Commercial building integrated energy system: sizing and energy-economic assessment

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Abstract

Integrated energy systems are one of the potential options for buildings that can reduce emission. In this research study, the energetic and economic performance of a micro-gas turbine combined heating and cooling plant coupled with a solar PV is analyzed for an office building in Iran. For each analysis, two different scenarios have been performed. System sizing parameters defined in a way that renewable to fossil fuel share is correlated to plant performance and economy. To model the studied system, a time-dependent method is used, which is the inherent characteristic of renewable energies. The renewable energies used here are solar heaters and solar panels. Contours of Net Present Value (NPV) are evaluated as a function of solar heating share and different economic parameters. In addition, optimal system sizing for a typical building is obtained and the results are provided. Effect of various major parameters shows that under the current condition and despite the supportive incentive for renewable energies, strategies and plans even without solar energy are not economically viable due to the high discount rates. In addition, results provide that, in reasonable and normal discount rate, fuel and grid electricity prices, governmental subsidization for conventional combined heat, and power (CHP) and combined cooling, heat, and power(CCHP) is not necessary, and only in this condition solar electricity selling price (i.e. governmental support program) is effective to increase renewable penetration. The results show that if the interest rate is less than 5%, the NPV becomes positive. Also, when the electricity price reaches $0.07/kWh or higher, the NPV becomes positive.

Keywords: economic assessment; system sizing; solar energy; commercial buildings; Energy

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1 INTRODUCTION

Currently, a large amount of energy needed in the world is provided by fossil energy, and one-third of this energy is consumed in buildings [1, 2]. Therefore, energy management in buildings to reduce energy consumption and environmental effects is discussed in many researches [3].

A number of researchers focus on optimizing the exterior design of buildings to reduce their energy requirements. In these studies, the architecture of the building and the materials used in the building are important. Another research field is energy systems performance strategy, where improving systems performance is an important goal in these studies [4].

Even by improving the efficiencies and operation system, buildings are still dependent on the energy networks like the electricity grid [5]. The recent trend in energy efficiency is to increase onsite generation to reduce transmission losses [6]. In addition to this tendency, buildings have a unique characteristic which known as demand diversity and due to these reasons, polygeneration is an attractive choice in buildings. Akbari et al. [7] studied grid-connected renewable energy for a remote village. After checking the annual wind speed and the intensity of sunlight in that area,

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they evaluated the use of renewable energy from a technical and economic point of view, and they concluded that in this area, the use of four wind turbines and network electricity system is an optimal system. Deymi-Dashtebayaz et al. [8] studied a near-zero energy building based on wind-solar energy and their goal was to cover the building's heating, cooling and electricity loads with renewable energies. They concluded that the solar energy system can supply up to 60% of the building's electrical load. In winter, 13% of the electricity needs are supplied from the power grid, and in summer, 69% of the wind turbine's production power is sold to the grid. Chen et al. [9] studied an integrated energy system (IES) based on photovoltaic, photo catalysis and photo thermal. They conclude that the IES can completely provide the needs of electricity, hydrogen energy and heating. Qu et al. [10] simulated thermal comfort in old buildings using Energy plus software. They concluded that the optimal combination includes vacuum insulated windows, 2-cm-thick polyisocyanurate panels and reduced plaster air penetration. Gholamian et al. [11] propose a CCHP system for a building to provide required cooling, heating and electricity of building. They concluded that the proposed system can after supplying the building's required energy, selling 715.32 kWh of electricity to the network to provide some additional costs of the building. When it comes to multigeneration energy systems for buildings, various configurations and technologies based on environmental effects, cost and efficiency can be selected. In general, the multigeneration system can be categorized according to the size of different scales of large, medium, small and micro [12]. Size of the system strongly affects system performance and economics. Proper design and sizing is very important because micro and small scales, which are very common in buildings, have higher cost and lower efficiency per kilowatt. Merkel et al. [13] studied on optimized model of a micro-CHP system and compare the results with base micro-CHP system in UK. They concluded that by optimizing the model, costs are reduced by 30%. Also, they concluded that effects of economic uncertainties should be accounted and can greatly affect the results. A hospital multigeneration planning was carried out by Arcuri et al. [14] using mixed integer programming and Mavrotas et al. [15] added a Monte Carlo approach to mixed integer programming for energy planning in a hospital to address economic uncertainties and provided the probability distribution for decision making. To address efficiency variations due to the variable load, Arcuri et al. [16] developed a complex model for a trigeneration plant and optimized both designing and operation strategy using nonlinear mixed integer programming. The annual total cost has been considered mostly as the objective function for minimization. Valero et al. [17] implemented the same objective function using linear integer programming for a trigeneration plant design in the Mediterranean climate and accounted selling surplus electricity to the grid, they examined effects of economic parameters in Spain on optimal design. CCHP and CHP plants are not the only choices that have been subjected to study. A climate-based optimal design and sizing of a SOFC micro-CHP residential building were studied by Yang et al. [18] using a detailed model but only performance and demand matching criteria are considered for optimization. Technology of fuel cell is a good alternative choice for conventional prime movers in micro polygeneration for buildings [19, 20]. The research process in polygeneration systems is moving towards renewable energy such as wind and solar energy, which makes the building's needs for energy tend to zero (i.e. zero energy buildings). Also, in some studies, the combination of solar cells with internal combustion engines or gas turbines (GTs) [21, 22] or fuel cell systems [23, 24] has been investigated. Common implemented optimal sizing approach is linear programming and total annual cost and efficiency are frequent objective functions. The use of renewable energy is economically expensive and countries need to pay special energy subsidies to buy the necessary equipment, so the initial investment is very high for zero energy buildings. Support plans and economic conditions of a country have a great impact on the use of renewable energy in buildings. Therefore, it is necessary to develop optimal modeling methods to investigate the impact of countries' policies on factory productivity and cost reduction [25]. In Iran, the government has taken two measures to encourage owners to use renewable energy. The first solution is the guaranteed purchase of electricity produced from renewable sources, such as solar energy [26]. Ghazali et al. [27] evaluated the use of photovoltaic cells in the facade of the building. They concluded that the payback period is 12 years. Ji et al. [28] investigated the approach of using solar energy in a building. They concluded that it is possible to maintain the temperature of the rooms of an office building at 21°C using solar heaters in Hefei, China. Soteris A. Kalogirou analyzed the use of solar energy for a zero energy building. They have provided good suggestions for the possible problems in the installation of photovoltaic cells on the roof and facade of the building [29]. The second solution is to gradually raise the price of natural gas and gradually reduce the subsidy on fossil fuels. These methods are useful in encouraging owners to use renewable mixed polyg eneration systems, but there are other main economic factors, which affect the viability of the plant and the most important want is discount rate.

In previous studies, system sizing and planning for a mixed conventional and renewable source is not considered or the method is not fast and easy to implement. Renewable and fossil fuel energy share is introduced in this research and system sizing and planning parameters are defined in a manner that at each designed configuration, contributions of energy resources are correlated to the plant economy. In addition, Iran's support programs on the use of renewable energy in the building sector have not been studied yet, and its impact in the current economic conditions has not been studied. In this research study, initially, sizing method for a mixed renewable-conventional energy system is proposed, which is simple and fast for sizing and planning. In the second step, the economy of the system is evaluated as a function of system design parameters and sizing parameters, such as PV output power to GT power ratio. Then, in order to understand the real effect of government support programs, the effects of factors, such as discount rate, fuel cost and supportive factors, have been analyzed.

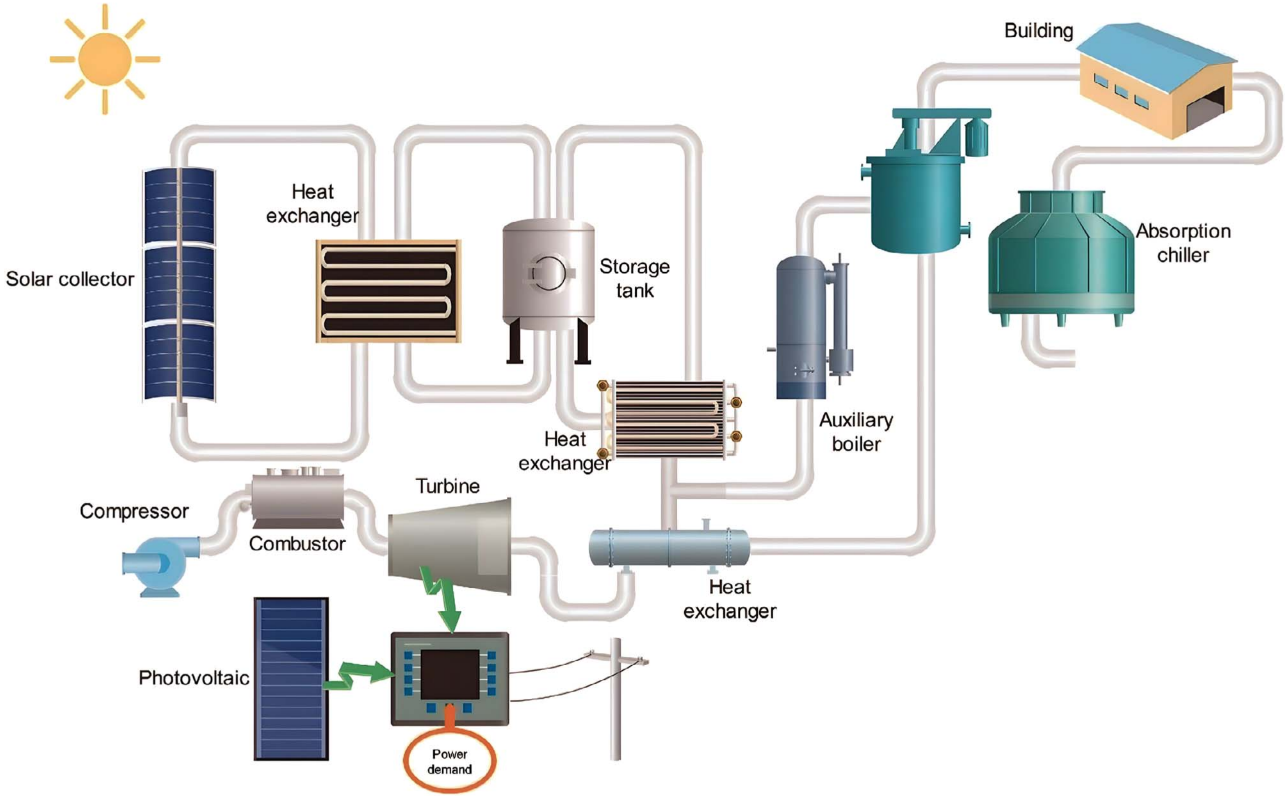

Figure 1. *Integrated system configuration.*

2 METHODOLOGY

In the present study, a methodology for sizing an IES for a typical commercial building in Tehran, Iran is presented, and the results are explained. The system consists of a solar heater, a solar PV, thermal energy storage, a micro-GT CHP system and a single effect Li/Br water absorption chiller. In addition, energy can be exchanged between the power grid and the building. This system is combined. This means that clean energy and conventional systems are combined to rise reliability of energy supply for a building.

The studied building is located in Tehran, Iran, and the weather data used here are from Mehrabad meteorological station. In order to provide the energy needed by the building during the day and night, a solar collector with a storage tank is combined with a CHP and also a fossil fuel heater is added.

Office buildings have specific load pattern and here for generality, average load during working hours of the building is included. Heating, cooling and electrical demands are taken as average during working hours. In addition, a yearly time period is divided into cold and hot seasons and cooling load is only applied in the hot season and heating load is applied in only cold months.

The described system is shown in Figure 1. After the water enters the solar collector, its temperature increases to approximately 60°C, and then, it enters to the HRSG and/or Axillary Boiler to deliver hot water. A single pressure heat recovery boiler is considered [30]. Also, solar panels and micro-GT provide the electricity required by the site. In some cases, when the produced electricity is in excess of the site's consumption, the electricity is sold to the grid. If solar panels and micro-GT cannot provide the electricity required by the site, it needs to be purchased from the network.

2.1 Building simplified load pattern

For the first step in sizing and planning of the system, a quick and simple model is required. One of the simplifications implied here is load pattern simplification. Here, profile presented in Figure 2 is considered as load patterns for a typical day.

This pattern is for all days and all loads including cooling, heating and power. During the rest of the day, loads are assumed to be zero. Start and ending times of working are 7:00 AM and 4:00 PM in this study.

2.2 Component models

2.2.1 *Solar system*

In order to obtain the average hourly radiation, the irradiance data of Mehrabad meteorological station in Tehran is used. Figure 3 presents these values for each month.

Equation $FR_{\tau\alpha}$- FR_{UL} is used to obtain the size of the solar heater. In order to evaluate the solar performance, the temperature

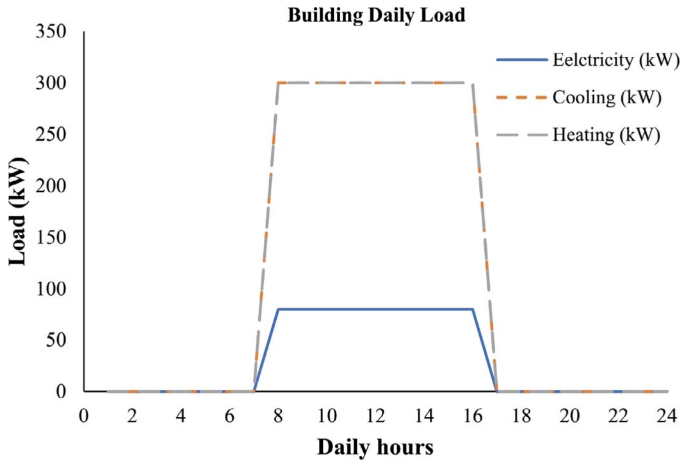

Figure 2. *Simplified Building load model.*

difference between the inlet fluid and the ambient temperatures is used as follows [31]:

$$\dot{Q}_{SH} = A_c\left(FR_{\tau\alpha} \times I - FR_{UL} \times (T_i - T_a)\right) \tag{1}$$

In this equation, $\dot{Q}_{SH}$is the amount of heat absorbed by the fluid. For flat plate collectors, the average values of FR_{UL} and $FR_{\tau\alpha}$ are 3.85 and 0.689 respectively.

The approximate cost of the solar collector is obtained by the following equation [32]:

$$Z_{SH} = 2.36\dot{Q}_{SH}\ (\$) \tag{2}$$

$$OM_{SH} = 0.05\dot{Q}_{SH}\ (\$/year) \tag{3}$$

Operation and maintenance (O&M) cost is correlated to the output capacity of the solar collector. The nominal efficiency of Solar PV is assumed constant.

For the solar PV, constant nominal efficiency model is used. So, the equation is:

$$\dot{W}_{PV} = IA_{PV}\eta_{PV} = \left(\frac{I}{1000}\right)\dot{W}_n \tag{4}$$

Here, $\dot{W}_{PV}$ is the real power and $\dot{W}_n$ is the ideal power which is the panel output at the standard condition and $I_0 = 1000\ W/m^2$ normal to the PV plane. "I "is the irradiance at the specific hour of the day. Like solar collector, PV cost is determined by [33]:

$$Z_{PV} = 2.93\dot{W}_n\ (\$) \tag{5}$$

$$OM_{PV} = 0.02\dot{W}_n\ (\$/year) \tag{6}$$

Here, OM_{PV}stands for O&M PV cost.

2.2.2 *CHP model*

To model GT and CHP, a single efficiency data is used as below:

$$\dot{m}_{f_{GT}} = \frac{\dot{W}_{GT}}{\eta_{GT}LHV} \tag{7}$$

%

$$\dot{Q}_{\text{CHP}} = \dot{m}_f LHV\eta_{\text{CHP}} - \dot{W}_{GT} \tag{8}$$

In this equation, $\dot{Q}_{\text{CHP}}$ is heat produced by CHP. Cost of CHP is calculating according to [34]:

$$Z_{\text{CHP}} = 6.67\dot{W}_{\text{GT}}^{0.8709}\ (\$) \tag{9}$$

$$OM_{CHP} = 40\dot{W}_{GT}\ (\$ - year) \tag{10}$$

The value of the LHV in this equation is for Iranian natural gas which is equal to 36 000 kJ/m^3 at standard condition. The efficiency of CHP and GT are taken as 82% and 33% respectively [35]. In public commercial buildings, the cost of natural gas is 0.0375\$/m^3. In Equation (10), OM_{CHP} is the cost of CHP O&M.

2.2.3 *Absorption chiller model*

The efficiency of the chiller is defined by COP coefficient and its total hourly cooling load is shown by $\dot{Q}_C$. Consequently the amount of needed heat to start the chiller is obtained from the following equation:

$$\dot{Q}_{HC} = \frac{\dot{Q}_C}{COP_{CH}} \tag{11}$$

For single effect absorption chillers, COP is typically 0.7 [36]. The purchase cost of absorption chillers is estimated based on the following formula [34]:

$$Z_{CH} = 1877.2\dot{Q}_C^{0.6874}\ (\$) \tag{12}$$

$$OM_{CH} = 10.24\dot{Q}_C\ (\$/year) \tag{13}$$

Where OM_{CH} is the O&M chiller cost.

2.2.4 *Axillary boiler model*

For the axillary boiler, $\eta_b = .85$, is assumed. So, the amount of fuel for boiler is:

$$\dot{m}_{f_b} = \frac{\dot{Q}_{H_b}}{\eta_b LHV} \tag{14}$$

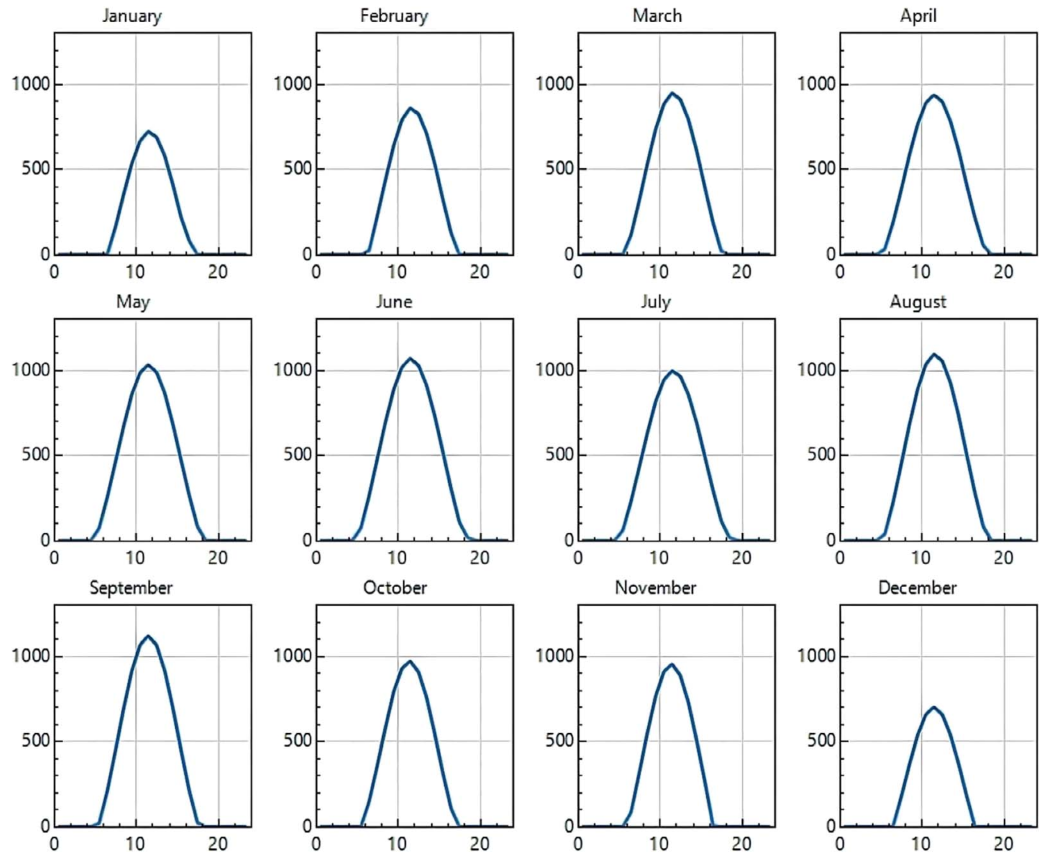

Figure 3. *Monthly average Plane of Array (POA) irradiance in 24 hours a day. (W/m2).*

In which $\dot{Q}_{H_b}$ is the rate of auxiliary boiler heat that should provide to the building. Axillary boiler cost is:

$$Z_b = \begin{cases} 93\dot{Q}_b\ \dot{Q}_b < 180 \\ 79\ \dot{Q}_b\ 180 < \dot{Q}_b < 350 \\ 65\ \dot{Q}_b\ 350 < \dot{Q}_b \end{cases} \quad (15)$$

$$OM_b = 10\dot{Q}_b\ \left(\$/year\right) \quad (16)$$

Here, $OM_b$is the O&M boiler cost.

2.2.5 *Integrated system model*

For integrated system modeling, we need to know independent variables such as PV output power, solar collector size and CHP power. The absorption chiller size is defined by $\dot{Q}_C$ which is the cooling capacity of the system. In order to calculate the cooling load, the size of the auxiliary boiler needs to be determined. To calculate the size of the boiler, we write:

$$\dot{Q}_{H_b} = \dot{Q}_{CHP} + \dot{Q}_{SH} - \dot{Q}_H - \dot{Q}_{HC} \quad (17)$$

Here, $\dot{Q}_{H_b}$ is maximum boiler heat in a year, which is also known as size of the boiler. Thus, the total mass flow rate of fuel is:

$$\dot{m}_f = \dot{m}_{f_{GT}} + \dot{m}_{f_b} \quad (18)$$

And excess power is:

$$\dot{P}_E = \dot{W}_{PV} + \dot{W}_{GT} - \dot{W}_D \quad (19)$$

In the above equation, the last term is demand of electricity. In Equation (19), all values are time-dependent variables and are determined during all hours of the year. If $\dot{P}_E$ is negative, it means that electricity needs to be purchased from the grid, and if $\dot{P}_E$ is positive, it means that excess electricity needs to be sold to the grid.

The price of electricity for home consumption in Iran is 0.045$/kWh.

According to the support program of the Iran government for the production of electricity by renewable energies, the government guarantees that the purchase price of electricity for small solar power plants with photovoltaic cells is 0.1225$/kWh, and for CHP units, it is 0.045$/kWh [37]. Therefore, the amount of profit from the sale of electricity to the grid is calculated from the following equation [34]:

$$\Pr = \begin{cases} 0.1225P_{E_{PV}} + 0.045P_{ECHP}\ \dot{P}_E > 0 \\ 0.045P_E\ \dot{P}_E < 0 \end{cases} \quad (20)$$

2.3 Basic scenarios and net profit

In order to check the economic capability of the plant, net profit/loss or cash flow should be defined. Here, for the building, income is considered as the amount of running cost reduction (i.e. electricity and fuel cost) if the base scenarios are:

1. A chiller for cooling and a fossil fuel boiler for heating are considered as the base common option for building HVAC system.

2- An absorption chiller and a fossil fuel boiler are considered for cooling and heating as common HVAC option.

In both scenarios, fuel cost, initial investment cost and O&M according to developed formulas are assessed and for both base scenarios, one may write:

$$Z_{t1} = Z_{b_1} + Z_{ECH} \tag{21}$$

$$Z_{t_2} = Z_{b_2} + Z_{CH_2} \tag{22}$$

$$C_1 = 0.0375 m_{f_1} + \frac{0.045 Q_C}{COP_{ECH}} + OM_1 \tag{23}$$

$$C_2 = 0.0375 m_{f_2} + OM_2 \tag{24}$$

In the above equations, we have:
Z_{t_1} and Z_{t_2}:total cost of components purchase.
C_1 and C_2: total current costs.

$$C = \Pr - 0.0375 m_f - \sum OM \tag{25}$$

$$Z_{NET_i} = Z_t - Z_{t_i} \tag{26}$$

$$C_{NET_i} = C - C_i \tag{27}$$

In NPV evaluation, i is 15% in Iran. Lifetime of the project N, in this case, is 20 years [38].$NPV=$

$$\sum_{t=1}^{20} C_t/(1+i)^t - Z_t \tag{28}$$

When NPV is positive, the project is worth investing.

The IES studied in reference [38] is considered to validate the model. The goal is to provide the heating, cooling and electrical loads of a building. Demand loads for each month are extracted and selected as equivalent values on all days of the month. There is a connection with the grid for buying and selling electricity. The exergy efficiency of the integrated system in this system is calculated as 42.61%, while this value is 44.98% in the reference paper. Based on this, the calculation error is equal to 5.14%, which shows the correctness of the modeling for other calculations.

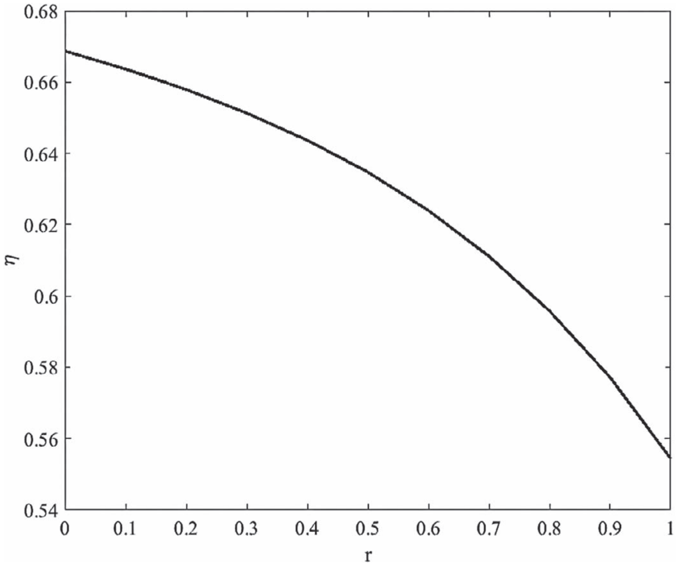

Figure 4. *Efficiency vs r.*

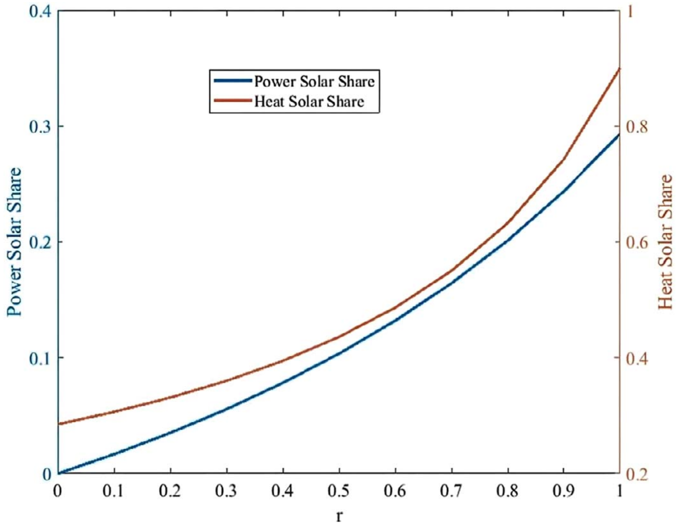

Figure 5. *Power and Heat solar share.*

3 RESULTS AND DISCUSSION

System sizing is power production ratio is a critical factor (solar PV to GT power):

$$\dot{W}_n = r\left(\dot{W}_n + \dot{W}_{GT}\right) \tag{29}$$

In these equations, (r) shows how much of total onsite generated power is produced by the renewable resource which affects the sizing of the system. In Figures 4 to 7, no purchase or sale of electricity to the grid is considered.

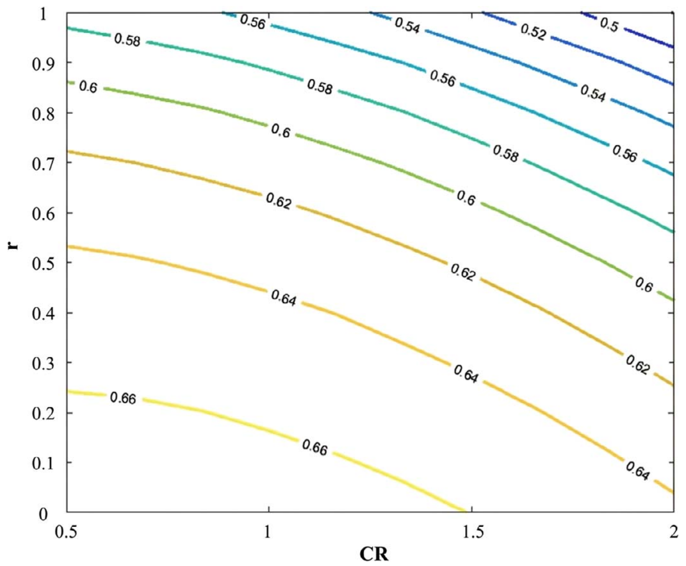

Figure 6. *Contour of efficiency at r, CR.*

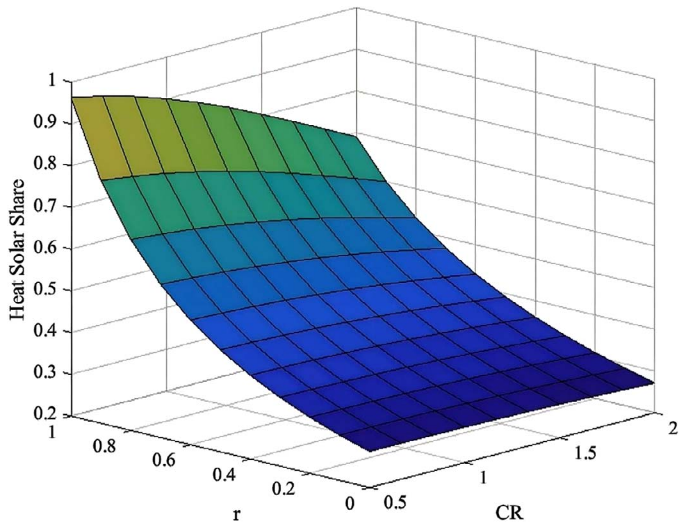

Figure 7. *Heat solar share variation.*

3.1 System performance

The system efficiency is drawn in Figure 4. The higher value of r means higher solar PV share (Figure 5), and when r increases, overall system efficiency reduces. Because GT efficiency is generally higher than solar PV. As a result, by increasing the share of solar electricity production and decreasing the share of electricity produced by the turbine, the efficiency of solar electricity prevails and reduces the overall efficiency of the integrated system.

Solar share definition is:

$$Power\ Solar\ Share = \frac{W_{PV}}{W_{total}} \tag{30}$$

$$Heat\ Solar\ Share\ (SS) = \frac{Q_{SH}}{Q_{total}} \tag{31}$$

Table 1. *Economic parameters in Iran*

Parameters	Value
Electricity sell price to network	
Solar PV	0.1225$/kWh
CHP	0.0275$/kWh
Electricity price for commercial building (category 5)	0.045$/kWh
Natural Gas price for commercial buildings	0.0375$/std m^3
Discount Rate	15%
Building average electricity load	84 kW
Building average cooling load	300 kW
Building average Heating load	300 kW
System analyzing period	20 years
Fuel LHV	36 000 kJ/std m^3
Location	Tehran

In Figure 5, by increasing the amount of r, the heat solar share increases because with the increase of r, the amount of power taken from the solar cells increases. Although the efficiency of solar heater is not a function of solar PV size, when solar power share increases, micro-GT size reduces. This means CHP system needs lower heat and heat solar share rises.

The ratio between cooling and heating is identified as Cooling Ratio. This parameter is important in system sizing. Overall system performance reduces by an increase in both variables as shown in Figure 6. The absorption chiller is the most widely used equipment when the share of cooling increases. As a result, the integrated system must produce more heat. Therefore, the contribution of the auxiliary boiler increases, and the efficiency of the system decreases.

With increasing CR, the solar heat share decreases because in order to provide the heat required by the chiller, the fuel rate in the auxiliary boiler needs to be increased (Figure 7).

3.2 Economic analysis

In the economic analysis, the target of the system is finding design or sizing parameters which provide a feasible economic plant. Feasibility of the integrated system depends not only on the performance of the system but also economic parameters such as discount rate, network electricity and natural gas prices and electricity selling price. Table 1 provides data for economic assessment of the system.

Here for relevant data analysis and presentation, few parameters are defined and utilized. Specified parameters and their related formula or description are shown in Table 2.

3.2.1 *Current condition*

Figure 8 provides NPV contours in *SS-i* plane. To obtain this figure, the CHP system is assumed to be off during the hours where there is no load. As it is shown for all cases and scenarios, maximum obtainable NPV for given set of design parameters (*r, PR, Ac*) has negative values except for the small range of low discount rate. This obviously shows that with current economic

Table 2. *Specified parameters and their related formula*

Parameters	description
Solar Share	$SS = \frac{Q_{SH}}{Q_{SH}+m_f LHV}$ all values are annual values
Solar Tech Price Factor	TR = (solar system price reduction)/(current market price)
Electricity sell price multiplier	EM = (selling price expected)/(current selling price)
Power generation to load Ratio	$PR = \frac{\dot{W}_n+\dot{W}_{GT}}{\dot{W}_D}$

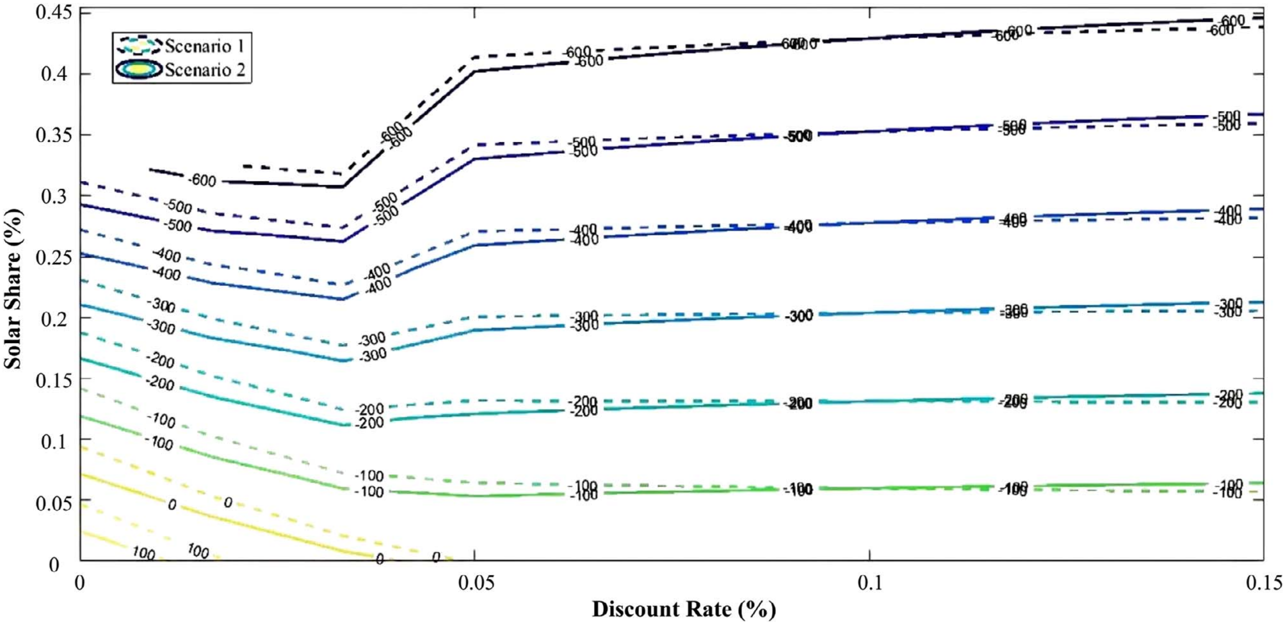

Figure 8. *Contours of NPV in discount rate-solar share plane at current condition. MGT is not working in off hours. All values in 1000$.*

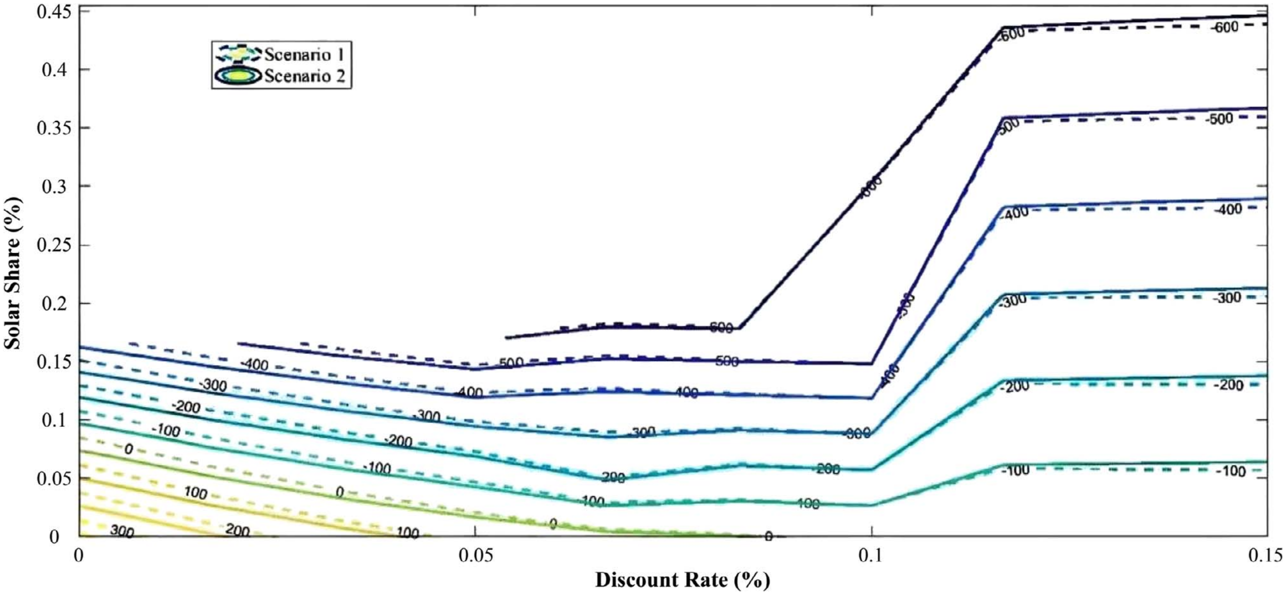

Figure 9. *Contours of NPV in discount rate-solar share plane at current condition. MGT is working in off hours. All values in 1000$.*

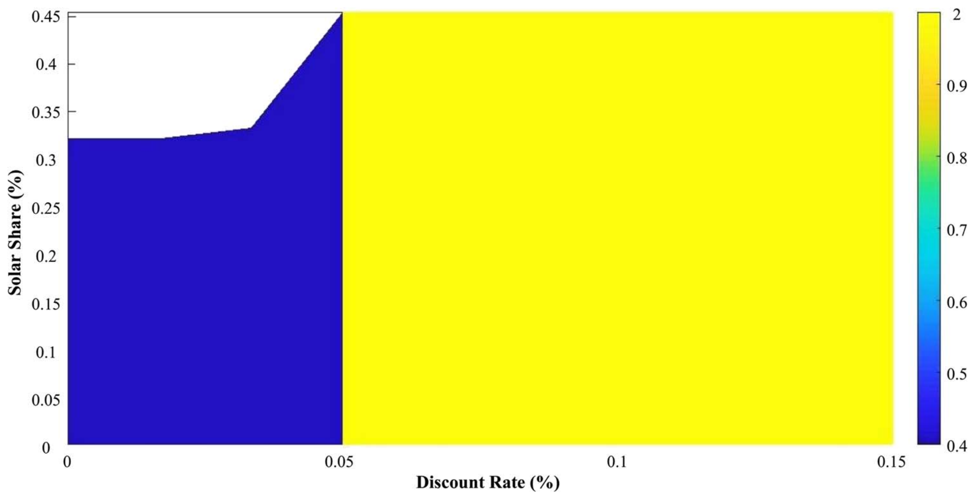

Figure 10. *r Values corresponding to NPV values in Figure 8.*

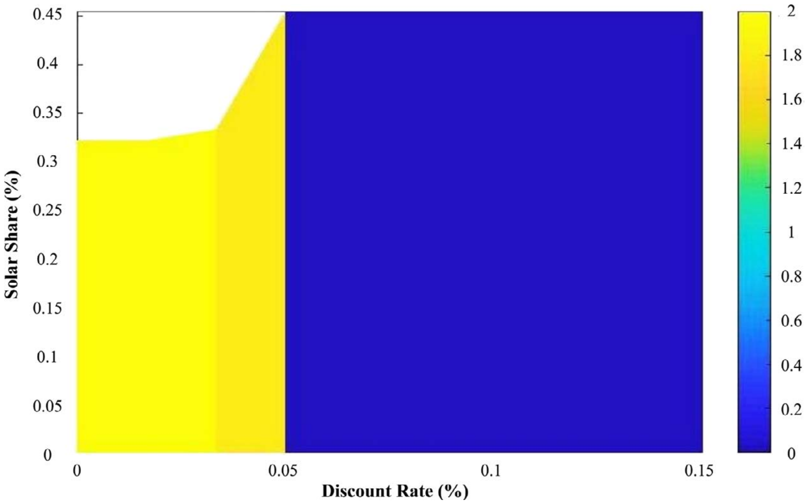

Figure 11. *PR values corresponding to NPV values in Figure 8.*

parameters and most importantly discount rate value, integrated system is not economical in Iran. Another crucial point is, solar share (SS) has the significant impact on plant economic performance. Using solar collector to produce the unit of heat requires significantly higher initial investment, which in high-interest rate environment affects the feasibility (NPV) of the plant greatly.

Figure 9 shows the effects of micro-GT full-time operation on NPV. In comparison to Figure 8, positive NPV region is extended for this case. Since more power is generated and sold to the grid by, in this case, revenue or positive cash flow increases which means higher NPV.

Since these figures show the maximum NPV *(r*, PR, Ac) versus solar share (or Ac), it is important to understand how two other factors *r*, and *PR* varies as well. Figure 10 and Figure 11 provide the color map value for *r* and *PR* corresponding to maximum NPV presented in Figure 8. For low interest rate region, maximum system size and a combination of solar PV and micro-GT is chosen. This reduces the amount of fuel consumption and produces maximum excess power which is sold to the grid. At low interest rate region, future cash flows preserve their values when discounted to start time of project that causes excess electricity to be valuable to the economics of the plant. When interest rate increases, power generation is limited to CHP plant or no on-site power generation at all since grid electricity price is low enough comparing to decrease in investment value.

The same trend can be found for the case of full-time GT working (Figures 12, 13).

The first region is similar to the case with no full-time micro-GT operation. However, for interest rates between the high and low values, PR decreases to 1, which means only demand is produced on site by PV so fuel cost for CHP, as a negative cash flow, reduces and in consequence NPV increases. However, for high-interest rates, there is still no on-site generation option as

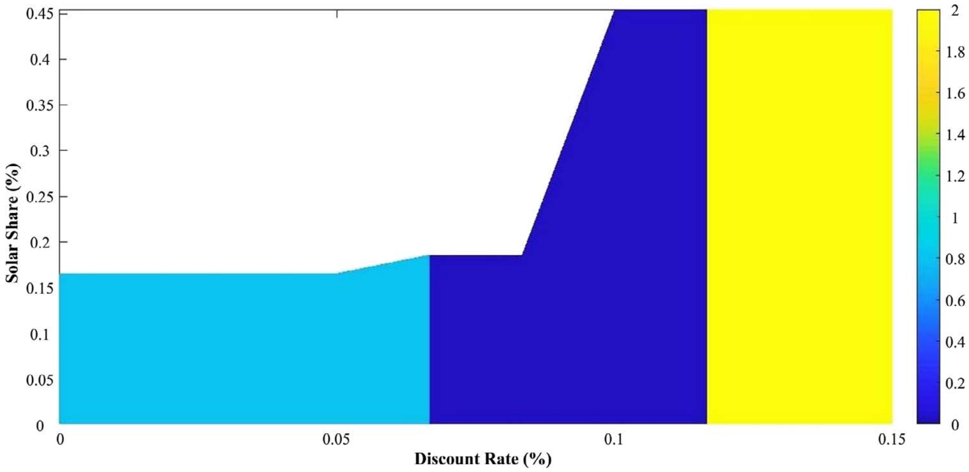

Figure 12. *r values corresponding to NPV values in Figure 9.*

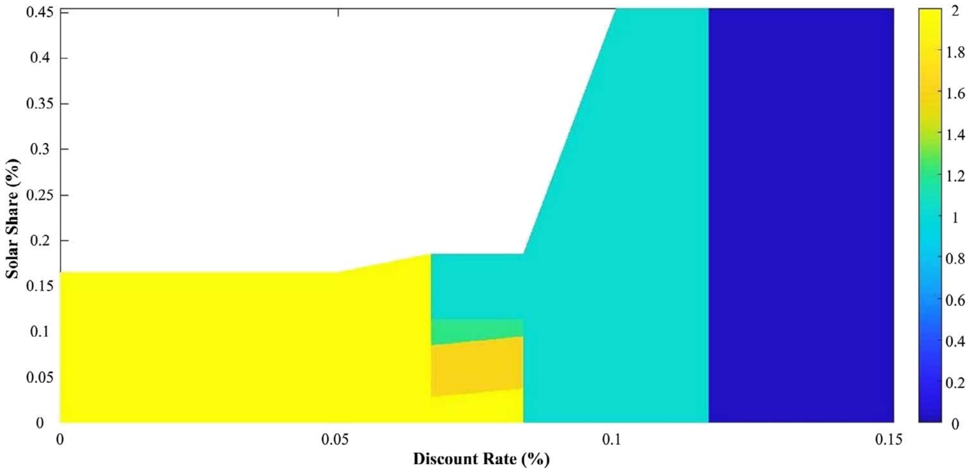

Figure 13. *PR values corresponding to NPV values in Figure 9.*

the optimum result. Because the full-time operation of CHP leads to higher NPV, we just consider this case since point forward.

Iran's power and energy market authorities and government provide a set of supportive programs for renewable and distributed energy generation growth. One of these programs is guaranteed to buy back of power produced by mentioned technologies with a preset value as mentioned, which is three times higher than network electricity price for solar PV. However, results for base case show that only for low-interest rates the system generates revenue and is economically viable. Effects of other parameters at discount rate of 15% are examined hereafter to understand if any other supportive parameters can cover disadvantages of high-interest rate.

3.2.2 *Grid electricity price*

Grid electricity price is a factor that affects the cash flows in our plant. When electricity price is low, net saving for on-site electricity generation, which is positive revenue, reduces and as a result NPV decreases. Figure 14 illustrates effects of this parameter on the NPV of the system. Since the interest rate is 15%, at low electricity cost rates NPV is negative. When electricity price is reaching 0.07$/kWh or higher, NPV becomes positive and system generates revenue. Although the NPV turns positive, Solar Share is still low due to high-investment cost at high interest rate.

3.2.3 *Electricity selling price to the grid*

Electricity selling price to the network is a key supportive parameter in Iran's renewable energy growth plan. Although the price in comparison with grid power price is high, due to high-interest rate and investment cost of the PV and solar heater, no economic viable solution is found for the system. In Figure 15, the effects of *EM* variations are shown. *EM* value of 2 means that the electricity selling price to the network is doubled in comparison to the base case. The effects of *EM* are very similar to electricity import cost. In high values, at least 1.6 times of current prices, the system starts generating revenue at low solar share percentage and NPV

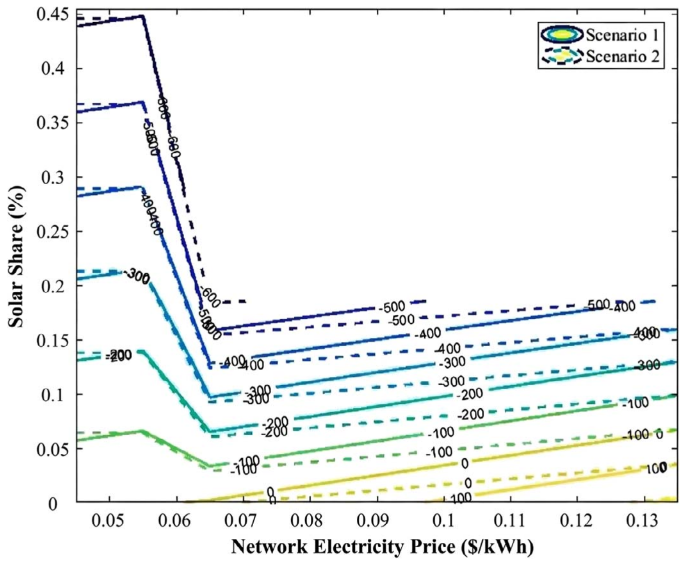

Figure 14. *Contours of NPV in network electricity price-solar share plane at current condition. All values in 1000$.*

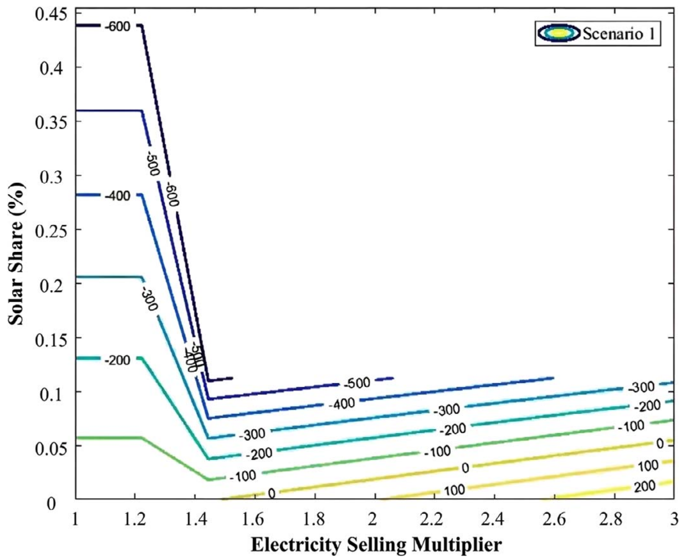

Figure 15. *Contours of NPV in EM-SS plane at current condition. All values in 1000$. Scenario 1 and 2 are nearly similar.*

becomes positive. However, like electricity cost effects, solar share remains at low values.

In Figure 16, optimal *r* values for the system at different *EM* are shown. As it is expected, *r* for low selling values is 1, while it is 0 for high EM. Zero value means all power should be generated by MGT system. In addition, Figure 17 shows that *PR* at high *EM* is maximum value or 2 which means twice the electricity demand value. Hence at high EM, MGT optimal size is twice the demand (maximum value in this analysis), and no PV is installed. At low selling price, importing electricity from the grid is the most preferable choice.

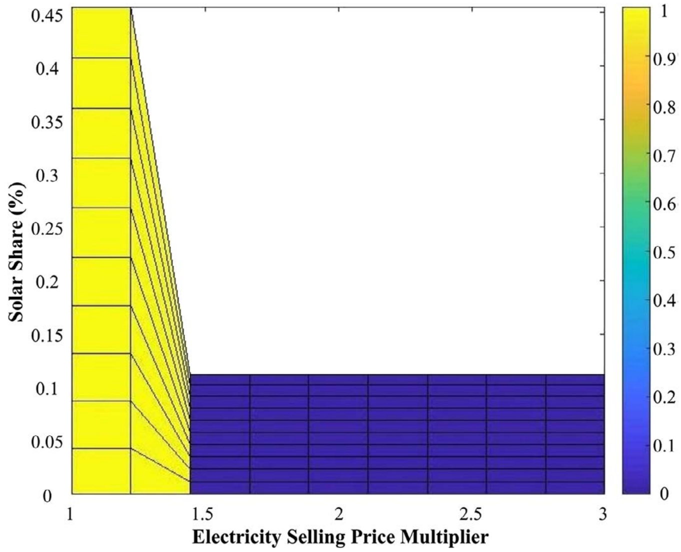

Figure 16. *r Values corresponding to NPV values in Figure 15.*

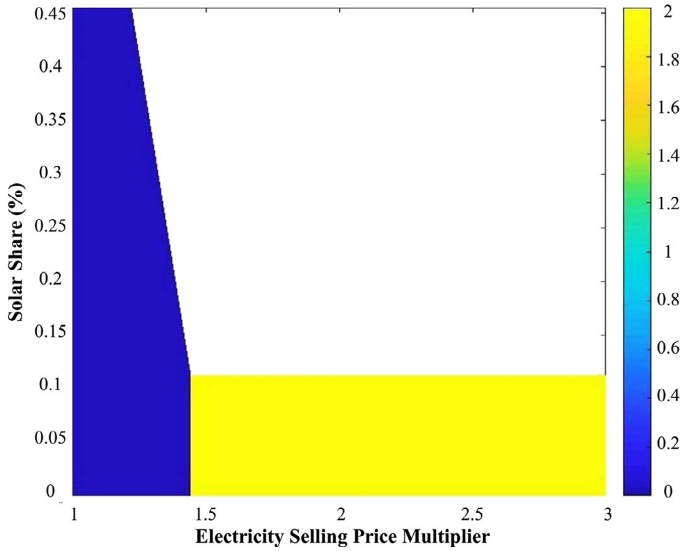

Figure 17. *PR values corresponding to NPV values in Figure 15.*

Fuel price and *TR* at high-interest rate did not lead to any significant improvement in NPV at current condition. While natural gas price increased three times and TR reduced to 0.5, no solution with positive NPV is found.

3.2.4 *Cost reduction for solar technology at normal economic condition*

Electricity and gas price in Iran is lower than global prices and the discount rate is significantly higher. These conditions are extremely against renewable and distributed energy market growth. In the following analysis, electricity price from the grid is doubled, natural gas price multiplied by 2.5, interest rate reduced to 4% but the selling electricity price to the grid is considered

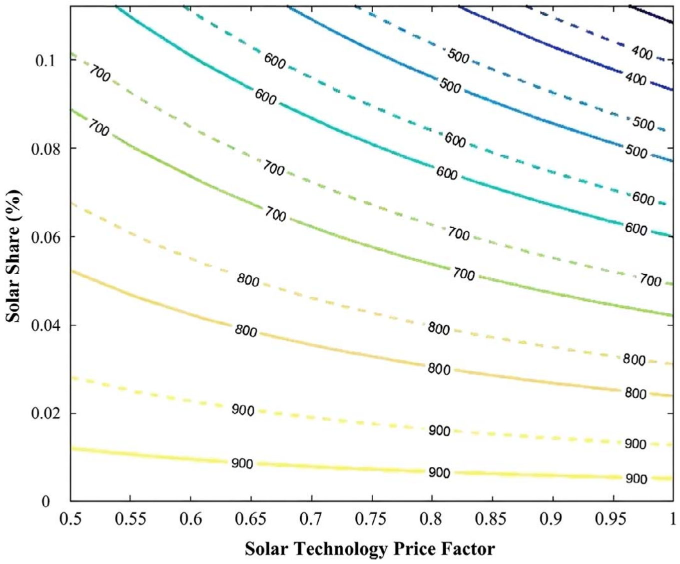

Figure 18. *Contours of NPV in TR-SS plane at current condition. All values in 1000$.*

as same as the cost of grid electricity. Results show that, even in case of no supporting action to sell electricity to the grid, NPV is positive almost in all cases, which means there is always an economically possible solution for all values of TR.

TR is the cost reduction in solar technology. In current condition, with high interest rate, even reducing TR to 0.5 does not lead to any positive NPV. This means that technological advances are not enough, and economical parameters play a key role in renewable growth planning in Iran. In Figure 18, it is shown that NPV is positive everywhere. This is mostly because in this case energy efficiency due to CHP and CCHP implementation generates considerable positive cash flows that are valuable even in 20 years of discounting because of low-interest rate. In this economically friendly condition, TR and EM can play their real motivational role toward renewable and solar energy.

4 CONCLUSION

In this study, using of renewable energy in a building is investigated and has been analyzed technically and economically. A simple and time-dependent method with inherited dynamic characteristics of the renewable energy resources like solar heater and solar panels is introduced and implemented. Detailed economic analysis of the system considering two basic scenarios for profit measuring (saving evaluation) is provided.

System sizing parameters are introduced as *r*, *PR* and *Ac* and the latter redefined in a more convenient way as solar share (SS). Then contour plots of NPV are provided for different parameters variations. In summary followings are the main findings of this research paper:

- Current economic and energy market conditions and parameters, does not support renewable energy growth or distributed energy system in kW scale in the building sector (or at least for case study).
- High-interest rate of 15% is the main issue in plant economy. Interest rate to generate a positive NPV must be lower than 5%. Even in this low-interest rate, renewable is not the first choice.
- When the electricity price reaches $0.07/kWh or higher, the NPV becomes positive and the system makes money. Although the NPV becomes positive, the share of solar remains low due to high investment costs with high interest rates.
- If interest rates remain constant, to produce a feasible plant, electricity to grid selling price should increase. At least 60% increase in electricity selling price is required to find a feasible NPV positive plant at the high-interest rate of 15%.
- If energy resources and interest rate reaches their normal prices, even for no renewable electricity price supporting program, the plant is economical and NPV is positive. However, without supporting programs and technological advancement in solar systems, energy efficiency options will be the first economic options.
- In current condition, supporting action for renewable and distributed generation is not enough in Iran based on this study. In fact, supporting programs are not functional in this economic condition. Building sector will not benefit from renewable energy and kW scale energy-efficient CHP and CCHP system with current plans and economic condition in Iran.

The current study addresses multiple parameters and issues. However, effect of taxation, loan and subsidization programs can be investigated as well. Furthermore, detailed dynamic modeling can improve the accuracy of the model and assessment which may be a subject of future study for specially Iran condition.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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DATA AVAILABILITY STATEMENT

All data are available upon request.

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