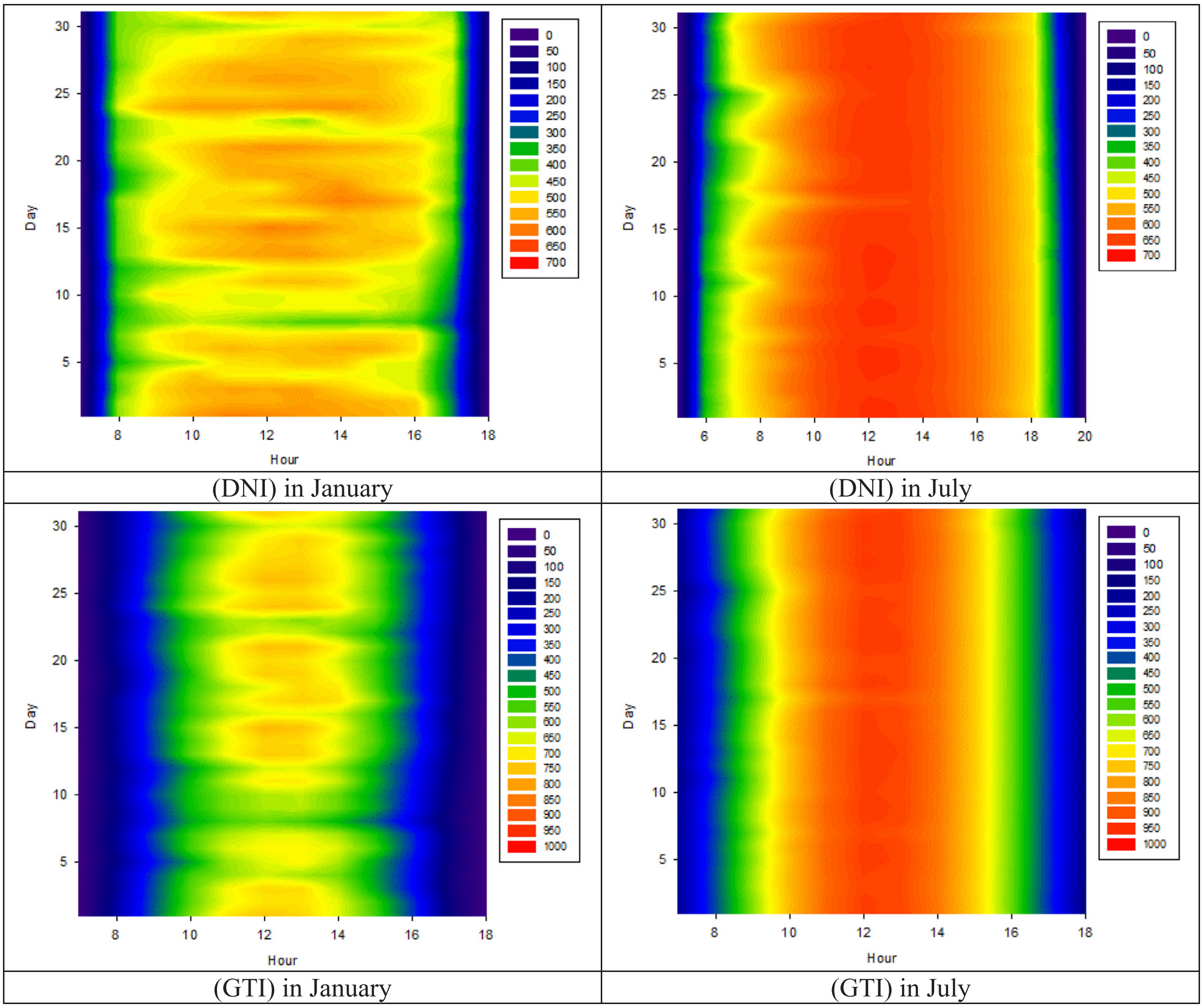

Fig. 6. Hourly (DNI) and (GTI) for Rafah city at January and July months.

Table 2
Key characteristics of various of solar electricity generations.

Solar technology	Total area	Capital cost	Fixed M&O
(PV) Rooftop	m^2/kW	$/kW	($/kW-y)
Residential	12	3480	33
Commercial	12	3120	20
(PV) Utility scale	m^2/MW	$/kW	($/kW-y)
Fixed	30,760	1450–2850	30
1-Axis Tracker	35,210	2300–3300	35
2-Axis Tracker	52,610	2350–3350	40
(CS)	m^2/MW	$/kW	($/kW-y)
2-axis (CPV) Tracker	36,830	2100–3300	67
Trough with 8 h storage	38,450	2700–4000	67
Tower with 8 h storage	40,470	2500–4400	67
Dish Stirling	40,470	4200–6600	67
Linear Fresnel	19,020	2500–5500	67

increase its resilience", funded by "Agencia Espanola de Cooperacion Internacional para el Desarrollo/Spanish Agency for International Development Cooperation and for humanitarian assistance" AECID, and implemented by Union of Agricultural Work Committees UAWC, solar energy systems have been installed in 29 poultry farms to provide illumination at night-poultry farms need at least 16 h a day of lighting throughout the year, with total capacity of 48 kW and total cost of $150,000, (operating).

While, and regardless, utility scale projects also have been approved by Palestinian Authority but still not achieved so far, some of these projects are listed below:

1. (PV) Solar project of 7 MW capacity and total cost of $12 million, in 2019 for providing 32 factories in Gaza industrial region, financed by the International Finance Corporation (IFC), the Canadian Program for Climate Change and International Investment Guarantee Agency.
2. A project, called "turn on the lights in Gaza", solar power plants will be built in three areas in the Gaza Strip and in total produce 40 MW of electrical power. The capital will be around €50 million ($59 million).

Although, the climatic condition is suitable for solar energy utilization, but there are two main obstacles limiting investment in this field in the Gaza Strip; the first one is the unstable political situation and, the second is the limited uninhabited land. Gaza considered as the most densely populated in the world. It is known that utility-scale solar power plants need vast areas and far away from buildings to avoid the shadow. Table 2, tabulates the land-use for various solar technologies and system configurations [16], the estimated capital cost, the annual maintenance and operation cost [17] and the estimated electricity output according to the solar radiation tabulated in the previous column. It should be noted here that, the area and the prices are not fixed and varying according to country's climate and economic laws

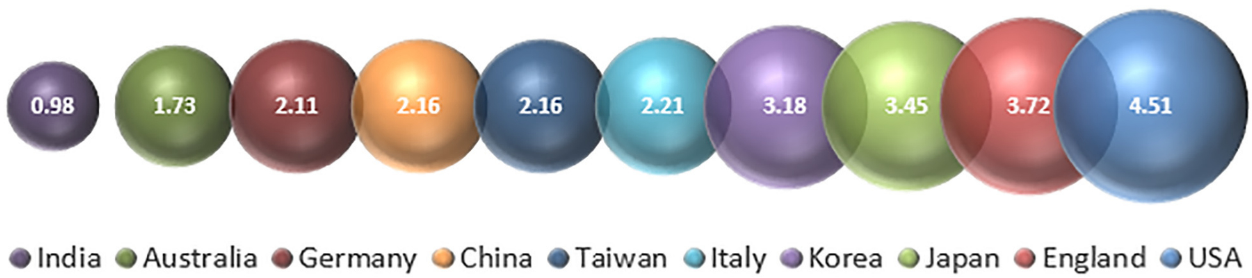

Fig. 7. Rooftop type solar system prices around the world [$/Wp]. [Source: Author's collection.]

and also to the type of technology used as it illustrated in Fig. 7.

Methodology and study overview

The study suggested two scenarios to amending the electricity crisis in Gaza Strip by means of exploitation of the abundant solar energy. The first scenario stipulates to provide the Strip with the demand electricity only (552 GWh/year), by means of establishment of 5 (PV) solar power plant in the five cities of the Gaza Strip. While the second scenario "independency project" which stipulates to feeding the Gaza Strip with the both important and demand electricity (714 from IEC and 61 from Egypt, and the 552 demand GWh/year). To figure out the reality of this sense, the study passed through the following 4-stages process:

1. Climatic data collection;
2. Electricity consumption data collection;
3. Estimation of the (PV) solar energy potential, the required area and the capital cost for establishment the (PV) solar projects;
4. Mapping the suitable area of the rooftop of buildings in Gaza Strip; and
5. Reporting

The research adopted the Solar radiation data was provided by Meteoblue as hourly time-series for 15 years from 2000 to 2015 for five cities in Gaza Strip, which are geographically presenting the entire Strip. Jabalia, Gaza, Deir-Albalah, Khan-Yunis, and Rafah. These data are treated and reformatted to create solar weather files for each city, by using FORTRAN software to fit the requirements format of the input data of SAM software (System Advisor Model is free software developed by the National Renewable Energy Laboratory from NREL) [18]. A study conducted to compare three commercial programs (PVSyt, SAM and PVLib), SAM is identified as potentially the most appropriate software for not only modelling the (PV) plant with considerable accuracy, but it also demonstrating several features that make it the most suitable of the three programs [19].

The data concerned the electricity consumption has been assembled from two authoritative sources in the State of Palestine, these are, the Palestinian Central Bureau of Statistics (PCBS), Palestinian Energy and Natural Resources Authority (PENRA).

The structures those are candidates for mounting the (PV) solar system elements are confined to commercial buildings, housings, hospitals, schools and universities. The number of these structures is tabulated in Table 3. The average area of the buildings in Gaza Strip is assumed to be 200 m^2 for every rooftop, and only 50% of this area is considered as a suitable for mounting (PV) solar system on the rooftop of the buildings [12].

Fig. 8 represents – a side of these mini-application – a photograph of a rooftop (PV) solar system on the roof of a residential building in the Gaza-Strip.

Results and discussion

Thanks to the SAM software, simulation and analysis of many utility scale renewable energy systems will be easy and rapidly. Uploading the climatic and electrical loads files to the program and making some corrections to the economic parameters, the results are appearing in few seconds. Fig. 9 is a 3-dimension bubble diagram illustrates average data for (LCOE) and the required land for establishing a solar field for the Gaza Strip for various utility-scale solar energy systems, some of them concentrated solar systems such as parabolic trough, central receiver tower (or heliostat field), Fresnel lens, Sterling dish and concentrated photovoltaic (CPV), and the others flat collectors like (PV) in fixed or one axis or duel axis tracking mode.

As it explicitly evident from Fig. 9, the fixed (PV) solar system wins the competition. This technology is simple and suitable for developing countries. The (PV) technology has proved their capability, reliability and flexibility and it achieves the highest marketing around the world. But in case of limiting areas one can chose the one axis or dual axes tracking system, these modes reduced area but increasing the capital cost and accordingly the (LCOE) will be increased.

The following approach has been followed for the two suggested scenarios. According to the required load the system capacity, (LCOE) and the capital cost have been obtained from the SAM software.

The first scenario

The rapid, secure and feasible action to solve the electricity crisis in the Gaza Strip is building (PV) solar systems on the rooftops of the buildings in each community or city. And because the electricity network infrastructure exists, the connections will be not cost money nor time.

As it mentioned above, the first scenario suggested to construct (PV) solar plants to cover the demand load (552 GWh/year). This can be achieved by dividing this load over the five main cities of the Strip. Thereby, the share of each city is about 110.4 GWh/year. Consequently, the SAM software has been executed with the input files for each city (TMY and electricity load) using trial and error technique in order to the annual energy of the (PV) power system a little greater than 110.4 GWh in order to cover the losses in the network. The obtained results have been tabulated in Table 4.

Looking in Table 4, the following can be observed

1. The annual energy is greater than the demand and not identical for all cities: we did not spend much effort and time to make the annual energy production of all cities identical and considered the surplus as a security factor;
2. The wide price ranges of the (LCOE) and the capital cost was a result of the different in the prices of the (PV) solar systems as it indicated above in Fig. 7.

The system nameplate size of the (PV) solar systems (A) and the capital cost of the plants (B) for the three modes of (PV) systems and for the five cities is presented graphically as a 3-dimensional column chart

Table 3
Number of structures and the suitable rooftop area for all cities of the Gaza Strip [20,21]

City	Number of					Area of [m^2]	
	Building	Housing	Hospital	School	University	Suitable Rooftop	Governorate
Jabalia	10,919	18,702	5	123	0	2,974,900	61,000,000
Gaza	21,750	20,697	14	267	6	4,273,400	74,000,000
Deir-Albalah	7258	20,851	2	100	1	2,821,200	58,000,000
Khan Yunis	9470	31,445	6	140	2	4,106,300	108,000,000
Rafah	6019	19,518	3	84	1	2,562,500	64,000,000
Gaza Strip (total)	55,416	111,213	30	714	10	16,738,300	365,000,000

in Fig. 10. In where, the cylindrical column shape presents the fixed mode, the pyramid column shape refers to the 1-axis tracking mode while, the box column shape indicates to the 2-axis tracking mode.

The second scenario

While, the first scenario solving the present situation, the second scenario represents the fully independence of the electricity sector from the import. In fact, the expansion of the first scenario with a time plan leads to the second scenario. In this sense, the second scenario is considered the happy end of the first scenario. With the same manner, the second scenario suggests construct (PV) solar plants covering all the electricity energy imported from Israel (714 GWh/year) and Egypt (61 GWh/year) in addition to the demand load (552 GWh/year). Accordingly, the total annual energy produced from the second scenario sense must be around 1327 GWh/year. Thereby, the share of each city is about 265.4 GWh/year. After running the SAM, the obtained results have been tabulated in Table 5.

Rooftop area estimation

According to PCBS and PEC, in Gaza, we assume that, the average rooftop areas 200 m^2 and about 50 percent of the rooftops are available for solar installations. The rooftop space requirement is 12 m^2 per kWp [1].

Consequently, and according to the information tabulated in Table 3 and regarding to the capacities of the solar panels that to be installed on the roofs of the buildings in each city in Tables 4 And 5, the space required for construction these plants are tabulated in Table 6. Table 6 contains the governorate areas of each city in the Strip, the total suitable rooftop area and the area required to build the (PV) solar systems for the three considered modes and for the two suggested scenarios.

As it presented in Table 6, the roofs of buildings can accommodate the area needed to build up all the options of the first scenario. While, there is not enough space to achieve the fixed mode of the second scenario. But the other two options can be captured over the roofs of the building in all cities, but of course the capital cost will increase.

These data are depicted as a 3-dimansion bubble chart in Fig. 11, to compare the occupied area as a percentage of the suitable rooftop area for the five cities, for the three arrangements and for both suggested scenarios.

As it is evident from Fig. 11, the rooftops areas of the buildings are able to comprise the full capacity of the first scenario for each city, of course the required area for the fixed mode is greater than the 1-axis trucking mode by 25% and by 27% in the case of 2-axis tracking mode. While, the second scenario has not enough spaces to mount all the capacity over the buildings in the cities Jabalia, Deir-Albalah and Rafah, the excess of (PV) panels will be carried over by Gaza and Khan Yunis. Otherwise, there is no choice rather than adopting one of the tracking modes.

Basing on the obtained results, the Gaza Strip urgently needs 555 MW of (PV) solar power system, deployed over an area of 6,525,000 m^2 or over the roofs of 32,625 buildings and the budget of this project must be at least 800 million $US. The expected price of electricity will be ranged between ($US 0.07–0.11) per kWh, which is less than by 4 times the present price ($US 0.29–0.46) per kWh.

Fig. 8. Solar panels on a rooftop of a building in Gaza Strip. [Source: http://gisha.org/en-blog/.]

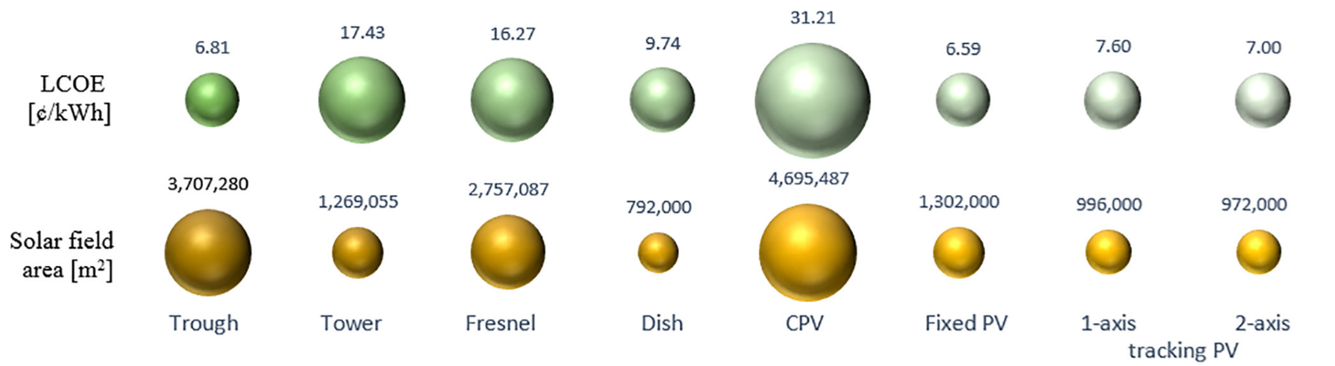

Fig. 9. Average (LCOE) [US₵/kWh] and the required area [m^2] in Gaza Strip for several types of utility scale solar energy according to the first scenario (a fifth of the load demand which is 110.4 GWh/year).

conclusions

According to forecasts, within the next five years, the value of the shortage in electricity will reach approximately 100% of electricity available (imported and generated) today. Exploitation of available renewable energies are the unique way to mitigate the miserable situation of the Gazan live, provide secure and sustainable power energy and reduce dependence on others.

Fortunately, Gaza Strip has significant potential for electricity solar-based power plant. DNI could reach up 7.95 kWh/m^2/day, while (GTI) reaches up to 7.55 kWh/m^2/day. These levels are more than the required for viable solar energy electricity systems. This article introduces a comprehensive comparison between (PV) and (CS) technologies regarding economic feasibility of utility scale solar power plants. Gaza Strip is taken as a case study. The different types of either (CS) or (PV) are tested under real hourly climatic data for 3 sites by using (SAM) software in order to identify the appropriate type of these systems to The Gaza Strip. The article produces fairly accurate forecasting for utility scale solar energy market in Palestine. The obtained results show that between all solar energy technologies only the solar (PV) and parabolic trough are preferred candidates in Gaza Strip energy market due to the lowest (LCOE).

Regardless, the trough parabolic (CS) technology proved their economic feasibility by achieving the lowest (LCOE), but, unfortunately, the exploitation of this technology is limited for utility scale due to lack of uninhabited area in the Strip. Unless we invest outside of the borders, for example in the Negev or Sinai, similar to the European project Desertec (energy from desert). Otherwise, the (PV) systems have the advantage of size flexibility, which allows wide adoption on residential and utility scale. The (PV) systems recently have been implemented for illuminating public roads and avenues.

Basing on the obtained results it can be said that, the Gaza Strip urgently needs to 555 MW of (PV) solar power system, deployed over an area of 6,525,000 m^2 or over the roofs of 32,625 buildings and the budget of this project must be at least 800 million $US. The expected price of electricity will be ranged between ($US 0.07–0.11) per kWh, which is less than by 4 times the present price ($US 0.29–0.46) per kWh.

However, the obtained results are very sensitive to the following points:

- In the first class the resets are critical sensitive to the all economic parameters (i.e. capital cost, fuel cost, interest-rate, inflation-rate, … etc);
- The results of course are sensitive to the thermal and electrical characteristics of the (PV) modules and the shadow cast (i.e. constant losses due to the rise of the cell's temperature over the standard test condition and also for the shadow cast).
- The meteorological data is considered as a main source of uncertainty. Unpublished work – with a relevant aspect – conducted by

Table 4
The first scenario key figure (110.4 GWh/year per city).

	Rafah	Khan Yunis	Deir-Albalah	Gaza	Jabalia
Fixed mode					
System nameplate size; [MWp]	107.0	108.0	109.0	110.3	111.5
Annual energy; [GWh]	110.45	110.47	110.49	110.49	110.49
Capacity factor; [%]	11.8	11.7	11.6	11.5	11.3
Energy yield [kWh/kWp]	1032	1025	1017	2010	993
LCOE [¢/kWh]	6.49–10.34	6.50–10.42	6.59–10.50	6.67–10.59	6.75–10.67
Net capital cost [M$]	154.9–305.0	156.0–307.2	157.0–309.3	158.8–312.9	160.6–316.4
1-Axis tracking mode					
System nameplate size; [MWp]	82.5	82.8	83.0	84.8	84.5
Annual energy; [GWh]	110.48	110.46	110.44	110.46	110.48
Capacity factor; [%]	15.4	15.3	15.2	15.1	15.0
Energy yield [kWh/kWp]	1345	1339	1333	1323	1313
LCOE [¢/kWh]	6.98–9.05	6.99–9.06	7.00–9.07	7.06–9.15	7.11–9.22
Net capital cost [M$]	185.2–265.6	185.8–266.5	186.4–267.3	187.6–267.0	188.7–270.6
2-axis tracking mode					
System nameplate size; [MWp]	81.0	81.0	81.0	81.8	82.5
Annual energy; [GWh]	110.47	110.47	110.47	110.48	110.49
Capacity factor; [%]	15.6	15.6	15.6	15.5	15.3
Energy yield; [kWh/kWp]	1369	1367	1364	1354	1343
LCOE; [¢/kWh]	7.53–9.63	7.57–9.68	7.60–9.72	7.66–9.80	7.71–9.87
Net capital cost; [M$]	192.8–274.7	194.0–276.4	195.2–278.1	196.4–279.8	197.6–281.4

(A) (B)

Fig. 10. The capacity (A) and the capital cost (B) of the (PV) rooftop solar plant for the five cities in Gaza Strip with different system arrangements.

the authors, reports the sensitivity of the results to the transposition model that used during the simulation and optimization processes.

Future plans and investigations

Palestine can reduce reliance on imported energy carriers by deployment of clean energy systems, especially solar, off/on shore wind, geothermal and biomass. Palestinian areas have large alternative energy potential which can be harnessed by a futuristic energy policy, large-scale investments and strategic assistance from neighbouring countries like Jordan and Egypt. Renewable energy can lay a strong foundation for an independent Palestinian state, generate employment opportunities, alleviate poverty and provide a visionary approach to the dreams of Palestinian youths. There for, we need to further scientific investigations to create a renewable energy map for all the Palestinian territories.

Starting with Gaza Strip, the present study is a part of series studies addressed to the availability of renewable energies for the Palestinian State territory, that will be carried by the authors. These studies will include wind, solar and biomass energies. It is hoped the results of this study will end the suffer of Gazian people and reducing dependency on electricity sector.

Acknowledgments

Authors would like to thank Mr. Amer Oudeh from Meteoblue AG for the support by providing us with meteorological observations for Gaza Strip. Our thanks also going to Mr. Said Nassar the Mayor of Deir-Albalah municipality and to Mr. Sameer Mutair the Co-chairman of the Palestinian Energy Authority and the Chairman of electricity distribution company in the Gaza Strip. Thanks also to the Palestinian Central Bureau of Statics. We would like to express our heartfelt gratitude to them for their collaboration.

Table 5
The second scenario key figure (265.4 GWh/year per city).

	Rafah	Khan Yunis	Deir-Albalah	Gaza	Jabalia
Fixed mode					
System nameplate size; [MWp]	257.5	259.5	261.5	264.5	267.5
Annual energy; [GWh]	265.8	265.8	265.8	265.7	265.6
Capacity factor; [%]	11.8	11.7	11.6	11.5	11.3
Energy yield; [kWh/kWp]	1032	1025	1017	2010	993
LCOE; [¢/kWh]	6.49–10.34	6.54–10.42	6.59–10.50	6.67–10.63	6.75–10.76
Net capital cost; [M$]	364.7–718.3	367.6–724.1	370.5–729.8	374.8–738.4	379.1–746.9
1-Axis tracking mode					
System nameplate size; [MWp]	194.0	194.8	195.5	197.0	198.5
Annual energy; [GWh]	265.5	265.6	265.6	265.7	265.7
Capacity factor; [%]	15.4	15.3	15.2	15.1	15.0
Energy yield; [kWh/kWp]	1345	1339	1333	1323	1313
LCOE; [¢/kWh]	6.98–9.05	6.99–9.06	7.00–9.07	7.06–9.15	7.11–9.22
Net capital cost; [M$]	437.2–626.8	438.4–628.5	439.5–630.1	443.0–635.1	446.4–640.0
2-Axis tracking mode					
System nameplate size; [MWp]	190.5	190.8	191.0	192.5	194
Annual energy; [GWh]	265.7	265.6	265.6	265.6	265.5
Capacity factor; [%]	15.6	15.6	15.6	15.5	15.3
Energy yield; [kWh/kWp]	1369	1367	1364	1354	1343
LCOE; [¢/kWh]	7.53–9.63	7.57–9.68	7.60–9.72	7.66–9.80	7.71–9.87
Net capital cost; [M$]	455.0–648.2	457.4–651.6	459.7–654.9	462.7–659.1	465.6–663.3

Table 6
Governorate, suitable available and required areas for solar installations in the cities in Gaza Strip.

		City					Total
		Jabalia	Gaza	Deir-Albalah	Khan Yunis	Rafah	
Governorate area		61,000,000	74,000,000	58,000,000	108,000,000	64,000,000	365,000,000
Total suitable rooftop area		2,974,900	4,273,400	2,821,200	4,106,300	2,562,500	16,738,300
1st Scenario	Fixed	1,332,000	1,314,840	1,302,000	1,290,840	1,284,000	6,523,680
	1-Axis	1,008,000	1,002,000	996,000	990,000	984,000	4,980,000
	2-Axis	984,000	978,000	972,000	969,000	966,000	4,869,000
2nd Scenario	Fixed	3,144,000	3,108,000	3,072,000	3,048,000	3,024,000	15,396,000
	1-Axis	2,376,000	2,361,000	2,346,000	2,334,000	2,322,000	11,739,000
	2-Axis	2,328,000	2,310,000	2,292,000	2,286,000	2,280,000	11,496,000

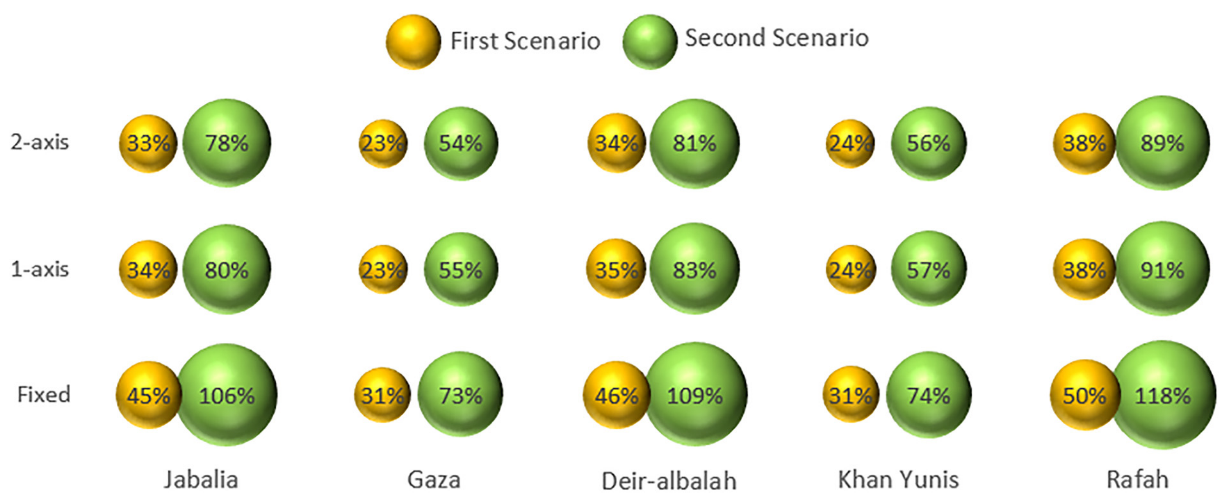

Fig. 11. Comparison of different modes of PV solar plants area as a percentage of areas of the Gaza Strip's cities for the proposed scenarios.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.seta.2018.12.010.

References

[1] Al Mezan Center for Human Rights. The reality of the electricity crisis and its repercussions on the human rights situation in Gaza Strip. Gaza: Studies Unit – Al Mezan; 2016.
[2] Abu-Hafeetha MF. Planning for solar energy as an energy option for Palestine (Master Thesis) Nablus, Palestine: An-Najah National University; 2009.
[3] Naim AN. Potential of Solar Pumping in Palestine. International Water Technology Conference (IWTC), Cairo. 2010. p. 1–11.
[4] Aydi JY. The solar energy potential of Gaza strip. Global J Res 2011;11(7):47–51.
[5] Hamed TA, Flamm H, Isma'il L. Assessing renewable energy potential in Palestine. Am Sol Energy Soc 2013:1–6.
[6] Juaidi A, Montoya FG, Ibrik Imad H, Manzano-Agugliaro F. An overview of renewable energy potential in Palestine. Renew Sustain Energy Rev 2016;65:943–60.
[7] Elnaggar M, Edwan E, Ritter M. Wind energy potential of Gaza using small wind turbines: a feasibility study. Energies 2017;10(1229):1–13.
[8] Ismail M, Moghavvemi M, Mahlia T. Energy trends in Palestinian territories of West Bank and Gaza Strip: possibilities for reducing the reliance on external energy sources. Renew Sustain Energy Rev 2013;28:117–29.
[9] A. Muhaisen, The energy problem in Gaza Strip and its potential solution, Energy and environmental protection in sustainable development, ICEEP 2007, Hebron-Palestine, 8-9 May 2007. www.PPU.EDU/ICEEP.
[10] Droege P, Teichman S, Valdes C. Urban energy transition: renewable strategies for cities and regions, Chapter: Solar for Gaza. Elsevier; 2018. p. 75–84.
[11] Nassar YF, Alsadi S. Economical and environmental feasibility of the renewable energy as a sustainable solution for the electricity crisis in the Gaza Strip. Int J Eng Res Dev 2016;12(3):35–44.
[12] Securing Energy for Development in West Bank and Gaza, summary report, world bank group, June 13, 2017.
[13] http://www.West-Bank-Gaza-PAD-PAD1608-June-30-2017-07102017.pdf.
[14] El-Khozenadar Hala, El-Batta Fady. Solar energy as an alternative to conventional energy in Gaza Strip: Questionnaire based study. An-Najah Univ J Res (N Sc) 2018;32(1).
[15] Mohammed Hijjo, Philipp Bauer, Felix Felgner, Georg Frey, Energy Management Systems for Hospitals in Gaza-Strip, IEEE 2015 Global Humanitarian Technology Conference.
[16] Sean Ong, Clinton Campbell, Paul Denholm, Robert Margolis and Garvin Heath, Land-use requirements for solar power plants in the United States, NREL/TP-6A20-56290 June 2013.
[17] Arne Olson, Doug Allen, Femi Sawyerr, Review of capital costs for generation technologies, Technical Advisory Subcommittee, Energy + Environmental Economics, January 31, 2017.
[18] NREL SAM U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, "System Advisor Model (SAM) —." [Online]. Available: https://sam.nrel.gov/.
[19] Tafadzwa Gurupira, Arnold Rix, PV simulation software comparisons: PVSYST, NREL SAM and PVLIB, 25th Southern African Universities Power Engineering Conference (SAUPEC, 2017) January 30–February 1, 2017, South Africa.
[20] Preliminary results of the population, housing and establishments census 2017, Palestinian Central Bureau of Statistics, Ramallah-Palestine, February 2018.
[21] Gaza Strip Governorates Statistical Yearbook 2014, Palestinian Central Bureau of Statistics, Ramallah-Palestine, November, 2015.