Journal of Renewable Energy and Environment

Journal Homepage: www.jree.ir

Materials and Energy Research Center
MERC

**Research Article**

# Sensitivity Analysis for 3E Assessment of BIPV System Performance in Abadan in Southwestern Iran

Sepideh Rahmati Dehkordi [a], Mehdi Jahangiri [b*]

[a] *Department of Architecture and Urbanism, Central Tehran Branch, Islamic Azad University, Tehran, Iran.*
[b] *Department of Mechanical Engineering, Shahrekord Branch, Islamic Azad University, Shahrekord, Iran.*

*PAPER INFO*

*Paper history:*
Received: 16 December 2020
Revised in revised form: 07 February 2021
Scientific Accepted: 16 February 2021
Published: 22 August 2021

*Keywords*:
BIPV,
HOMER,
$CO_2$ Emission,
Photovoltaic,
3E Analysis

*ABSTRACT*

In Iran, due to the problems and constraints of fossil fuels and the need to maximize the use of solar potential, one of the best ways is the application of photovoltaic systems integrated with buildings. Due to the significant dependence of solar cell performance on the availability of radiation, it is necessary for architects to have an accurate assessment of the amount of electricity produced in different conditions. Therefore, in the present work, using HOMER software, the energy-econo-Enviro (3E) potential of a Building Integrated Photovoltaic (BIPV) in Abadan was studied. The effect of slope and azimuth of solar cells as well as cloudiness and system losses were investigated using sensitivity analysis. The results showed that the PV-grid system was the most economical option and after the azimuth angle of zero degree, the positive azimuth angle was the most economical. The results also showed that the slope of 30 degree and the angle of azimuth equal to zero was appropriate, for which the price per kWh of generated electricity was calculated to be \$0.09. For the use of solar cells in the vertical wall of the building, the southwest direction was the most suitable and based on the results, it was suggested that the western wall of the building should be in the form of “inclined PVs with windows”. The authors of this paper hope that the results of the present work can be used by architects and energy decision-makers as a guide in developing the BIPV use in Iran.

https://doi.org/10.30501/jree.2021.262420.1173

## 1. INTRODUCTION

About half of the world’s energy consumption is allocated to buildings, which makes buildings the largest energy consumption source in the world and they are equally important sources of carbon dioxide emissions and play an important role in environmental pollution [1-3]. Therefore, it is necessary for architects to reduce the emission of environmental pollutants by constructing efficient buildings that require less energy for cooling, heating, and lighting [4].

The advantage of integrated photovoltaics over more common non-integrated systems is that the initial cost for the former can become negligible by purchasing cost-effective building materials and deactivating some of BIPV modules’ functions [5]. Compared to other methods that use photovoltaics, some other unique features of BIPV in buildings include shielding against adverse weather conditions, light purification, prevention of heat loss, and non-requirement of space for installation of modules [6]. These advantages make BIPV one of the fastest growing systems in the photovoltaic industry.

To design and employ building elements such as walls, windows, and awnings, designers usually pay much more attention to the geographical latitude of the place and climate, neighborhoods, sizes, etc. For designing and combining photovoltaics with buildings, one should also be mindful of all the necessities and delicacies required for the design process [7]. In case of designing a building based solely on climatic conditions of a place and integrates the photovoltaic system with the building properly to ensure a suitable view, the architect should emphasize the element of residents’ comfort in association with building conditions and make it a self-sufficient building [8-11].

One-third of BIPV projects belong renovation projects while the other two-thirds to new buildings. Half of the BIPV components are used in the facade, one third in the ceilings, and the rest in combination in the roof and facade [12]. In 2019, about 9 % of the global PV and construction markets were allocated to BIPV, which required much more attention to this issue [13]. According to the statistics given in Figure 1, Japan, France, and Italy are the leaders in the use of BIPV. At the end of 2018, the installed BIPV capacity for these countries was 3, 2.7, and 2.5 GW, respectively [14].

According to Figure 2 concerning the BIPV market forecast [15], the investment cost in this sector will reach about 11600 million dollars in 2027. In addition, the commercial and residential sectors will be accounting for a very large share of investments and the industrial sector will have a small share. In Iran and around the world, despite the enactment of laws to

---

*Corresponding Author’s Email: jahangiri.m@iaushk.ac.ir (M. Jahangiri)
URL: https://www.jree.ir/article_135329.html

Please cite this article as: Rahmati Dehkordi, S. and Jahangiri, M., "Sensitivity analysis for 3E assessment of BIPV system performance in Abadan in southwestern Iran", ***Journal of Renewable Energy and Environment (JREE)***, Vol. 9, No. 1, (2022), 1-12. (https://doi.org/10.30501/jree.2021.262420.1173).

reduce buildings' energy waste, unawareness of housing professionals about new technologies and materials and, sometimes, wrong management policies in the field of construction have marginalized the use of BIPV technology in architecture [7]. Therefore, since most of Iran's regions enjoy significant radiation potential [16, 17], the use of BIPV in Iran is quite reasonable.

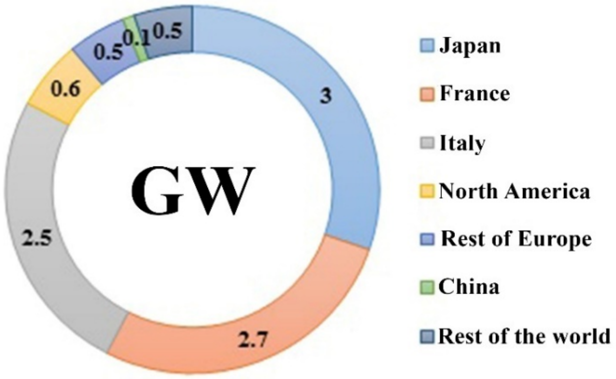


**Figure 1.** Leading countries in the use of BIPV [14]

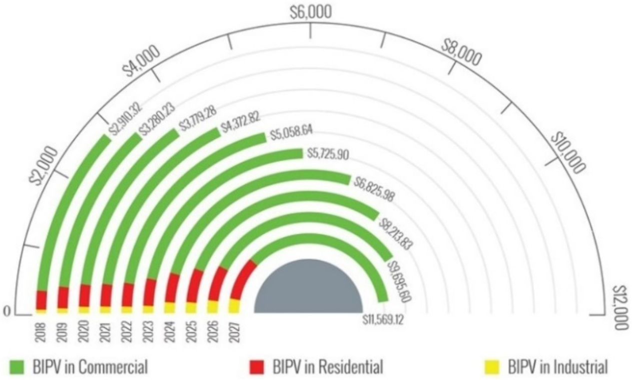


**Figure 2.** BIPV market forecast by 2027 [15]

The following is a review of recent research works on the use of BIPV in different countries. Given that the present work involves simulation, relevant studies have been considered.

Kuehner et al. (2017) [18] explored the possibility of developing BIPV in Switzerland. Hourly energy demand of the buildings was estimated using CitySim Pro software and then, by using HOMER Pro software, a number of procedures including optimization, performance evaluation, etc. were performed for different BIPV capacities. According to the results, full reliance on renewable energy is not yet realistic due to its random nature and that the use of daily and seasonal storage systems is also very important. With a Cost of Energy (COE) estimated at 0.183 $/kWh and a renewable energy fraction of 47 %, a scenario based on the simultaneous production of biomass through a BIPV-wind turbine battery was introduced as the most proper option.

Tadesse (2017) [19] evaluated the design of an off-grid BIPV system and carried out a feasibility analysis on it for the University of Bahir Dar in Ethiopia using HOMER software. The goal was to supply 76 kWh/day of electricity with a peak load of 12 kW. With a total NPC of $176815 and a COE of 0.558 $/kWh as the result of the most economical scenario under consideration, there will be an economic saving of $40185 over 25 years compared to using the national electricity grid.

Aelenei et al. (2018) [20] investigated the energy production potential for a building equipped with 12 kW solar cells on the facade and 12 kW solar cells on the roof in Portugal. They examined the effect of adding batteries while the systems under study were connected to the national electricity grid. The results showed that if a battery with a capacity of 13.5 kWh was used, the best economic result would ensue such that the total Net Present Cost (NPC), rate of return on investment, and the annual electricity sold to the grid were 1416.1 Euros, 8.1 years, and 12737 kWh, respectively.

Ramanan et al. (2019) [21] evaluated the performance of a grid-connected BIPV system for residential buildings in southern India. Using HOMER software, they investigated the effect of the slope of the solar modules and their azimuth angle. The results of the analysis showed that the optimal orientation for the installation of solar modules would be the facade and the eastern wall, while a sloping roof was recommended for the southern wall, because the annual energy rates produced for the 90 degree slope of solar cells in the south, east, and west directions were 1050 kWh, 1198 kWh, and 1150 kWh, respectively.

Zomer et al. (2020) [4] evaluated the performance of a BIPV in Brazil under partial shading from architectural perspectives. Three different PV types with different slopes and azimuth angles were studied. The simulations were performed using PVSyst commercial software. Comparisons between actual measured data and simulations pointed to the good agreement. Among the studied modes, the one with a bus station roof enjoying an installed capacity of 2.44 kW, an annual production of 1.503 kWh/kWp, and a performance factor of 92 % was the most appropriate configuration for the conditions under study.

Ni et al. (2020) [22] used the PVsyst and HOMER software to design and economically configure a BIPV system in China. In the first stage, using PVsyst software, according to the geographical location of the building and the operational characteristics of the load, suitable PV modules and the required area for the modules were selected. Then, using HOMER software, they looked into the total installation and operation costs, battery life, and so on. The results showed that using a system consisting of 6 kW PV cells with a total NPC of $22326 would achieve a solar power generation at a cost of 0.406 $/kWh. For this system, a battery with a lifetime of 20 years based on its performance was considered.

Based on the above findings and other implications, it can be realized that the environmental impact of using BIPV systems has not been studied or done. Therefore, for the first time, the present studied investigated the techno-econo-enviro performance of a BIPV system in Abadan city located in Khuzestan province in southwestern Iran. One-year analyses were performed through HOMER software and sensitivity analysis was applied to effective parameters. Although the present work is a case study, the proposed method can be used anywhere in the world for BIPV analysis, energy simulation, and calculations and performance comparisons of different configurations.

## 2. DIFFERENT TYPES OF BIPV

In the BIPV building, the architect can use six modes to ensure its full integration:"saw-toothed north light roof", "Atrium", "Vertical with windows", "inclined wall with windows", "inclined PVs with windows", and "fixed shadows for walls" for wall and roof [23]. These modes are shown in Figures 3 to 8.

The six modes shown in Figures 3 to 8 and their impact on building performance are briefly described [23]. The skylight on the roof greatly reduces the need for electricity during the day by providing indirect lighting, and if combined with photovoltaics, they can also meet the need for night lighting. In the BIPV building with the aim of integrating photovoltaics with the roof, the architect can design the roof in the form of toothed skylights integrated with photovoltaics or replace translucent photovoltaic panels with glass and skylights and atriums (Figures 3 and 4). In a photovoltaic system integrated with a façade, heat penetration is prevented, electricity is generated, and the view to the outside and the provision of natural light are achieved (Figures 5 and 6). Photovoltaic panels can be used in combination with the building as Shadowing, Louver or Light-shelf (Figures 7 and 8). In this case, by installing sloping and horizontal canopies, there is no direct radiation into the space, which reduces the load of cooling equipment and provides partial electricity required for cooling equipment.


**Figure 3.** Saw-toothed north light roof


**Figure 4.** Atrium


**Figure 5.** Vertical with windows


**Figure 6.** Inclined wall with windows


**Figure 7.** Inclined PVs with windows


**Figure 8.** Fixed shadows

## 3. THE CITY UNDER STUDY

As can be seen in Figure 9, in the hot and dry climate of Abadan, radiation on the walls and ceiling has a great role in increasing the cooling load of the building; therefore, architects must install photovoltaic panels so that the amount of radiation on the surface and the roof of the building would remain low. The purpose of this work is to prevent the penetration of radiation and heat into the building and to generate the electricity needed for cooling [4].

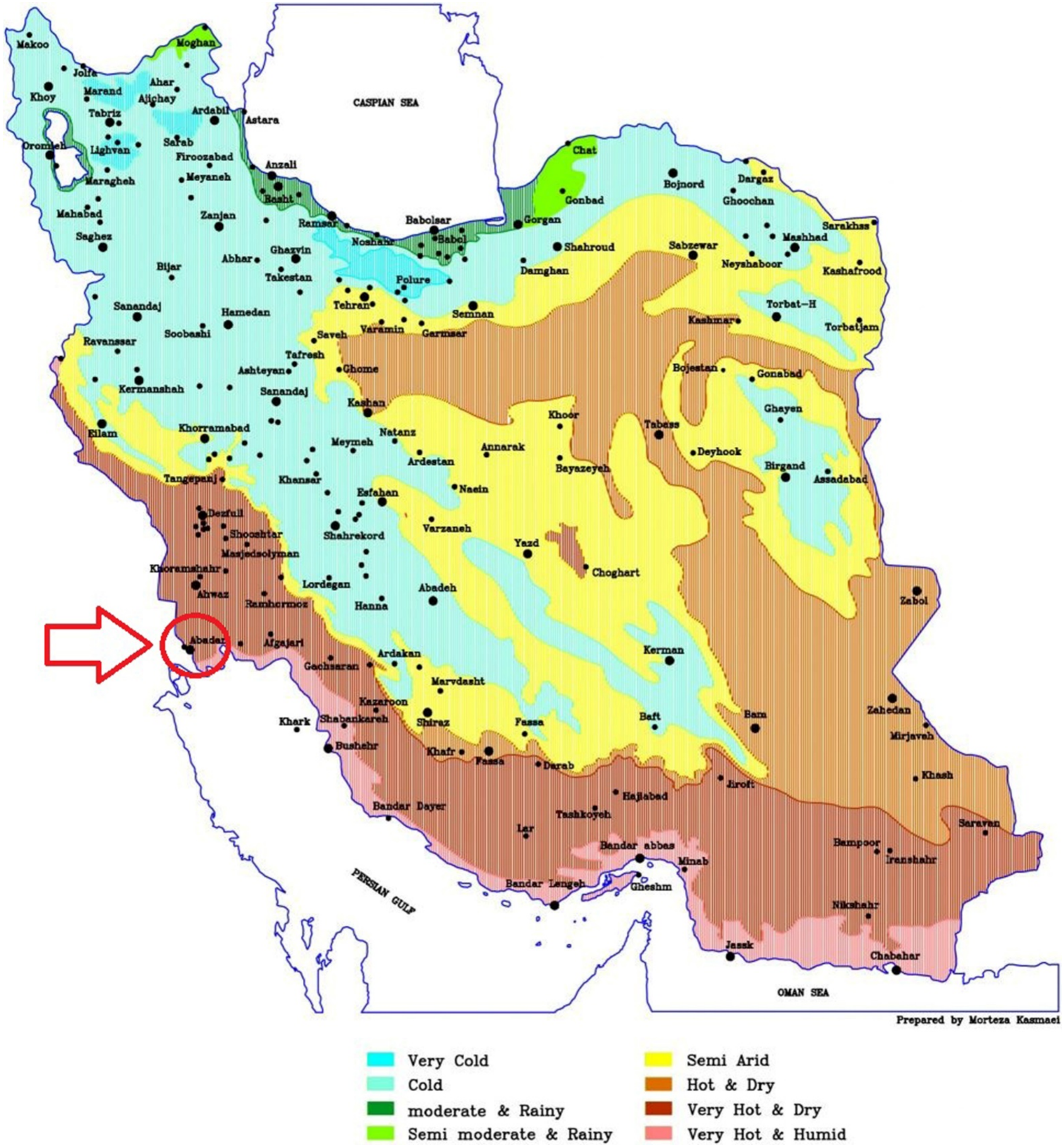


**Figure 9.** Climatic divisions of Iran and Abadan in particular [24]

## 4. METHODOLOGY

Analysis of photovoltaic panels and their smart application in buildings, as if there are no appendages and additional elements in the facade or roof, could illustrate some sensitive issues that must be considered in the building design [6]. Therefore, architects and designers need to be aware of the amount of energy received by PV cells in the study area, PV efficiency, and price of solar electricity per kWh as one of the building materials in different directions and slopes to the sun radiation [4].

Based on the above finding and due to the gap in the knowledge and skills of architects regarding the supply of all or part of the energy required for a BIPV building [6], the present work employed HOMER software to study the techno-econo-enviro in the electricity supply of a 5-storey BIPV in the city of Abadan. The reason behind choosing the present building which involves performing a feasibility study of BIPV construction in Abadan is that with a rise in the number of floors and height of the building, the ratio of facade to roof surface increases and, as a result, facade is a good option for installing photovoltaic cells. In other words, BIPV is more valuable for designing photovoltaic systems in urban centers with high density.

Climate data on solar radiation collected over an average of 20 years [25-27] have been extracted from the NASA site. The schematic of the simulation performed in the present work is shown in Figure 10. According to the figure, the BIPV building under study has the possibility of exchanging electricity with the national electricity grid, which converts the DC electricity generated by solar cells to the AC power consumed by an electric converter. The advantage of connecting the BIPV building under study to the grid power is reducing the cost of the photovoltaic system by selling the surplus electricity to the grid.

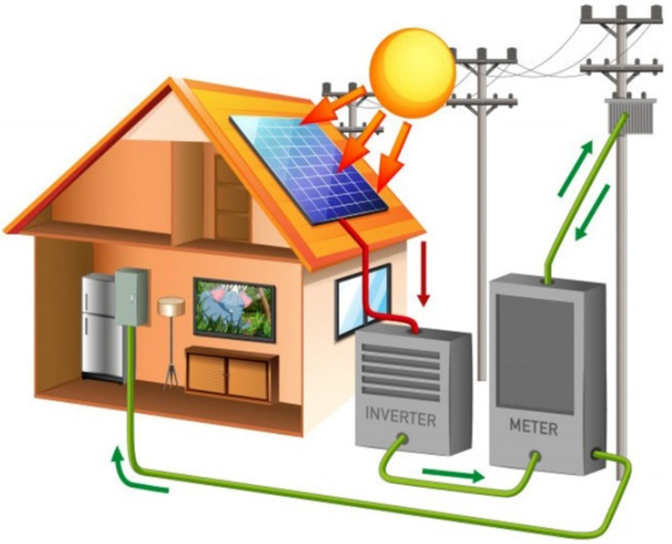


**Figure 10.** Schematic of the simulated system

HOMER software uses the following equations to calculate the amount of electricity generated by photovoltaic cells and to calculate the air clearness index [28-30] by taking the average monthly radiation data and the geographical location of the study area.

$$\mathrm{H_{oh}} = \frac{24 \times 60}{\pi} \mathrm{G_{sc}} \times \mathrm{d_r} \times (\omega_s.\sin\varphi.\sin\delta + \cos\varphi.\cos\delta.\sin\omega_s) \tag{1}$$

$$\mathrm{d_r} = 1 + 0.033 \cos\left(\frac{2\pi n}{365}\right) \tag{2}$$

$$\delta = 0.409 \sin\left(\frac{2\pi n}{365} - 1.35\right) \tag{3}$$

$$\omega_s = \mathrm{Arc}\cos\ (-\tan\varphi.\tan\delta) \tag{4}$$

$$\overline{\mathrm{k_T}} = \frac{\overline{\mathrm{H}}}{\overline{\mathrm{H_{oh}}}} \tag{5}$$

$$\mathrm{P_{pv}} = \mathrm{Y_{pv}} \times \mathrm{f_{pv}} \times \frac{\overline{\mathrm{H_T}}}{\overline{\mathrm{H_{T,STC}}}} \tag{6}$$

Regarding the performance of HOMER software, different configurations including the lowest total NPC should be ranked in the first place based on the total NPC parameter [31, 32]. Given the uncertainty involved, the mentioned software can perform sensitivity analysis for some parameters such as the intensity of radiation reaching the surface of photovoltaic cells as well as the extent of losses such as dust, wiring, shading, etc. Economic calculations in HOMER software are performed through the following equations [33-35].

$$\mathrm{NPC} = \frac{\mathrm{C_{ann,total}}}{\mathrm{CRF\ (i, R_{proj})}} \tag{7}$$

$$\mathrm{CRF} = \frac{\mathrm{i}\,(1+\mathrm{i})^{\mathrm{N}}}{(1+\mathrm{i})^{\mathrm{N}} - 1} \tag{8}$$

$$\mathrm{i} = \frac{\mathrm{i}' - \mathrm{f}}{1 + \mathrm{f}} \tag{9}$$

$$\mathrm{COE} = \frac{\mathrm{C_{ann,total}}}{\mathrm{E_{Load\ served}}} \tag{10}$$

If net electricity is calculated on a monthly basis, HOMER software calculates the total annual energy cost through the following equation [36]:

$$\mathrm{C_{grid.energy}} = \sum_{\mathrm{i}}^{\mathrm{rates}} \sum_{\mathrm{j}}^{12} \begin{cases} \mathrm{E_{net\ grid\ purchases.i.j}} \cdot \mathrm{c_{power.i}} & \text{if } \mathrm{E_{net\ grid\ purchases.i.j}} \geq 0 \\ \mathrm{E_{net\ grid\ purchases.i.j}} \cdot \mathrm{c_{sellback.i}} & \text{if } \mathrm{E_{net\ grid\ purchases.i.j}} < 0 \end{cases} \tag{11}$$

The above equation involves buying/selling electricity from/to the national electricity grid on a monthly basis for a period of one year. The formula has two conditions that are based on whether the purchasing of electricity from the grid is positive (or zero) or negative. The reason for this is that the purchasing price of electricity from the grid is different from the selling price of electricity to the grid.

According to Figures 3 to 8, to investigate the effect of solar cell slope on the generated electricity, six angles of 15, 30, 45, 60, 75, and 90 degrees were considered. Also, since different weather conditions and losses must be considered, in the present work, three values of 50 %, 70 % and 90 % were considered for the derating factor parameter. The azimuth angles for solar cells were considered at -90, -45, 0, 45, and 90 degrees so that the most appropriate orientation could be selected and the potential of different walls be investigated.

## 5. REQUIRED DATA

The performed simulation flowchart is shown in Figure 11. As can be seen, the data required for the simulation are presented as input to the simulation and optimization sections as well as to the sensitivity analysis. Required data include power consumption profile (Figure 12), solar radiation data (Figure 13), constraints and search space (Table 1), and prices and characteristics of the equipment used (Table 1). According to Figure 12, the maximum electrical load required in different months occurs within the duration of 18 PM to 22 PM. The average annual load is 21 kWh/day with a peak value of 2.7 kW. According to Figure 13, the maximum, minimum, and average amounts of radiation were 7.4 kWh/m$^2$-day (June), 3 kWh/m$^2$-day (December), and 5.4 kWh/m$^2$-day, respectively. The average annual air clearness index could be equal to 0.624 based on the geographical location of the studied station (latitude 30.4 E, longitude 48.30 E, and time zone GMT + 03: 30).

Other software inputs in the present work include the annual interest rate of 18 % [37, 38], project lifetime of 25 years [39, 40], emission fines equal to zero [41, 42], and electricity exchange price with the national electricity grids at three off-peak times (23 PM to 8 AM), normal times (8 AM to 16 PM), and peak times (16 PM to 23 PM) being equal to 0.05, 0.07, and 0.12 $/kWh [43, 44], respectively.

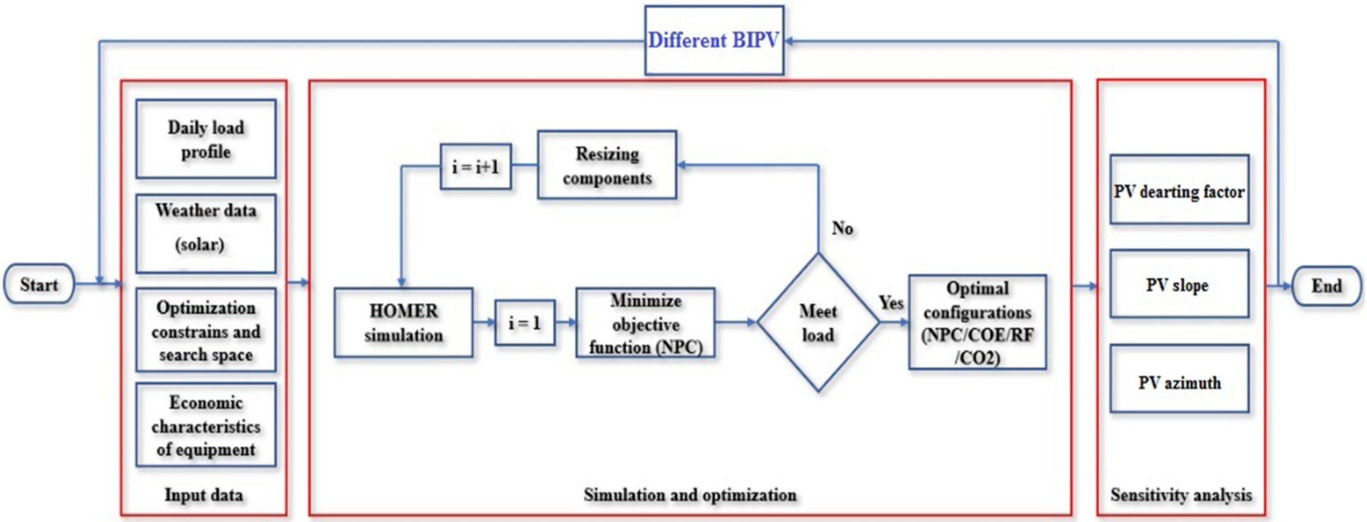


**Figure 11.** Optimization flowchart for the present work by HOMER software

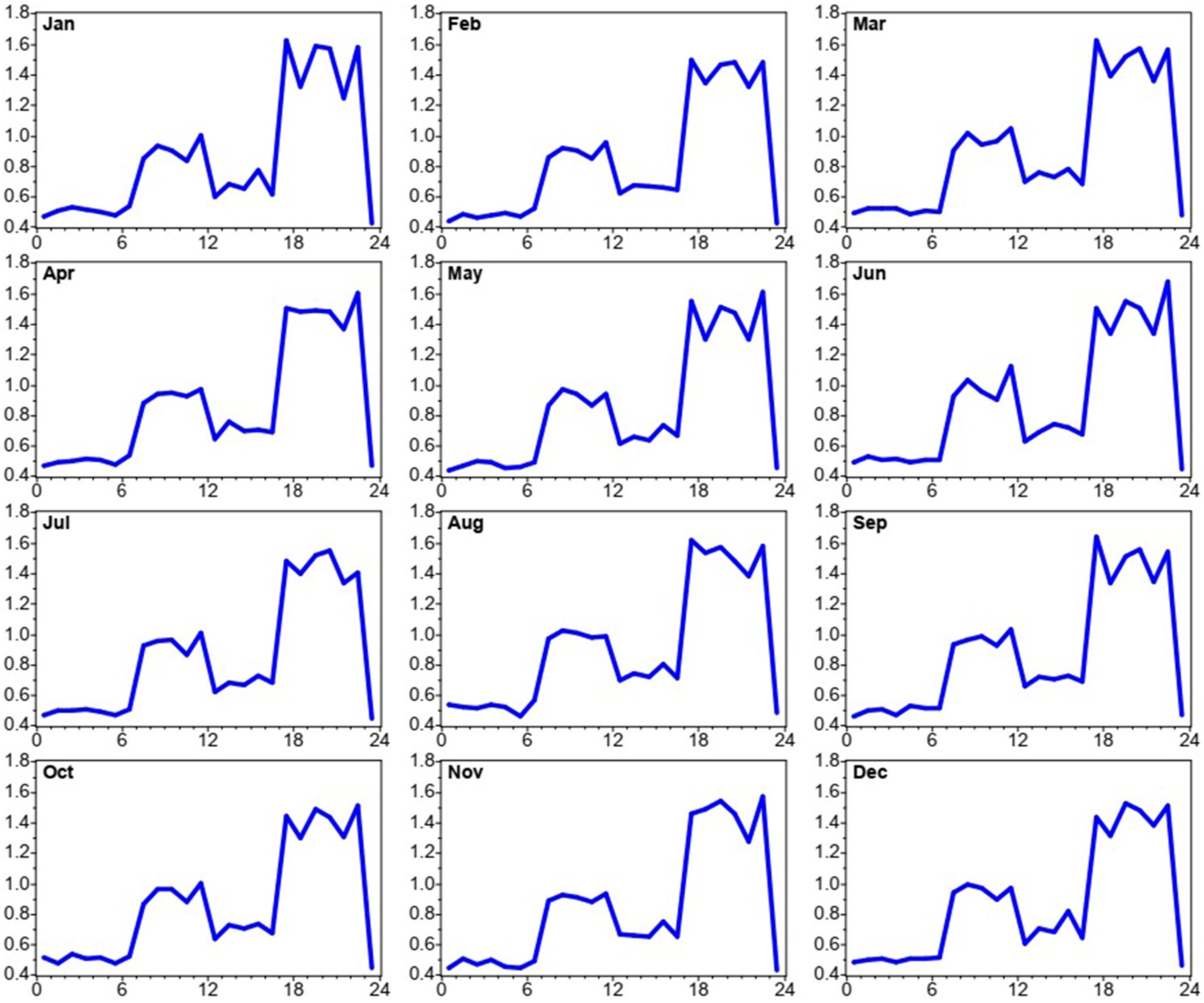


**Figure 12.** Profile of the average required electricity per kW over a year

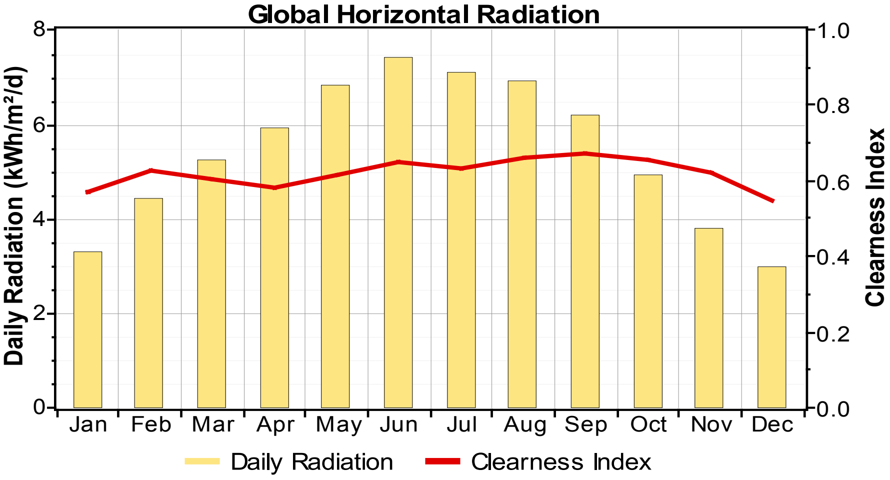


**Figure 13.** Average monthly radiation and air clearness index for Abadan

**Table 1.** Information of the BIPV system under study

| Equipment | Cost ($) | | | Size (kW) | Other information |
|---|---|---|---|---|---|
| | Capital | Replacement | O & M | | |
| PV [45] | 1000 | 1000 | 5 | 5-50 | Lifetime: 25 years<br>Ground reflectance: 20 % |
| Battery T-105 [46] | 174 | 174 | 5 | 0-20 | Nominal Voltage: 6<br>Nominal capacity: 225 Ah |
| Converter [47] | 200 | 200 | 10 | 0-20 | Lifetime: 10 years<br>Efficiency: 90 % |

## 6. RESULTS AND DISCUSSION

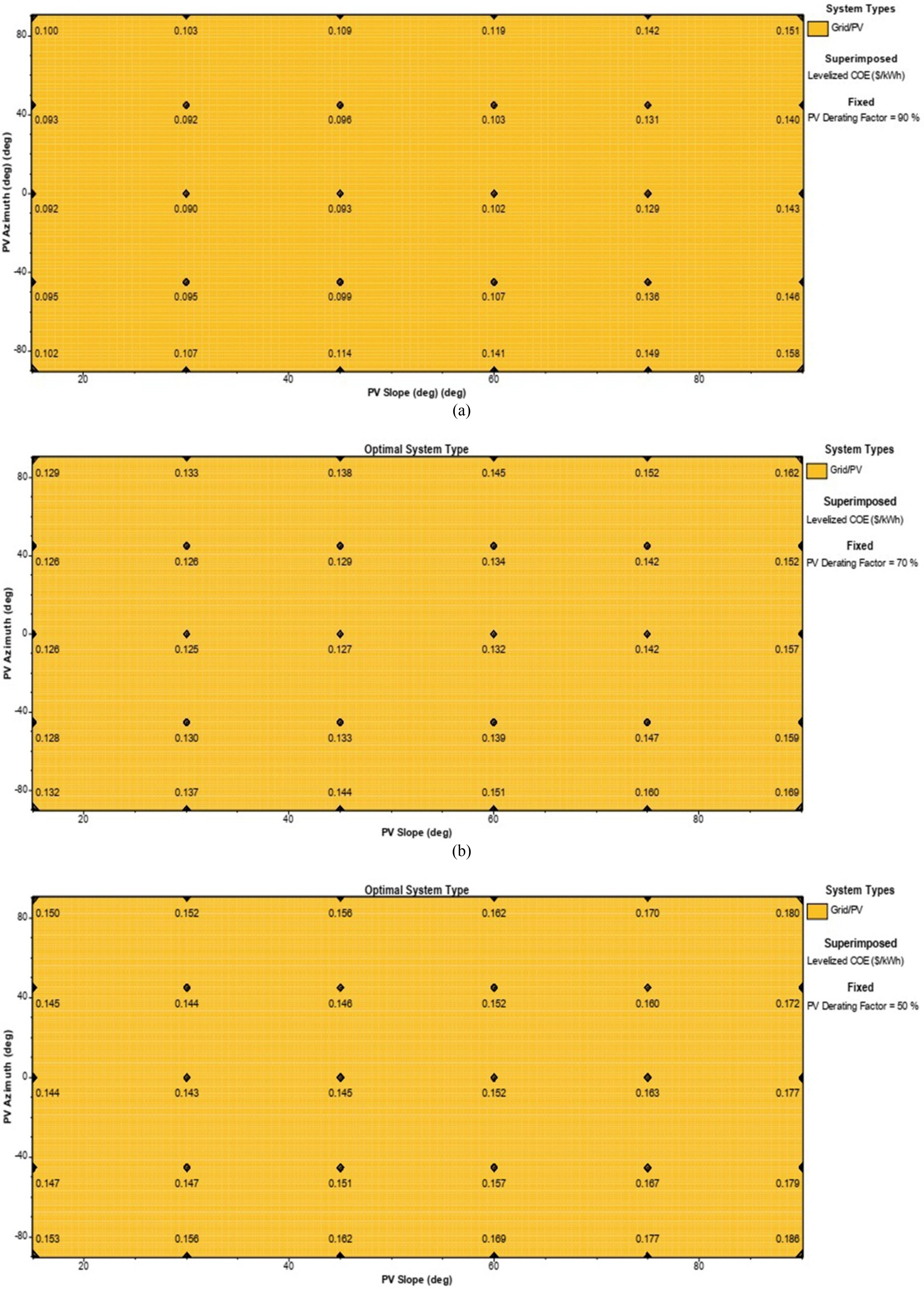
The results of simulations and sensitivity analysis on the COE parameter are shown in Figures 14a to 14c for derating factors of 90 %, 70 % and 50 %, respectively. The results illustrated that for all cases, use of a solar cell-national grid is the most optimal and economical option. Based on the comparison between Figures 14a to 14c, it can be seen that upon increasing the derating factor, which corresponds to greater radiation reaching the surface of PV or less losses in the BIPV system, the amount of COE decreases significantly. The outcome showed that the most suitable direction for the azimuth angle would be the zero degree angle, i.e., the direction of the solar cells to the south. It can also be seen that positive angles of azimuth (orientation of solar cells to the west) have better results than the negative counterpart (orientation of solar cells to the east). This result is justified by the fact that the use of national electricity grid on the west side of the building is more significant than that on the east side.

The lowest price of solar power generated per kWh based on the results for a slope of 30 degree, zero azimuth angle, and derating factor of 90 % was 0.09 $/kWh. This price ranged between the prices of the national electricity tariff at peak load and normal load times and was 25 % less than that at the time of peak load, which is very significant. Also, based on the results for different slopes of solar cells, it is seen that the angle of 30 degree could be more suitable than other angles because it would lead to the lowest amount of COE for the optimal azimuth angle of zero degree. The results of a 15 degree slope of solar cells have values very close to the optimal angle of 30 degree.

For derating factors equal to 90 %, 70 % and 50 %, the minimum COE values were 0.09, 0.125 and 143 $/kWh, respectively. For the vertical placement of solar cells on the wall of the building (slope equal to 90 degree), the most suitable azimuth angle to the southwest (angle + 45 degree) could bring about greater cost effectiveness and the appropriate azimuth angle might be determined better upon further reducing the derating factor. In other words, for less radiation or more cloudy conditions or more system losses, it is recommended the solar cells be placed in the study station to reduce costs to the southwest.

Given that the city under study is very hot and the thermal loss of solar cells is considerable and that Abadan has been facing dust and fine dust problems in recent years, the derating factor is considered equal to 70 % for further research.

Figure 15 shows the amount of net electricity purchasing from the grid. The results demonstrate that the lowest electricity purchased from the grid, equivalent to the highest electricity sales to the grid, was 1915 kWh/year at the azimuth angle of zero and the slope of the solar cells was equal to 30 degree. If solar cells were used as applications in vertical walls, then the optimum mode increased by about 90 % compared to the optimal mode of purchasing power from the grid, i.e., an angle of 30 degree and zero azimuth. Based on Figure 15, it was only at the azimuth angle of zero degree that the 30 degree slope of the solar cells had the lowest power purchase from the grid, and at other azimuth angles, the 15 degree slope was more appropriate. In other words, in a case involving the special form of the building, it is not possible to use solar cells in the south, and it is recommended that the slope of the solar cells to receive the maximum amount of radiation or the minimum net electricity purchase from the grid is 15 degree. The latter mode is equivalent to using the "inclined wall with windows" mode (shown in Figure 6) for the station in question.



(a)

(b)

(c)

**Figure 14.** Sensitivity analysis for the optimal systems on the COE parameter and derating factors of: a) 90 %, b) 70 %, c) 50 %

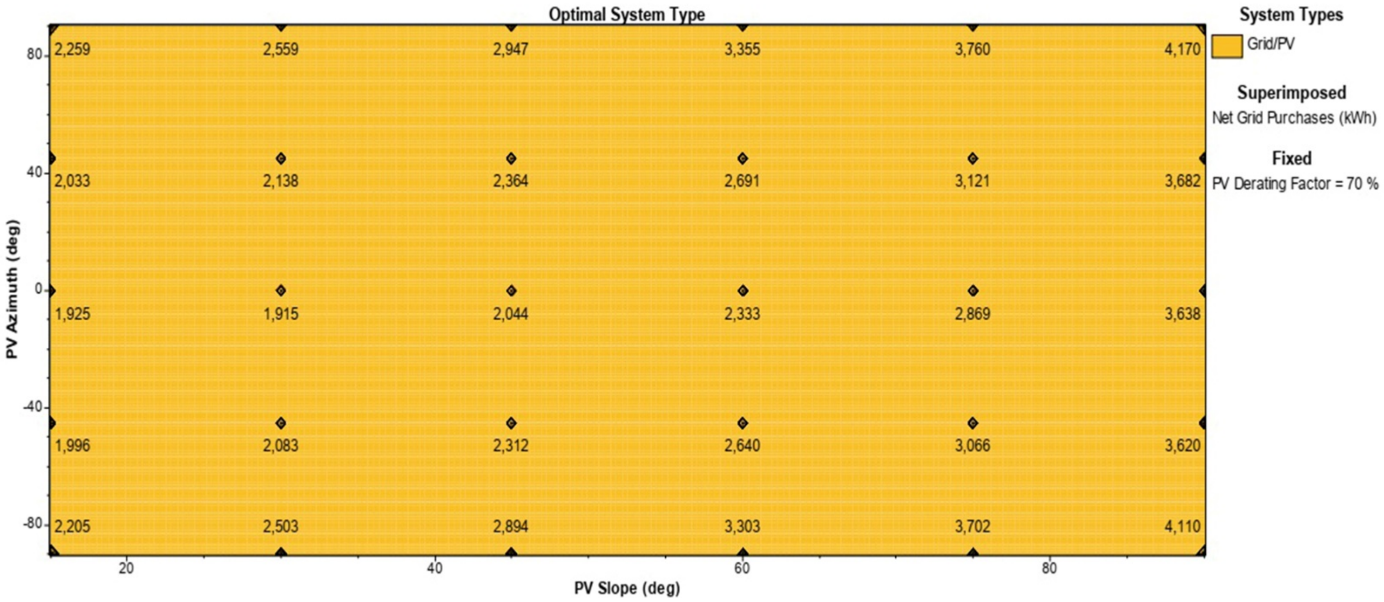


**Figure 15.** Sensitivity analysis for the optimal systems on the net grid purchase parameter and the derating factor of 70 %

Figure 16 shows the amount of electricity generated by solar cells at different slope angles and azimuth angles of -90 to +90. According to the results, the highest amount of electricity generated in the azimuth angle was zero and the slope was 30 degree with an amount of 7634 kWh/year. At azimuth angles of +45 and -45, with respective values of 7622 and 7362 kWh/year, the same slope of 30 degree had the highest amount of electricity produced by solar cells. However, at azimuth angles of +90 and -90 with a slope of 15 degree, the electricity generated by solar cells was about 5 % higher than that at an angle of 30 degree. For the 90 degree slope of the solar cells, i.e., the position of the solar cells on the vertical walls, it can be seen that the angle of azimuth at -90 degree, i.e., the eastern wall, generated much more electricity than that at the angle of azimuth +90 degrees, i.e., the western wall. In other words, it is recommended that the western wall of the building be made inclined for the station under study so that a greater amount of electricity could be generated if solar energy was used.

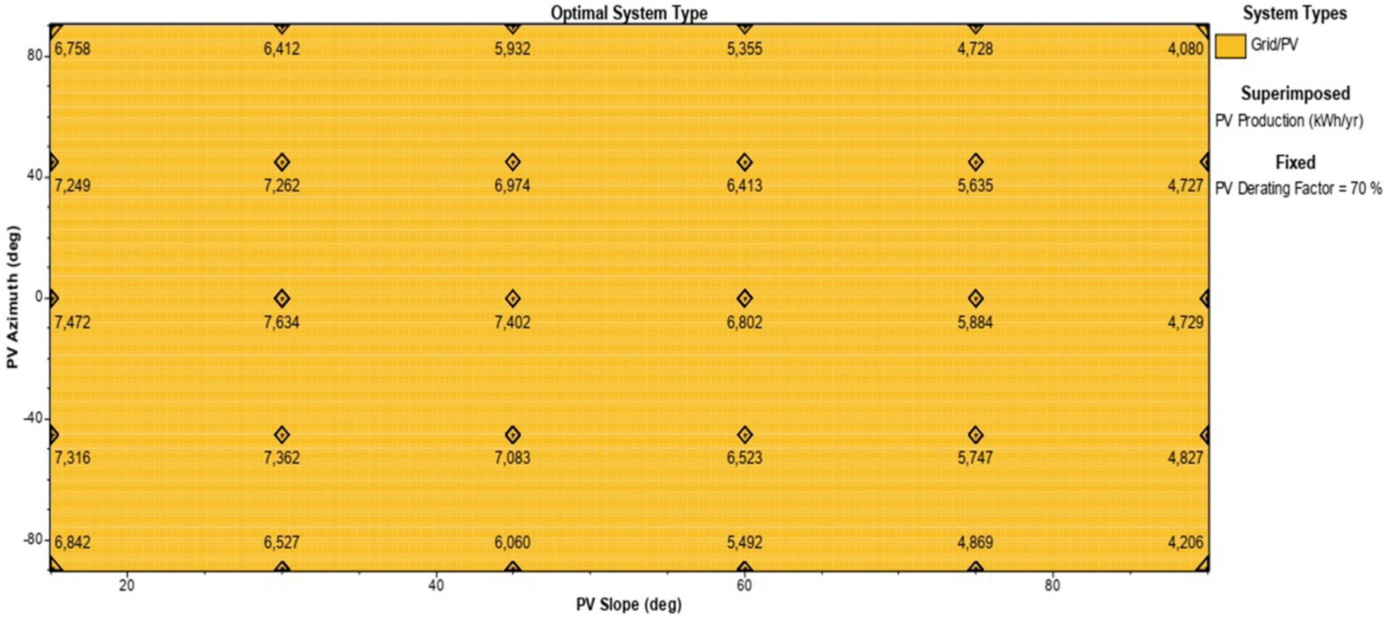


**Figure 16.** Sensitivity analysis for the optimal systems on the PV production parameter, derating factor: 70 %

Figure 17 shows the amount of $CO_2$ emissions for different scenarios with azimuth angle and slope of solar cells. Given that one of the most important advantages of BIPV buildings is their environmental friendliness, it is necessary to study this parameter. According to the findings, the scenarios with the lowest amount of pollutant production included the azimuth angle of zero degree and slope angle of solar cells equal to 30 degree (1210 kg/year emission of pollutants), the azimuth angle of zero degree, and the slope angle of solar cells equal to 15 degree (1217 kg/year pollutant production), and azimuth angle of -45 degree, and the slope angle of solar cells equal to 15 degree (1261 kg/year pollutant production). In general, it can be said that upon an increase in the slope of solar cells and in the azimuth angle, the production of pollutants will increase.

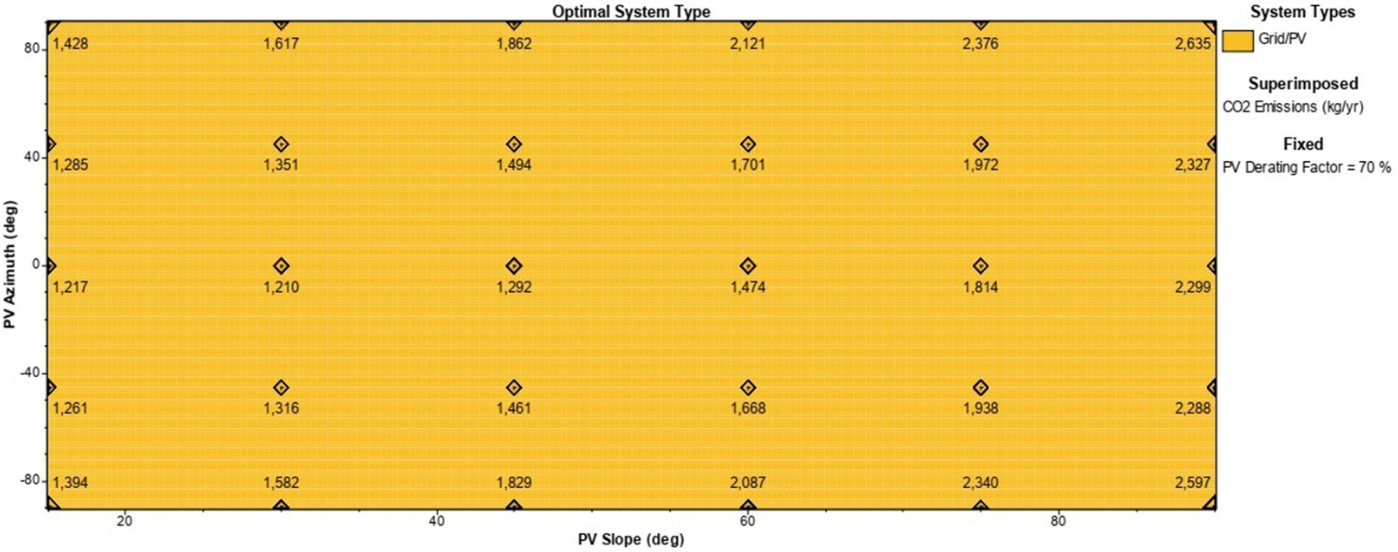


**Figure 17.** Sensitivity analysis for the optimal systems on the $CO_2$ emission parameter and derating factor of 70 %

## 7. CONCLUSIONS

Today, the use of photovoltaic systems in combination with buildings has become of great importance and attractiveness among designers and architects. Therefore, the performance of these buildings and also their design must be correct and flawless so that after the installation of photovoltaics, the photovoltaic system or the building itself would not cause any problems. According to the above, in the present work, for the first time, techno-econo-enviro evaluation and sensitivity analysis on the variable parameters of a BIPV in Abadan were carried out. Sensitivity analysis was performed on PV slope, PV azimuth, and derating factor parameters and their effect on COE, Net grid purchases, PV production, and $CO_2$ emission parameters was investigated. The analysis was performed using HOMER software and the main results are as follows:

- Using solar cell with the national electricity grid was the most economical option in all cases.
- From an economic point of view, zero azimuth angle, positive azimuth angle, and negative azimuth angle were the most appropriate, in order.
- The minimum COE was equal to 0.09 \$/kWh; at a slope of 30 degree, the azimuth angle was zero and the derating factor was equal to 90 %.
- To place solar cells on vertical walls, the southwestern azimuth angle was the most economically appropriate scenario.
- According to the climatic conditions of the study city, the derating factor parameter equal to 70 % is recommended.
- The lowest amount of electricity purchased from the network with a rate of 1915 kWh/year was related to the slope of 30 degree and the azimuth angle of zero.
- If the south of the building was not reachable or operable, a slope of 15 degree would be recommended, being equivalent to using the “inclined wall with windows” mode.
- It is recommended that the western wall of the building be built in the “inclined” mode.
- The minimum pollutant produced due to the use of the national electricity grid was 1210 kg/year.

## 8. ACKNOWLEDGEMENT

The authors would like to thank all the organizations that provided data for this work.

## NOMENCLATURE

| | |
|---|---|
| i | Annual interest rate (%) |
| f | Annual inflation rate (%) |
| i' | Nominal interest rate (%) |
| CRF | Capacity Recovery Factor |
| $R_{proj}$ | Lifetime of project (year) |
| $k_t$ | Clearness index |
| $\overline{H_{T,STC}}$ | Incident radiation on the cell’s surface under standard conditions (1 kW/m$^2$) |
| $G_{sc}$ | Solar constant (0.082 MJ/m$^2$-min) |
| $Y_{PV}$ | Output power of solar cell under standard conditions (kW) |
| $f_{PV}$ | Derating factor (%) |
| $\overline{H_T}$ | Incident radiation on the cell’s surface on a monthly basis (kW/m$^2$) |
| $H_{oh}$ | Extraterrestrial radiation (MJ/m$^2$-day) |
| $P_{PV}$ | Output power of PV cells (kW) |
| $d_r$ | Inverse relative distance earth-sun |
| $C_{ann,total}$ | Total annual cost (\$) |
| H | Monthly average daily radiation on a horizontal plane (MJ/m$^2$-day) |
| $C_{grid, energy}$ | Total annual energy charge (kWh) |
| $E_{net grid purchases}$ | The net grid purchases (grid purchases minus grid sales) (kWh) |
| GMT | Greenwich Mean Time |
| $C_{power}$ | The grid power price (\$/kWh) |
| N | Useful life-time (year) |
| $C_{sell back}$ | The sellback rate (\$/kWh) |
| PV | Photovoltaic |
| NPC | Net Present Cost (\$) |
| COE | Levelized Cost of Electricity (\$/kWh) |
| BIPV | Building Integrated Photovoltaic |
| $E_{load served}$ | Real electrical load by system (kWh/year) |
| **Greek letters** | |
| $\omega_s$ | Sunset hour angle (Radian) |
| n | Number of day during the year |
| $\varphi$ | Latitude (Radian) |
| $\delta$ | Declination of sun (Radian) |

## REFERENCES

1. Kalbasi, R., Izadi, F. and Talebizadehsardari, P., "Improving performance of AHU using exhaust air potential by applying exergy analysis", ***Journal of Thermal Analysis and Calorimetry***, Vol. 139, (2020), 2913-2923. (https://doi.org/10.1007/s10973-019-09198-1).
2. Li, Z., Du, C., Ahmadi, D., Kalbasi, R. and Rostami, S., "Numerical modeling of a hybrid PCM‑based wall for energy usage reduction in the warmest and coldest months", ***Journal of Thermal Analysis and Calorimetry***, Vol. 144, (2020), 1985-1998. (https://doi.org/10.1007/s10973-020-09861-y).
3. Nariman, A., Kalbasi, R. and Rostami, S., "Sensitivity of AHU power consumption to PCM implementation in the wall-considering the solar

radiation", ***Journal of Thermal Analysis and Calorimetry***, Vol. 143, (2020), 2789-2800. (https://doi.org/10.1007/s10973-020-10068-4).

4. Zomer, C., Custódio, I., Antoniolli, A. and Rüther, R., "Performance assessment of partially shaded building-integrated photovoltaic (BIPV) systems in a positive-energy solar energy laboratory building: Architecture perspectives", ***Solar Energy***, Vol. 211, (2020), 879-896. (https://doi.org/10.1016/j.solener.2020.10.026).
5. Building Integrated Photovoltaics for Norway. (http://bipvno.no), (Accessed: 27 Nov. 2020).
6. Tabakovic, M., Fechner, H., Van Sark, W., Louwen, A., Georghiou, G., Makrides, G., Loucaidou, E., Ioannidou, M., Weiss, I., Arancon, S. and Betz, S., "Status and outlook for building integrated photovoltaics (BIPV) in relation to educational needs in the BIPV sector", ***Energy Procedia***, Vol. 111, (2017), 993-999. (https://doi.org/10.1016/j.egypro.2017.03.262).
7. Bonomo, P., Chatzipanagi, A. and Frontini, F., "Overview and analysis of current BIPV products: New criteria for supporting the technological transfer in the building sector", ***VITRUVIO-International Journal of Architectural Technology and Sustainability***, Vol. 1, (2015), 67-85. (https://doi.org/10.4995/vitruvio-ijats.2015.4476).
8. Haugjord, A., "Building integrated photovoltaics with thermal energy storage: A techno-economic performance assessment under grid constraints", Master's Thesis, University of Agder, (2020). (https://uia.brage.unit.no/uia-xmlui/bitstream/handle/11250/2679376/Alexander%20Haugjord.pdf?sequence=1).
9. Kalbasi, R., Shahsavar, A. and Afrand, M., "Incorporating novel heat recovery units into an AHU for energy demand reduction-exergy analysis" ***Journal of Thermal Analysis and Calorimetry***, Vol. 139, (2020), 2821-2830. (https://doi.org/10.1007/s10973-019-09060-4).
10. Nguyen, Q., Naghieh, A., Kalbasi, R., Akbari, M., Karimipour, A. and Tlili, I., "Efficacy of incorporating PCMs into the commercial wall on the energy-saving annual thermal analysis", ***Journal of Thermal Analysis and Calorimetry***, Vol. 143, (2020), 2179-2187. (https://doi.org/10.1007/s10973-020-09713-9).
11. Kalbasi, R., Shahsavar, A. and Afrand, M., "Reducing AHU energy consumption by a new layout of using heat recovery units", ***Journal of Thermal Analysis and Calorimetry***, Vol. 139, (2020), 2811-2820. (https://doi.org/10.1007/s10973-019-09070-2).
12. Delponte, E., Marchi, F., Frontini, F., Polo, C., Fath, K. and Batey, M., "BIPV in EU28, from niche to mass market: an assessment of current projects and the potential for growth through product innovation", ***Proceedings of 31st European Photovoltaic Solar Energy Conference Exhibition***, (2015), 3046-3050. (https://doi.org/10.4229/EUPVSEC20152015-7DO.15.4).
13. BIPV market and stakeholderanalysis and needs, PVSites, (http://www.pvsites.eu), (Accessed: 27 Nov. 2020).
14. Updated on BIPV market and stakeholder analysis, BIPV boost, Public reports. (https://bipvboost.eu/public-reports), (Accessed: 27 Nov. 2020).
15. Worldwide BIPV Market, 24-7 press release. (https://www.24-7pressrelease.com/press-release/455396/worldwide-bipv-market-to-reach-57-billion-in-2023-says-new-n-tech-report), (Accessed: 29 Nov. 2020).
16. Jahangiri, M., Ghaderi, R., Haghani, A. and Nematollahi, O., "Finding the best locations for establishment of solar-wind power stations in Middle-East using GIS: A review", ***Renewable and Sustainable Energy Reviews***, Vol. 66, (2016), 38-52. (https://doi.org/10.1016/j.rser.2016.07.069).
17. Kalbasi, R., Jahangiri, M., Nariman, A. and Yari, M., "Optimal design and parametric assessment of grid-connected solar power plants in Iran, a Review", ***Journal of Solar Energy Research***, Vol. 4, (2019), 142-162. (https://doi.org/10.22059/jser.2019.282276.1114).
18. Kuehner, A.L., Mdeihli, N., Coccolo, S., Perera, A.T.D., Mohajeri, N. and Scartezzini, J.L., "Extending building integrated photovoltaics (BIPV) using distributed energy hubs. A case study in Cartigny, Switzerland", ***Energy Procedia***, Vol. 122, (2017), 487-492. (https://doi.org/10.1016/j.egypro.2017.07.299).
19. Tadesse, M., "Design and feasibility analysis of Building Integrated PV (BIPV) system: Case study in Bahir Dar university lecture halls building", ***American Journal of Mechanical Engineering***, Vol. 5, (2017), 24-32. (https://doi.org/10.12691/ajme-5-1-5).
20. Aelenei, D., Lopes, R.A., Aelenei, L. and Gonçalves, H., "Investigating the potential for energy flexibility in an office building with a vertical BIPV and a PV roof system", ***Renewable Energy***, Vol. 137, (2019), 189-197. (https://doi.org/10.1016/j.renene.2018.07.140).
21. Ramanan, P., Kalidasa Murugavel, K., Karthick, A. and Sudhakar, K., "Performance evaluation of building-integrated photovoltaic systems for residential buildings in southern India", ***Building Services Engineering Research and Technology***, Vol. 41, (2019), 492-506. (https://doi.org/10.1177/0143624419881740).
22. Ni, Z., Jiang, J., Cai, X., Hu, L., Shi, G., Cao, H., Lu, W. and Wu, Z., "System design and economic configuration of building integrated photovoltaic", ***Proceedings of 37th European Photovoltaic Solar Energy Conference and Exhibition***, (2020), 1891-1895. (https://www.eupvsec-planner.com/presentations/c49007/system_design_and_economic_configuration_of_building_integrated_photovoltaic.htm).
23. Thomas, R. ed., Photovoltaics and architecture, Taylor & Francis, (2003). (https://www.amazon.com/Photovoltaics-Architecture-Randall-Thomas/dp/0415231825).
24. Climate of Iran, Iran Traveling Center. (https://www.irantravelingcenter.com/climate-of-iran), (Accessed: 24 Nov. 2020).
25. Jahangiri, M., Haghani, A., Heidarian, S., Alidadi Shamsabadi, A. and Pomares, L.M., "Electrification of a tourist village using hybrid renewable energy systems, Sarakhiyeh in Iran", ***Journal of Solar Energy Research***, Vol. 3, (2018), 201-211. (https://jser.ut.ac.ir/article_68643.html).
26. Jahangiri, M., Soulouknga, M.H., Bardei, F.K., Alidadi Shamsabadi, A., Akinlabi, E.T., Sichilalu, S.M. and Mostafaeipour, A., "Techno-econo-environmental optimal operation of grid-wind-solar electricity generation with hydrogen storage system for domestic scale, case study in Chad", ***International Journal of Hydrogen Energy***, Vol. 44, (2019), 28613-28628. (https://doi.org/10.1016/j.ijhydene.2019.09.130).
27. Jahangiri, M., Alidadi Shamsabadi, A., Mostafaeipour, A., Rezaei, M., Yousefi, Y. and Pomares, L.M., "Using fuzzy MCDM technique to find the best location in Qatar for exploiting wind and solar energy to generate hydrogen and electricity", ***International Journal of Hydrogen Energy***, Vol. 45, (2020), 13862-13875. (https://doi.org/10.1016/j.ijhydene.2020.03.101).
28. Jahangiri, M., Nematollahi, O., Haghani, A., Raiesi, H.A. and Alidadi Shamsabadi, A., "An optimization of energy cost of clean hybrid solar-wind power plants in Iran", ***International Journal of Green Energy***, Vol. 16, No. 15, (2019), 1422-1435. (https://doi.org/10.1080/15435075.2019.1671415).
29. Rezaei, M., Khalilpour, K.R. and Jahangiri, M., "Multi-criteria location identification for wind/solar based hydrogen generation: The case of capital cities of a developing country", ***International Journal of Hydrogen Energy***, Vol. 45, (2020), 33151-33168. (https://doi.org/10.1016/j.ijhydene.2020.09.138).
30. Jahangiri, M., Alidadi Shamsabadi, A., Riahi, R., Raeiszadeh, F. and Dehkordi, P.F., "Levelized cost of electricity for wind-solar power systems in Japan, a review", ***Journal of Power Technologies***, Vol. 100, (2020), 188-210. (http://papers.itc.pw.edu.pl/index.php/JPT/article/view/1359).
31. Pahlavan, S., Jahangiri, M., Alidadi Shamsabadi, A. and Rahimi Ariae, A., "Assessment of PV-based CHP system: The effect of heat recovery factor and fuel type", ***Journal of Energy Management and Technology***, Vol. 3, (2019), 40-47. (https://doi.org/10.22109/jemt.2018.137207.1106).
32. Mostafaeipour, A., Jahangiri, M., Haghani, A., Dehshiri, S.J.H., Dehshiri, S.S.H., Sedaghat, A., Saghaei, H., Akinlabi, E.T., Sichilalu, S.M., Chowdhury, M.S. and Techato, K., "Statistical evaluation of using the new generation of wind turbines in South Africa", ***Energy Reports***, Vol. 6, (2020), 2816-2827. (https://doi.org/10.1016/j.egyr.2020.09.035).
33. Jahangiri, M., Rizi, R.A. and Alidadi Shamsabadi, A., "Feasibility study on simultaneous generation of electricity and heat using renewable energies in Zarrin Shahr, Iran", ***Sustainable Cities and Society***, Vol. 38, (2018), 647-661. (https://doi.org/10.1016/j.scs.2018.01.043).
34. Jahangiri, M., Haghani, A., Alidadi Shamsabadi, A., Mostafaeipour, A. and Pomares, L.M., "Feasibility study on the provision of electricity and hydrogen for domestic purposes in the south of Iran using grid-connected renewable energy plants", ***Energy Strategy Reviews***, Vol. 23, (2019), 23-32. (https://doi.org/10.1016/j.esr.2018.12.003).
35. Jahangiri, M., Haghani, A., Mostafaeipour, A., Khosravi, A. and Raeisi, H.A., "Assessment of solar-wind power plants in Afghanistan: A review". ***Renewable and Sustainable Energy Reviews***, Vol. 99, (2019), 169-190. (https://doi.org/10.1016/j.rser.2018.10.003).

36. Mostafaeipour, A., Rezaei, M., Jahangiri, M. and Qolipour, M., "Feasibility analysis of a new tree-shaped wind turbine for urban application: A case study", ***Energy & Environment***, Vol. 31, (2020), 1230-1256 . (https://doi.org/10.1177%2F0958305X19888878).
37. Ebrahimi, S., Jahangiri, M., Raiesi, H.A. and Rahimi Ariae, A., "Optimal planning of on-grid hybrid microgrid for remote island using HOMER software, Kish in Iran", ***International Journal of Energetica***, Vol. 3, (2018), 13-21. (https://doi.org/10.47238/ijeca.v3i2.77).
38. Jahangiri, M., Khosravi, A., Raiesi, H.A. and Mostafaeipour, A., "Analysis of standalone PV-based hybrid systems for power generation in rural area", ***Proceedings of International Conference on Fundamental Research in Electrical Engineering***, (2017), 1-10. (https://civilica.com/doc/672922).
39. Mostafaeipour, A., Sedaghat, A., Hedayatpour, M. and Jahangiri, M., "Location planning for production of bioethanol fuel from agricultural residues in the south of Caspian Sea", ***Environmental Development***, Vol. 33, (2020), 100500. (https://doi.org/10.1016/j.envdev.2020.100500).
40. Vahdatpour, S., Behzadfar, S., Siampour, L., Veisi, E. and Jahangiri, M., "Evaluation of off-grid hybrid renewable systems in the four climate regions of Iran", ***Journal of Renewable Energy and Environment (JREE)***, Vol. 4, (2017), 61-70. (https://doi.org/10.30501/jree.2017.70107).
41. Jahangiri, M., Nematollahi, O., Sedaghat, A. and Saghafian, M., "Techno-economical assessment of renewable energies integrated with fuel cell for off grid electrification: A case study for developing countries", ***Journal of Renewable and Sustainable Energy***, Vol. 7, (2015), 023123. (https://doi.org/10.1063/1.4918592).
42. Zaniani, J.R., Dehkordi, R.H., Bibak, A., Bayat, P. and Jahangiri, M., "Examining the possibility of using solar energy to provide warm water using RETScreen4 software (Case study: Nasr primary school of Pirbalut)", ***Current World Environment***, Vol. 10 (Special Issue), (2015), 835. (http://doi.org/10.12944/CWE.10.Special-Issue1.101).
43. Moein, M., Pahlavan, S., Jahangiri, M. and Alidadi Shamsabadi, A., "Finding the minimum distance from the national electricity grid for the cost-effective use of diesel generator-based hybrid renewable systems in Iran", ***Journal of Renewable Energy and Environment (JREE)***, Vol. 5, (2018), 8-22. (https://doi.org/10.30501/jree.2018.88377).
44. Rahimi Ariae, A., Jahangiri, M., Fakhr, M.H. and Alidadi Shamsabadi, A., "Simulation of biogas utilization effect on the economic efficiency and greenhouse gas emission: A case study in Isfahan, Iran", ***International Journal of Renewable Energy Development***, Vol. 8, (2019), 149-160. (https://doi.org/10.14710/ijred.8.2.149-160).
45. Rezk, H., Alghassab, M. and Ziedan, H.A., "An optimal sizing of stand-alone hybrid PV-fuel cell-battery to desalinate seawater at saudi NEOM city", ***Processes***, Vol. 8, (2020), 382. (https://doi.org/10.3390/pr8040382).
46. Jahangiri, M., Haghani, A., Heidarian, S., Mostafaeipour, A., Raiesi, H.A. and Alidadi Shamsabadi, A., "Sensitivity analysis of using solar cells in regional electricity power supply of off-grid power systems in Iran", ***Journal of Engineering, Design and Technology***, Vol. 18, (2020), 1849-1866. (https://doi.org/10.1108/JEDT-10-2019-0268).
47. Ghaderian, A., Jahangiri, M. and Saghaei, H., "Emergency power supply for NICU of a hospital by solar-wind-based system, a step towards sustainable development", ***Journal of Solar Energy Research***, Vol. 5, (2020), 506-515. (https://doi.org/10.22059/jser.2020.306423.1166).