ISSN: 2251-9246
EISSN: 2345-6221
pp. 151:156

# Preliminary Assessment of Using Solar-Based Systems in The Facade of Building in Abadan: A Sustainable Development Approach

Sayed Ehsan Badakhshian*, Mohammad Baharvand

Department of architecture, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran,Ehsanbadakhshian@khuisf.ac.ir

**Abstract**

Building integrated photovoltaic (BIPV) systems have significant advantages and potential for widespread use in buildings. These systems are popular among architects and design engineers today. Despite these cases, so far no feasibility study has been performed on the supply of electricity and heat required for the building of a residential apartment in Iran using solar energy in the facade of the building. Therefore, in the present work, a 5-storey apartment in Abadan has been evaluated using TSOL Pro 5.5 and HOMER 2.81 simulation software. The solar power generation system is connected to the national electricity grid and the solar heat generation system uses a gas boiler as backup. The results showed that 55% of electricity generated, ie 6077 kWh/year is generated by the solar system connected to the grid and 7.4% of the total heat required, ie 1604 kWh/year is supplied by the solar collector system. About 1.3 tons of $CO_2$ emissions are generated annually due to the use of the national electricity grid. Performing accurate energy-technical-environmental analysis makes the results of the present work with high accuracy correspond to reality.

Keywords: 3E analysis; BIPV/T; CO2 pollutants; Electricity grid.
Article history: Received 2022-05-24; Revised 2022-06-08; Accepted 2022-06-08.

https://doi.org/10.30495/ijsee.2022.1959496.1204

## 1. Introduction

Today, buildings have become the third-largest consumer of energy after industry and agriculture, accounting for up to 40% of total energy consumption in developed countries [1, 2] and 10% of world greenhouse gas emissions [3]. According to the International Energy Agency, the energy demand for buildings will grow by 30% in 2040 [4]. Energy consumption is increasing rapidly with population growth, urbanization, and demand for building services and comfort levels. Therefore, reducing building energy consumption has a very important role in controlling global energy demand and reducing climate change [5, 6]. Adopting energy-efficient strategies to integrate design into the building structure can be considered necessary [7]. For example, improvements in architectural design, building materials, and heating, ventilation, and air conditioning (HVAC) systems can be implemented to address energy waste issues [7, 8]. One of the highly recommended solutions is the use of integrated photovoltaic/thermal (BIPV/T) systems in the building due to its thermal comfort aspects [9-11]. Increasing the penetration of renewable energy into energy infrastructure can play a key role in changing this trend towards a more sustainable and cleaner energy [12-14].

In 2020, 25.2 GWh of new solar heat capacity was added to the solar heat capacity and the total capacity of the world increased to about 501 GWh [15]. Photovoltaic (PV) is becoming the least expensive option for electricity generation in most parts of the world, and investment in this sector is expected to increase in the coming years. In 2020 alone, PV production increased by 156 TWh (23%) compared to 2019, reaching 821 TWh [16]. PV-heating systems (which generate both solar heat and solar electricity) have a growing trend in global markets. The global market for this technology has grown by an average of 9% between 2018 and 2020 (Figure 1).

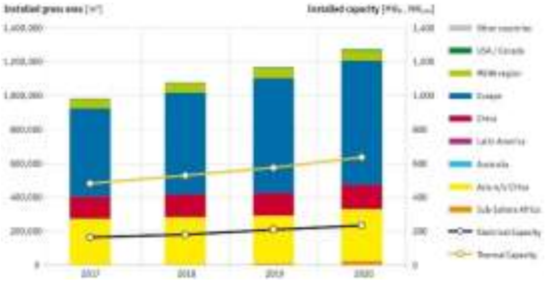

Fig. 1. The global PV-Thermal market from 2017 to 2020 [17].

Table 1 reviews recent studies on electricity and heat generation. The purpose of the work, the methodology of doing the work, and the result are among the items examined.

Literature review

| *Reference* | *Purpose* | *Methodology (Software)* | *Result* |
|---|---|---|---|
| [18] | Feasibility study of sanitary hot water supply and space heating of a family of four in 10 provinces of Canada | TSOL Pro 5.5 | The most suitable station in terms of using a solar water heater (SWH) is Regina, which provides 35% of the total heat load. |
| [19] | Investigate the potential of using SWH for a residential apartment in 37 stations in Algeria | TSOL Pro 5.5 | If SWH is used in 37 stations, 150160 kWh will be produced for space heating and 99861 kWh for sanitary hot water. |
| [20] | Feasibility study of supplying electricity to a rural household in Iran (Bar Aftab Jalaleh village) using an off-grid solar power system | HOMER | About 70% of the energy required is provided by solar cells at a cost of $ 0.792 per kWh. |
| [21] | Evaluation of simultaneous production of electricity and solar heat for a public health center located in Sar Agha Seyed village in Chaharmahal and Bakhtiari province | HOMER | Continuous and stable supply of electricity and heat to the medical center was done due to the sensitivity of these centers. |
| [22] | Economic and technical feasibility of using photovoltaic systems to supply electrical energy to a building of Hamadan Research Center | COMFAR Software | The economic evaluation shows that solar energy alone is not economically justifiable to supply electrical and thermal energy to the building. |

Based on the above studies, none of the work done so far has provided solar electricity and heat using solar cells and solar collectors on the facade of the building. Therefore, in the present work for the first time, simulations have been performed for energy and environmental analysis using commercial software. The authors of the present work hope that the results of the present work can serve as a guide for users of BIPV/T buildings.

## 2. Location understudy

As shown in Figure 2, the study site is the city of Abadan in southwestern Iran. The geographical coordinates of this city are 20º 30' North and 17º 48' East and the height above sea level is 3 m [23]. Due to the location of one of the largest oil refineries in the world, several petrochemical companies and being strategic, this city has been selected for review. The building in question is a 5-storey residential building that will supply part of the electricity and heat required by solar energy in the form of BIPV/T.

Fig. 2. Schematic of the use of solar energy in the city of Abadan

## 3. Methodology

For one-year simulations in the present work, HOMER 2.81 and TSOL Pro 5 software have been used. HOMER 2.81 is responsible for solar power supply and its task is to perform sensitivity analysis and technical-economic-energy-environmental analysis [24]. TSOL Pro 5.5 is responsible for supplying solar heat and performs analyzes similar to HOMER software [25]. The data used for the simulations were an average of 20 years and were extracted from Meteonorm 7 software [26].

HOMER 2.81 software uses the following equation to generate solar power by photovoltaic cells [27, 28]:

$$E_{PV} = E_{RPV} \times g_{PV} \times \frac{\bar{I}_T}{\bar{I}_{T.STC}} \times \left(1 + \beta_P \times (T_C - T_{C.STC})\right) \quad (1)$$

HOMER 2.81 software also uses the following equations for economic analysis [29, 30]:

$$\text{total NPC} = \frac{C_{ann,tot}}{CRF(i, R_{proj})} \quad (2)$$

$$LCOE = \frac{C_{ann,tot}}{E_{served}} \quad (3)$$

TSOL Pro 5.5 software uses the following equation for the amount of heat generated by solar collectors [31, 32]:

$$\rho = G_{dir} \cdot \eta_0 \cdot f_{IAM} + G_{diff} \cdot \eta_0 \cdot f_{IAM.diff} - k_0\,(T_{cm} - T_A) - k_q\,(T_{cm} - T_A)^2 \quad (4)$$

## 4. Required data

HOMER 2.81 software requires a 24-hour power consumption profile for simulation, as shown in Figure 3 for one year. Also, due to the fact that the system in question is connected to the national electricity grid, a 3-time electricity tariff has been included for the simulations, which is 23 PM to 8 AM (Off-Peak), 8 AM to 4 PM (Normal) and the rest of the time (Peak). Tariffs for household electricity (both for purchase and sale) are $ 0.05, 0.07, and $ 0.12 per kW for Off-Peak, Normal and Peak times, respectively [33].

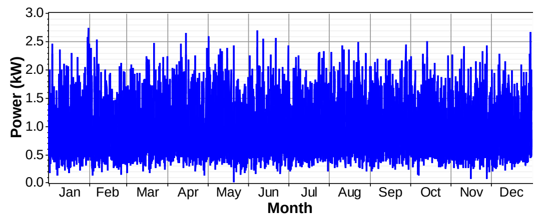


Fig. 3. 24-hour power consumption profile

The annual interest rate is 18% [34] and the lifetime of the project is 25 years [35]. The list of technical and price information of the equipment used in the solar power sector is presented in Table 2 [36-38]. TSOL Pro 5.5 software for simulating climatic data such as temperature and radiation, which receives them from Meteosyn 7 software as input [39]. The amount of sanitary hot water required for each unit is 110 liters with a temperature of 60 oC, which is required all year round [40]. The amount of space heating is 10 kW per unit and the infrastructure area of each unit is 80 m2.

Information of BIPV system under study

| *Equipment* | *Cost ($)* Capital | Replace | OM | *Size (kW)* | *Other info* |
|---|---|---|---|---|---|
| PV [36] | 1000 | 1000 | 5 | 5-50 | Lifetime: 25 years<br>Ground reflectance: 20% |
| Battery T-105 [37] | 174 | 174 | 5 | 0-20 | Nominal Voltage: 6<br>Nominal capacity: 225Ah |
| Converter [38] | 200 | 200 | 10 | 0-20 | Lifetime: 10 years<br>Efficiency: 90% |

The need for space heating is only in the cold seasons of the year (November to March). The dimensions of the solar collectors used are 15 $m^2$, whose angle is equal to the latitude of the study area [41] and their orientation is to the south [42, 43]. The length of outdoor piping was 45 m and the length of indoor piping was 5 m in the calculations.

Schematics of systems designed to supply electricity and solar heat are presented in Figures 4 and 5, respectively. A 25 kW gas boiler is also used for the auxiliary boiler.

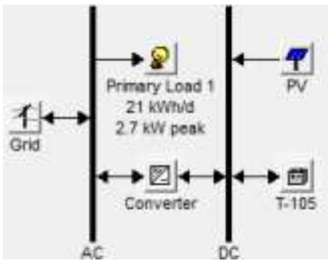


Fig. 4. Schematic of solar electricity system

Fig. 5. Schematic of solar heating system

## 5. Results

Due to the installation of solar cells on the facade of the building, the results of sensitivity analysis are presented in Figure 6. The parameter studied is LCOE and the effect of azimuth angle and derating factor on it has been evaluated. From the results, it is clear that the azimuth angle of 45o (southwest) is the most appropriate angle in terms of solar power generation costs. Also, as the derating factor increases, as the radiation reaching the surface of the solar cell increases, so the cost of generating solar power is reduced. According to the results of Figure 6 for the derating factor equal to 90%, the cheapest solar electricity is produced at a price of $ 14/kWh. The results of this superior scenario are presented in Table 3.

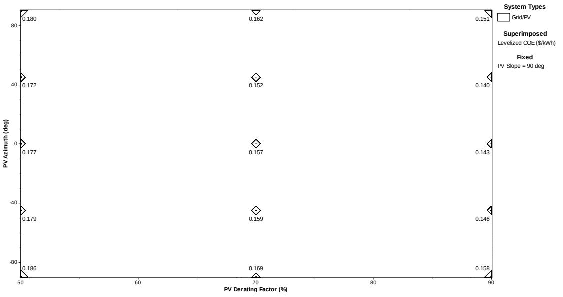


Fig. 6. Results of electricity simulation

Table.1.
Results of the best economic scenario in the field of solar power generation

| *Scenario* | *Equipment* | *Initial capital ($)* | *Operating cost ($)* | *Total NPC ($)* | *PV production (kWh/year)* |
|---|---|---|---|---|---|
| PV-grid | PV (5 kW), Converter (2 kW), Grid | 5400 | 363 | 7384 | 6077 (55%) |

| *Excess electricity (kWh/year)* | *Capital factor (%)* | *Converter losses (kWh/year)* | *Grid purchased (kWh/year)* | *Grid sold (kWh/year)* | *$CO_2$ (kg/year)* |
|---|---|---|---|---|---|
| 944 | 13.9 | 513 | 5.23 | 2014 | 1901 |

According to the results of Table 3, the optimal system is a 5 kW solar power plant connected to the grid, which annually produces 6077 kWh of solar electricity, which is 8.5% of the total electricity consumption is excess. The capacity factor of solar cells in Abadan is 13.9% and 4.62% of the total electricity generated in the converters is wasted annually. Also, the net amount of electricity purchased from the grid during the year is 3009 kWh, which leads to the production of 1.9 tons of CO2 pollutants. The results of installing solar collectors on the facade of the building are presented in Table 4.

Table.2.
Solar heat generation results

| *Solar contribution to DHW* | *Solar contribution to heating (kWh)* | *Total solar fraction (%)* | *$CO_2$ emissions avoided (kg/year)* | *Natural gas saving ($m^3$/year)* | *Optical losses (kWh/y)* | *Thermal losses (kWh/y)* | *Piping losses (kWh/y)* | *Tanks losses (kWh/y)* |
|---|---|---|---|---|---|---|---|---|
| 16.4 (19.3%) | 0 (0%) | 7.4% | 594 | 281 | 2901 | 1635 | 928 | 581 |

Based on the results of Table 4, the designed system, which includes 15 square meters of solar collector, was able to produce 19.3% of the total heat required, ie 1604 kWh of solar heat to produce the required hot water. The designed system could not produce any heat to provide space heating. In total, the designed system was able to produce 7.4% of the total heat required and prevented the consumption of 281 cubic meters of natural gas per year, resulting in the prevention of 594 kg of CO2 pollutants. Losses during the year are 6045 kWh, which are related to optical, thermal, piping and tanks, respectively, from the highest to the lowest.

Figure 7 shows the total solar fraction in the months of the year. According to the results in June, July and August, the total solar fraction is above 40%, which is due to less need for solar heating in hot seasons. Also, in January and December, the total solar fraction is zero, which is due to the great need for heat in these two cold months of the year.

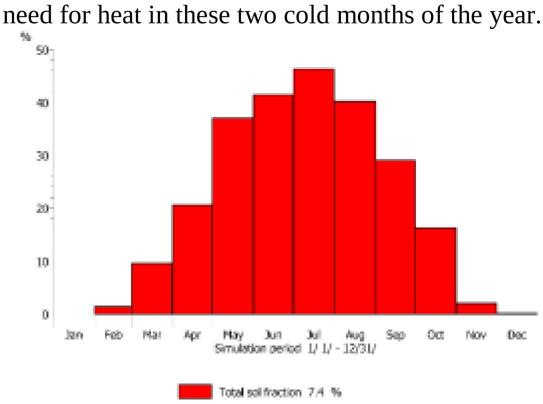


Fig. 7. Results of thermal simulation

## 6. Conclusion

The integration of the two systems of solar electricity and solar heating and their use in the facade of the building causes significant savings in cost and energy and building materials used in the facade of the building. According to studies, nothing has been done in this field in Iran so far. Therefore, a 5-storey residential building located in Abadan has been evaluated for technical-energy-environmental. HOMER 2.81 commercial software is used to simulate photovoltaic panels used in the facade and TSOL Pro 5.5 commercial software is used to dynamically simulate solar collectors used in the facade. According to the simulations performed, the important results of the present work are:

- PV-grid system with a cost of $ 0.14/kWh is the most economical scenario.

- An azimuth angle of 45$^o$ (southwest) is the most economical.

- Of the total electricity consumption, 8.5% is an excess.

- The net amount of electricity purchased from the grid is about 3 MWh/year.

- The amount of solar electricity produced is about 6 MWh.

- The solar power system produced was 5 kW and the solar heating system was 15 kW.

- The solar fraction of the total heat supply is 7.4%, ie 1604 kWh/year.

- 1.9 tons of $CO_2$ pollutants are produced annually due to the use of the national electricity grid, and due to the use of solar collectors, the release of about 0.6 tons of $CO_2$ pollutants is prevented.

- The annual losses of the solar heating system are about 6 MWh and the annual losses of solar electricity are about 0.6 MWh.

## References


[1]. Yousefi, Y., Jahangiri, M., Shamsabadi, A.A. and Dehkordi, A.R., 2019. Designing a mediator space and the study of its effect on the energy consumption of a residential building using EnergyPlus software in Savadkuh, Iran. Journal of Engineering, Design and Technology, 17 (4), pp. 833-846. https://doi.org/10.1108/JEDT-01-2018-0005.

[2]. Zaniani, J.R., Ghahfarokhi, S.T., Jahangiri, M. and Shamsabadi, A.A., 2018. Design and optimization of heating, cooling and lightening systems for a residential villa at Saman city, Iran. Journal of Engineering, Design and Technology, 17 (1), pp. 41-52. https://doi.org/10.1108/JEDT-01-2018-0003.

[3]. Cai, H., Wang, X., Kim, J.H., Gowda, A., Wang, M., Mlade, J., Farbman, S. and Leung, L., 2022. Whole-building life-cycle analysis with a new GREET® tool: Embodied greenhouse gas emissions and payback period of a LEED-Certified library. Building and Environment, 209, p. 108664. https://doi.org/10.1016/j.buildenv.2021.108664.

[4]. U.S. EIA, 2012. Annual Energy Review 2011, U.S. Energy Information Administration**.** Doi:/EIA-1384 (2011).

[5]. Omidi, A., Jahangiri, M., Mohammadidehcheshmeh, F. and Mostafaeipour, A., 2021. Comprehensive assessment of agricultural waste effect on the thermal bridge phenomenon using ZUB ARGOS software, a case study in Iran. Energy and Buildings, 245, p.111089. https://doi.org/10.1016/j.enbuild.2021.111089.

[6]. Mostafaeipour, A., Goudarzi, H., Khanmohammadi, M., Jahangiri, M., Sedaghat, A., Norouzianpour, H., Chowdhury, S., Techato, K., Issakhov, A., Almutairi, K. and Hosseini Dehshiri, S.J., 2021. Techno-economic analysis and energy performance of a geothermal earth-to-air heat exchanger (EAHE) system in residential buildings: A case study. Energy Science & Engineering, 9(10), pp.1807-1825. https://doi.org/10.1002/ese3.952.

[7]. Turney, D. and Fthenakis, V., 2011. Environmental impacts from the installation and operation of large-scale solar power plants. Renewable and Sustainable Energy Reviews, 15(6), pp.3261-3270. https://doi.org/10.1016/j.rser.2011.04.023.

[8]. Zogou, O. and Stapountzis, H., 2011. Energy analysis of an improved concept of integrated PV panels in an office building in central Greece. Applied Energy, 88(3), pp.853-866. https://doi.org/10.1016/j.apenergy.2010.08.023.

[9]. Asefi, G., Habibollahzade, A., Ma, T., Houshfar, E. and Wang, R., 2021. Thermal management of building-integrated photovoltaic/thermal systems: A comprehensive review. Solar Energy, 216, pp.188-210. https://doi.org/10.1016/j.solener.2021.01.005.

[10]. Kuhn, T.E., Erban, C., Heinrich, M., Eisenlohr, J., Ensslen, F. and Neuhaus, D.H., 2021. Review of technological design options for building integrated photovoltaics (BIPV). Energy and Buildings, 231, p.110381. https://doi.org/10.1016/j.enbuild.2020.110381.

[11]. Gholami, H. and Røstvik, H.N., 2020. Economic analysis of BIPV systems as a building envelope material for building skins in Europe. Energy, 204, p.117931. https://doi.org/10.1016/j.energy.2020.117931.

[12]. Zhao, X., Mahendru, M., Ma, X., Rao, A. and Shang, Y., 2022. Impacts of environmental regulations on green economic growth in China: New guidelines regarding renewable energy and energy efficiency. Renewable Energy, 187, pp. 728-742. https://doi.org/10.1016/j.renene.2022.01.076.

[13]. Almutairi, K., Mostafaeipour, A., Baghaei, N., Techato, K., Chowdhury, S., Jahangiri, M., Rezaei, M., Hosseini Dehshiri, S.J., Goudarzi, H. and Issakhov, A., 2021. Techno-economic investigation of using solar energy for heating swimming pools in buildings and producing hydrogen: a case study. Frontiers in Energy Research, 9, p. 680103. https://doi.org/10.3389/fenrg.2021.680103.

[14]. Jahangiri, M., Haghani, A., Heidarian, S., Alidadi Shamsabadi, A. and Pomares, L.M., 2018. Electrification of a tourist village using hybrid renewable energy systems, Sarakhiyeh in Iran. Journal of Solar Energy Research, 3(3), pp.201-211.

[15]. REN21. Executive summary, solar thermal heating. https://www.ren21.net/gsr-2021/pages/summary/summary/#:~:text=SOLAR%20THERMAL%20HEATING,Brazil%20and%20the%20United%20States.

[16]. Iea. 2021. Solar PV. https://www.iea.org/reports/solar-pv/ [1 November 2021].

[17]. SHC. 2021. Key Findings from Solar Heat Worldwide 2021. https://www.iea-shc.org/solar-heat-worldwide.

[18]. Jahangiri, M., Alidadi Shamsabadi, A. and Saghaei, H., 2018. Comprehensive evaluation of using solar water heater on a household scale in Canada. Journal of Renewable Energy and Environment, 5(1), pp.35-42. https://doi.org/10.30501/JREE.2018.88491.

[19]. Pahlavan, S., Jahangiri, M., Alidadi Shamsabadi, A. and Khechekhouche, A., 2018. Feasibility study of solar water heaters in Algeria, a review. Journal of Solar Energy Research, 3(2), pp. 135-146.

[20]. Jahangiri, M., Haghani, A., Heidarian, S., Mostafaeipour, A., Raiesi, H.A. and Shamsabadi, A.A., 2020. Sensitivity analysis of using solar cells in regional electricity power supply of off-grid power systems in Iran. Journal of Engineering, Design and Technology. 18(6), pp. 1849-1866. https://doi.org/10.1108/JEDT-10-2019-0268.

[21]. Khalili Samani, M., Valikhani Dehaghani, M., Mohamadi Janaki, D. 2022. Management and Environmental Assessment of Simultaneous Production of Solar Electricity and Heat (Case Study: Sar Agha Seyed Rural Health Center). International Journal of Smart Electrical Engineering. Articles in Press. https://doi.org/10.30495/IJSEE.2022.1957192.1195.

[22]. Darabi, M. and Piri, S., 2015. Fuzzy Method in Feasibility Study of Using Biomass Solar Hybrid Source and Photovoltaic system for Designing a Research Center Building in Smart Grid of Hamedan. International Journal of Smart Electrical Engineering, 4(02), pp.51-57.

[23]. Rahmati Dehkordi, S. and Jahangiri, M., 2022. Sensitivity Analysis for 3E Assessment of BIPV System Performance in Abadan in Southwestern Iran. Journal of Renewable Energy and Environment, 9(1), pp.1-12. https://doi.org/10.30501/JREE.2021.262420.1173.

[24]. Pahlavan, S., Jahangiri, M., Alidadi Shamsabadi, A. and Rahimi Ariae, A., 2019. Assessment of PV-based CHP

system: The effect of heat recovery factor and fuel type. Journal of Energy Management and Technology, 3(1), pp.40-47. https://doi.org/10.22109/JEMT.2018.137207.1106.

[25]. Jahangiri, M., Akinlabi, E.T. and Sichilalu, S.M., 2021. Assessment and modeling of household-scale solar water heater application in Zambia: technical, environmental, and energy analysis. International Journal of Photoenergy, 2021, p. 6630338. https://doi.org/10.1155/2021/6630338.

[26]. 26- Jahangiri, M., Khosravi, A., Raiesi, H.A. and Mostafaeipour, A., 2017. Analysis of standalone PV-based hybrid systems for power generation in Rural area. In International Conference on Fundamental Research in Electrical Engineering, July, Tehran, Iran, pp. 1-10.

[27]. Vahdatpour, S., Behzadfar, S., Siampour, L., Veisi, E. and Jahangiri, M., 2017. Evaluation of off-grid hybrid renewable systems in the four climate regions of Iran. Journal of Renewable Energy and Environment, 4(1), pp.61-70. https://doi.org/10.30501/JREE.2017.70107.

[28]. Moein, M., Pahlavan, S., Jahangiri, M. and Alidadi Shamsabadi, A., 2018. 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, 5(1), pp.8-22. https://doi.org/10.30501/JREE.2018.88377.

[29]. Ariae, A.R., Jahangiri, M., Fakhr, M.H. and Shamsabadi, A.A., 2019. 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, 8(2), pp. 149-160. https://doi.org/10.14710/ijred.8.2.149-160.

[30]. Abdali, T., Pahlavan, S., Jahangiri, M., Alidadi Shamsabadi, A. and Sayadi, F., 2019. Techno-Econo-Environmental study on the use of domestic-scale wind turbines in Iran. Energy Equipment and Systems, 7(4), pp.317-338. https://doi.org/10.22059/EES.2019.37669.

[31]. Siampour, L., Vahdatpour, S., Jahangiri, M., Mostafaeipour, A., Goli, A., Shamsabadi, A.A. and Atabani, A., 2021. Techno-enviro assessment and ranking of Turkey for use of home-scale solar water heaters. Sustainable Energy Technologies and Assessments, 43, p. 100948. https://doi.org/10.1016/j.seta.2020.100948.

[32]. Kalbasi, R., Jahangiri, M., Mosavi, A., Dehshiri, S.J.H., Dehshiri, S.S.H., Ebrahimi, S., Etezadi, Z.A.S. and Karimipour, A., 2021. Finding the best station in Belgium to use residential-scale solar heating, one-year dynamic simulation with considering all system losses: economic analysis of using ETSW. Sustainable Energy Technologies and Assessments, 45, p.101097. https://doi.org/10.1016/j.seta.2021.101097.

[33]. Jahangiri, M., Karimi Shahmarvandi, F. and Alayi, R., 2021. Renewable energy-based systems on a residential scale in southern coastal areas of Iran: trigeneration of heat, power, and hydrogen. Journal of Renewable Energy and Environment, 8(4), pp.67-76. https://doi.org/10.30501/JREE.2021.261980.1170.

[34]. Alayi, R., Seydnouri, S.R., Jahangeri, M. and Maarif, A., 2021. Optimization, Sensitivity Analysis, and Techno-Economic Evaluation of a Multi-Source System for an Urban Community: A Case Study. Renewable Energy Research and Application, 3 (1), pp. 21-30. https://doi.org/10.22044/RERA.2021.10752.1054.

[35]. Mostafaeipour, A., Qolipour, M., Rezaei, M., Jahangiri, M., Goli, A. and Sedaghat, A., 2020. A novel integrated approach for ranking solar energy location planning: a case study. Journal of Engineering, Design and Technology, 19 (3), pp. 698-720. https://doi.org/10.1108/JEDT-04-2020-0123.

[36]. Rezk, H., Alghassab, M. and Ziedan, H.A., 2020. An optimal sizing of stand-alone hybrid PV-fuel cell-battery to desalinate seawater at saudi NEOM city. Processes, 8(4), p. 382. https://doi.org/10.3390/pr8040382.

[37]. Teshnizi, E.A., Jahangiri, M., Shamsabadi, A.A., Pomares, L.M., Mostafaeipour, A. and Assad, M.E.H., 2021. Comprehensive Energy-Econo-Enviro (3E) Analysis of Grid-Connected Household Scale Wind Turbines in Qatar. Jordan Journal of Mechanical & Industrial Engineering, 15(2), pp. 215-231.

[38]. Ghaderian, A., Jahangiri, M. and Saghaei, H., 2020. Emergency power supply for NICU of a hospital by solar-wind-based system, a step towards sustainable development. Journal of Solar Energy Research, 5(3), pp.506-515. https://doi.org/10.22059/JSER.2020.306423.1166.

[39]. Mortazavi, M., Yaghoubi, S. and Jahangiri, M., 2022. Investigating the Effect of Buffer Tank Type on Technical and Environmental Performance of Solar Heating Systems in Iran. International Journal of Smart Electrical Engineering, 11(02), pp. 55-61. https://doi.org/10.30495/IJSEE.2022.1952896.1174.

[40]. Rezapour, S., Jahangiri, M., Shahrezaie, A.G., Goli, A., Farsani, R.Y., Almutairi, K., Ao, H.X., Dehshiri, S.J.H., Dehshiri, S.S.H., Mostafaeipour, A. and Techato, K., 2022. Dynamic simulation and ranking of using residential-scale solar water heater in Iran. Journal of Environmental Engineering and Landscape Management, 30(1), pp.30-42. https://doi.org/10.3846/jeelm.2022.15483.

[41]. Jahangiri, M., Mostafaeipour, A., Rahman Habib, H.U., Saghaei, H. and Waqar, A., 2021. Effect of Emission Penalty and Annual Interest Rate on Cogeneration of Electricity, Heat, and Hydrogen in Karachi: 3E Assessment and Sensitivity Analysis. Journal of Engineering, 2021, p. 6679358. https://doi.org/10.1155/2021/6679358.

[42]. Jahangiri, M., Rezaei, M., Mostafaeipour, A., Goojani, A.R., Saghaei, H., Dehshiri, S.J.H. and Dehshiri, S.S.H., 2022. Prioritization of solar electricity and hydrogen co-production stations considering PV losses and different types of solar trackers: A TOPSIS approach. Renewable Energy, 186, pp. 889-903. https://doi.org/10.1016/j.renene.2022.01.045

[43]. Alizadeh, K., Jahangiri, M. and Bakhtdehkordi, M., 2021. Comprehensive 3E analysis and optimization of off-grid renewable-based microgrids to meet the clinic energy demand, a case study for medical tourism. Energy Equipment and Systems, 9(3), pp.291-305. https://doi.org/10.22059/EES.2021.246081.