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Research Article

Impacts of Demand Side Management Methods on the Feasibility of a Residential PV System

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Abstract

Energy consumption rising and fossil fuels drawbacks, which comprised of emissions and the concern of depletion, have forced nations to replace other sources such as the renewable energies to achieve a reasonable solution. Solar energy is one of the most promising resources to overcome the increasing demand in residential sector. In this regard, the PV systems are kind of conventional technologies which are widely integrated in buildings. However, the widespread utilization of these new resources, the feasibility analysis is needed to assess the economic profitability. This paper focus on the feasibility assessment of a residential PV system in the content of different electricity pricing schemes including flat pricing (S1), Time-of-Use pricing (S2) and Time-of-Use/tiered pricing (S3). Hence, the economic indicators (NPV and payback time) were calculated for the mentioned pricing models. The results showed that the S3 scheme has the highest NPV value (11258$) and the lowest payback period (3.8 years). In conclusion, the last two methods, known as Demand Side Management (DSM), are more beneficial compared to the flat pricing and proposed for the implementation of a PV system in Iran's residential sector.

Keywords: residential PV, feasibility study, flat pricing, demand side management, System Advisor Model

Introduction

Increasing in energy consumption is one of the major concerns among nations. Furthermore, countries are facing the limitation problems and environmental disadvantages relating to fossil fuels. Therefore, replacing alternatives is a reasonable solution, which in turn has brought some developments to decrease the dependence on fossil fuels. It is clear cut that the renewable energy substitution can reduce the fossil fuels drawbacks; however, investing huge sums of money is needed. There exist some investigations that proves the effectiveness of replacing renewables regarding costs and reliability (Yousefi et al., 2017a; Han et al., 2017; Lund, 2003; Kasaeian et al., 2018).

There is a growing energy demand in residential sector, thus implementing new renewable technologies is an efficient way to overcome this problem. The smart homes are of significance example in order to manage the optimal energy by considering renewable technologies (Zhou, 2016; Premarathne, 2015; Yousefi et al., 2017b). Some investigations have been done in case of building-integrated PV systems, for example, in Bangladesh, the economic and

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environmental evaluations of utilizing solar PV for electricity grid in houses was assessed (Hasanuzzaman et al., 2015). In a research by Young et al. (2019), the economic impacts of residential PV and battery energy storage on electricity network businesses were quantified. Lu et al. proposed a residential demand response model considering distributed PV consumption based on dynamic electricity price (Lu et al., 2019). In another paper a combined economic dispatch and demand response optimization model under renewable obligation was presented and real data from a large-scale demand response program were used in the proposed model (Hlalele, 2021). Foles et al. (2020) evaluated different photovoltaic system configurations with and without batteries for the normal low voltage Portuguese consumer profile with 3.45 kVA contracted power. They presented the systems' cost-effectiveness, within the Portuguese legislation, which promotes and enables policies for self-generation and self-consumption. In another study, the probability of residential PV systems producing low-voltage were investigated through a Monte Carlo simulation (Tie et al., 2015). Also, the existence restrictions for the building-integrated PV feasibility was identified by Ruhang (2016).

Another example is a near zero energy building using PV modules for supplying electricity, since the solar PV generation technology resulted the high efficiency (Koo et al., 2017). Regarding to the renewable energy development, the effect of investment costs and governmental policies are not negligible in all cases. There are some studies allocated to the importance of policies for promoting renewable energies in the world (Elma et al., 2017; Hills and Michalena, 2017; Jimenez et al., 2016; Orioli and Gangi, 2017). Also, in a study, the impact of governmental subsidies was economically analyzed as an important parameter, since it is indifferent provided that the initial costs of renewable energy installation are low (Nie and Yang, 2016). Furthermore, governments have intended to put some tariff in order to widely use the renewable energies. In Europe, there are a number of feed-in tariffs regarding PV energy which make it more profitable and economic (Ramírez et al., 2017). Also, the financial viability of renewable projects was examined under subsidies and legislations in Korea. The results demonstrated that renewable projects were highly hinged on the investment costs (Koo, 2017). Besides, an array of provisions and subsidies has been offered to the developers of PV systems by Indian government (Sahu, 2016). In Iran, the impact of city council legislations on implementing the solar water heaters was studied and the payback time was calculated as 17 months (Yousefi et al., 2017c).

As the pricing policy of renewable energies can play a vital role in their implications, some investigations were carried out to assess this issue. For example, in Canada, the nodal pricing system was utilized for the PV cases and compared to the uniform pricing (Brown and Rowlands, 2009). In another study, the impact of PV size and the electricity price on the optimal heat pump system sizing, heater, and the thermal storage were analyzed through some scenarios (Fischer et al., 2016). As the state of pricing, one of the most prominent schemes is time-of-use (TOU) method, in which the electricity price is higher in the peak hours.

The drawbacks and risk of using TOU program was presented by Qiu et al. (2017). The TOU pricing was also used for maximizing the self-consumption of PVs in an energy management structure (Liu et al., 2016). In Iran, unfortunately, the fossil fuels price is very low and this leads to the lack of renewable energy attention as well (Noorollahi et al., 2017). Hence, in this study, the importance of PV in an integrated building is basically focused.

In this regard, the economic feasibility of utilizing solar energy in the residential sector is evaluated in Iran. Therefore, different grid electricity pricing methods are considered and the system is analyzed in each case. To perform the simulations, System Advisor Model (SAM) software, developed by NREL, is utilized. The concept of using this software as a comparison tool can be regarded as the novelty of this research.

Material and Methods

Building specifications

Building sector, accounts for a considerable share in total energy consumption; as in US and Europe, about 40% of the total energy consumption belongs to the building sector (Yousefi et al., 2018). Therefore, it is an important issue to consider energy management in building sector. In this paper, the studied building is comprised of one floor with the total area of 105 m2, located near Tehran, the Iranian capital city. The electricity consumption, which is included of cooling, lightening, electric appliances, and the electronic equipment, is calculated from the electricity bills of the building. The annual hourly electricity load is illustrated in figure 1. Obviously, the maximum energy consumption is for the months June to September. This sharp augmentation is hinged on the weather temperature, which is getting to be warm in the summer and increases in cooling demand.

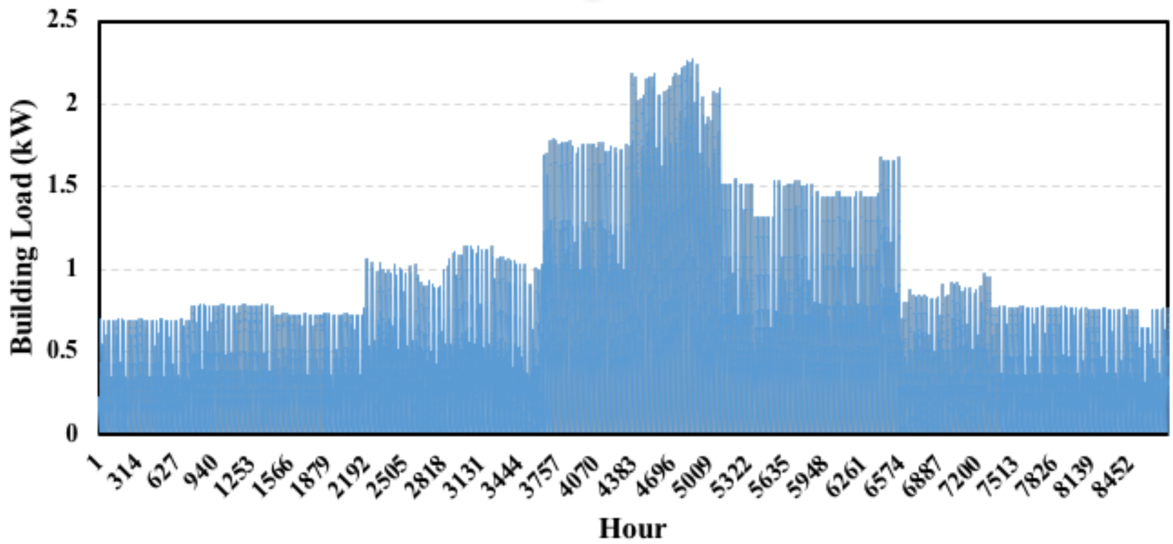

Figure 1. Building hourly load

Solar data

Iran is located in the Middle East, between 25° and 40° north latitude. Having about 2800 sunny hours per year (Yousefi and Ghodusinejad, 2017), it has a significant potential of solar radiation in the whole country. Moreover, the world's Sun Belt passes through this country influencing the annual average of sun radiation. Based on calculations, the amount of actual solar radiation in Iran, is varying in the range of 1800-2200 kWh/m2 per year (Alamdari et al., 2013; Najafi et al., 2015). Figure 2 shows the annual average horizontal irradiation in Iran. According to figure 2, the high radiation area is depicted by near red color and the low radiation locations move toward the green color. The annual average daily irradiance in the building site is also depicted in figure 3.

Input data

There are different tabs in SAM software to input the required data for each project. But on the whole, the input data can be divided into two main categories. At first, technical data of the project (here the PV system) are needed. The second part is related to the economic data of the project. Some other data such as meteorological characteristics, electric load, etc. are also required for each project. The details of the PV system and economic data considered in this project are presented in the following.

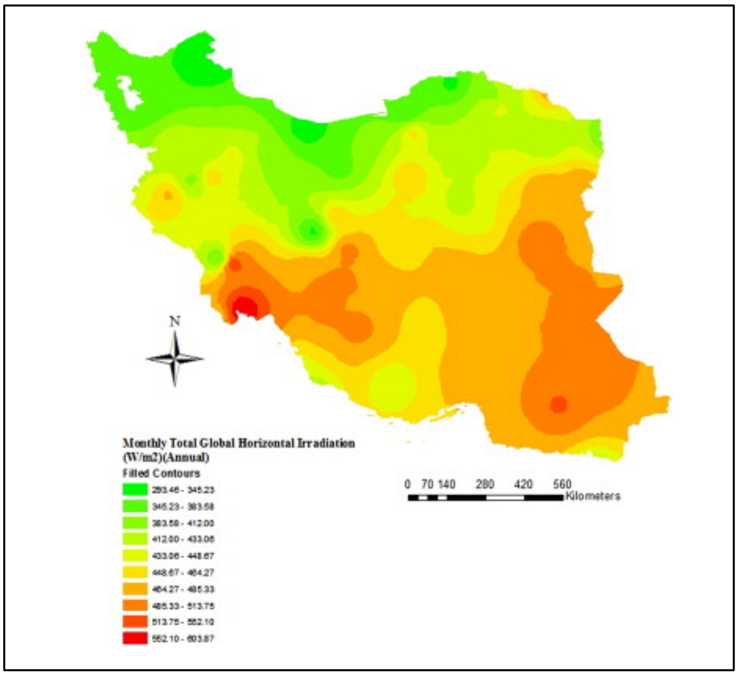

Figure 2. Annual average solar irradiance in Iran (Alamdari et al., 2013)

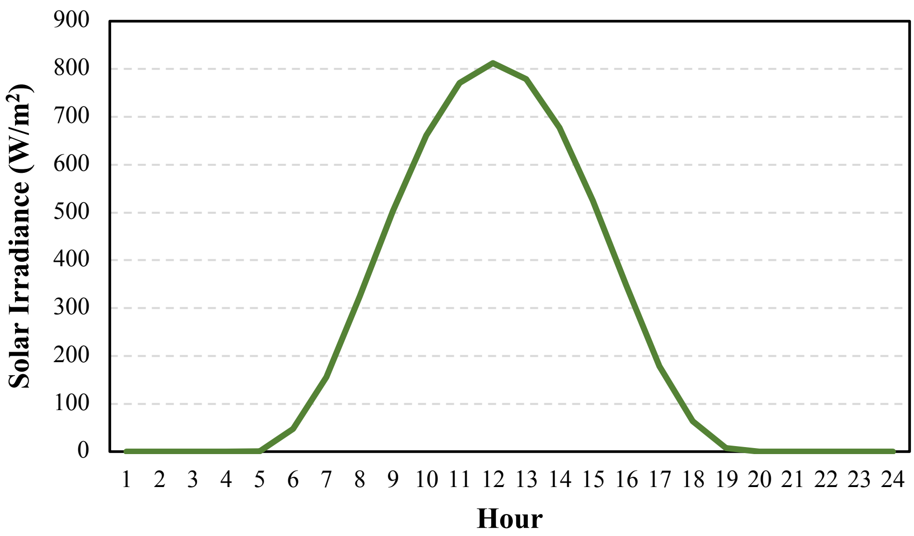

Figure 3. Daily solar irradiance in Tehran (annual average)

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- **PV system:**

According to the building base load, Shinsung Solar Energy (SS-DM320B3 model) solar modules are selected for the project. The modules output power is about 320 Wdc, which fifteen modules are estimated for the mentioned building to supply around 5 kW power. Furthermore, one 5000kW ABB inverter is chosen. Also, the storage system is negligible due to the fact that the solar system is operating in grid-connected mode. To model the performance quality of the modules, a 1% decrease in power output per year is intended. The solar power system specifications can be seen in table 1.

Table 1. Technical characteristics of the estimated PV system

Characteristics	Amount
Solar module	
Nominal efficiency (%)	16.92
Maximum power (Wdc)	319.917
Maximum power voltage (Vdc)	37.9
Maximum power current (Adc)	8.4
Module area (m^2)	1.891
Inverter	
Maximum power dc (Wdc)	5190.29
Maximum power ac (Wac)	5000
Efficiency (%)	96.819

- **Economic data:**

Since the main goal of this study is the economic feasibility, economic data and the cost of the project is of great importance. SAM software has the full economic modeling features by which we can analyze all benefit and economic evaluations of renewable energy projects. Economic data can be divided into two parts; first, the costs of solar system installation, and then, the market information, government incentives and the financial and economic parameters in general. Table 2 shows the solar system installation costs. It is needless to say that the maintenance costs are also considered in this project, which is equal to 15$ for the first year and turning to rise 2% each year. Moreover, the maintenance cost based on power unit is estimated as 25 $/KW in annum.

Table 2. PV system installation cost

Subject	Unit cost	Total cost ($)
Direct costs		
Solar module	0.4 $/Wdc	1,919.50
Inverter	0.1 $/Wdc	479.88
BOS equipment	0.05 $/Wdc	239.94
Installation labor costs	100 $	100
Marginal profit for the installation company	0.02 $/Wdc	95.98
Indirect costs		
Grid connections license	30$	30
Total installation costs		2,865.29
Total installation cost per capacity ($/Wdc)		0.6

According to the table 2, the total costs are calculated as about 2865$. It is considered that 60% of the initial cost is provided by a bank loan. The loan term and the loan rate are set as three years and 18%, respectively. Therefore, the net cash payment of 1146$ is needed during the project life of 25 years and an annual inflation rate of 30%.

Simulation scenarios

As stated previously, the goal of this paper is to analyze the economic feasibility and performance of a residential PV system under different grid electricity pricing methods. Therefore, three different scenarios are considered in SAM software. These include flat pricing, Time of Use (TOU) pricing, and finally TOU/tiered pricing. Based on the Feed-in-Tariff (FIT) law of Iran, the power purchase value for PV projects with the capacity of less than 20 kW, is around 0.037$, and this value is set for all scenarios.

- **Flat pricing (S1):**

In the first scenario, the utility power price is based on flat pricing method, i.e. the power cost is fixed for all hours of the day during the whole year. This is a basic method for power pricing and some buildings are still using this system as metering method in Iran. The power price is set as 0.018$ for this scenario.

- **TOU pricing (S2):**

Time of Use (TOU) pricing is considered as the second scenario. TOU pricing is one of most used time-based Demand Side Management (DSM) methods all around the world. In this scenario, the day is divided into three parts namely peak, off-peak and mid-peak. The values of power price in this scenario are presented in table 3.

Table 3. TOU power prices

	Hours	Price
Off-peak	0-6, 23	0.034
Mid-peak	7-18	0.043
Peak	19-22	0.053

- **TOU/tired pricing (S3):**

In the third scenario, in addition to TOU pricing, the power cost is also related to the level of customer consumption. The electricity cost of the customer will be higher as the consumption increases. The day is divided into three parts as in table 3, and for each part, six levels of consumption are considered. Therefore, there are 18 different values for the grid electricity price according to the time and level of consumption. This method is mostly used in Iran rather than the first method (S1). The values in this scenario are provided in table 4.

Table 4. TOU/tiered power prices

Maximum Usage	Power price ($)		
(kWh)	Off-peak	Mid-peak	Peak
100	0.01	0.012	0.015
200	0.012	0.014	0.017
300	0.024	0.03	0.038
400	0.044	0.055	0.069
500	0.051	0.064	0.08
+500	0.065	0.08	0.101

Results and discussion

The net savings of the system, net present value, and payback period are some financial indicators to assess the economic feasibility of this project. The first point is considered as the residue value of the electricity bill for the system without PV and the integrated one. It is clear that the S3 pricing scheme has the highest value of net saving, while the electricity bill is greater for the S2 methodology. Besides, the net present value is calculated higher for the S3 scenario. Moreover, the payback period is evaluated lower for the third scenario (S3), which reassures the economic profitability of this model. Table 5 shows the economic results of the simulation for three mentioned scenarios in detail. As in table 5, in all the economic factors, DSM pricing scenarios, i.e. S2 and S3, has a better value than flat pricing scenario; while S3 is the best among all.

Table 5. Economic results of the simulation for three scenarios

	S1	S2	S3
Annual generated power (kWh) (year 1)	8736	8736	8736
LCOE (cents/kWh)	2.12	2.12	2.12
Electricity bill without system ($) (year 1)	77	183	185
Electricity bill with system ($) (year 1)	-214	-149	-211
Net savings with system ($) (year 1)	290	332	396
Net present value ($)	7224	8819	11258
Payback period (years)	5.4	4.6	3.8

SAM provides the after-tax cash flow of the project to give a better insight about the economic feasibility of the system. As stated in the Manual of the software, the cash flow represents the project's net annual cash flow including the value of energy generated by the system. In other words, the cash flow for each year of the project lifetime is calculated as the sum of the total costs and the energy value through the year. Total annual costs are comprised of total incomes including incentives and tax savings, minus the annual spending including operating costs and debt payments. The cash flow is important, since the NPV is the net present value of the cash flow.

The cash flow of the project for three scenarios is depicted in figure 4. As can be seen, the cash flow trend for all three scenarios is ascending, causing the NPV to be positive and the project to be economically feasible. Moreover, the rate of ascending increases from S1 to S3. Hence, the NPV of S3 is higher than the two others.

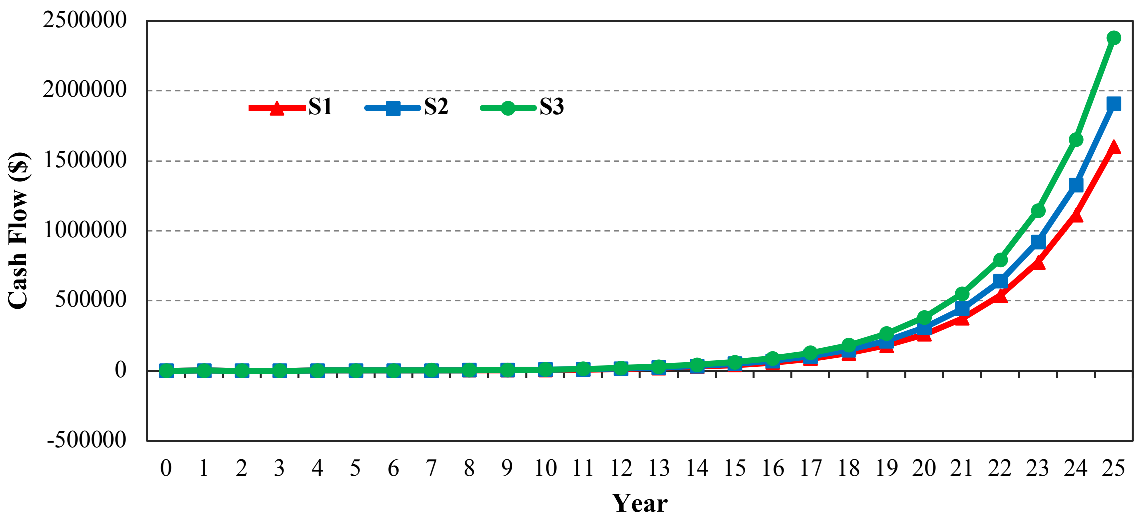

Figure 4. After-tax cash flow

Also, figure 5 demonstrates the monthly utility bill with/without PV system for three scenarios. The maximum price is allocated to the third scenario and clearly for the assumption without the PV case on July. It can be observed that the utility bill for S2 is higher than the two other scenarios for all months except in June and July. Besides, in some months (April and May), the bill amount is negative, which shows that the sold electricity value is more than the purchased one. The fact that the value of utility bill during all months decreases as the PV system is installed in the building, is also clear in figure 5.

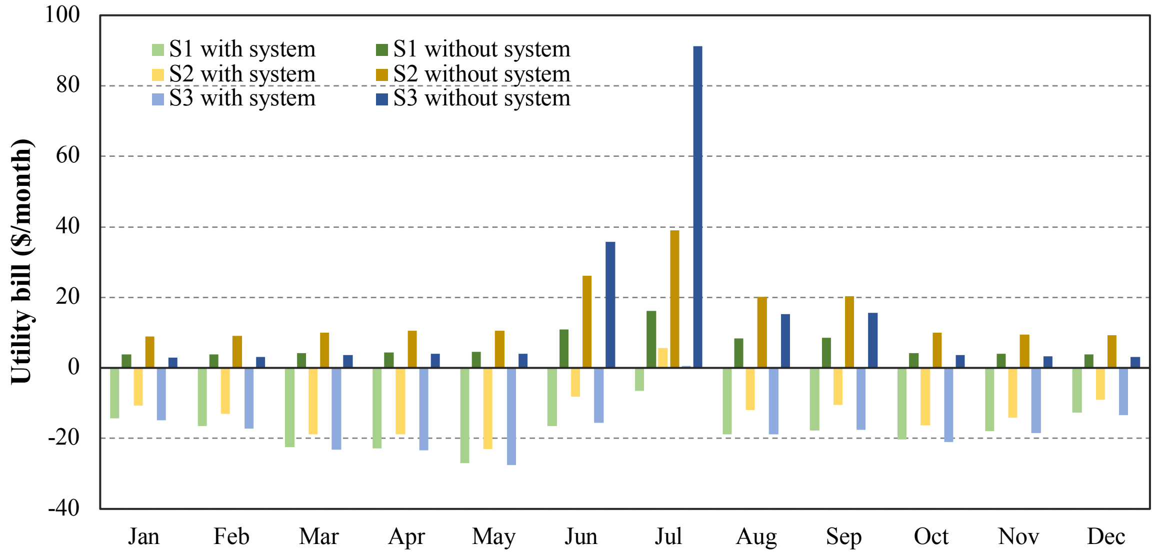

Figure 5. Monthly utility bill for the three scenarios with/without the PV system

To clarify the electrical power behavior in a building, the hourly power transaction with the grid is analyzed and shown in figure 6. As it is obvious in the figure 6, the power transaction between the building and the grid is mostly positive during the hours of the year, i.e. most of the time, the building is exporting the power to the grid. There exists some extent of negative values representing the power entered to the grid. The most power import from the grid happens in the middle of the year, i.e. during summer peak.

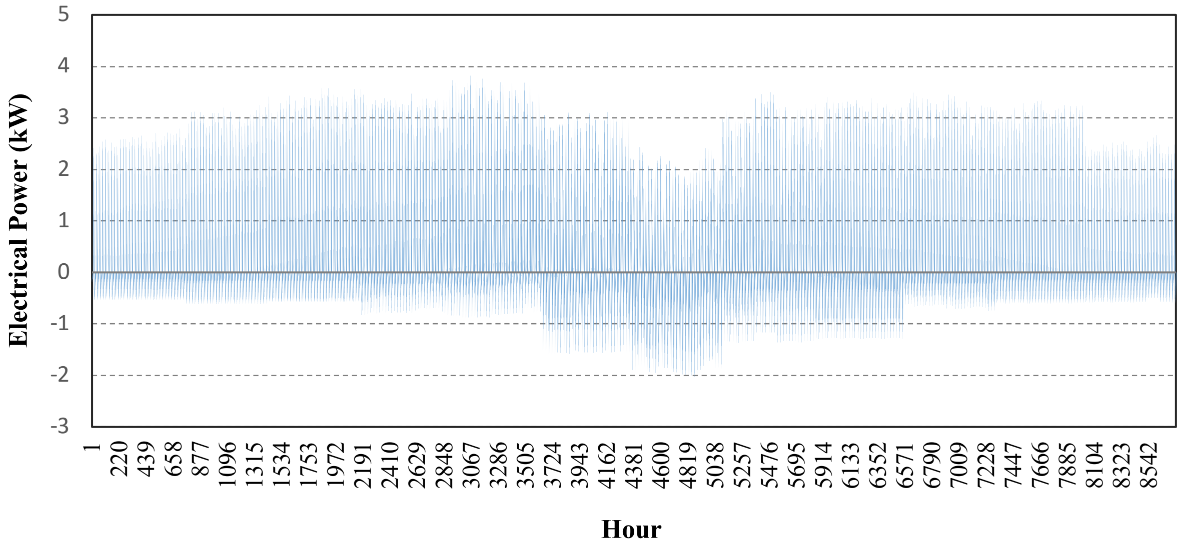

Figure 6. Hourly building electrical power transaction with the grid

The heat map of the project is also simulated and shown in figure7 and figure 8. Figure 7 depicts the electricity from the system to the grid that is widely distributed during the year. The maximum transaction signifies in around 12 o'clock. On the other hand, the electricity from the system to the load is presented in figure 8 by emphasizing the contrast with the figure 7. To elaborate more on this issue, there is a great overlap between the two figures bellow, since the higher load electricity is distributed more through June to August. From figure 8, it is also vivid that the highest value of power injection from the system to the load happened in mid-year and mid-day hours.

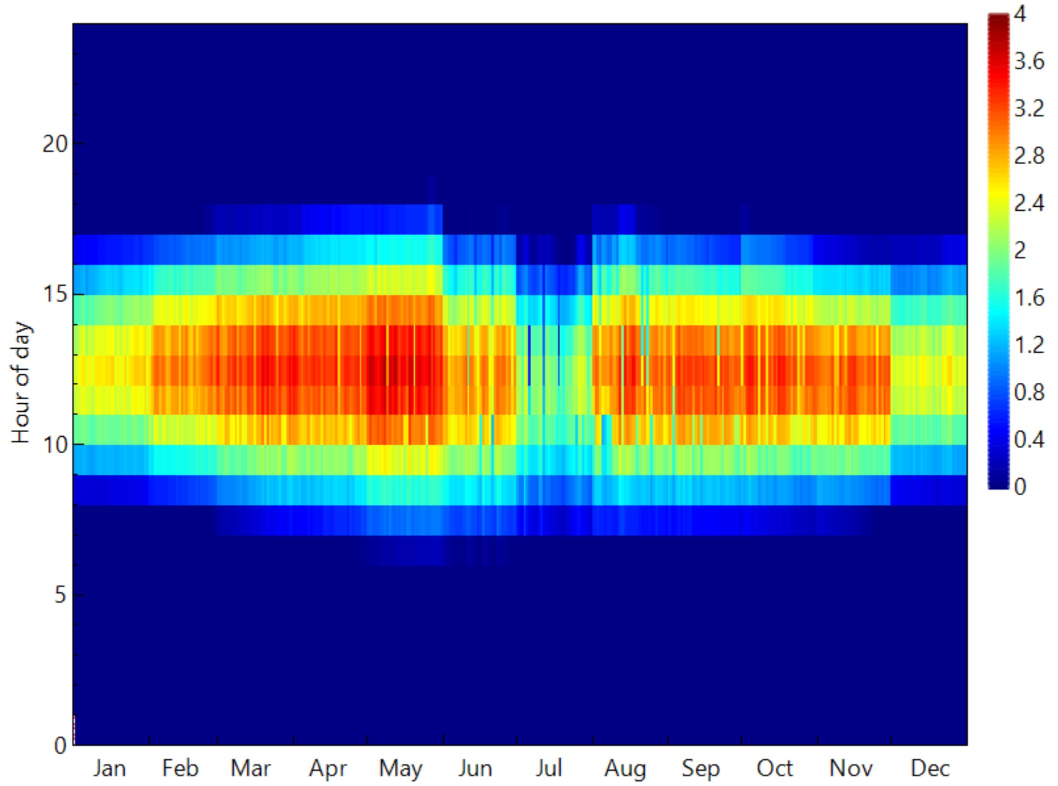

Figure 7. Electricity from the system to the grid (kWh)

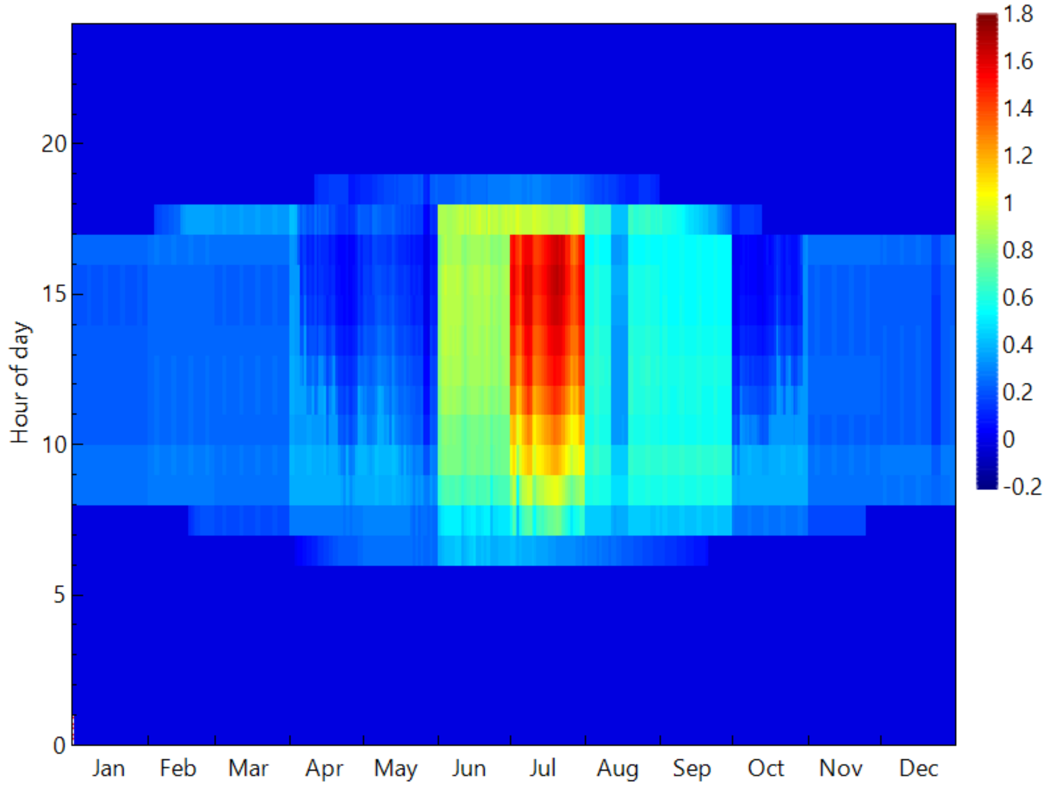

Figure 8. Electricity from the system to load (kWh)

Owing to the fixed panel capacity for the three scenarios, the monthly average profile is obtained and discussed below (figure 9). Precisely, the blue line is for the building load, yellow represents the PV generated power, and red is the power transaction with the grid. In fact, the generated power from PV is generally more than the building load (monthly average). This brings on the positive value for the grid and a good source of revenue and value-creation for the building.

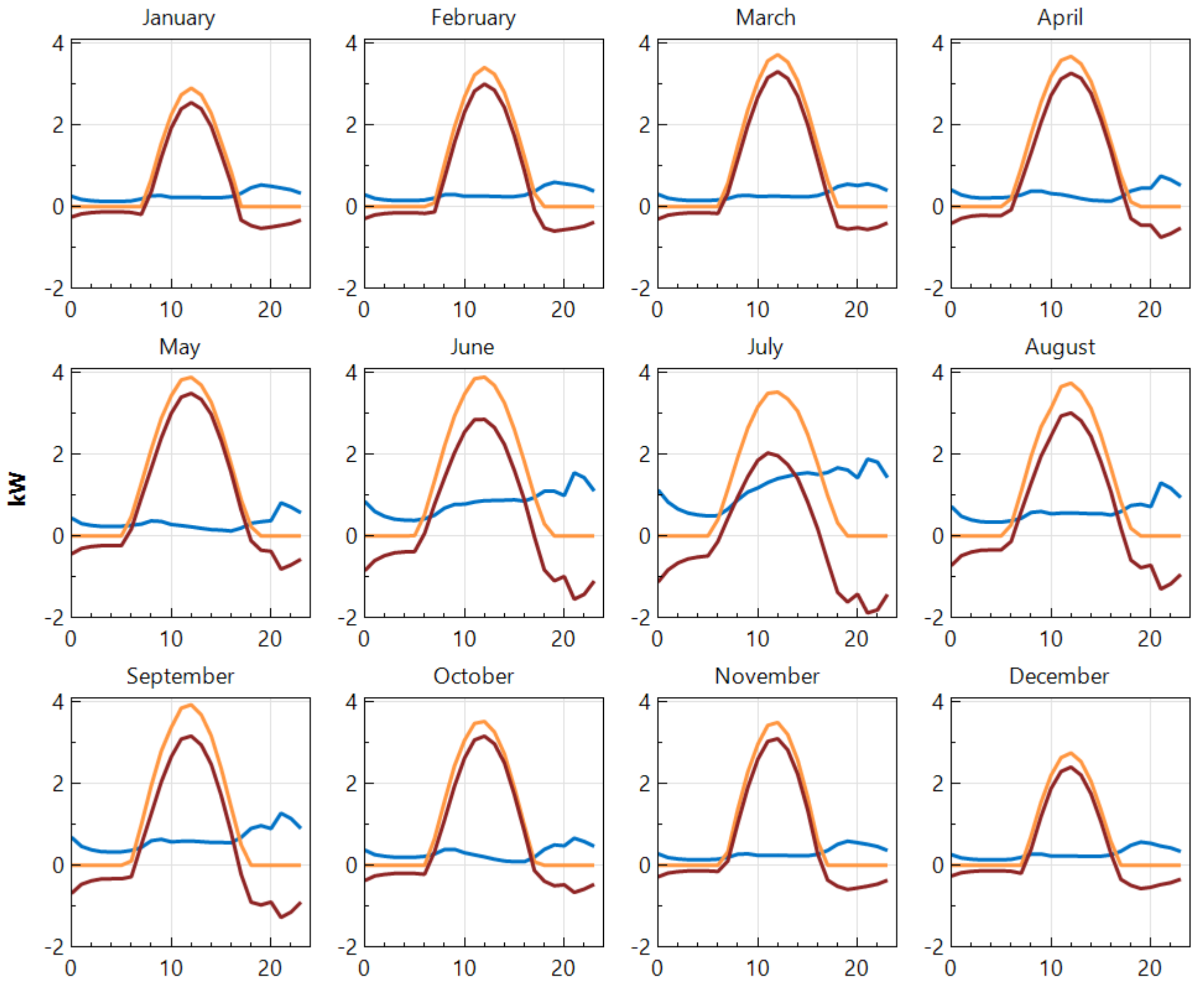

Figure 9. Hourly electricity profile (Month average –in kW)

Conclusion

In this paper, the feasibility study of a residential PV system was conducted. For this, three different utility power pricing schemes were considered including flat pricing (S1), Time-of-Use pricing (S2) and Time-of-Use/tiered pricing (S3). A 5 kW PV system was considered to be integrated with a residential building in Tehran and economic and technical performance of the system was analyzed. System Advisor Model (SAM) software was used to perform the simulations.

The results indicated that the economic performance in S3 is better than the two others. The NPV for S3 was calculated as 11258$ while it was 8819$ and 7224$ for S2 and S1, respectively. Besides, the payback period of the project in S3 was 3.8 years, which is lower than 4.6 and 5.4 years for S2 and S1, respectively. These assert that the project is more profitable at the presence of DSM methods.

Another fact is the savings achieved in utility bills payment. By installing the PV system, a good saving in bill payment was achieved in all three scenarios. Again, S3 had a better situation in savings compared to the other scenarios. By applying DSM methods, the bill payment of the customer increased, but the saving was still higher than in flat pricing.

The importance of DSM methods is evident in electricity markets. The results of the paper assert that these positive effects can also be seen in residential PV systems. Since, the economic performance of the system is better and the project, with DSM pricing schemes, is more beneficial for the customer than with simple flat pricing.

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