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Research Paper

Economic Evaluation of Supplying Commercial Thermal Load by a New CPVT System: A Case Study in Iran

Amir Abedanzadeh[1], Hasti Borgheipour[2], Samaneh Fakouriyan[3], Farschad Torabi[4]

[1] Renewable Energies and Environmental Department, Faculty of New Sciences and Technologies, University of Tehran, Tehran, 1439957131, Iran, Email: amir.abedanzadeh@ut.ac.ir
[2] Faculty of Civil & Earth Resources Engineering, Central Tehran Branch, Islamic Azad University, Tehran, 1469669191, Iran, Email: Hasti_bo@yahoo.com
[3] Renewable Energies and Environmental Department, Faculty of New Sciences and Technologies, University of Tehran, Tehran, 1439957131, Iran, Email: samane.fakouriyan@ut.ac.ir
[4] Faculty of Mechanical Engineering, K.N. Toosi University of Technology, Tehran, 1991943344, Iran, Email: ftorabi@kntu.ac.ir

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Corresponding author: F. Torabi (ftorabi@kntu.ac.ir)

Abstract. This paper aims to provide a concentrated photovoltaic thermal (CPVT) system regarding the high potential of receiving solar energy in Iran. Generated thermal energy of the system supplies the average thermal load of a commercial building and also its generated electricity is sold to the grid according to Iran's feed-in tariff (FiT). In order to calculate the system profitability, an economic evaluation is done in 20 years that is regarded as a novel approach. Furthermore, sensitivity analyses are performed to develop the results to the other locations with different economic conditions and various potential of energy resources, and also to present an appropriate financial outlook. The results demonstrate that the system is highly profitable given net present value (NPV) of 551.55 k$, internal rate of return (IRR) of 150.79%, benefit to cost ratio (BCR) of 10.32, payback time (PBT) of 0.51 years, and levelized cost of energy (LCOE) of 0.1293 $/MWh. Moreover, sensitivity analyses show that the system profitability is greatly appropriate even regarding the variety of unpredictable parameters. For instance, if the generated energy decreases by 20%, IRR and PBT will equal 120.63% and 0.63 years respectively, and the system can still maintain its high profitability. Moreover, it has been revealed that the enhancement of FiT can increase the system's economic efficiency. According to the results, it is noticeably profitable to use the CPVT systems to produce electrical and thermal power in countries with a high potential of receiving solar energy (especially middle-eastern countries).

Keywords: Renewable energy, Solar energy, Concentrated photovoltaic thermal (CPVT), Economic evaluation, Net present value (NPV).

1. Introduction

Nowadays fossil fuel resources such as coal, natural gas, and petroleum are finite; they can also lead to the emission of greenhouse gas. Hence, there is a magnificent desire to use renewable energies [1, 2]. Due to being clean, abundant, and free, solar energy is considered an ideal alternative to fossil fuels [3]. Among different types of solar energy technologies, photovoltaic systems are a proper choice and have been developed greatly [2, 3]. But only a small part of absorbed energy by the PV panels is converted to electricity, and the remaining absorbed energy appears as heat. So in order to use solar energy optimally, photovoltaic thermal (PVT), concentrated photovoltaic (CPV), and concentrated photovoltaic thermal (CPVT) technologies have been developed considerably in recent years [4-6]. PVT technology decreases the electrical efficiency drop that arises from high PV panel temperature, through transferring heat to the heat transfer fluid (HTF), and uses the generated thermal energy [7]. CPV technology concentrates solar radiation on a PV panel which increases the PV system's performance and is classified into low concentrated photovoltaic (LCPV) and high concentrated photovoltaic (HCPV) groups [8]. PVT systems require a large number of PV panels to generate high-quality thermal energy that increases investment costs and rises PV panel temperature hugely in CPV systems. These problems have been resolved in CPVT systems and highly efficient electrical and thermal energy is produced considering the average temperature of the PV panel [4]. Some of the researches in the field of these technologies are as follows:

Carmona et al. experimentally evaluated a PVT-PCM system in comparison with a traditional PV module; they concluded the electrical and thermal advantages for the PVT-PCM module. also, their results demonstrate PV temperature decreases through the PVT-PCM system [9]. Moreover, Bamisile et al. developed a hybrid system consisting of wind turbines, CPVT system, and biogas that produces 3.4 MW electricity, 17.546 kg/s hot air, 12.41 L/sec hydrogen, 10.31 L/min freshwater, and 144.18 L/min hot water. Their findings also show that the range of produced energy varies from 64.91% to 71.06% and the range of produced exergy varies from 31.8% to 53.81% [10]. In another study, Burhan et al. introduced a CPVT system based on hydrogen and MgO with electrical storage that produces electricity and high-temperature thermal energy at the efficiency rates of 30% and 70%, respectively. Furthermore, the material storage efficiency of the proposed system, based on MgO, is estimated to be 80% at the temperature of 400°C which is

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easily achievable by the concentrated thermal energy density factor of 240X [11]. In addition, Ustaoglu et al developed a new combination of the CHCT-PVT system to enhance the electrical efficiency and shrink the reflector size, and then compared it with conventional V-trough PVT (VT-PVT) and compound parabolic concentrator-PVT (CPC-PVT) systems. The results demonstrated that the efficiency of the CHCT-PVT system is 42.9% and 58.97% greater than the efficiency of CPC-PVT and VT-PVT systems, respectively [7]. Wang et al. simulated a CPVT system with uniform reflected radiation and studied tracker systems. They asserted that the optical efficiency equals 66.2% with a tracker error of 1℃ and also the results of thermodynamic analysis explained the PV conversion efficiency of 30.5% and the total energy efficiency of 26.6% indicating that both values are greater than normal CPV systems. The optimal temperature of the receiver tube equals 356℃ that can maximize the total output power [3]. Furthermore, Khan S.A. et al designed a CPVT system with hydrogen storage and analyzed it based on thermodynamic characteristics in order to supply electricity, cold and hot water, heating, ventilation, and air conditioning (HVAC) demands a residential building with continuous energy consumption. It is claimed that a portion of the generated electricity by CPV is used to electrolyze hydrogen and oxygen. The results revealed the total energy productivity of 67.52%, total exergy productivity of 34.89%, and the concentrated coefficient factor of 1862X for the system [12]. Yazdanifard et al. investigated numerical modeling of a CPVT which utilizes PCM and nanofluid. They concluded the 14.9% improvement in total exergetic efficiency and PV temperature below 50 °C [13]. Cabral et al. developed and examined a trough LCPVT system with a low concentration coefficient. Their results indicated the overall heat loss coefficient of 4.1 W/m^2.°C as well as the electrical and optical efficiency of 59% and 8%, respectively [14]. Moreover, Rejeb et al. developed a concentrated photovoltaic thermal–thermoelectric (CPVT-TE) system that combines a CPVT system with thermoelectric modules; as a practical method, it can also enhance the electricity production. Their findings demonstrated the electrical efficiency of the CPVT-TE system using 0.5% of graphene/water nanofluid boosts equals 11.15% and 5.14% in summer and winter, respectively [15]. Herez et al. proposed the modeling and simulation of a trough CPVT system using the iterative procedure; they also conducted a parametric analysis to evaluate the effect of Reynolds number, receiver side length, receiver tube length, and the absorber thickness on electrical and thermal efficiency. They concluded that thermal efficiency reduces 8.31% and 2.12% for laminar and turbulent flow, sequentially, due to the increase in Reynolds number. The findings also showed that thermal efficiency increases 35% and 0.78%, respectively, due to the enhancement of receiver side length from 0.03 m to 0.2 m and receiver tube length from 4 m to 20 m. Nevertheless, the electrical efficiency rises by 38.25% and 5.78% for laminar and turbulent flow, respectively, due to the increase in Reynolds number and it decreases by 10.5% and 2% due to the enhancement of the receiver side and tube length. In addition, changing the absorber thickness from 0.02 m to 0.2 m does not affect the thermal and electrical efficiency of the system [16]. Ahmed et al. investigated an HCPVT system with concentrated coefficients of 500X to 2000X in order to find an advanced panel cooling method. They also performed the 3D computational evaluation and modeling of the system and entered the practical data into the simulation process to investigate the thermal conductivity of different fluids. Their results for 2000X of concentrated ratio indicated that Al_2O_3/Water and SiO_2/Water nanofluids can hold the maximum temperature at 95.25℃ and 67.1℃ for the Reynolds number of 8.25 and 82.5, respectively. Furthermore, the overall efficiency has enhanced by 3.82% using SiO_2/Water nanofluid, Reynolds number of 8.25, and the concentration ratio of 500X [17]. Borba et al. provided a new optimization model to design hybrid solar photovoltaic systems and its simulation in order to supply hotels energy loads in Rio de Janeiro. Sixteen hotels have been optimized totally and their results indicate this system is able to supply 26–48% of electrical demands, 40–50% of cooling requirements, and 20–45% of hot water respectively [18]. In a seminal study, Riahi et al. designed a CPVT and thermoelectric hybrid system and conducted practical tests accordingly. Based on the results, they argued that the electrical efficiency increases by 7.46% compared to the CPVT system, over solar radiation of 935 W/m^2 and the temperature of 33℃. Moreover, they examined this system in Tunisia on large-scale and found that it is feasible to produce 359 kWh of energy considering system aperture area of 39 m^2 [2]. Gakkhar et al. proposed a CPVT system and analyzed it theoretically and experimentally. In their study, the flow rate varies from 0.083 to 0.117 kg/s using different configurations. Their results indicate the optimum flow rate of 0.108 kg/s that leads to an overall efficiency enhancement up to 69.19%. In addition, this system can reduce CO2 emission by 40.2 t/year under the optimal conditions [19]. Huaxu et al. investigated different nanofluids to use in a CPVT system and conducted the practical examination on ZnO nanofluid. They concluded that this nanofluid has shown a more efficient performance compared to polypyrrole and Ag–SiO2 nanofluids [20]. In a seminal study, Al-Nimr et al. developed a novel hybrid solar cooling system driven by a CPVT unit. This study aimed to optimize the PV cooler's performance in order to improve the overall performance. The results showed the reduced PV cooling can lead to maximizing total cooling capacity. Furthermore, given the 1000 W/m^2 solar radiation, the overall coefficient of performance increases from 0.151 to 0.233 due to the increase in PVT outlet temperature from 65℃ to 90℃ [21]. Al-Hrari et al. developed a heat flux and mass numerical model to investigate the probability of producing freshwater by a CPVT system that is coupled with direct contact membrane distillation (DCMD). Their findings revealed the average electrical efficiency of about 18%, the thermal efficiency of 25%, and the overall efficiency of 71%. According to the practical test results, this device can produce 3 kg/m^2/hr of fresh water by consuming 9200 kJ of energy per one kilogram of water [22].

As a result, there are a great number of researches on the simultaneous production of electrical and thermal energy using solar energy technologies such as PV, PVT, CPV, and CPVT as well as improvement of their performance. However, CPVT systems have not been used to supply thermal loads in business buildings so far. Using these systems can noticeably decrease the energy consumption of different buildings and lead to significant profitability for investors on these projects. Furthermore, there are no researches on the economic evaluation of CPVT systems, and the lack of awareness regarding the economic profitability of these systems has reduced investment on these projects. In addition, the economic evaluation of CPVT systems can provide a proper financial perspective for investors to invest confidently. In this regard, the present study aims to compensate for shortcomings in previous researches by supplementing a commercial thermal demand using a set of CPVT systems in Shiraz, Iran as well as conduct an economic evaluation of the investment over 20 years. Considerable highlights in this study are as follow:

- According to the case study, a novel method is provided to cool down PV solar panels and also to receive thermal energy;
- The electrical data in this paper are collected based on the case study experimental tests;
- The thermal data in this paper are based on the case study simulation in Solid works software;
- The received thermal power of the presented CPVT system is much higher than the electrical power. This is also crucial since the degradation factor will have no apparent effects on the system's profitability after several years and the thermal power can still be received from the device; and
- In this paper, sensitivity analysis is conducted over uncertain economic indicators.

Therefore, in the proposed study, a new CPVT system is developed to investigate whether a set of the provided system can supply the commercial thermal load in Shiraz, Iran; it is also noteworthy that regarded as a novel approach. Besides, another objective of this study is considered economic evaluation and sensitivity analysis on parameters with economic uncertainty to calculate the economic profitability of the provided system and better analysis of the results.

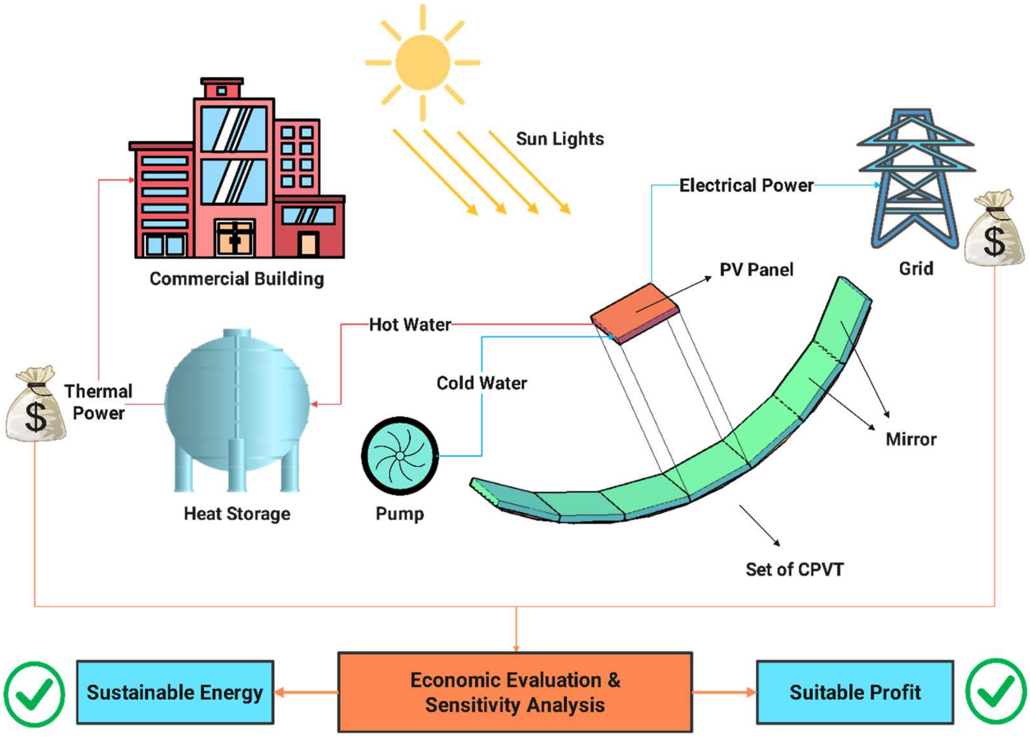

Fig. 1. Schematic configuration of the considered system

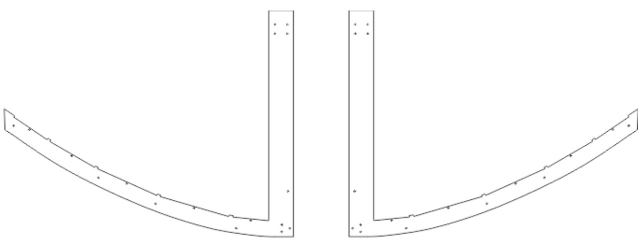

Fig. 2. Reflector section

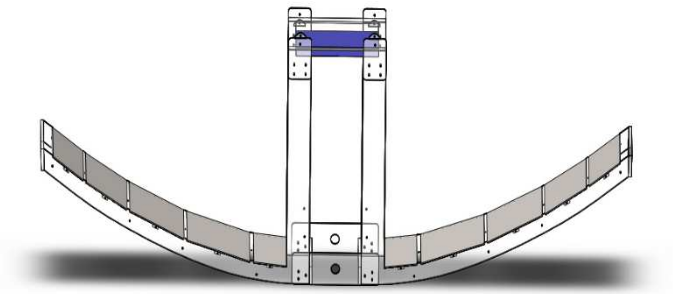

Fig. 3. Device overview

2. Methodology

2.1 The proposed strategy in this paper

The authors aim to develop a system to satisfy the thermal power demand of a commercial building in Shiraz, Iran using the generated thermal power of a CPVT system and to sell the produced electrical power to the grid concurrently. Furthermore, this study also intends to conduct an economic evaluation on the proposed project according to the costs imposed by the system, its economic profitability, as well as the dealing tariffs of electricity and natural gas in Iran. In addition, sensitivity analysis would be performed on parameters with economic uncertainty.

In this study, the authors have used a CPVT case study in order to supply the thermal demand of a commercial building in Shiraz. At first, the thermal demand of a commercial building in Shiraz would be calculated, and then the case study is described. Consequently, the economic evaluation of the CPVT system would be provided with regards to the power generation of the CPVT system set, the tariff of selling electricity to the grid, and also the price per cubic meter of the natural gas in Iran. The schematic configuration of the considered system is shown in Fig. 1.

2.2 Introducing the case study

In 2013, Vahdati developed a CPVT device operating like a Trough CPVT. The difference between this device and conventional trough collectors is that the reflection area is not a continuous parabolic and consists of pieces of mirrors. These interrupted mirror pieces can cause uniform reflection on a 10 W panel surface given the concentrated coefficient of 4.87X. The schematic design of the device and characteristics of the PV panel are presented in Fig. 2 and Fig. 3 as well as Table 1. Thereafter, Vahdati has tested the system electrically. Based on this method, the panel output power has increased to 42W, and the respective experimental results and V-I figures are shown in Table 2 and Table 3 as well as Fig. 4 and Fig. 5 [23].

Table 1. PV module characteristics in STC

Parameter	Value
Dimensions (mm)	336×287×25
Standard test condition	AM 1.5, 25°C, STC: 1000 W.m-2
Nominal performance temperature (°C)	48
Operating temperature range (°C)	-40 to 85
Temperature coefficient for I_m (%/°C)	+0.1
Temperature coefficient for V_m (%/°C)	-0.38
System maximum voltage (V)	DC 715/1000
Open circuit voltage (V)	21.6
Short circuit current (A)	0.64
Maximum power voltage (V)	17.3
Maximum power current (A)	0.87

Table 2. Flat module practical test data

Voltage (V)	Current (A)	Power (W)
21.69	0	0
20.94	0.11	2.3
20.16	0.24	4.83
19.34	0.37	7.15
18.7	0.44	8.22
17.29	0.55	9.5
15.13	0.58	8.7
0	0.61	0

Table 3. Concentrated module practical test data

Voltage (V)	Current (A)	Power (W)
21.61	0	0
21	0.47	9.87
20.1	1.21	24.32
19.43	1.87	36.33
18.37	2.31	42.43
17.32	2.52	43.64
15	2.67	40.05
0	2.91	0

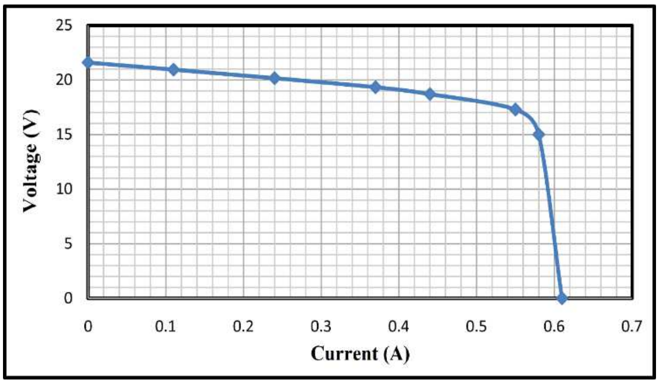

Fig. 4. Flat module V-I

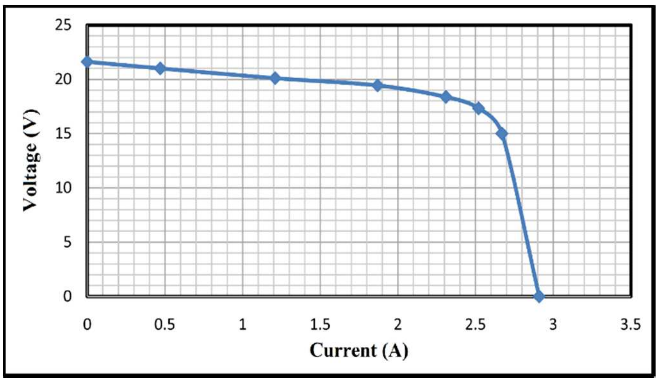

Fig. 5. Concentrated module V-I

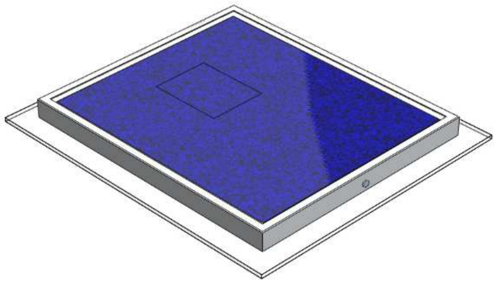

Fig. 6. Front scheme of the panel

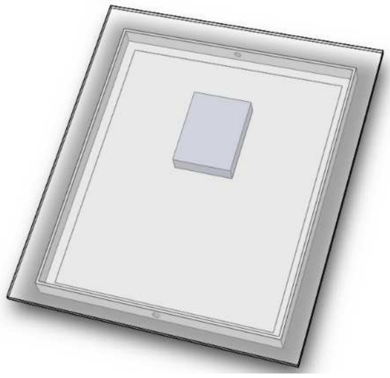

Fig. 7. Rear scheme of the panel

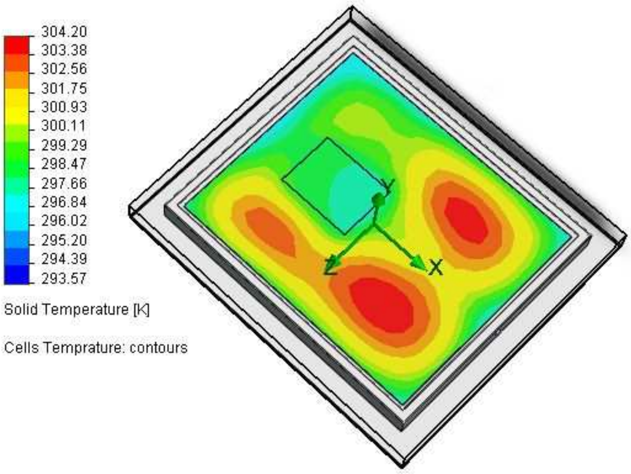

Fig. 8. Cell temperature contours

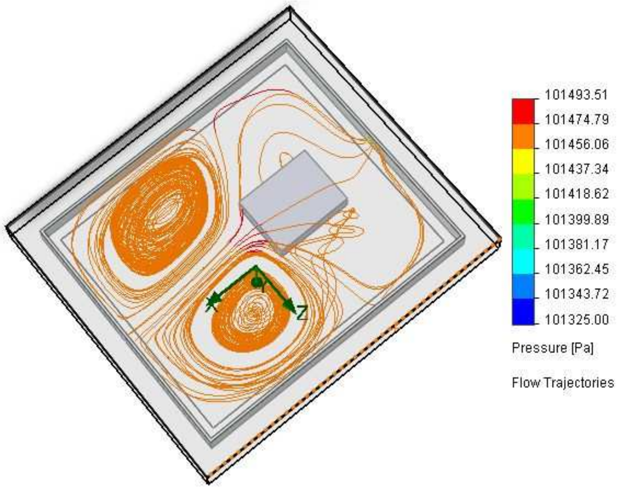

Fig. 9. Flow trajectories

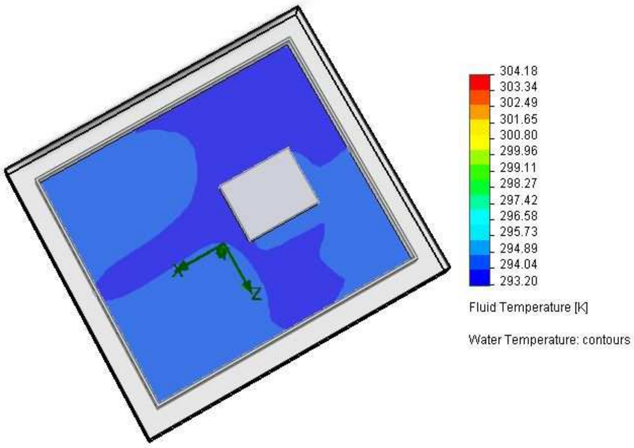

Fig. 10. Water temperature contours

Table 4. Simulation data

Num.	Flow (kg/s)	Outlet water temperature (K)	Inlet water temperature (K)
1	0.1	306.18	298
2	0.1	311.20	298
3	0.1	304.20	298
Ave.	0.1	307.193	298

Table 5. Shiraz average monthly sunshine hours [24]

Month	Sunshine hours (hr)
Jan	233.77
Feb	232.85
Mar	240.40
Apr	228.10
May	306.50
Jun	362.55
Jul	330.20
Aug	342.50
Sep	315.75
Oct	287.70
Nov	214.95
Dec	213.80
Ave.	275.76

Table 6. FiT of grid-connected photovoltaics in Iran [25]

System nominal power (kW)	FiT ($/kWh)
<20	0.248
<100	0.216
<10000	0.151

Meanwhile, it is crucial to perform cooling down on the panel given the concentration of solar radiation and excessive increase of the panel temperature. Accordingly, Vahdati has simulated the cooling panel system using Solid works software. In this simulation, the researcher has used water flow behind the panel for cooling down the system. Water flow enters through an inlet canal and exits the outlet canal after cooling the panel. Inlet and outlet water specifications as well as simulation results are reported in Table 4 and Fig. 6-10. Hence, the device is able to generate hot water and the generated thermal power of the system can be measured based on the water flow specifications [23].

2.3 Generated electrical and thermal power of the device

If the solar panel can be cooled down by increasing the water flow, the concentration coefficient of the device will improve as well [23]. Thus, calculations are performed given higher cooling and high concentration coefficient in the present study. It is believed that the system's electrical and thermal power may rise due to the enhancement of water flow and concentration coefficient of the case study device. Furthermore, regarding the commercial thermal demand in Shiraz, the number of sunny hours in the city which is illustrated in Table 5 [24], and also comparison to the generated thermal power of the CPVT device, it is possible to estimate how many of these devices are required to supply the demanded load and the results are shown in Table 9. Finally, the authors have calculated the annual generated electrical and thermal energy for the proposed CPVT system set that are presented in Table 10. Equations 1 is used to calculate the thermal energy generated by 1 CPVT system. Also, according to Eqn.2, the thermal powers will be multiplied by n through serializing n number of devices.

$$\dot{Q} = \dot{m}C\Delta T \tag{1}$$

$$\dot{Q}_1 = \dot{Q}_2 = \ldots = \dot{Q}_n \tag{2}$$

$$\Rightarrow \dot{m}C\Delta T_1 = \dot{m}C\Delta T_2 = \ldots = \dot{m}C\Delta T_n$$

$$\Rightarrow \Delta T_1 = \Delta T_2 = \ldots = \Delta T_n$$

$$\Rightarrow \Delta T_1 + \Delta T_2 + \ldots + \Delta T_n = n\Delta T_1$$

2.4 Feed-in tariff in Iran

Iranian Ministry of Energy authorized a free-tax plan to encourage investment in renewable energies in 2014 so as to maximize the consumption of renewable and clean energy resources, avoid the consumption of fossil fuel, and eliminate the environmental pollutants as well as greenhouse gases. According to this tariff plan, investors can sell the entire generated energy (regardless of domestic consumption) to the grid at the small (residential), moderate (commercial), and large scales (power plant) during a twenty-year period which is reported in Table 6 [25]. Besides, the price of each cubic meter of Iranian natural gas would equal 0.033 $ and contain 9.99 kWh of energy [26]. Finally, these tariffs are also used to calculate the profitability of the system.

2.5 Economic Evaluation

The components of this CPVT system include PV module, inverter, mirror, structure, and etc. The breakdown costs of the CPVT system and the inverter characteristics are reported in Table 7 and Table 8, respectively.

Table 7. The cost breakdown of the CPVT system

Equipment	References	Cost (k$)	Total Share (%)
PV Module	[27]	20.64	34.88
Mirror	[28]	1.86	3.14
Structure	[29]	13.76	23.25
Inverter	[30]	10.24	17.30
Pump	[31]	2.20	3.72
O&M & Replacement Costs	[32]	9.10	15.38
Other	[33]	1.38	2.33
Total	-	59.18	100.00

Table 8. The electrical parameters of Fronius Eco 25.0-3-S [34]

Parameter	Value
Maximum input power (W)	37800 peak
Maximum input current (A)	44.2
Nominal input voltage (V)	1000
MPP voltage range (V)	580-850
Number of MPP trackers	1
Nominal output power (W)	25000

The following equation is used to calculate the break-even point:

$$UC_{util} \times W_{av} \times m = FC + (UC_{prod} \times W_{av} \times m) \tag{3}$$

where UC_{util} refers to the unit cost per kWh of energy purchased from the device ($/kWh), UC_{prod} denotes the unit cost per kWh of produced energy ($/kWh), FC represents fixed costs ($), W_{av} is the average output power (or consumption) (kWh), and *m* refers to working hours (hr).

NPV calculates the present value of the entire cash flow period (i.e. capital cost and net savings) that adds to the life of the project. Expenses are shown with a negative value and savings with a positive value. NPV refers to the sum of all present values where the higher values of NPV indicate higher efficiency for the proposed project. The NPV is determined through the following equation [35]:

$$NPV = -C_0 + \sum_{t=0}^{n-1} \frac{CF_t}{(1+i)^t} \tag{4}$$

where CF_t is the cash flow at year *t* ($), C_0 denotes the initial costs ($), *n* refers to the number of years in terms of the concentrator's lifetime, and *i* reflects the interest rate (IR-%). The interest rate at which the NPV becomes zero is called the IRR. where higher IRR values reflect more interest in the project [36]. Also, NPV equals:

$$NPV = NPB - NPC \tag{5}$$

where NPB and NPC refer to present net benefits and net costs, respectively [30].

Inflation is defined as the rate of any increase in the average price of goods and services. In some countries, inflation is expressed in terms of the retail price index, which is defined centrally and reflects inflation relative to a range of goods. Inflation reduces the real value of cash flow over time and the real value of the money earned during *n* years is determined using the following equation [36]:

$$RV = S \times (1 + \frac{R}{100})^{-n} \tag{6}$$

where *RV* is the real value of S (money) that is earned over *n* years in $, S represents the cash flow over *n* years in $, and R is the inflation rate in %. Similar to the interest rate, it is common to use the inflation factor to assess the effect of inflation on a project. The inflation factor is obtained from the following equation:

$$IF = (1 + \frac{R}{100})^{-n} \tag{7}$$

Multiplying cash flow by inflation factor indicates the real value of cash flow:

$$RV = S \times IF \tag{8}$$

Finally, the real interest rate equals the subtraction of the *IR* and the inflation factor:

$$\text{Real Interest Rate} = \text{IR} - \text{Inflation Factor} \tag{9}$$

According to the latest announcement of the Central Bank of The Islamic Republic of Iran, the average inflation rate corresponded to 12.15% in 2018 [37].

Moreover, financial evaluation of projects can be measured using the benefit-to-cost ratio (BCR). The BCR is a financial measure of whether a project's benefits outweigh its costs. This ratio is equal to the total present value of the benefits divided by the total present value of the costs:

$$BCR=\frac{\text{Total Benefits}}{\text{Total Costs}}=\frac{NPB}{NPC} \tag{10}$$

LCOE is the ratio of all operating costs for an energy system to the amount of energy that is produced by that system over its lifetime. For this purpose, all of the cost factors including fuel, taxes, loans, operating costs, demolition, and etc. should be taken into account. In particular, for CPVT systems, the total produced energy (electrical and thermal) should be considered. The LCOE equation is as follows [38]:

$$LCOE=\frac{\sum_{t=0}^{n-1}\frac{C_t}{(1+i)^t}}{\sum_{t=0}^{n-1}\frac{E_t}{(1+i)^t}} \tag{11}$$

where n refers to the system life by year, C_t represents total system costs, E_t is the total energy produced by the system in year t, and i refers to IR (interest rate).

2.6 Study Assumptions

- According to Vahdati's research, if the entrance water flow to the CPVT system is increased, the device's coefficient factor can be boosted to 30X [23]. Hence, the calculations are performed based on the coefficient factor of 30X.
- The commercial building is located in Shiraz, Iran (52° east longitude and 29° north latitude) and the heating is considered as the dominant energy requirement of the building.
- The sunny hours of the last two years in Shiraz has been extracted from synoptic data of the Meteorological Department of Iran [24].
- The required heat load, atmospheric conditions of the desired location, and other necessary information are extracted from HOMER software.

3. Results and Discussions

In order to supply the commercial thermal load, the number of necessary supplying devices is estimated by comparing the average commercial thermal demand and the average generated thermal power of a CPVT device where the results are shown in Table 9. Subsequently, the monthly generated thermal power of the CPVT system would be calculated and compared with the commercial thermal demand. The monthly thermal demand of a commercial building in Shiraz is estimated using HOMER software and is depicted in Fig. 11. The respective results are illustrated in Fig. 12 and clearly show that the thermal power of this system differs throughout the year; besides, it is able to satisfy the required commercial load annually.

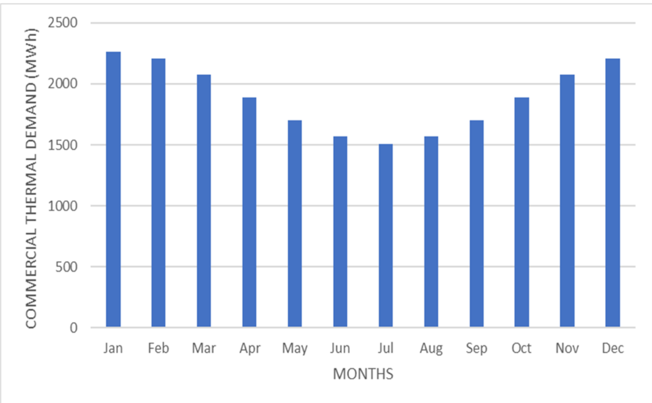

Fig. 11. Commercial thermal demand in Shiraz

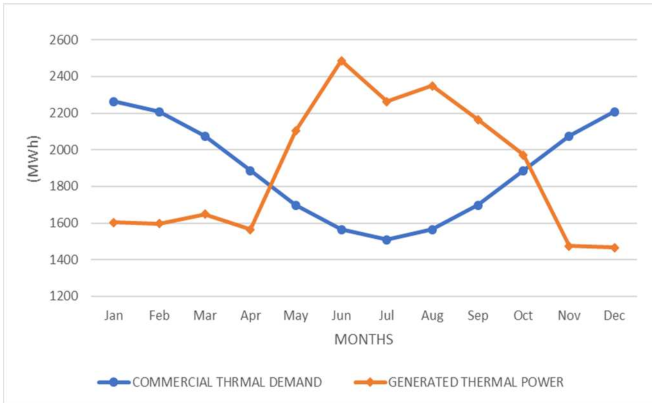

Fig. 12. Thermal energy generation and commercial demand comparison

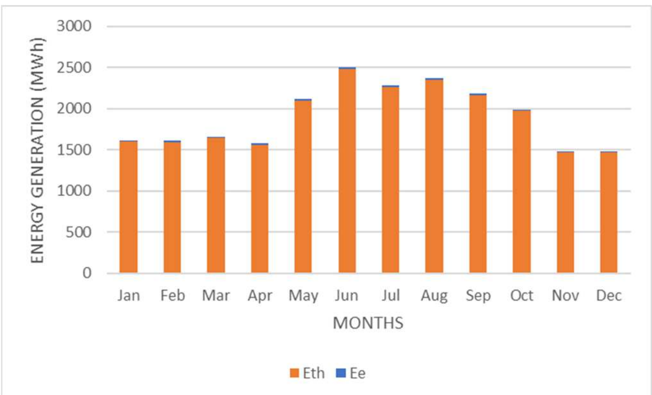

Fig. 13. Monthly energy generation of system

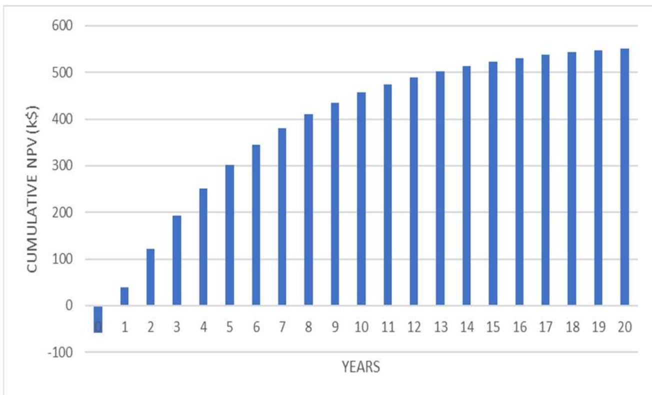

Fig. 14. Cumulative NPV of the project

Table 9. Comparison of generated and demand power

Parameter	Value
Ave. Commercial thermal demand – (MWh)	1886.40
Ave. CPVT generated thermal power – (MWh)	6.54
Required device number	289

Table 10. Economic measures of the project

Parameter	Value
E_e (GWh/year)	0.19
E_{th} (GWh/year)	22.69
E_{tot} (GWh/year)	22.89
E_e during the project lifetime (GWh)	3.86
E_{th} during the project lifetime (GWh)	453.85
E_{tot} during the project lifetime (GWh)	457.71
FiT ($/kWh)	0.216
CNG price ($/m^3)	0.033
Electrical income (k$/year)	41.70
Thermal income (k$/year)	74.92
Total income (k$/year)	116.62
Project lifetime (year)	20
IR (%)	18
IF (%)	15
RIR (%)	3
Tax (%)	0
NPB (k$)	610.73
NPC (k$)	59.18
NPV (k$)	551.55
IRR (%)	150.79
PBT (year)	0.51
BCR	10.32
LCOE ($/MWh)	0.1293

In the following section, the economic evaluation and financial outlook of the project are illustrated according to the energy tariffs in Iran; besides, the impact of parameters with uncertainty is also analyzed.

3.1 Economic evaluation of the provided system

According to Table 7, the system's NPC includes start-up equipment costs, O&M, replacement costs, transportation costs, and etc. O&M and replacement costs make up for 10% of the start-up equipment costs, inverter maintenance costs (which equals half of its price [30]), panel cleaning costs, water pump maintenance, installation systems, and etc. that add up to 9.1 k$. The highest costs provoked by this system are associated with the solar panels, structures, inverters, as well as O&M and replacement costs, which are equal to 34.88, 23.25, 17.3, and 15.38% of the total NPC, respectively. Finally, the overall NPC is calculated at 59.18 k$. It is also noteworthy that the solar panels' costs significantly reduced through concentrating systems.

The generated electrical (E_e) and thermal (E_{th}) energy are summarized in Fig. 13. According to sunny hours in Shiraz (Table 5), the E_{th} is greater than E_e. Moreover, the highest and lowest amount of energy has been generated in June and December, respectively. The E_e, E_{th}, and the total generated energy (E_{tot}) equal 0.19, 22.69, and 22.98 GWh/year, respectively. Thereupon, the system's NPB can be calculated with regards to the FiT and the price of Iranian natural gas, which adds up to 610.73 k$/year. Then, the economic indicators have been determined and are presented in detail in Table 10. In addition, the annual costs and the project cumulative NPV are given in Fig. 14. The NPB, NPV, and NPC of the system were reported 610.73 k$, 551.55 k$, and 59.18 k$, respectively. In addition, the BCR corresponds to 10.32, accordingly. Also, the system IRR is calculated as 150.79% and the LCOE is calculated as 0.1293 $/MWh that are regarded highly significant and much lower than the residential and commercial cost of energy which is within the range of 0.01–0.02 $/kW [39]. Furthermore, the system payback time (PBT) is determined 0.51 years, and the system will be thoroughly profitable hence after. These factors clearly represent the system's highly financial profitability which requires the encouragement of investment.

There are many parameters with high rates of uncertainty in grid-connected systems whose changes affect the generated energy and the system's profitability. For instance, the generated energy decreases due to the passage of time and depreciation of equipment. In other words, the researchers should take into account the effect of degradation factor on the generated energy in economic evaluation. On the other hand, climate conditions and solar radiations vary in different locations that can influence the energy production of the system. Accordingly, the impact of energy production changes should be considered in order to provide an appropriate financial outlook of the system for investment in other parts of the country. As a result, it is essential to conduct sensitivity analysis on this parameter. The analysis of the influence of energy production changes on PBT, IRR, NPV, and LCOE is illustrated in Fig. 15 and Fig. 16. In other words, the effects of the positive and negative changes generated energy in the system are compared to the estimated energy production (457.71 GWh/year). According to Fig. 15, IRR will decrease and PBT will increase as a result of the reduction of the generated energy. For example, if the generated energy decreases by 20%, IRR and PBT will equal 120.63% and 0.63 years, respectively. Contrarily, IRR will increase and PBT will decrease significantly if the generated energy increases. For example, given the 20% increase in generated energy, IRR and PBT will equal 180.95% and 0.42 years, respectively. Moreover, Fig. 16 indicates that the LCOE and NPV will equal 0.1616 $/MWh and 429 k$ if the produced energy reduces by 20%; Nevertheless, these values will equal 0.1077 $/MWh and 673 k$, respectively, as a result of a 20% increase in the generated energy. These two figures can clearly illustrate the low energy price and high profitability of the system; besides, it shows that the system will still be highly profitable and justifiable to investment even if the energy production depresses by 20%.

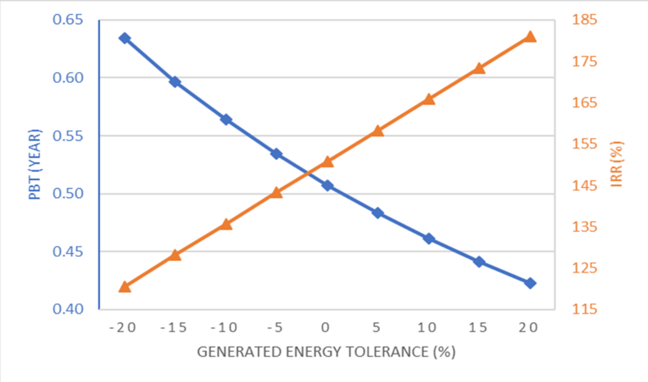

Fig. 15. System profitability under the tolerance of energy generation

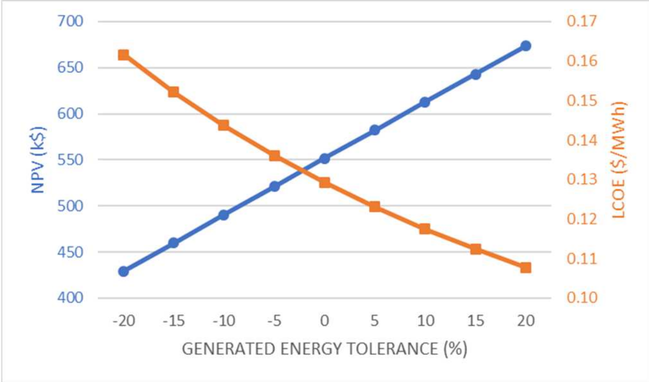

Fig. 16. System profitability under the tolerance of energy generation

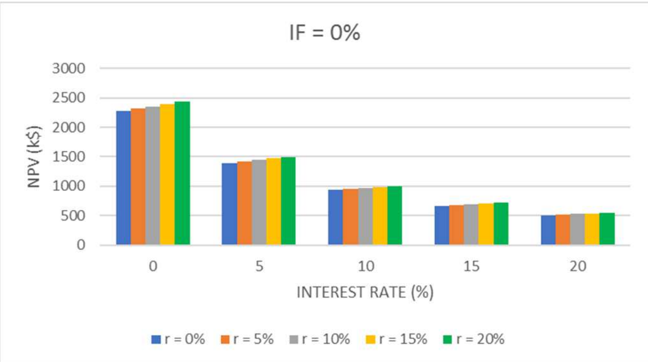

Fig. 17. Project NPV under variation of annual inflation, interest, and FiT (r) updating rates

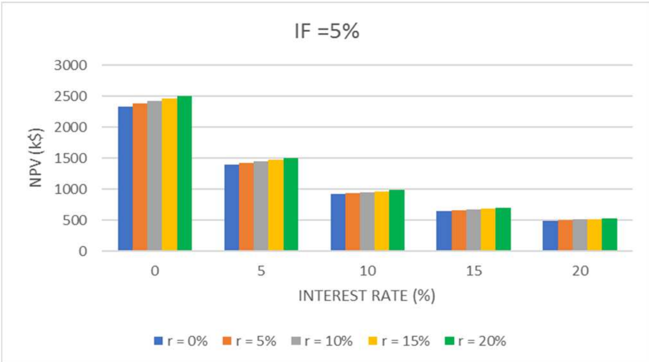

Fig. 18. Project NPV under variation of annual inflation, interest, and FiT (r) updating rates

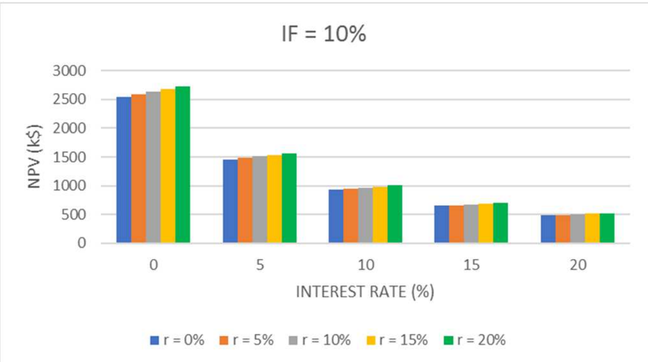

Fig. 19. Project NPV under variation of annual inflation, interest, and FiT (r) updating rates

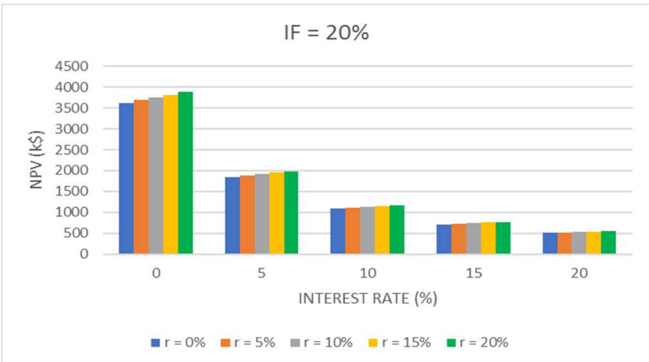

Fig. 20. Project NPV under variation of annual inflation, interest, and FiT (r) updating rates

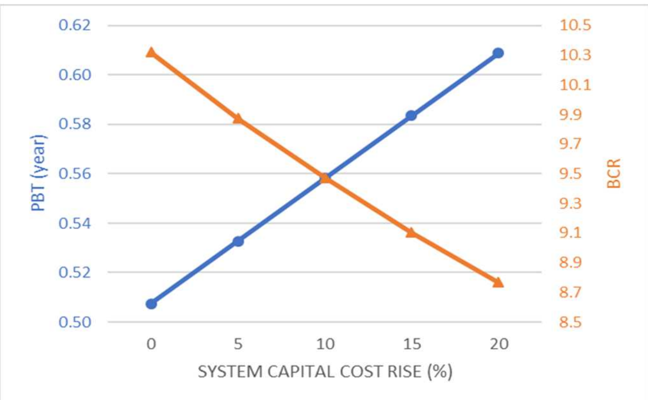

Fig. 21. Economic outlook of system under capital cost rise

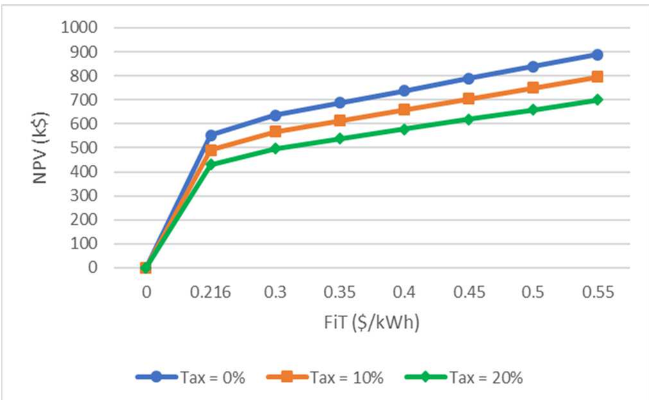

Fig. 22. Project NPV under various FiT and tax rates

The sensitivity analysis also includes the study of changes in interest rate, inflation rate, FiT (r), NPV, and their reciprocal interactions that are presented in Fig. 17-20. These four diagrams are respectively drawn for the inflation rates of 0, 5, 10, and 20% so that each column represents an increase in the FiT. For instance, if r = 5%, it means that the electricity tariff for the grid increases by 5%. These figures indicate that the NPV will be higher if the inflation rate and FiT increase. However, rising interest rates correlate negatively with the NPV. Furthermore, it can be concluded that any changes in the inflation rate and the FiT cannot lead to a significant change in the NPV and it remains in the range of 483.9 k$ and 768.48 k$ for the high-interest rates (15-20%) compared to low-interest rates. However, the reduction of the interest rate can result in significant NPV changes due to the inflation rate and the FiT modifications. For example, if the inflation rate increases by 20%, the NPV will enhance by around 486.02 k$ given the interest rate of 5%. Furthermore, if the inflation rate increases by 20%, the NPV will enhance by 1.44 M$ at the interest rate of 0%. In addition, these figures can reveal that if the interest rate reduces to 50%, the NPV will rise by about 50 to 100% given a fixed inflation rate which is predictable. Finally, any changes in energy tariffs will have greater effects at lower interest rates.

The changes in equipment prices can affect the system's profitability; sensitivity analysis of this parameter is crucial, especially in the countries with high fluctuating currency rates. This analysis has been conducted for the proposed system and the results are summarized in Fig. 21 where the PBT and BCR changes have been drawn according to the rises in capital costs. In case the capital costs increase by 10%, it can lead to an increase in the PBT by 0.56 years and a decrease in the BCR by 9.47. Given the high profitability of the system, even a 20% rise in capital costs may result in an increase in the PBT by 0.61 years and a decrease in BCR by 8.77. Nonetheless, the system would still have high BCR and short PBT as it shown in Fig. 21.

The FiT and taxes differ in each country. In Iran, generating electricity by renewable energy resources is tax-free and the FiT has increased during recent years and can also increase in the future. Therefore, the sensitivity analysis of the effects of these two parameters on the system's total profitability is essential. Fig. 22 shows the effect of the FiT and tax changes on the NPV. If the FiT equals 0.4 and 0.5 $/kWh, NPV equals 737.58 and 838.68 k$ respectively for the tax of 0%. And this increase for the tax of 20% corresponds to 578.23 and 659.11 k$, individually. Hence, this approach can result in high profitability in Iran; it can also be used in other countries (especially the middle- eastern countries) with higher taxes. Meanwhile, the economic conditions, solar radiation, temperature, humidity, and other effective factors on the absorption of solar energy should be taken into account as well.

3.2 Study Limitations

- Like other solar energy systems, the proposed system produces energy only during the daylight hours and not at night. Furthermore, atmospheric factors such as cloudy weather, rain, dust, etc. reduce energy production.
- The thermal energy produced by the system in the summer is more than the demand and in the winter is less than the demand; In a way that can supply the required thermal load on average. Therefore, in the winter, backup thermal energies such as natural gas should be used to supply the required load, and in addition, the excess thermal energy produced in the summer should be controlled. For example, the generated thermal energy can be used in combined cycles to generate electrical power.
- This system requires high initial capital cost.

4. Conclusion

In this paper, at first, a CPVT system (case study) was investigated and used in order to supply the thermal load for commercial buildings in Shiraz, Iran. After calculating the commercial thermal load (demand), it was estimated to require 289 CPVT devices (supply) to satisfy this load. Afterward, a set of 289 CPVT devices as well as some other indicators such as BCR, IRR, NPV, NPB, NPC, LCOE, and PBT have been economically examined within a 20-year period in order to calculate the system's profitability. Eventually, sensitivity analysis has been conducted on uncertain economic parameters. The most significant results of the present study are summarized as follows:

- The high energy generation of the system causes LCOE to reduce up to 0.1293 $/MWh at total energy production of 22.89 GWh/year.
- The system's NPC, NPV, NPB, and IRR values have been calculated as 59.18 k$, 551.55 k$, 610.73 k$, and 150.79%, respectively. It indicates a proper opportunity for investment in the present situation.
- The system's PBT is estimated as 0.51 years and the system will be fully profitable during the next 19.49 years. Moreover, the obtained BCR of 10.32 indicates a reasonable benefit to cost ratio for the system and guarantees high profitability of investment in this project.
- The sensitivity analyzes in the present study reveal that changes in economic factors have a significant role in the profitability of the system. These factors include the system's generating energy, tax, FiT, interest rate, and inflation rate. It is also expected that less energy will be generated during the implementation of the proposed system compared to the calculated theoretical energy. Nonetheless, these analyzes indicate the high profitability of this project, even in the worst cases, due to the high profitability of the system.
- The comparison of the system’s produced thermal load to the thermal load demand in Shiraz shows that the demand load can be supplied by the implementation of CPVT systems. This causes a significant reduction in gas consumption and the release of greenhouse gasses that reflect other objectives of the present study. Similarly, the middle-eastern countries have a high potential for absorbing solar radiation; hence, using CPVT systems is justifiable in these countries.
- The proposed system can be used to satisfy thermal loads of other buildings such as residential and public buildings, offices, and etc.

Author Contributions

Amir Abedanzadeh: Conceptualization, Writing-Original draft preparation, Methodology, Investigation, Writing-Reviewing and editing, Data curation. Hasti Borgheipour: Writing-Reviewing and editing and Supervision, Methodology. Samaneh Fakouriyan: Conceptualization, Methodology, Writing-Reviewing and editing. Farschad Torabi: Conceptualization, Investigation, Supervision, Visualization. The manuscript was written through the contribution of all authors. All authors discussed the results, reviewed, and approved the final version of the manuscript.

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Conflict of Interest

The authors declared no potential conflicts of interest concerning the research, authorship, and publication of this article.

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Data Availability Statements

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Nomenclature

C_0	Initial costs ($)	BCR	Benefit to cost ratio
CF_t	Cash flow ($)	CHCT-PVT	Compound hyperbolic concentrator -trumpet photovoltaic thermal
C_t	Total costs ($)	COP	Coefficient of performance
E_e	Generated electrical energy (GWh/year)	CPC-PVT	Compound parabolic concentrator - photovoltaic thermal
E_{th}	Generated thermal energy (GWh/year)	CPV	Concentrated photovoltaic
E_{tot}	Total generated energy (GWh/year)	CPVT	Concentrated photovoltaic thermal
$\dot{m}$	Mass flow rate (kg/s)	CPVT-TE	Concentrated photovoltaic thermal - thermoelectric
$\dot{Q}$	Thermal power (W)	DCMD	Direct contact membrane desalination
UC_{prod}	Generated energy price ($/kWh)	FiT	Feed-in tariff
UC_{util}	Purchased energy price ($/kWh)	HCPV	High concentrated photovoltaic
W_{av}	Generated (or consumed) power (W)	HTF	Heat transfer fluid
C	Specific heat capacity (J/kg.°C)	HVAC	Heating, ventilation, and air conditioning
FC	Fixed costs ($)	IRR	Internal rate of return (%)
i	Interest rate (%)	LCOE	Levelized cost of energy ($/kWh)
IF	Inflation factor	LCPV	Low concentrated photovoltaic
IR	Interest rate (%)	LPH	Liter per hour
m	Working hours (hr)	MPP	Maximum power point
n	Lifetime (years)	NPB	Net present benefit ($)
R	Inflation rate (%)	NPC	Net present cost ($)
RV	Real value ($)	NPV	Net present value ($)
S	Cash flow over n years ($)	PBT	Payback time (years)
T	Temperature (°C)	PV	Photovoltaic
t	Number of the year	PVT	Photovoltaic thermal
		RIR	Real interest rate (%)
		TEA	Techno-economic analysis
		VT-PVT	V-trough photovoltaic thermal

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ORCID iD

Amir Abedanzadeh https://orcid.org/0000-0003-4078-4009
Hasti Borgheipour https://orcid.org/0000-0002-0337-6850
Samaneh Fakouriyan https://orcid.org/0000-0002-4748-2137
Farschad Torabi https://orcid.org/0000-0002-7112-3126

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