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Research Article

Effects of Different Target Solar Fractions on Providing Heat Required for Space Heating, Sanitary Hot Water, and Swimming Pool in Iran: A Case Study in Cold Climate

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Due to limited fossil fuel resources, population growth, and the need to save energy and prevent the emission of pollutants, solar heating is of great importance as a strategic solution. Due to these cases, in the present work, for the first time, the use of flat plate solar water heaters (SWHs) in Shahrekord located in the cold climate of Iran has been studied. The aim is to supply heating for space, sanitary hot water, and swimming pool of a residential apartment. Also, technical-economic-energy-environmental analyses have been done. Three low, medium, and high solar fraction scenarios have been selected for evaluations, and one-year dynamic analysis has been performed by TSOL 2018 commercial software. The required climatic data have been extracted by Meteonorm 7.3 software. The results showed that in most cases of heat supply, i.e., high solar fraction scenario, the percentage of solar heat supply for sanitary hot water, space heating, and swimming pool is 97.8%, 22.3%, and 44.3%, respectively, and the total solar fraction is 41%. Also, in this case, the release of more than 4 tons of CO_2 pollutants has been prevented. Energy balance diagrams for different scenarios showed that 60% of losses are optical and thermal and also the highest rate of losses was related to the swimming pool. The lowest cost of heat generated and the lowest payback time were $ 0.028/kWh and 11.4 years, respectively, which were related to the high solar fraction scenario.

1. Introduction

Energy consumption reflects the socioeconomic growth rate of any country today [1]. Energy from fossil fuels produces a large number of greenhouse gases, which is the main cause of global warming [2–4]. The effects of global warming can be seen in almost every part of the world [5]. It is predicted that if the current emission rate continues, global warming will increase by 1.5°C at an average surface temperature between 2030 and 2052 [6–8]. Dealing with the undesirable effects of climate change is the biggest concern of society around the world [9–12]. A possible solution is to take benefit of renewable technologies and replace fossil technologies with them [13–17]. Among all renewable energy sources, solar energy is widely available and is present in almost all parts of the world [18–23]. In recent decades, global solar thermal capacity has increased sharply and is now widely used around the world to provide heating and cooling [24–28]. In 2019, solar heating systems generated 479 GW of heat, equivalent to 43 million tons of oil saved, which prevented the release of 138 million tons of CO_2 (Figure 1) [30].

Figure 2 illustrates the geographical breakdown of the cumulatively installed solar water heating capacity by the

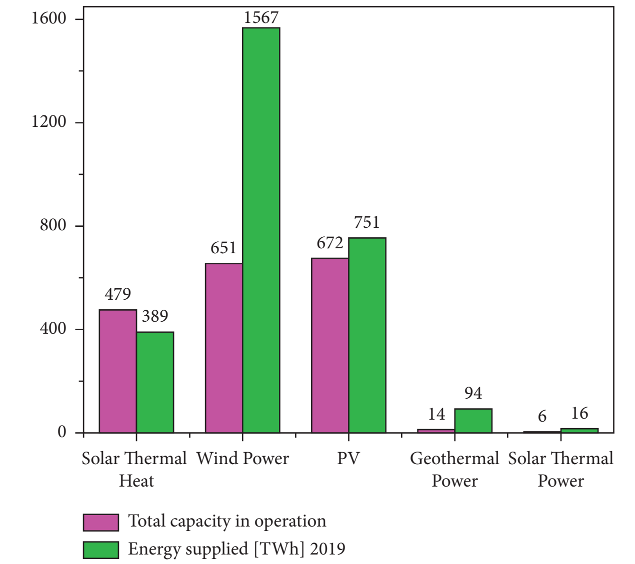


Figure 1: Global capacity in operation (GW) and energy supplied (TWh) [29].

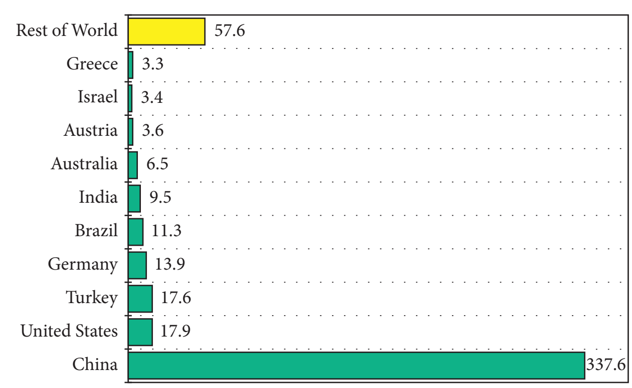


Figure 2: Global solar water heating capacity 2018 (in GW), by country [31].

end of 2018 [31]. China had installed a total of 337.6 GW of solar water heating by the end of that year. This rate was significantly higher than any other country and accounted for 70% of the global capacity. For the first time ever, the global cumulative operating solar heat capacity decreased in 2019, which was 1% less than the total of 482 GW last year (Figure 3) [32].

Iran is not only rich in fossil fuels but is also in renewable energy due to the diversity of climate and land area [33]. The solar source in Iran is one of the best sources in the world [17, 34]. In the following (Table 1), solar collector installation projects in the last two years in Iran are examined.

So far, in none of the previous studies, the simultaneous production of solar heat for swimming pool, space heating, and domestic hot water has been done. Therefore, in the present work, for the first time, a dynamic simulation of the use of SWHs in the cold climate of Iran for all the required heat of a residential apartment (space heating, sanitary water heating, and swimming pool water heating) has been performed. The heat supply required for the swimming pool is the first to be considered in the studies. The simulations were

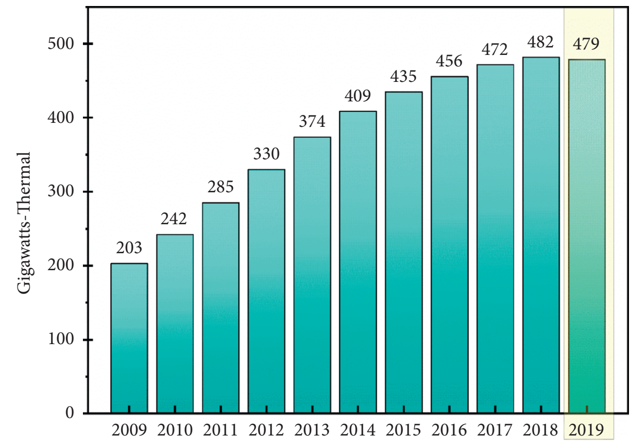


Figure 3: Solar water heating collectors' global capacity, 2009–2019 [31].

performed by TSOL 2018 software and the climatic data were provided by Meteonorm 7.3 software. Although the present work is a case study, its results can be applied to other locations with similar climates. Also, the methodology of the present work and the way of analyzing the results can be used for any other place in the world.

2. Station and Building under Study

The city under study in the present work is Shahrekord, whose location is shown on the climatic map of Iran [42] and the radiation map of Iran [43] in Figures 4(a) and 4(b), respectively. As can be seen from the figures, it is located in a cold climate with a position of 32′ 35° N and 50′ 86° E and has average radiation of more than 5.1 kWh/m^2-day. Shahrekord is the highest center of Iran provinces [44] and, according to the 2020 census, has a population of 204679 people [45]. The building under study is an 80 m^2 apartment that has a private indoor pool with a length of 8 m, a width of 4 m, and an average depth of 2 m.

3. Software Used

For one-year dynamic simulation, TSOL 2018 commercial software has been used, which has the ability to supply the required space heat, sanitary water consumption, and swimming pool by SWHs [46]. Design, optimization, and accurate calculation are other features of the software [47]. The software database has 4000 types of collectors, 5000 types of heat generators, 600 types of heat storage tanks, 200 solar heating systems, and 8000 different weather stations [45]. TSOL 2018 software receives the required climatic data from Meteonorm 7.3, which is installed simultaneously with it [37].

4. System under Study and Data Required

The schematic of the system understudy is shown in Figure 5. Based on the figure, it is clear that the orientation of solar collectors is at an angle of 32° (equal to latitude) [47] and to the south. The aim is to supply 110 liters of sanitary hot water per day with a temperature of 60°C [37] and to

Table 1: SWH installation projects in the last two years in different regions of Iran [35, 36].

No.	No. of collectors	Region
1	250	Forest regions of West Azerbaijan
2	90	Rural areas of Lordegan, Chaharmahal and Bakhtiari
3	35	Rural areas of Hormozgan
4	600	Kohgiluyeh and Boyer-Ahmad villages
5	295	Villages of Kermanshah Province
6	600	100 villages of Zanjan Province
7	122	Parks in the center of Tehran
8	41	Marivan and Sarvabad villages, Kurdestan
9	72	Nomadic areas of Sabzevar, Razavi Khorasan
10	800	Forest areas of Chaharmahal and Bakhtiari Province
11	500	Forest areas of Fars Province

Table 2: Recent studies in the field of SWHs in Iran and the world.

Reference	Purpose	Results
[37]	Environmental, technical, and financial study of evacuated tube SWH in seven cities from different geographical areas of India	At least 50% of incentives should be provided by the government to increase the implementation of such a system in this country with the interest of households.
[38]	Use of TSOL and MeteoSyn software packages for SWH in a residential apartment at 37 stations in Algeria	If SWH is used in 37 stations, 150160 kWh of thermal energy will be generated to heat for space heating and 99861 kWh for sanitary hot water, which will reduce 56783 kg of annual CO_2 emissions.
[39]	The provision of sanitary hot water and space heating needs for a four-person family in 10 Canadian provinces was examined. Feasibility analysis was conducted by T ∗ SOL Pro 5.5 software and radiation data were provided by by MeteoSyn software.	The most suitable station in terms of using SWHs is Regina, which provides 35% of the total heat for space heating and sanitary hot water purposes.
[40]	The use of home-scale SWHs was examined for 45 stations in Turkey. The technical and environmental analysis was performed by commercial software TSOL PRO 5.5 on two types of flat plate water heaters and evacuated tube.	The results showed that evacuated tube performance is better than flat plate in all stations.
[41]	Design of a solar water heating system with seasonal thermal energy storage and a heat pump for a villa with an area of 192 m^2 in Tehran	All the heating energy required for the villa is obtained with a solar collector level of 46 m^2, a tank capacity of about 2850 m^3, an insulation thickness of 55 cm, and a required heat pump performance coefficient of about 9.02.

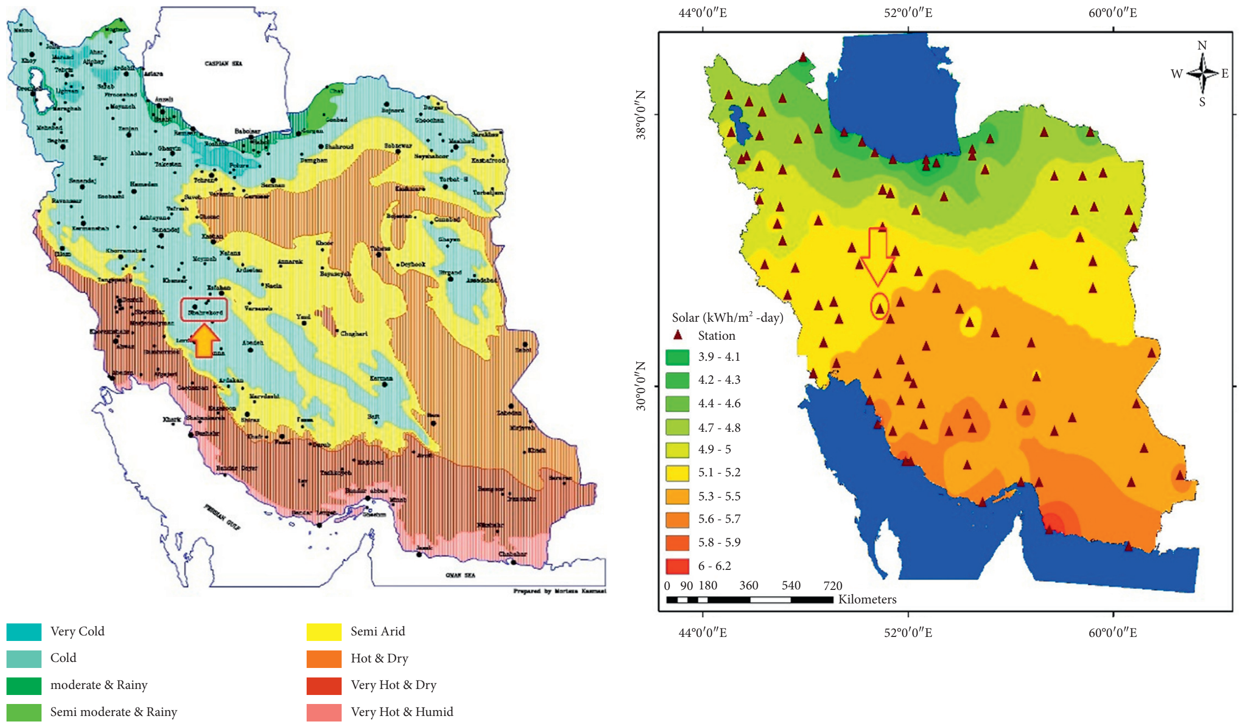
provide space heating and pool water using SWHs and an auxiliary gas boiler of 25 kW. Also, a 300 liter sanitary hot water tank and a 1000 liter space heating hot water tank have been used [46]. According to the location under study, the period of sanitary hot water required is the whole year and the period of space heating is 8 months (October to May). Solar fraction values of low (35%), medium (50%), and high (65%) were considered for which 8 m^2 collector, 12 m^2 collector, and 17 m^2 collector were used, respectively. The freshwater required for the swimming pool is 50 liters/day and the time period of using the pool is included in the calculations all year round. The lifetime of collectors used is 20 years, the annual interest rate in Iran is 18% [48], natural gas price is \$ 0.012/m^3 [49], price per m^2 of SWH is \$ 200, amount of allowance for solar heating is \$ 0.024/kWh, and operating and maintenance cost is 1% of the total system cost.

5. Governing Equations

The radiation received by the collectors is equal to the sum of the direct and diffused radiation. Direct radiation is received from Meteonorm 7.3 software and for diffuse radiation hitting the surface of the collectors, based on the air filtration coefficient (k_t), there are the following equations in which α is the angle of the solar collector [39]:

$$\begin{aligned} 0 \le k_t \le 0.3&: \frac{I_d}{I} = 1.02 - 0.245k_t + 0.0123 \sin \alpha, \\ 0.3 < k_t \le 0.78&: \frac{I_d}{I} = 1.4 - 1.749k_t + 0.177 \sin \alpha, \\ k_t > 0.78&: \frac{I_d}{I} = 0.486k_t - 0.182 \sin \alpha, \end{aligned} \tag{1}$$

where I is the total radiation on a horizontal surface in terms of kJ/m^2 and I_d is the diffused radiation on a horizontal surface in terms of kJ/m^2.



(a) (b)

Figure 4: Location of Shahrekord on (a) climatic map of Iran [34] and (b) radiation map of Iran [35].

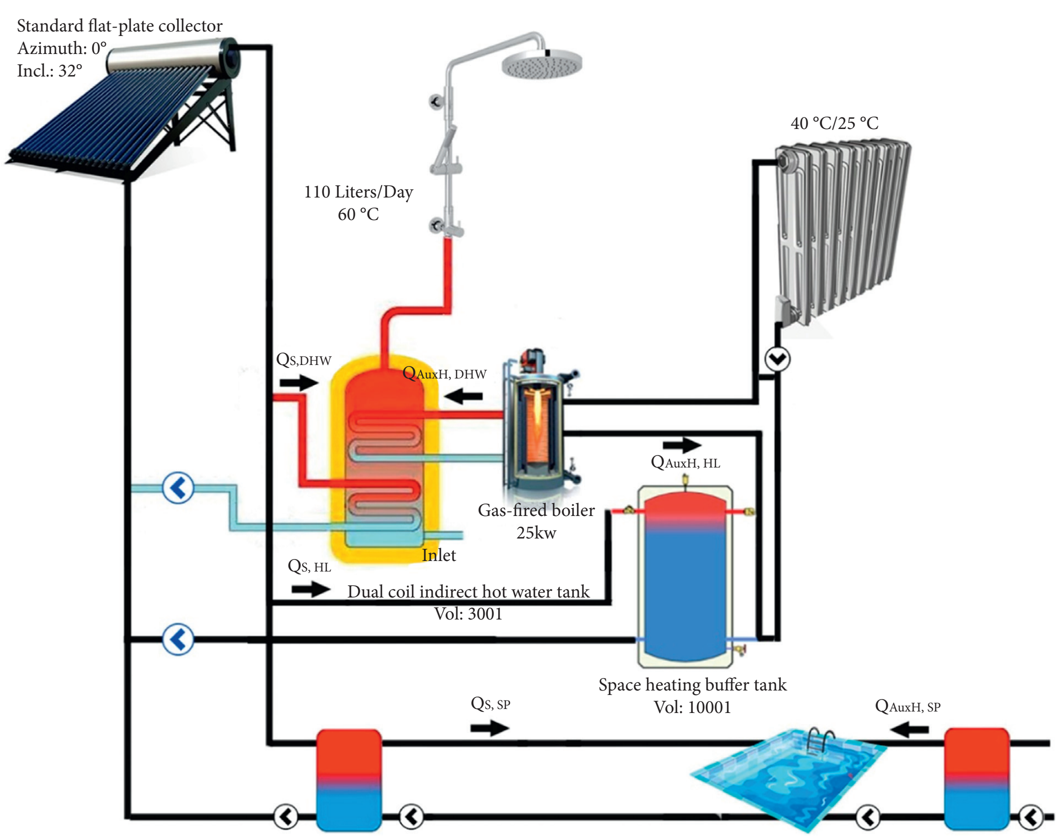


Figure 5: Schematic of the simulated system.

Since some of the radiation received by the collector is wasted, the energy balance is expressed by the following equation [37]:

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

where G_{dir} is the direct strike radiation to the collector surface, G_{diff} is the diffused radiation striking the collector surface, η_0 is the collector efficiency, f_{IAM} is the direct radiation correction factor, $f_{\text{IAM, diff}}$ is the diffused radiation correction factor, k_0 is the first-order loss coefficient, k_q is the second-order loss coefficient, T_{cm} is the average collector temperature, and T_A is the air temperature.

Also, in the discussion of pollution, it should be noted that the software considers the amount of CO_2 emission prevention for natural gas fuel consumption equal to 5.14 g/kJ [45]. The parameters of total solar fraction, solar fraction of sanitary water consumption, solar fraction of space heating, and solar fraction of swimming pool are obtained by the following equations, the parameters of which are shown in Figure 5:

$$\begin{aligned}
\text{total solar fracion} &= \frac{Q_{\text{S,DHW}} + Q_{\text{S,HL}} + Q_{\text{S,SP}}}{Q_{\text{S,DHW}} + Q_{\text{S,HL}} + Q_{\text{S,SP}} + Q_{\text{AUXH,DHW}} + Q_{\text{AUXH,HL}} + Q_{\text{AUXH,SP}}}, \\
\text{DHW solar fracion} &= \frac{Q_{\text{S,DHW}}}{Q_{\text{S,DHW}} + Q_{\text{AUXH,DHW}}}, \\
\text{heating solar fracion} &= \frac{Q_{\text{S,HL}}}{Q_{\text{S,HL}} + Q_{\text{AUXH,HL}}}, \\
\text{swimming pool solar fracion} &= \frac{Q_{\text{S,SP}}}{Q_{\text{S,SP}} + Q_{\text{AUXH,SP}}}.
\end{aligned} \quad (3)$$

In the present work, economic calculations are based on the net present value (NPV) method. This parameter, which is one of the main and most widely used methods of investment evaluation, is calculated by the following equation [46]:

$$\text{NPV} = R_t - C, \quad (4)$$

where R_t is the total revenue and C is the cost of the SWH system, each of which is calculated by the following equations:

$$\begin{aligned}
C &= C_0 + \sum_{n=1}^{N} \frac{C_{O\&M} \times (1+e)^n}{(1+d)^n}, \\
R_t &= \frac{Q_u}{\eta_h} \sum_{n=1}^{N} \frac{(1+e)^n}{(1+d)^n},
\end{aligned} \quad (5)$$

where C_0 is the total purchase cost, $C_{O\&M}$ refers to the total annual operating and maintenance costs, e is the system lifetime, d is the reduction rate, n is the number of years, η_h is the efficiency of the auxiliary gas boilers, and Q_u is the useful energy collected by the SWHs.

6. Results

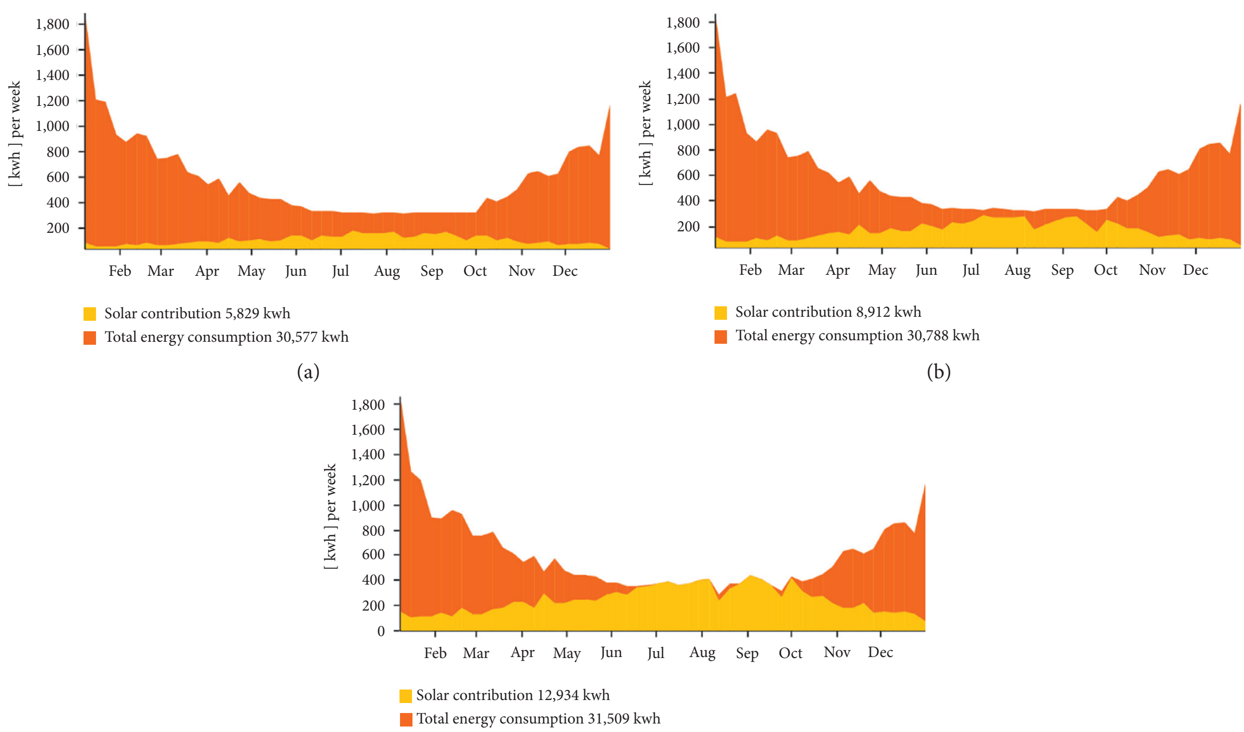
The simulation results for the three scenarios of a low, medium, and high solar fraction are given in Table 3. It is clear from the results that almost a large part of the heating required for sanitary hot water in all scenarios is provided by SWHs and the main difference is in the space heating and swimming pool water heating. In the most possible case, i.e., using 17 m^2 of flat plate solar collector, 22.3% of the required space heat and 44.3% of the required heat of the swimming pool are provided by solar heating, in which case 18576 kWh of heating is supplied by the auxiliary gas boiler which prevents the release of more than 4 tons of CO_2 emission. The highest solar fraction with a rate of 41% is related to the scenario of using 17 m^2 of solar collector and leads to a system efficiency of 33.6%.

Figures 6(a)–6(c) compare the solar heating produced with the total heat required for the three scenarios under study. It is clear from the figures that the highest percentage of heat supply required is in the 4 warm months of the year that there is no need to heat the space. In the cold months of the year, the main need is provided by gas boiler. For the high solar fraction scenario, in July, August, and September, almost all of the 400 kWh/week of heat needs are met by solar heating.

An energy balance schematic for different solar fraction scenarios is shown in Figure 7. This schematic helps engineers to examine different points of the system and identify critical points and help improve the efficiency of the system by trying to solve the problem of heat loss in the solar heating system. The results show that the higher the radiation received, the higher the optical and thermal losses, which is obvious because more radiation is received for more collectors. Another point that can be seen from the results of Figure 7 is the very high percentage of optical and thermal losses, which account for almost 60% of the total received radiation. These losses depend on the type of solar collectors, air temperature, etc., and not much can be done to reduce them. Other major losses occur in swimming pools, and very

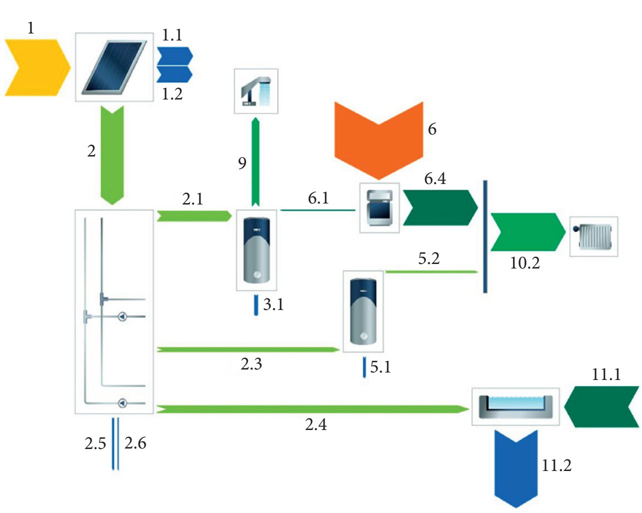
Table 3: Simulation results for different scenarios.

Scenario	Solar energy (kWh) DHW	Heating	Swimming pool	Auxiliary heating (kWh)	CO_2 avoided	Total solar fraction (%)	System efficiency (%)
Low	2812 (94.8%)	662 (5.5%)	2355 (15.1%)	24749	1768	19.1	32.2
Medium	2924 (96.6%)	1616 (13.4%)	4373 (27.8%)	21876	2725	28.9	32.8
High	2983 (97.8%)	2688 (22.3%)	7262 (44.3%)	18576	4037	41	33.6



(c)

Figure 6: Produced solar heating compared to the total heat required for solar fraction scenarios. (a) Low. (b) Medium. (c) High.



1	Irradiation on collector surface (active)	18,092 kwh
1.1	Optical collector losses	5,627 kwh
1.2	Thermal collector losses	5,201 kwh
2	Energy from collector array	7,532 kwh
2.1	Solar energy to storage tank	3,162 kwh
2.3	Solar energy to buffer tank	1,267 kwh
2.4	Solar energy to swimming pool	2,355 kwh
2.5	Internal piping losses	493 kwh
2.6	External piping losses	255 kwh
3.1	Tank losses	1,060 kwh
5.1	Buffer tank losses	605 kwh
5.2	Buffer tank to heating	662 kwh
6	Final energy	29,851 kwh
6.1	Supplementary energy to tank	155 kwh
6.4	Supplementary energy to space-heating	11,387 kwh
9	DHW energy from tank	2,253 kwh
10.2	Heat to LT heating	12,049 kwh
11.1	Supplementary energy to swimming pool (from final energy)	13,206 kwh
11.2	Swimming pool losses	14,549 kwh

(a)

Figure 7: Continued.

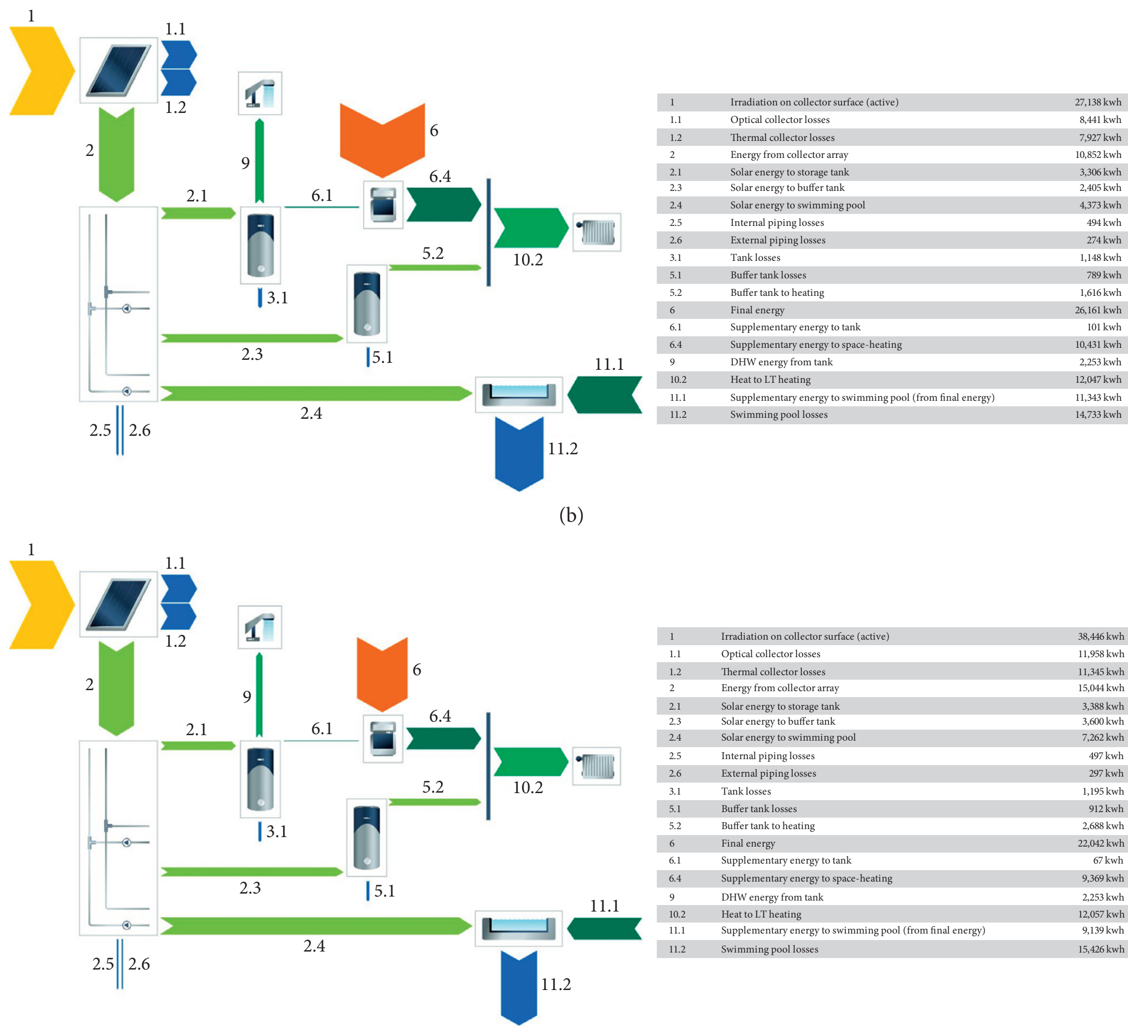


FIGURE 7: Schematic of energy balance for different solar fraction scenarios. (a) Low. (b) Medium. (c) High.

TABLE 4: Results of economic analysis performed for the studied scenarios.

Scenario	Cost of energy (\$/kWh)	NPV (\$)	Capital return time (years)
Low	0.03	−885	12
Medium	0.029	−1303	11.7
High	0.028	−1801	11.4

high and serious measures must be taken to reduce them. Losses in storage tanks and piping systems are also in the last ranks of losses.

Economic analysis for different solar fraction scenarios is given in Table 4. The results of Table 4 show that with increasing solar fraction (increasing the number of solar collectors), the price per kWh of solar heat produced decreases and also the payback time decreases. According to the results, the most suitable scenario, which is a high solar fraction, has a price of \$ 0.028 per kWh of generated heat and a return on investment of 11.4 years. The reason for this high return on investment is the low price of natural gas in Iran. Figure 8 shows the economic chart of the top scenario over its 20-year lifetime. According to the figure, at the end of the twentieth year, there will be a profit of \$ 4220.

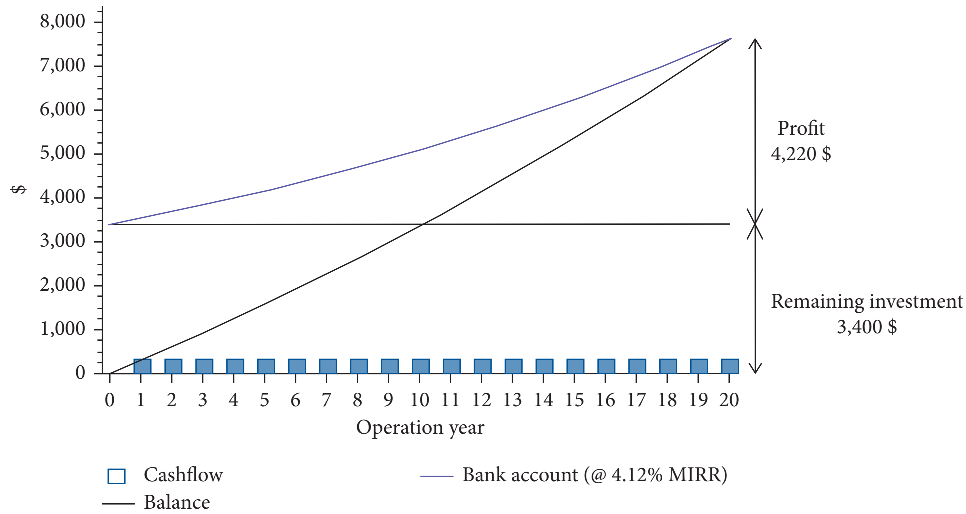


Figure 8: Economic analysis for the superior scenario over the lifetime of the project.

7. Conclusion

Despite the geographical location of Iran, which has a very high intensity of radiation, studies in this regard have not been sufficient. In all previous works, only space heating and sanitary water heating were studied, and this is the first time that the pool heating is evaluated for a residential apartment in Shahrekord located in the cold climate of Iran. TSOL 2018 commercial software and Meteonorm 7.3 have been used for one-year dynamic simulation. The results showed the following:

(i) The total solar fraction for low, medium, and high target solar scenarios is 19.1%, 28.9%, and 41%, respectively.

(ii) The lowest amount of auxiliary gas boiler use with 18576 kWh is in the high solar fraction scenario.

(iii) In the high solar fraction scenario, the release of more than 4 tons of CO_2 pollutants is prevented.

(iv) The highest system efficiency is 33.6%.

(v) The highest losses in the studied system are related to swimming pool losses, optical losses, and heat losses, respectively.

(vi) The lowest heat generated cost is $ 0.028 per kWh.

(vii) The minimum return on investment is 11.4 years.

8. Future Works

In the continuation of the present work, all climates of Iran can be evaluated and the effect of using SWHs in different climates can be compared. Also, using ranking methods, it is possible to check all the stations in Iran and find the station that is superior in all aspects of energy, economy, environment, etc. Also, the effect of using different types of solar collector technologies, the effect of using different hot water storage tanks, the effect of work fluid, etc. are among the items that are suggested to be addressed in future works.

Abbreviations

N:	Project lifetime (year)
ρ:	Collector energy balance (kW)
C:	Cost of the SWH system ($)
e:	Useful life (year)
n:	Number of years (-)
d:	Rate of decline (%)
NPV:	Net present value ($)
α:	Tilt angle (°)
I:	Total hourly radiation on a horizontal surface (kJ/m^2)
SWH:	Solar water heater (-)
T_A:	Air temperature (K)
C_0:	Total purchase cost ($)
k_t:	Hourly clearness index (-)
R_t:	Total revenue ($)
η_h:	Efficiency of the auxiliary boiler (%)
$C_{O\&M}$:	Total annual operating and maintenance costs ($)
T_{cm}:	Average temperature of collector (K)
k_q:	Quadratic heat transfer coefficient (W/m^2.k^2)
$Q_{S,SP}$:	Solar heating for swimming pool (kW)
$Q_{S,DHW}$:	Solar heating for DHW (kW)
$Q_{S,HL}$:	Solar heating for heating load (kW)
$Q_{AuxH,SP}$:	Auxiliary heating for swimming pool (kW)
$Q_{AuxH,DHW}$:	Auxiliary heating for DHW (kW)
$Q_{AuxH,HL}$:	Auxiliary heating for heating load (kW)
I_d:	Hourly diffuse radiation on a horizontal surface (kJ/m^2)
G_{dir}:	Part of solar radiation striking a tilted surface (kW)
η_0:	Collector's zero-loss efficiency (%)
f_{IAM}:	Incidence angle modifier factor (-)
G_{diff}:	Diffuse solar radiation striking a tilted surface (kW)
$f_{IAM,\ diff}$:	Diffuse incidence angle modifier factor (-)
k_0:	Simple heat transfer coefficient (W/m^2.k)

Q_u: Useful energy collected by the solar collectors (kW).

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] R. Alayi and J. Javad Velayti, "Modeling/optimization and effect of environmental variables on energy production based on PV/wind turbine hybrid system," *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 7, no. 1, pp. 101–107, 2021.

[2] M. Jahangiri, A. Haghani, A. Alidadi Shamsabadi, A. Mostafaeipour, and L. M. Pomares, "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, pp. 23–32, 2019.

[3] M. Jahangiri, R. A. Rizi, and A. A. Shamsabadi, "Feasibility study on simultaneous generation of electricity and heat using renewable energies in Zarrin Shahr, Iran," *Sustainable Cities and Society*, vol. 38, pp. 647–661, 2018.

[4] M. Jahangiri and A. A. Shamsabadi, "Designing a horizontal-axis wind turbine for south Khorasan province: a case study," *International Journal of Precision Engineering and Manufacturing*, vol. 18, no. 10, pp. 1463–1473, 2017.

[5] R. Alayi, M. R. Basir Khan, and M. S. G. Mohmammadi, "Feasibility study of grid-connected PV system for peak demand reduction of a residential building in Tehran, Iran," *Mathematical Modelling of Engineering Problems*, vol. 7, no. 4, pp. 563–567, 2020.

[6] T. F. Stocker, D. Qin, G. K. Plattner et al., "Summary for policymakers," in *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, pp. 3–29, Cambridge University Press, Cambridge, UK, 2013.

[7] S. Pahlavan, M. Jahangiri, A. Alidadi Shamsabadi, and A. Baharizadeh, "Assessing the current status of renewable energies and their limitations in Iran," *International Journal of Renewable Energy Development*, vol. 9, no. 1, pp. 97–105, 2020.

[8] A. Rahimi Ariae, M. Jahangiri, M. Haghgo Fakhr, and A. Alidadi Shamsabadi, "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, no. 2, pp. 149–160, 2019.

[9] A. Mostafaeipour, S. J. H. Dehshiri, S. S. H. Dehshiri, and M. Jahangiri, "Prioritization of potential locations for harnessing wind energy to produce hydrogen in Afghanistan," *International Journal of Hydrogen Energy*, vol. 45, no. 58, pp. 33169–33184, 2020.

[10] M. Rezaei, K. R. Khalilpour, and M. Jahangiri, "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, no. 58, pp. 33151–33168, 2020.

[11] M. Jahangiri, A. Haghani, A. Mostafaeipour, A. Khosravi, and H. A. Raeisi, "Assessment of solar-wind power plants in Afghanistan: a review," *Renewable and Sustainable Energy Reviews*, vol. 99, pp. 169–190, 2019.

[12] M. Jahangiri, O. Nematollahi, A. Sedaghat, and M. Saghafian, "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, no. 2, Article ID 023123, 2015.

[13] O. Nematollahi, P. Alamdari, M. Jahangiri, A. Sedaghat, and A. A. Alemrajabi, "A techno-economical assessment of solar/wind resources and hydrogen production: a case study with GIS maps," *Energy*, vol. 175, pp. 914–930, 2019.

[14] J. Zaniani, R. Dehkordi, A. Bibak, P. Baya, and M. Jahangiri, "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, no. 1, pp. 835–841, 2015.

[15] M. Jahangiri, A. A. Shamsabadi, A. Mostafaeipour, M. Rezaei, Y. Yousefi, and L. M. Pomares, "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, no. 27, pp. 13862–13875, 2020.

[16] M. Jahangiri, M. H. Soulouknga, F. K. Bardei et al., "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, no. 54, pp. 28613–28628, 2019.

[17] M. Jahangiri, O. Nematollahi, A. Haghani, H. A. Raiesi, and A. Alidadi Shamsabadi, "An optimization of energy cost of clean hybrid solar-wind power plants in Iran," *International Journal of Green Energy*, vol. 16, no. 15, pp. 1422–1435, 2019.

[18] H. Khalili, A. Arash, and R. Alayi, "Simulation and economical optimization hybrid system PV and grid in Ardabil city," *Journal of Current Research in Science*, vol. 3, no. 5, p. 83, 2015.

[19] A. Mostafaeipour, M. Qolipour, M. Rezaei, M. Jahangiri, A. Goli, and A. Sedaghat, "A novel integrated approach for ranking solar energy location planning: a case study," *Journal of Engineering, Design and Technology*, vol. 19, no. 3, pp. 698–720, 2020.

[20] J. Riahi Zaniani, S. Taghipour Ghahfarokhi, M. Jahangiri, and A. Alidadi Shamsabadi, "Design and optimization of heating, cooling and lightening systems for a residential villa at Saman city, Iran," *Journal of Engineering, Design and Technology*, vol. 17, no. 1, pp. 41–52, 2019.

[21] M. B. Sibuea, S. R. Sibuea, and I. Pratama, "The impact of renewable energy and economic development on environmental quality of ASEAN countries," *AgBioforum*, vol. 23, no. 1, pp. 12–21, 2021.

[22] R. Kumar, A. Bewoor, and R. Alayi, "Utilization of kitchen waste-to-energy: a conceptual note," *Renewable Energy Research and Applications*, vol. 2, no. 1, pp. 91–99, 2021.

[23] H. Xiang, P. Ch, M. A. Nawaz, S. Chupradit, A. Fatima, and M. Sadiq, "Integration and economic viability of fueling the future with green hydrogen: an integration of its determinants from renewable economics," *International Journal of Hydrogen Energy*, vol. 46, no. 77, pp. 38145–38162, 2021.

[24] Z. Ahmed, M. Ahmad, H. Rjoub, O. A. Kalugina, and N. Hussain, *Economic Growth, Renewable Energy Consumption, and Ecological Footprint: Exploring the Role of Environmental Regulations and Democracy in Sustainable Development*Wiley, Hoboken, NJ, USA, 2021.

[25] A. Razzaq, Y. Wang, S. Chupradit, W. Suksatan, and F. Shahzad, "Asymmetric inter-linkages between green technology innovation and consumption-based carbon

emissions in BRICS countries using quantile-on-quantile framework," *Technology in Society*, vol. 66, Article ID 101656, 2021.

[26] T. S. Adebayo and H. Rjoub, "Assessment of the role of trade and renewable energy consumption on consumption-based carbon emissions: evidence from the MINT economies," *Environmental Science and Pollution Research*, vol. 28, no. 41, pp. 58271–58283, 2021.

[27] N. Mughal, A. Arif, V. Jain et al., "The role of technological innovation in environmental pollution, energy consumption and sustainable economic growth: evidence from south Asian economies," *Energy Strategy Reviews*, vol. 39, Article ID 100745, 2022.

[28] T. S. Ge, R. Z. Wang, Z. Y. Xu et al., "Solar heating and cooling: present and future development," *Renewable Energy*, vol. 126, pp. 1126–1140, 2018.

[29] Statista, *Leading Countries by Cumulative Solar Water Heating (SWH) System Capacity Worldwide as of 2018,* Statista, Hamburg, Germany, 2021.

[30] IEA, *Solar Heat Worldwide 2021*, IEA, Paris, France, 2020.

[31] REN 21, *Renewables 2020 Global Status Report*, REN 21, Paris, France, 2021.

[32] M. Norouzi, M. Yeganeh, and T. Yusaf, "Landscape framework for the exploitation of renewable energy resources and potentials in urban scale (case study: Iran)," *Renewable Energy*, vol. 163, pp. 300–319, 2021.

[33] R. Kalbasi, M. Jahangiri, A. Nariman, and M. Yari, "Optimal design and parametric assessment of grid-connected solar power plants in Iran, a review," *Journal of Solar Energy Research*, vol. 4, no. 2, pp. 142–162, 2019.

[34] M. Jahangiri, O. Nematollahi, E. Heidari Sooreshjani, and A. Heidari Sooreshjani, "Investigating the current state of solar energy use in countries with strong radiation potential in Asia using GIS software, a review," *Journal of Solar Energy Research*, vol. 5, no. 3, pp. 477–497, 2020.

[35] Ministry of Energy, Ministry of Energy, *Renewable Energy and Energy Efficiency Organization (SATBA)*, Tehran, Iran, 2020.

[36] S. Singh, A. Anand, A. Shukla, and A. Sharma, "Environmental, technical and financial feasibility study of domestic solar water heating system in India," *Sustainable Energy Technologies and Assessments*, vol. 43, Article ID 100965, 2021.

[37] S. Pahlavan, M. Jahangiri, A. Alidadi Shamsabadi, and A. Khechekhouche, "Feasibility study of solar water heaters in Algeria, a review," *Journal of Solar Energy Research*, vol. 3, no. 2, pp. 135–146, 2018.

[38] M. Jahangiri, A. Alidadi Shamsabadi, and H. Saghaei, "Comprehensive evaluation of using solar water heater on a household scale in Canada," *Journal of Renewable Energy and Environment*, vol. 5, no. 1, pp. 35–42, 2018.

[39] L. Siampour, S. Vahdatpour, M. Jahangiri et al., "Techno-enviro assessment and ranking of Turkey for use of home-scale solar water heaters," *Sustainable Energy Technologies and Assessments*, vol. 43, Article ID 100948, 2021.

[40] A. Shamsabadi, M. Jahangiri, T. Rezaei, R. Yadolllahi Farsani, and A. Seryani, The Design of a seasonal heat storage system with a geothermal heat pump for a residential building in Tehran," *Journal of Engineering, Design and Technology*, vol. 20, 2021.

[41] S. Rahmati dehkordi and M. Jahangiri, "Sensitivity analysis for 3E assessment of BIPV system performance in Abadan in southwestern Iran," *Journal of Renewable Energy and Environment*, vol. 9, no. 1, pp. 1–12. In press, 2021.

[42] M. Moein, S. Pahlavan, M. Jahangiri, and A. Alidadi Shamsabadi, "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*, vol. 5, no. 1, pp. 8–22, 2018.

[43] K. Alizadeh, M. Jahangiri, and M. Bakhtdehkordi, "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*, vol. 9, no. 3, pp. 291–305. In press, 2021.

[44] 2020 Census, *Statistical Center of Iran*, 2020 Census, Jeffersonville, IN, USA, 2021.

[45] R. Kalbasi, M. Jahangiri, A. Mosavi et al., "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*, vol. 45, Article ID 101097, 2021.

[46] M. Jahangiri, E. T. Akinlabi, and S. M. Sichilalu, "Assessment and modeling of household-scale solar water heater application in Zambia: technical, environmental, and energy analysis," *International Journal of Photoenergy*, vol. 2021, Article ID 6630338, 2021.

[47] R. Kalbasi, M. Jahangiri, and A. Tahmasebi, "Comprehensive investigation of solar-based hydrogen and electricity production in Iran," *International Journal of Photoenergy*, vol. 2021, Article ID 6627491, 2021.

[48] R. Alayi, S. R. Seydnouri, M. Jahangeri, and A. Maarif, "Optimization, sensitivity analysis, and techno-economic evaluation of a multi-source system for an urban community: a case study," *Renewable Energy Research and Application*, vol. 3, no. 1, pp. 21–30. In press, 2021.

[49] Natural Gas Prices, "Global petrol prices," 2021, https://www.globalpetrolprices.com/natural_gas_prices.