Renewable Energy 36 (2011) 591–594

Contents lists available at ScienceDirect

Renewable Energy

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

Assessment of the potential for distributed photovoltaic electricity production in Israel

Ran Vardimon*

Department of Materials & Interfaces, Weizmann Institute of Science, Rehovot 76100 Israel

ARTICLE INFO

Article history:
Received 6 December 2009
Accepted 23 July 2010

Keywords:
Photovoltaics
Rooftop Area
Potential
Solar radiation
GIS
Geographic Information system

ABSTRACT

A significant portion of Israel's electricity can be produced either by large utility-scale solar power stations or with small, distributed solar power systems. Producing energy in large solar power stations requires vast tracts of land and may necessitate an extensive upgrade of the power grid. Distributed production using photovoltaic panels on rooftops, on the other hand, does not have these drawbacks and takes advantage of the omnipresence of insolation. However, it is not clear if sufficient rooftop area is available. Assessment of available rooftop area in Israel, using a complete set of GIS data covering the country, shows that a yearly electricity production, equivalent to 32% of the national consumption, can be achieved in the long run. Furthermore, a more economic and feasible scenario for the near future is derived, assuming PV installations only on large (>800 m^2) rooftops and with lower panel efficiencies (10%). It is found that even in this case, a substantial 7% of today's national electricity production can be met.

1. Introduction

Photovoltaic (PV) solar electricity is one of the leading approaches to renewable production of electrical energy and, thus, to reducing CO_2 emissions. Solar energy is an obvious source of renewable energy for a country with high average insolation like Israel.

Solar-thermal and PV power plants are being deployed at a growing pace around the world. Still, producing a substantial fraction of any country's electrical energy through these technologies requires significant tracts of land; this could prove irreversibly destructive to Israel's environment, reducing scarce open landscapes and cutting down natural habitats. As will be shown below, producing 10% of Israel's electrical power needs (some 50 TWh yr^{-1}) using PV cells with 16% peak efficiency and a load factor of 1/6 requires a net area of 24 km^2, a considerable area for a country the size of Israel (total area ~20,000 km^2). Also, large centralized renewable electricity producing plants are likely to be located far from the large population centers so that investment in infrastructure for transporting the electricity would be necessary. A long distance between the power plant and the consumers also means higher transmission losses.

PV, as any solar technology, offers an opportunity to exploit the dispersed nature of solar energy and to create a spatially distributed system for electricity production. Production units can be small and located on top of residential buildings. Larger systems can be located on top of commercial or industrial buildings. Rooftops provide free available area, eliminating the need to use extra land area, and since electricity is generated close to the consumer, transmission loss is minimal. Another advantage – which might be significant – is that placing panels on a building's rooftop can decrease the solar heating of the building [1,2].

An important question is whether enough roof area exists for producing a significant amount of electricity. To address this question data compiled by the Israeli Central Bureau of Statistics was used. Aerial orthophotos (planimetrically corrected aerial photographs) were analyzed and used to calculate the total rooftop area in Israel. Typical solar panel efficiencies and local insolation data were obtained. These sets of data allowed calculating the potential of distributed PV production in Israel and comparing it to the total electricity consumption.

Previous works [3–5] have shown that GIS data can be used to assess rooftop area, and that such assessments can be scaled up, for example, by a statistical relation between rooftop area and population density [6]. In contrast to those, the calculations done here are based on *a complete GIS dataset of the whole country*, and, thus, the building areas presented here are highly accurate.

2. Solar radiation in Israel

Solar intensity varies with geographical location, the season, time of day, and weather conditions. However, monthly and yearly averages of local radiation are relatively stable. Values of yearly

* Tel.: +972 8 9346338.
E-mail address: ran.vardimon@weizmann.ac.il.

0960-1481/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.renene.2010.07.030

Table 1
Yearly Insolation measured on a horizontal surface in kWh m^{-2} yr^{-1}.

	Global	Diffuse
Mitzpe Ramon	2190	589
Eilat	2122	582
Sde Boker	2089	544
Arad	2053	560
Beersheba	2043	629
Jerusalem	1991	590
Besor	1985	636
Sedom	1982	661
Beit Dagan	1901	593
Haifa	1883	583

insolation measured by the Israeli Meteorological Service at various sites in Israel are presented in Table 1. The measurements took place over a three-year period between 2004–2006.

3. PV electricity output

Commercial PV panels are rated in kW_p (kilowatt peak) units. This rating represents the DC power output of a panel under standard test conditions (STC). These conditions define the irradiation and spectrum of the incident light as well as the temperature of the solar cells. Actual output of a solar panel placed outdoors can vary greatly with respect to local conditions such as irradiation and cloud cover. For example, a solar cell placed in Israel can, on average, generate up to twice as much electricity as a similar cell in N. Germany.

When calculating the solar potential, the local conditions should be considered. In other words, there should be a way to convert the panel output under STC to actual energy output over the year. Such simulations have already been done [7] for five major cities in Israel and are shown in Fig. 1. The results show a ~25% efficiency loss compared to global insolation values. Similar losses have been reported for other locations [8].

The mean DC output (E_{DC}) is 1460 kWh kW_p^{-1} yr^{-1} (i.e., averaged over a 24 h day the panel will generate 4 h of peak power). This figure will serve us as a nationwide average for the following calculations and should hold as a good approximation as yearly insolation results vary only slightly between locations (up to ±8%).

The next step is to estimate the yearly solar yield per unit area. This value depends on the efficiency of the solar panel that is being used. We will take $\eta = 16\%$ for an efficiency value of a (relatively high efficiency) commercial panel. Efficiency is measured under STC, where incident light intensity is $I_{STC} = 1$ kW m^{-2}. Thus, a 1 m^2 panel with the above efficiency will, under STC, produce 0.16 kW_p.

Connecting the solar panel to the electricity grid requires converting the output to AC. Conversion losses are ~10%, accounting for mean inverter efficiency [9] (92%) and wiring losses (1–2%) stated by a local installer [10], yielding $\eta_{AC} = 90\%$. The total solar yield per unit area E_{AC} can now be calculated:

$$E_{AC} = E_{DC} \cdot I_{STC} \cdot \eta \cdot \eta_{AC}$$

Table 2 summarizes the parameters used for calculating the final AC yearly energy output per unit area. Comparing the energy output to mean yearly insolation shows that the total efficiency of converting sun light to electricity is 10%.

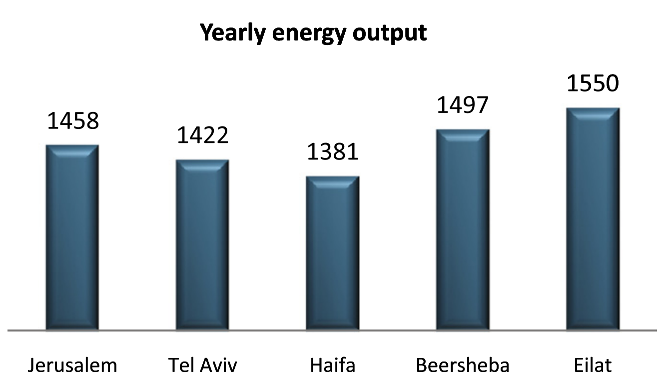

Fig. 1. DC electrical power output of a horizontally inclined solar panel in five major cities in Israel (in kWh kW_p^{-1} yr^{-1}).

4. Available rooftop area

In order to estimate the available area on rooftops in Israel, calculations of rooftop areas were obtained from the Israeli Central Bureau of Statistics. Some more detailed analysis on the same data was performed, in cooperation with the Land Development Authority of Jewish National Fund ("Keren Kayemet le-Israel"). All calculations were performed using a Geographic Information System (GIS) data set, which was constructed by the Survey of Israel (updated up to 2007). Orthophotos covering all towns in the country were analyzed by photogrammetric means to bound all buildings with polygons. The data set, consisting of some 1,200,000 buildings, covers all of Israel. Furthermore, all buildings were classified by purpose (commercial, industrial, etc.) according to governmental surveys. Fig. 2 shows an example of polygon bounding of buildings in a residential area.

Rooftop areas were summed up by building type, by size, by town and nationwide, using ArcGIS software. Only buildings from seven categories, which seemed suitable for solar system installations, were analyzed and the results can be seen in Table 3. The "Residential" category includes residential houses, buildings, and also partially residential ones (e.g. including commercial floors).

Since rooftops generally contain all sorts of structures and equipment (such as HVAC: Heating, Ventilating and Air Conditioning), the available flat, unshaded rooftop area required for PV installations is limited. In this respect, Israel is a unique case because of the abundance of solar water-heaters on most residential rooftops. Although water-heaters are an excellent example for exploiting the sun power they reduce the available space for solar PV panels.

To estimate the adequate rooftop area for PV installations, estimates from a few sources were obtained. A national study in the U.S. [12] estimates that an average 32% of total rooftop area is available for PV installations. According to the study, the average availability changes significantly depending whether the roof is pitched (18%) or flat (65%). A later study [13] reports that in the warmer US climate zones the availability values change slightly: 24% for pitched roofs and 60% for flat roofs. Similar figures were also quoted by a large local Israeli solar system installer [10] from their experience with installations in Israel: For pitched roofs, ~20% of the area is available, while flat roofs have an availability ratio of 50–70%. They also noted that in general, the percentage of rooftop area availability tends to increase with rooftop area and that the availability of large commercial and industrial buildings can reach 90%. Another study in a residential neighborhood in Switzerland shows an even higher rooftop availability of 49% [11].

Table 2
Calculation of AC output per unit area.

		Units	Value
Panel efficiency	η	%	16
DC-AC Conversion efficiency	η_{AC}	%	90
Solar energy input	E_{DC}	kWh kW_p^{-1} yr^{-1}	1462
AC output	E_{AC}	kWh m^{-2} yr^{-1}	210