

# SOLAR PHOTOVOLTAIC POWER PLANTS IN THE CITY

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## Annotation

The article discusses the energy and economic characteristics of solar power plants that can be built in the city. Solar power plants in urban areas can be placed on rooftops, on awnings over parking lots, on awnings over roads, as well as on the walls of multistorey residential and office buildings. It is shown that it is most effective to place solar power plants on the walls of high-rise buildings. Each such station will be able to provide residents with a reduction in energy consumption from the network by a quarter or a third.

**Keywords:** Solar photovoltaic power plant (SPPP), SPPP on the walls of buildings, thermal power plants, energy cost, Dead Sea, Mediterranean Sea

## 1. The status quo

The Electricity Authority presented in 2020 an Overview of the possibility of increasing renewable energy up to 30% of annual consumption [1]. Solar panels are recognized as the main source of renewable electricity for Israel. To achieve the target, 29 terawatt-hours of renewable electricity must be produced in 2030. According to the actual production data in the country, each kilowatt of installed panels produces 1500...1843 kWh per year. According to the review, photovoltaics should therefore have a peak power of about 16,000 MW. On the basis of the data of normative acts of recent years, 9 ... 11 dunams of territory are required for 1 megawatt. (1000 dunams=1 km<sup>2</sup>). To obtain such a capacity of 16,000 MW peak, 160 km<sup>2</sup> of the economic territory of Israel must be allocated. The disadvantage of ground structures is the use of land resources and damage to territories.

According to the Review on the possibility of increasing renewable energy up to 30% of annual consumption [1], building on rooftops or dual-use structures will require an additional cost of about 4 billion shekels.

During the midday hours, solar energy in large quantities can begin to exceed demand or the capacity of the grid to receive it. Then the energy must either be stored for later use, or not used, which leads to a decrease in the efficiency of solar panels.

## 2. Operating Solar photovoltaic power plants (SPPP)

**2.1.** Ground-based SPPPs were built in Israel and in many countries of the world, their total capacity is tens of GW. For example, in Germany, the share of renewable energy reaches 50% (2023), in Israel, about only 10% of the energy consumed. The peak power of solar photovoltaic panels is 0.18 kWp per 1 m<sup>2</sup> of panel area. For greater electrical efficiency of the panels, the panels are installed at an angle to the horizon. In order for the panels not to shade each other, the distances between the rows of panels have to be increased. The territories occupied by the operating SPPP are therefore 2.2...2.5 times larger than the area of the actual panels. On the Figure 1 clearly shows what large distances between the rows of panels must be provided.

**2.2.** Floating SPPPs have been built in Israel and in many countries of the world, their total capacity is already megawatts. Figure 2 shows one of the floating stations in operation. The specific productivity and power of floating stations correspond to ground stations. The advantage of floating SPPP is the non-use of expensive economic territories for solar stations, as well as a some reduction in water evaporation from the surface of the reservoir, which improves the country's water balance.

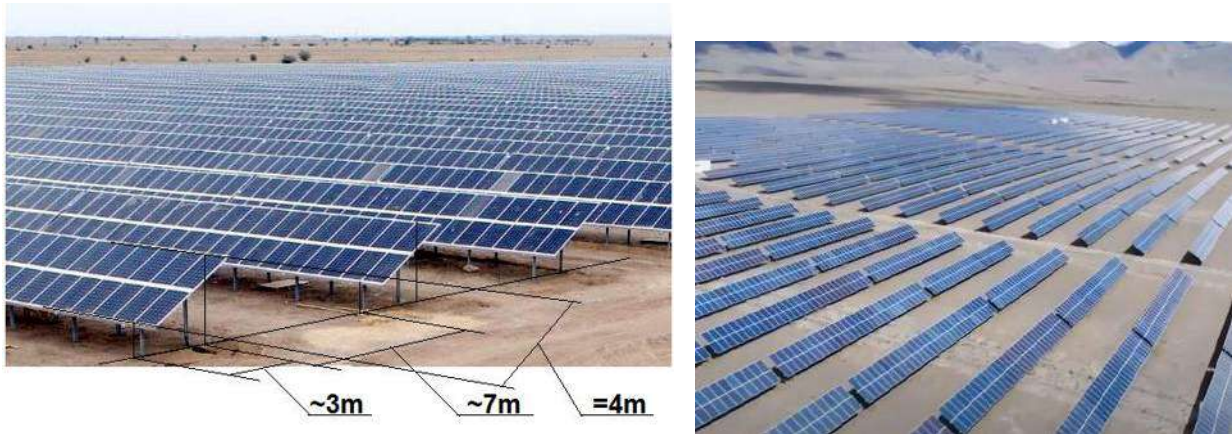


Figure 1



Figure.2

### 3. Proposed Solar Photovoltaic Power Plant Projects

**3.1.** Several projects have been developed for the construction of floating SPPPs in Israel. Pilot projects have been proposed for reservoirs in the Eshkol region, for Lake Kinneret, for the Dead Sea and for the Mediterranean Sea. The projects were considered at the Conference 2021 (Israel Independent Academy for the Advancement of Science). The expected return on investment for different of these water bodies is estimated at 3-6 years.

For example, in Figure 3 shows a project for the deployment of a pilot SPPP in the northern Dead Sea

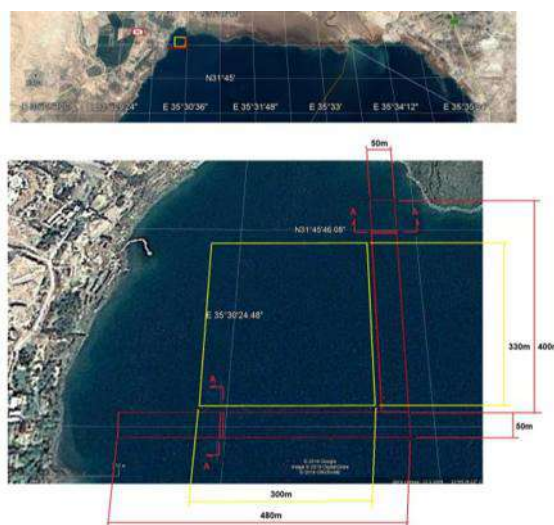


Figure 3

basin. With large-scale construction on the Dead Sea, floating SPPP can be built on an area of 300 ... 500 square km with a capacity of 2 ... 3 GW. In addition, floating stations will be able to reduce the evaporation of water from the surface of the Dead Sea by 300...500 million cubic meters per year.

**3.2. SPPP on the roofs.** According to the Report, this dual use of areas for solar panels (to achieve the goal of a 30% share of renewable energy) will require an additional investment of 4 billion shekels in the construction of anchoring facilities. The use of roofs of low-rise buildings for the installation of SPPP, however, has become quite widespread in Israel and in other countries. For example, see Figure 4.

According to an analysis by the Department of Energy [1], most of the potential of the dual use method will be exhausted in Israel by the middle of the decade, so relying on it alone will not work. While the Department of Energy is proposing to increase the area for building solar panels by tens of thousands of dunams, environmental organizations and the Department of Environmental Protection oppose the move.

In addition, most of the sites in Israel suitable for solar panels are located in the north and south, and not in the demand zones in the center. Also, their cost is high compared to ground facilities, which are located in uninhabited areas.



Figure 4

**3.3. SPPP on canopies over car parks.** (co-authored with Dr. M. Kozlov and Mr. A. Kozlov). Sheds for parking spaces are built in many countries. The cost of such sheds is about \$ 0.15/watt of solar panel power. See Figure 5. For example, in France, a law has been passed requiring the installation of SPPP over parking lots.



Figure 5

A pilot project has been developed for a canopy for a solar power plant over a car park with 320 spaces (48 m wide and 104 m long) near the Netanya railway station. The overall height for vehicles is 2.5 m. The area of the canopy is about 53,000 m<sup>2</sup>, the total installed peak power of 2500 panels will be about 800 kW. Annual energy production will be at least 1200,000 kWh. With a tariff of 0.19 NIS / kWh, we have a yield per year of at least \$ 69,000 ( $=0.19 \times 1200,000 / 3.3$ ) per year.

Figure 6 shows the location of parking lots near Netanya railway station: the green boxes are the existing car parks and the red box is the possible proposed parking.

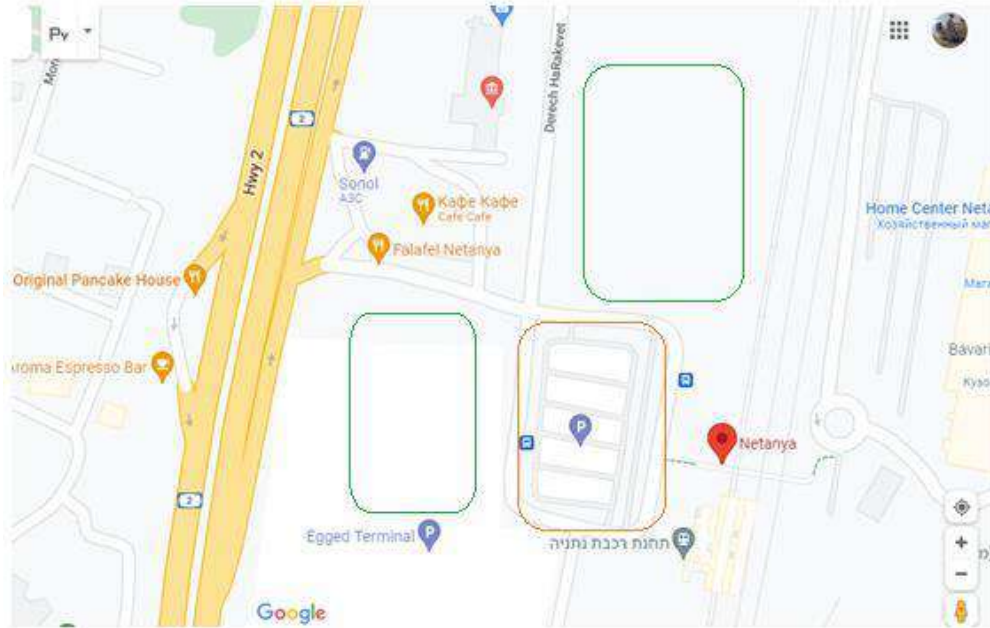


Figure 6

The estimated cost of materials, labor and equipment will be about \$ 300,000 and the payback will be no more than 4 years.

The initial investment for the development of a pilot project, approvals, geological surveys and other preparatory work can presumably amount to \$ 10...20 thousand and can be specified during the development of the Business Plan.

Figure 7 shows the placement of cars in part of the proposed parking area.

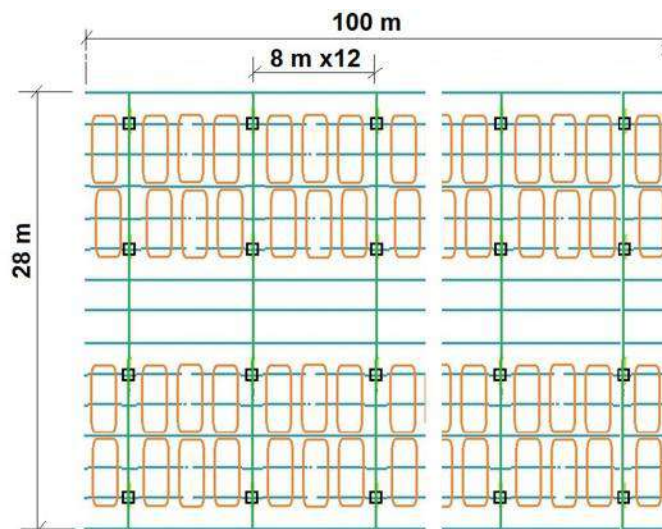


Figure 7

**3.4. SPPP on canopies over highways** (co-authored with Dr. M. Kozlov and Mr. A. Kozlov). We propose to use the space above the highways and install canopies over them, on which to place solar photovoltaic power plants. Israel has over 20,000 kilometers of highways. The average width of many roads is 15 meters, the total area of all solar canopies can be about 300 sq. km. It is advisable to place solar panels horizontally and close to each other in order to more rationally use the territory of the sheds. The area of the actual solar panels can be at least 200 sq. km (canopies are not provided over the intersections). Modern solar panels have a peak power of  $0.18 \text{ kW/m}^2$ , so the total power of the panels on the canopies can reach 36 GW ( $= 0.18 * 200\,000\,000$ ). This is almost twice the installed capacity (16 GW in 2023). power plants of the domestic power industry



Figure 8

According to the Report Estimating the Optimum Tilt Angles for South-Facing Surfaces in Palestine [2], horizontal panels produce 1552 kWh per 1 kWp per year. Installation of panels with a slope to the south gives an increase in annual energy by 15...17% of the panel, but the required area for placing the panels is more than 2 times the area of the panels. During the year, solar panels above the country's highways could generate 56 TWh of "green" electricity. ( $=1552*36$ ), which is twice the planned figures for 2030. Below we consider the use of the planned 30% of the amount of "green" energy of 30 TWh per year.

To generate 30 TWh of energy per year, the peak power of the panels should be around 20 GW ( $=30,000 \text{ GWh}/1550 \text{ h}$ ). The cost of the panels is \$ 0.2/W (May 2023), the total cost of the panels will be \$ 4 billion ( $0.2*20,000,000,000$ ).

To convert the direct current at the output of solar panels into alternating current, the total power of the inverters must also be about 20 GW. For example, 28 thousand PCS630 inverters with a capacity of 693 kW each will be required. The cost of such an inverter is about \$32 thousand, the total cost of inverters will be \$ 0.9 billion.

The design of the roadside sheds is similar to the parking lot sheds built in many countries and costs about \$ 0.15/watt of solar panel power. The cost of steel structures above the roads will be \$ 3 billion ( $0.15*20,000,000,000$ ). In general, the cost of building a solar power plant over the country's roads could be about \$ 8 billion.

In Israel, the results of the second competitive selection were summed up (January 2021). The results set a record low tariff for solar energy suppliers of NIS 0.1745/kWh = \$ 0.0544/kWh. At the established tariff, the total cost of 30 TWh of green electricity will be \$1.63 billion ( $=0.0544*30$ ). The payback period of the power plant above the roads will be no more than 5 years ( $=8/1.63$ ).

Solar power plants above the roads will also perform the function of protecting the highway from solar radiation, creating comfortable conditions for cars, passengers and for the road surface.

It is proposed to build a pilot project - a section of a solar power plant above a road 24 m wide and 150 m long. The overall height for vehicles is 6 m. The construction of roadside awnings is similar to the parking lot awnings shown above. A pilot solar canopy over the road to accommodate solar panels is shown in Figure 9.

The solar canopy rests on 4 vertical supports. 3 longitudinal trusses are installed on the supports (shown in green). On the longitudinal trusses, transverse trusses 2 are reinforced (shown in blue). The cross trusses are completely covered by solar panels 1 (shown in red).

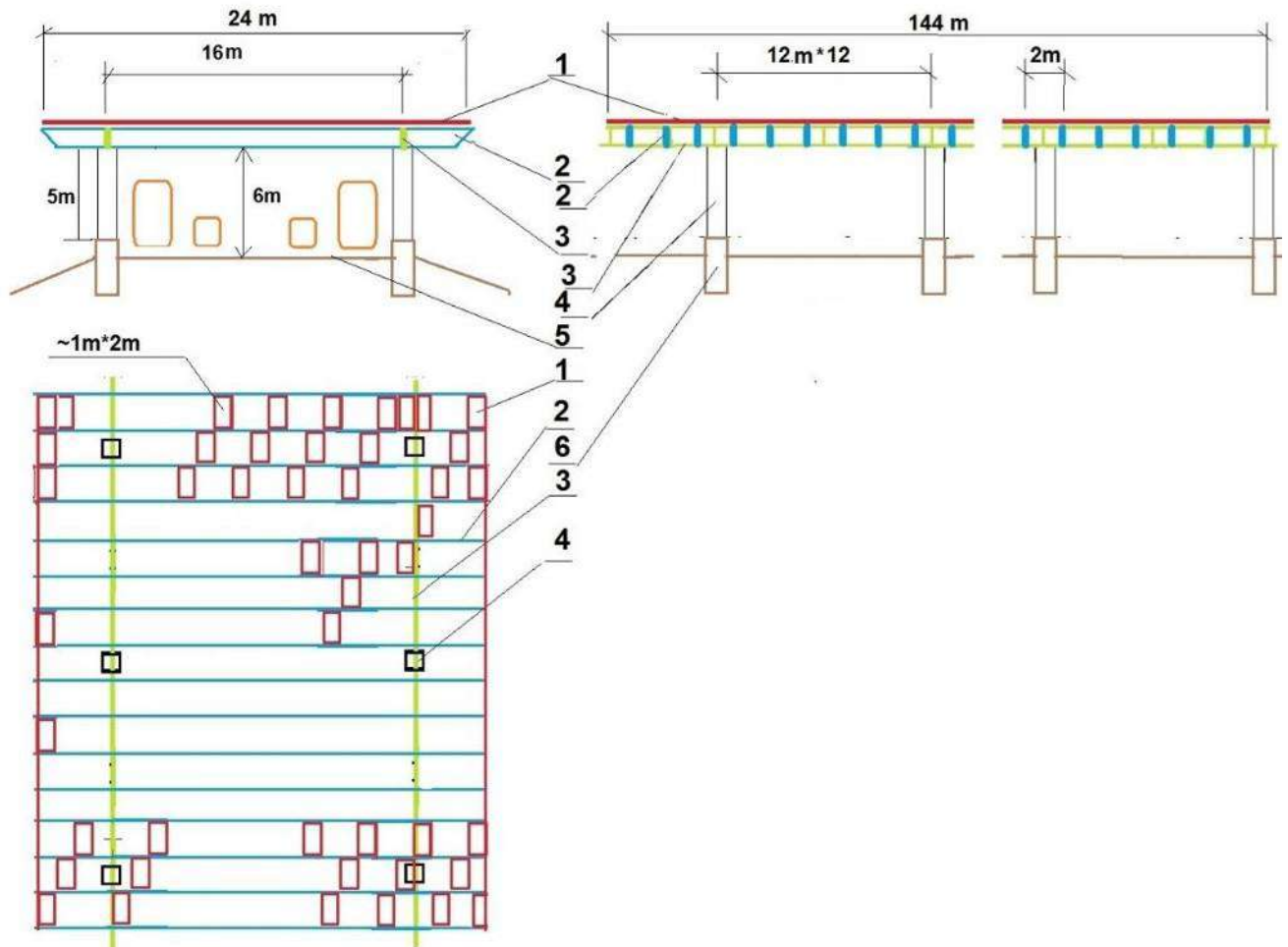


Figure 9.

### 3.5. SPPP on the walls of buildings.

Most of the areas suitable for solar panels in Israel are located in the north and south, while the demand zones are in the center. Dust and dirt can be a real problem for existing solar panels because they interfere with their operation, especially in particularly dusty or desert areas. Pressure washers or tractors with hydraulic brushes are commonly used to clean solar panels, but they use a lot of water. The technology for cleaning and washing windows and vertical glass walls is widely used and is substantially cheaper than tractors for washing sloped rows of solar panels.

Consider the installation of SPPP on the walls of buildings. On Figure 10 shows such a building where the entire wall is covered - lined with solar panels. [10]



Figure 10

Researchers at the Leipzig University of Applied Sciences claim [5] that installing solar panels facing east and/or west will produce more renewable electricity and reduce one of the side effects of traditional solar power farms – an abundance of electricity at noon and a shortage in the morning or afternoon. Their study was published in the August 2022 issue of Smart Energy. When installing panels facing east or west, most of the electricity is generated in the morning and evening. This will reduce the need for electricity storage and therefore save a lot of valuable land needed for electricity generation.

On Figure 11 is a diagram provided by the Leipzig University of Applied Sciences. The diagram below shows a typical solar power generation with traditional orientation (black curve), vertical east-west orientation (green), south orientation (blue), and a combination of orientations. The east-west orientation starts producing electricity many hours earlier and continues to produce energy many hours later than a conventional solar farm. During the midday hours, there is a big drop in performance. The energy received from vertical panels facing south is the area under the blue curve on the graph and the energy received from the panels facing east (or west) is the area below the green curve on the graph. In the first approximation, these areas are equal, therefore we assume that we get almost the same energy from the southern, eastern, and western walls.

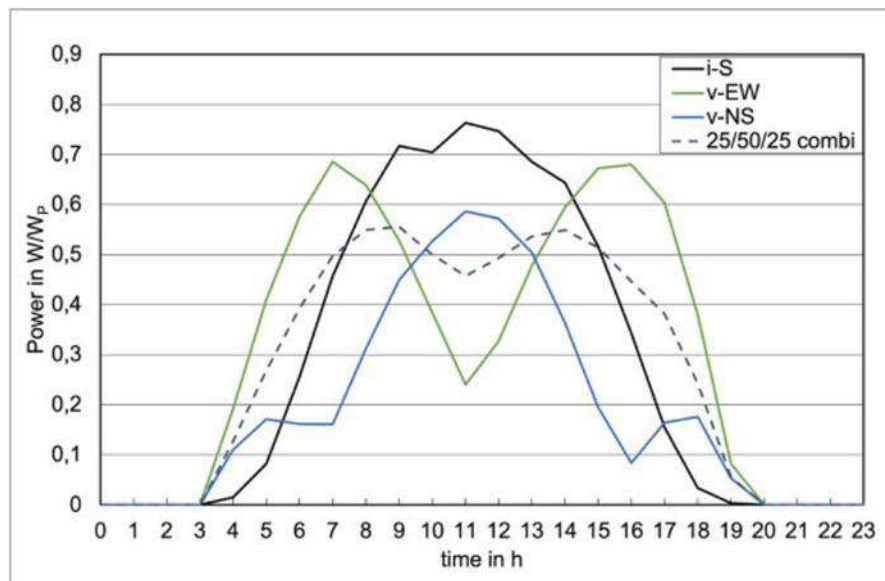


Figure 11

According to the Report [2] (Table 15) for the vertical position of the panels (90° angle in the table) from the panels facing south, the researchers received 5.36 kWh per day on average per year from a 5

kWp panel. Those. on average, the panels deliver 1.07 kWh/kWp/year per day. As shown above, we can roughly assume that we get almost the same energy from the southern, eastern, and western walls. Consider a residential building, which is lined with square tiles, which allows you to visually assess the area of the walls from the photo. See Figure 12. Tiles have a size of 1 m by 1 m (actually a little more).

In the photo we have 2 identical buildings. At the left building in the photo, the western wall is illuminated by the sun, the southern facade is no longer illuminated. At the right building, the eastern wall is illuminated in the morning, and the southern wall in the afternoon. During a sunny day, the sun illuminates 2 walls of each building.

The roof of buildings in Israel is usually occupied by solar water heaters and therefore cannot be used to install solar panels. In the buildings under consideration, the floor height is 3 m, in the building there are 2 walls (lit by the sun) each 20 m long, 6 windows on 2 walls 1 m each. The total area of the walls without windows of each floor is  $114 \text{ m}^2 (= 40 * 3-6)$ . Under the sun, these buildings have 6 floors, the area under the panels is  $684 \text{ m}^2$ .

On the walls on 6 floors (out of 13) you can install 342 conventional panels with a capacity of 0.35 kWp, a total of 120 kWp. As above, we have shown that on average, the panels deliver 1.07 kWh/kWp/year per day. We accept that we receive almost the same energy from the southern, eastern, and western walls. In our buildings with 120 kW peak we can receive 128 kWh on average per day and 46,800 kWh per year.

The average Israeli family consumes 8162 kilowatt-hours per year (2023) [6] In our building, the energy of 46,800 kWh can provide 6 average families.  $(=46,800/8162)$  24 families live on the considered 6 floors; Panels on the walls will be able to reduce by a quarter the electricity consumption of these families from the network.

Higher-rise residential buildings are less shaded and solar panels can be installed on 3 walls and more floors. See Figure 13.



Figure 12



Figure 13

In Figure 13 we have a photo of a group of high-rise residential buildings. The buildings have 19 floors and are located far enough from each other that they do not cover the walls from the sun. On these buildings, solar panels can be installed on 15...16 floors and on 3 walls. Energy from 3 walls is one and a half times more and residents will be able to reduce electricity bills by a third. If... the Hevrat Hashmal company will agree to receive SPPP energy at affordable prices, close to selling prices.

A significant amount of energy can be obtained from the installation of solar panels on high-rise glazed office buildings. The return on investment when placing SPPP on the walls of various buildings and

structures is mainly determined by the prices that Hevrat Hashmal is willing to pay for solar green energy.

**3.6.** About the price of facing buildings with solar panels. The price of solar panels in recent years has been around \$ 0.2 per watt peak. The panels have dimensions, for example, 1\*2 m, power 350 watts peak. The panel costs \$70 and has an area of 2 m<sup>2</sup>, i.e. the price of wall cladding panels is \$ 35 per sq. meter (without the cost of installation work).

The price of external cladding with stone tiles of the facade of buildings under construction is \$ 10.00-12.00 per square meter. [7]

Laying stone tiles on walls costs between \$ 70 and \$ 250 per square meter. [8]

Installing a glass curtain wall on office buildings costs between \$ 2000 and \$ 6000 per sq. meter. Although these glass walls are not load-bearing, they are usually part of a wall system and have a lightweight metal frame such as aluminum. This means that they require careful installation with adjacent structural elements. [9]

So, we see that facing buildings with stone tiles costs about \$ 100 per square meter, cladding buildings with glass packages costs thousands of dollars per square meter. And the price of solar panels for wall cladding is \$ 35 per sq. meter.

#### **4. Findings**

- The Department of Energy proposes to increase the area for the construction of solar panels by tens of thousands of dunams, but environmental organizations and the Ministry of Environmental Protection oppose such use of expensive economic areas.
- The Department of Energy believes that most of the potential of the dual-use method will be exhausted in Israel by the middle of the decade, so relying on it alone will not work.
- The allocation of tens of square kilometers for the construction of ground-based renewable energy facilities (both solar and wind facilities) seems to be an irrational use of expensive economic territories and a violation of the ecology of the Negev or Galan Heights.
- An alternative to ground structures (irrational spending of public funds) and a large reserve for increasing areas for solar panels in the country is the construction of SPPP on the walls of high-rise buildings, as well as on water bodies, for example, in the Dead or Mediterranean Seas. And this is already hundreds of square kilometers suitable for solar panels. The design of high-rise buildings, which provides for immediately facing the building with solar panels (instead of ceramic tiles or glass packages), will significantly reduce the cost of building SPPP.

#### **5. Conclusion**

Submit this article for consideration by specialists from the Ministries of Energy, Construction and Ecology.

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