Economic Evaluation of Renewable Energy Systems, Case Study: an Eco-House Powered by Nano-Crystal PV in New Aswan, Egypt

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Abstract. Based on the tendency of depending on the renewable energy resources in Egypt of the last decades, it is necessary to confirm that the use of solar energy in all applications is an effective energy source. This is driven by advanced technologies such as the use of better and cheaper material, more efficient production processes, increasing efficiencies as well as other conventional systems. Many researches are presented to develop the photovoltaic panels through their power efficiency and reasonable price to fulfil the buildings’ energy requirements. Nanotechnology is used to enhance the properties of the PVs in order to produce more power and increase their useful life. This research presents a design of a Nano-crystal PV system for providing the electrical loads in an eco-house according to its energy requirement. It is found that providing electricity to the eco-house in New Aswan city in the Egyptian south valley using Nano-crystal photovoltaic system is very beneficial and competitive with the other types of conventional energy sources. In addition to the decreasing prices of these systems and their increasing efficiencies, it is maintaining a clean environment for people. The proposed Nano-Crystal PV panels are applied in the eco-house which is designed to be eco-friendly with its context and the life cycle cost of the alternatives energy proposals are compared. The main results prove that the NCPV is economical than others.

Keywords: Renewable Energy, Nano-crystal Photovoltaic, Eco-house, Life Cycle Costing, New Aswan City.

1. Introduction
World will face a global energy crisis due to a decline in the availability of fossil fuel and the dependency on it is not recommended recently. These conventional energy sources will not only be available but also are responsible on the environmental pollution. This has led to an increasing interest in alternate fuel research such as fuel cell technology, solar energy, geothermal energy, and wind which called renewable energy sources [1]. Today, solar energy is expected to play a very important role in meeting energy demands in the near future.
In Egypt, there are many new projects such as those carried out in the new and south valley like Benban Solar Project which has already provided new job opportunities and produced clean and sustainable energy [2]. In addition, the use of nanomaterials in the construction industry should be considered not only for improving their properties and functions but also in the energy conservation [3].

1.1. Methodology
This research applies the Nanotechnology in energy production due to its high efficiency and low cost of the PV third generation type. This Nano-Crystal PV type will apply to power an eco-house at New Aswan city which depends on solar energy and local building materials. Throughout the economical vision, the proposed NCPV will be compared with the conventional PV through their life cycle cost. The final finding of this comparison clarified that the proposed NCPV is economical than others.
2. Energy problems in Egypt

The increase in population (1.9% /year) [4] with concentration on 6.8% of total area of Egypt [5]. The construction sector produced around 30% of solid waste generation and this is considered one of the biggest challenges facing the population cities [6].

The degradation in the crude oil production over the last few years combined with high concerns about the depletion rate of the Egypt’s natural gas reserves presents a clear statement for the important role of renewable energy to meet the growth of electricity demand [7].

2.1 Electricity in Egypt (2007-2017)

In 2007-2008 The electricity consumption in residential (38%), industry (35%), commercial (8%) and governmental (5%), as shown in figure 1. “Buildings reached 58.2% of total energy in Egypt” [8].

![Figure 1. Electricity consumption in Egypt 2008 [8]](image1)

In 2015-2016, electricity consumption in residential (46.9%), industry (24.5%), commercial (12%) and governmental (4.0%) as shown in figure 2. “Buildings reached 62% of total energy demand” [8] which is a real problem in energy consumption in Egypt.

![Figure 2. Electricity consumption, Egypt 2016 [8]](image2)

3. Renewable energy resources

Non-renewable resources are used faster than they can be replaced. Oil, natural gas, and coal are currently abundant and relatively inexpensive, but using them causes air and water pollution, degrades large areas of land, and releases greenhouse gases to the atmosphere. Renewable energy represents an important option for the change in energy mix. [9]. In 2009, renewable energy, mainly hydropower, accounted for 12 per cent of Egypt’s electricity generation. Egypt’s hydropower potential is about 3,664 MW with an estimated energy of 15,300 GWh per annum. [6]. Renewable resources solar, wind and bio-mass energy offer significant potentials, so they are used gradually as shown in figure 3.
3.1. Solar energy
Solar energy is a renewable type of energy with a diversity of applications, decentralized and availability. It will protect the environment from pollution and avoid CO2 and other gases’ emissions. Due to its geographic location, Egypt has sunshine all the year with solar radiation which reaches 6-7 kWh/m2/day [10]. As a result, the new job opportunities for solar energy development and other renewable resources in Egypt are really significant [11].

3.1.1. Photovoltaic system (PV).
PV system converts sunlight directly into electricity, and its system may include an AC/DC inverter, back-up source of energy, battery to store the electricity. On the other hand, the solar energy is not predictable and also the power generation depends on the amount of sunlight. Thus, there is no generated power during nights and overcast conditions. In addition, the conventional PV system has low efficiency which is 17% only [12]. So, the advanced technologies are urgently requested to improve the PV efficiency and reduced its cost.

3.1.2. Building integrated PV (BIPV).
Essentially, BIPV refers to the integration of PV materials into building envelopes. Therefore, providing it with multiple functions such as acting as part of the building structures by replacing traditional building materials and producing electricity on-site. The electricity produced can be partially or fully used to balance the electrical requirements of the indoor energy systems. Thus, mitigating the power supply pressures of the traditional power grids, and further reducing the fossil fuel consumption and greenhouse gas emissions. In fact, BIPV shows a high level of innovation and potential to realize green or zero-energy buildings in the future [13].

3.1.3. Nano PV system (Nanocrystal PV).
The author has mentioned at the previous research [15] that the Nano-crystals are solar cells based on a substrate with a coating of Nano-crystals. This coating is typically based on silicon, CdTe or CIGS and the substrates are generally silicon or various organic conductors (as shown in figure 4). A thin film of Nano-crystals is obtained by a process known as "spin-coating". It made of silicon Nano-crystals, could prove to be cheap, giving them a significant advantage over other approaches to high-efficiency solar cells [16].
Figure 4. The classification of the three generations of solar photovoltaic (PV) cells [14]

Figure 5. Nano 3G PV efficiency and cost [16]

Advanced types of PV panels like Nano-crystal, Perovskite, bio-hybrid and Nano-silicon solar cells have high power efficiency and less environmental pollution. Nano-solar has a carbon footprint of 14 grams of carbon dioxide equivalent per kilo Watt-hour (g CO2 eq/kWh) over the full product life cycle from aluminium to the recycling of the panel after 25 to 30 years. Nano-solar carbon footprint is similar to first solar and has almost 2.8 times fewer emissions than conventional PV crystalline silicon solar modules [15]. Figure 5 shows the efficiency and costs projections for the first, second and third generation of PV technology (Thin films). Nano PV’s (3G) efficiency will be 40 % and the production cost will be below 0.50$/W [16].

4. Case study
This case study is conducted for an eco-house in New Aswan - Egypt. Egyptian people should be encouraged to develop the huge desert areas in Egypt to create new settlements far away the narrow and crowded Nile river valley [15]. The proposed eco-house depends on solar energy to run its
electrical appliances. The average daily solar energy in the south valley is about 6 kWh/m²/day as shown in figure 6, which considered to be a high solar energy input [10].

4.1. Case study data
The case study site is located in the new Aswan city Egypt which has a high solar radiation.

Figure 6. Solar radiation on the Egypt sky kWh/m²/day [15].

Figure 7. Solar radiation on horizontal/ tilted surface and monthly mean values of R.H. [10]

Figure 8. The cloudiness in south valley, Egypt [10].
4.1.1 Solar radiation on new Aswan city. The monthly values of relative humidity, and cloudiness (number of cloudy days per month) in new Aswan city are shown in figures 7, 8. It is clear that the relative humidity increases during winter months and decreases during summer. The maximum number of cloudy days is considered to be 2 days during spring and winter [9].

4.1.2. Proposed eco-house design. An ecological residential building design respects the surround environment by applying the ecological features such as eco-materials, renewable energy, water and waste management. The proposed eco-house is 85 m² (shown in figure 9, 10). According to the ecological strategy, there is no air conditioning units but the weather condition in new Aswan city is too hot in summer and spring seasons, so this proposed eco house used the desert air-conditioning units due to their low electricity consumption and relatively low negative impact on environment and it is worked by cold water [17].

Figure 9. Proposed Eco-house ground floor plan (designed by the researcher)

Figure 10. Proposed Eco-house façade (designed by the researcher)
4.2. PV system design

The eco-houses in New Aswan city are expected to be very simple and do not need large quantities of electrical energy for lighting or operating electric appliances. They are expected to have electrical loads as shown in Table (1).

Table 1. The daily energy load in eco-house, new Aswan (made by the researcher)

| Load                      | No. of units | Winter operating period/day | Summer operating period/day |
|---------------------------|--------------|-----------------------------|-----------------------------|
| DC lamps                  | 2            | 17.00 to 00.00              | 20.00 to 02.00              |
| 15 W Led 5W Led           | 10           |                             |                             |
| Refrigerator AC 100 W     | 1            | 24 h/day                    | 24 h/day                    |
| TV & Receiver DC 80W      | 1            | 17.00 to 23.00              | 17.00 to 00.00              |
| Computer & Printer DC 100W| 1            | 17.00 to 19.00              | 19.00 to 21.00              |
| Washing machine AC 250W   | 1            | 12.00 to 14.00              | 12.00 to 16.00              |
| Electric Fan DC 40W       | 3            | _                           | 06.00 to 14.00              |
| Desert AC 1000W           | 1            | _                           | 14.00 to 00.00              |
| Total Energy (W h/day)    |              | 4,140W                      | 15.600W                     |

The average daily load energy of New Aswan Eco-house = 9.87 kWh/day

4.2.1. Photovoltaic Area

\[
P V \text{ Area} = \frac{E_l}{H \times \eta_{PV} \times TCF \times \eta_{out}} \quad [10]
\]

If the cell temperature is assumed to reach 60°C, then the temperature correction factor (TCF) will be 0.8. Assuming \( \eta_{PV} = 17\% \), \( \eta_{out} = 0.765 \) (as introduced by Buresch, 1983) [19].

\[
P V \text{ Area} = \frac{9.87}{6 \times 0.17 \times 0.8 \times 0.765} = 15.81 \text{ m}^2 \text{ (based on table 1 result)} \quad [2]
\]

\[
\text{Nano-Crystal PV (Area)} = \frac{9870}{6 \times 0.22 \times 0.8 \times 0.765} = 12.22 \text{ m}^2 \quad [3]
\]

PV Peak Power = PV area × Solar Peak Power (1000W) × η PV

PV Peak Power = 15.81 × 1000 × 0.17 = 2,687.7 W
The chosen conventional PV modules are mono-crystalline silicon, 75 W peak power. Thus, 40 modules are used to supply the eco-house with the required energy. The proposed modules are Nano-Crystal PVs, 100 W peak power. Thus, 30 modules are used to supply the eco-house with the required energy. To make up a 9.87 kW PV solar system that needs 10 PV panels, assuming that using 1,000W. Each panel will be about 1.6m x 1m, so at least 16m2 of roof space will be needed. But in case of using Nano-Crystal PV panels, that needs 8 NCPV panels, assuming that using 1,233W. At least 12.22 m2 of roof space will be needed.

4.2.2 Batteries design.

\[
\text{Battery storage} = \frac{N_{CEL}}{\text{DOD} \times \eta_{out}} \quad [18]
\]

DOD: depth of discharge for the batteries

\[
\text{Battery storage} = \frac{9870 \times 2}{0.8 \times 0.765} = 32,255 \text{ Wh}
\]

If a 24 V system is chosen the required Amp. H of batteries = 32,255/24 = 1344 AH

This battery bank can drive the loads for 2 days without any sunshine.

4.2.3 Inverter DC/AC. Total power of AC loads = 100 + 250 + 1000 = 1359 × 1.2 = 1620 W (according to table: 1)

The specifications of inverter will be 1620 W, 24 VDC, and 220 VAC.

4.2.4 PV cost (according to market price). PV cost according to the market price = 9870 w/h × 0.8$ = 7896$

(5)

The initial cost of the PV system = PV array cost + first group of batteries cost + BCC cost + inverter cost + auxiliaries cost = (7896$ × 1.2) + 2000$+500$+400$+200$ = 12,575$

(6)

4.2.5 Nano-Crystal PV cost. Nano-Crystal PV cost according to the market price = 9870 w/h × 0.9$ = 8883$

The initial cost of the PV system = PV array cost + first group of batteries cost + BCC cost + inverter cost + auxiliaries cost = (8883$×1.2) + 2000$+500$+400$+200$ = 13,760$

(7)

Figure 11. Proposed Eco-Houses with NCPV (made by researcher).
4.3. Present worth method (PW)
The PW method requires conversion of all present and future payments to a baseline of today’s costs as shown in the table no.2 taking into account the interest rate is 16% according to the central bank of Egypt [20]. Based on table no. 2 results, alternative no. 2 (Nano Crystal PV system) as shown in figure 11 is more economical than conventional PV system.

The cost of 1 kWh from the PV sys. = 15,054$/90,063.8 = 0.167$/kWh
The cost of 1 kWh from the Nano Crystal PV sys. = 14,110$/108,076.5 = 0.131$/kWh

Table 2. Comparison between two alternatives using the present worth method [20]

| Item                      | Alternative 1 PV Panels | Alternative 2 Proposed NCPV |
|---------------------------|-------------------------|-----------------------------|
| Initial Cost              |                         |                             |
| Initial Cost              | 12,575$                 | 13,760$                     |
| Useful life               | 25 years, i = 16%       | 30 years, i = 16%           |
| PW of Replacement Cost    | 3000$                   | 600$                        |
| P/F, I, n                 | P1 = \( \frac{P}{F} \)  | Every 10 years              |
| P1 (8)                    |                         | P1 = 182.92                 |
| P2 (16)                   |                         | P2 = 55.81                  |
| P3 (24)                   |                         | P3 = 17                     |
| P4 (30 years)             |                         | P4 = 6.9                    |
| Total Replacement         |                         | 262.7$                      |
| Salvage Cost              |                         |                             |
| P/F, I, n                 | 1,600$                  | 3,000$                      |
| P = \( \frac{1.600}{(1+0.16)^{25}} \) | P = \( \frac{3000}{(1+0.16)^{30}} \) |
| (18.64$)                  | (34.94$)                |                             |
| Annual PW of Maintenance & Operation Cost | 200$ | 20$ |
| P = \( \frac{[(1+i)^n-1]}{(1+i)^{n}x} \) | P = \( \frac{[(1+i)^n-1]}{(1+i)^{n}x} \) |
| 9$                        | 121.9$                  |                             |
| N P W                     | 15,054$                 | 14,110$                     |
| Saving                    | 944$                    | -                           |

Governmental electricity tariff of 1 kWh without subsidization equal 1.30 EGP according to the Ministry of electricity and renewable energy, Egypt 2019 [21, 22].
Comparison Result: The Proposed Nano PV System is the economical alternative with cost 0.131$/kWh.

This study shows that the life cycle cost of Nano-Crystal photovoltaic system is less than the conventional PV system for providing an Eco-house unit with the energy supply. In contrast, the cost of the available local electricity with subside is less than NCPV system but this case is not permanent in the nearest future in Egypt.

Conclusions

- South Valley region in Egypt is considered as high potential areas for new communities’ establishment due to their natural resources specially sun radiations.
- Renewable energy is the actual solution to face the future challenges in the energy demand in Egypt specially, solar energy. In addition, it protects environment from CO2 and other green gas emissions which released from fossil fuel energy resources.
- Conventional PV panels have low efficiency compared with the advanced types like Nano-crystal, Perovskite and Bio-hybrid solar cells and Nano-materials which are used in new PV production like TiO, CdTe, and GIGS. Proposed Nano solar energy is the optimum solution to power the building with a high efficiency throughout all seasons and it uses less area on building roof or site land and it self-cleaning system as well.
- The architectural design of eco-house depends mainly on the natural resources such as sun, wind, ground water and local materials. This eco-house is a prototype of residential units which will be repeated in New Aswan City.
- Nano-crystal photovoltaic panels system is an adequate energy generation system for an eco-house in the desert zone where the main services are not available.
- In order to achieve an eco, eco house (economical, ecological house); life cycle cost should be applied throughout all the design and operation phases.
- According to the economical vision; electricity which comes from the public utility is cheap compared with the renewable energy resources, but it isn’t available in the desert zones. So, the proposed energy system used in this zones to generate electricity is very effective particularly when its life cycle cost is competitive with the other types of conventional energy sources.
- On the other hand, the high initial costs, the lack of qualified skilled workers and the difficulty of convincing people to accept the advanced ideas represent the challenges of the sustainable development in Egypt.
- Finally, the public awareness of the importance of renewable energy is highly recommended in our society.

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