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RESEARCH PAPER

A Simulation-Optimization Model for Solar PV Panel Selection under Solar Irradiance and Load Uncertainty

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Abstract

In this research, a multi-objective model is presented considering simulated behavior of high-efficiency rooftop solar PV panels in a factory, which are among the largest producers of greenhouse gases. The paper proposes a simulation-optimization approach that is used to maximize the net present value (NPV) of economic benefits along with minimizing the payback period (PBP) of the investment and maximizing solar energy consumption rate (SECR). In addition, the solar PV panels degradation and maintenance cost, as well as the uncertainty in solar irradiance and demand load, are also considered. The study consists of two scenarios, in the first of which both electricity tariffs and feed-in-tariffs (FiT) are fixed by a long-term contract. The second scenario investigates the situation in which subsidies on electricity tariff are removed. The best types of panels are found in each scenario considering the trade-offs between objective functions. The preferred trade-off solution in the first scenario, with a 2% increase in PBP, achieves more than 10% growth in NPV which is about $15000 in a year. In the second scenario, with only about a 0.2% decrease in NPV and a 3% increase in PBP, the preferred solution attains a 9% increase in SECR.

Keywords:
Simulation;
Rooftop Solar PV Panels;
Electricity Tariffs Policy;
Maintenance;
Uncertainty

Introduction

Manufacturing facilities are high consumers of electric energy, mainly due to the power-intensive tools in the production process, the heating ventilation, air conditioning equipment and other critical areas on the production floor, the facility which operates in 24/7-mode consumes an average of 15–30 MW power [1]. Numerous policies have been proposed to decrease energy consumption and lessen utility bills. The before-mentioned policies comprise turning-off idle machines [2], using onsite generation systems [3] and the progression of manufacturing lines with more energy-efficient machines [4]. All these strategies aim to reduce the electric power transferred from the utility grid and eventually decrease the carbon dioxide (CO_2) emitted by power plants. The industrial sector has a major role in greenhouse gas emissions, so it can be seen as an emerging market for solar technologies [5]. Recently, residential buildings (small-scale rooftops) integrated with solar panels have gained lots of attention and become a popular topic for research. Moreover, solar farms, as the large-scale

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applications, has become widespread while medium-scale installations (e.g. industrial rooftops) has been limited.

Today, using photovoltaic systems is very popular in developed countries. As energy consumption and amount of CO_2 emission in Iran are very high. Consequently, the need for the deployment of photovoltaic systems and other renewable energies is felt strongly. The advancement of technology in photovoltaic systems and the reduction of photovoltaic panels costs have led to the more frequent use of these systems in buildings including factories [6].

There are several studies that investigate why solar panels, due to their advantages, could not be entered into the market appropriately. Dehghani et al. [7] examined the supply chain of photovoltaic panels as an influential factor in the commercialization of PV panels. Manouchehrabadi et al.[8] studied the supply chain of solar panels in domestic and foreign solar cell types and related governmental incentives on domestic suppliers' support to obtain the optimal governmental strategy. Furthermore, Manouchehrabadi et al.[9], in another study, investigated the solar panels' supply chain in three scenarios considering domestic suppliers, foreign suppliers, and the role of government in the competitive situation. Regarding the environmental impacts of solar panels, Manouchehrabadi et al. [10] investigated supplying and employing used solar panels as a raw material of newly produced panels. Another study worked on the environmental aspects of solar panels' supply chain, considering technical, geographical, and social criteria to stimulate the extensive use of photovoltaic panels [11].

Maintenance of photovoltaic system consists of the actions needed to operate and maintain the solar panels and their support facilities in a circumstance to be able to do their predesignated task over their lifetime. Accordingly, given the absence of maintenance activities, the results of estimating the life-cycle cost are not realistic. In the optimization of maintenance planning, one of the key questions is "how to recognize the population degradation of solar panels?" [12]. There are several papers in the solar energy area that take the maintenance cost into account [13-19]. However, to our knowledge, there is only one study [20] that considers the maintenance along with failure rate and lifespan assessment in photovoltaic systems, which is one of the contributions of our paper.

Several factors can affect the energy produced by photovoltaic panels, of which the most significant one is solar irradiance that is mostly modelled deterministically in literature. Different types of uncertainty including economic uncertainty [21], load uncertainty [22,23], power output and distributed energy uncertainty [24,25] have been applied. Research on the solar irradiance uncertainty has been mostly restricted to weather forecast [26] as well as generator allocation [27]. Although the uncertainty of the irradiance has a significant effect on the produced energy and therefore, on the optimal decision, to the best of our knowledge, the parameter has not been well studied in the area of the energy modeling of buildings. In the current work, by considering Tehran's real irradiance data, we try to cope with the uncertainty of this parameter.

As initial costs for installing renewables are remarkably high and due to governmental supports, there is not always enough funding available to integrate buildings with renewables; therefore, studying the economic aspects of building energy modeling will be considered as an essential subject. Accordingly, Rysanek and Choudhary [21], Tan et al. [28], Fan and Xia [20], Jafari and Valentin [29], Wu et al. [30], Liu et al. [31], Wang et al. [32], Malatji et al. [33], Nottrott et al. [22] studied NPV of costs and profits of energy modeling in buildings, and Fan and Xia [20], Jafari and Valentin [29], Wu et al. [30], Liu et al. [31], Wang et al. [32], Valdiserri and Biserni [34], Wang and Xia [12] optimized the NPV while reducing payback period of investment costs. An effective procedure to return more value is selling the surplus energy produced from renewables which has been studied by Rysanek and Choudhary [21], Wang et al. [24], Akbari et al. [25]. In conclusion, it is essential to investigate and optimize the economic features of installing photovoltaics in buildings for householders and investors before decision-making.

In this paper, we applied a comprehensive model for exhaustive investigation about solar panel installation in factories. Due to real-world circumstances such as demand load uncertainty, environmental aspects, and climatic variables, the behavior of solar panels in factories is simulated. By selecting the optimum type of panel, the model brings economic and environmental advantages. Moreover, we make an effort to cope with solar irradiance and demand load uncertainty to get more promising results. Considering the significance of using renewables by factories, the proposed multi-objective model tries to maximize net present value (NPV), while reducing the payback period furthermore, another objective tries to increase the rate of consumption of energy generated by solar panels. The CO2 emission is included in the model by the carbon tax, considering the amount of CO2 released by the production of silicon solar panels. Another innovation of this study is investigating the effect of electricity tariffs on the profitability of using photovoltaics, in this regard, we perused a new tariffs policy. Therefore, the study segmented into two different scenarios with constant and variable electricity tariff. Hence, firstly we obtain the number of photovoltaic panels considering area constraint. Then, we enter the quantity and specification of each solar panel and other input data in a simulation process (by the Simphony software). The simulation consists of seven different scenarios, considering one for each specific type of panel. The model is constrained by the particular size of the rooftop. A more detailed classification of the studied parameters, methodology and uncertainty in the literature is depicted in Table 1.

Although the existing research is valuable, the environmental and monetary consequences of employing solar panels in industrial factories is not investigated. The main contributions of this study, which distinguished our efforts from related studies are as follows.

- Providing a framework in which the most suitable solar panels considering climatic uncertainty and government incentive scheme for industrial rooftops.
- Investigating the impact of the new government incentive plan on the revenue obtained from the installation of solar panels.
- Studying the reduction of CO_2 production and carbon tax in industrial plants due to the installation of solar panels.

The rest of the paper is organized as follows. In Section 2 the research methodology is presented. Section 3 addresses the uncertainty in solar irradiance, and also gives the details of the distribution fitted on Tehran's solar irradiance data. In Section 4, a mathematical formulation of the problem is proposed and described. The first and second scenarios are investigated in Section 5 and 6 respectively and simulation results are presented. Optimization results are clarified in Section 7, and finally, some concluding remarks are given in the last section.

Table 1. Comparison of some related researches in the area of buildings integrated with photovoltaics

Ref	NPV	Payback period	Maintenance	CO2 Emissions	Electricity Sale	Simulation	Optimization	Uncertainty	Uncertainty Type	Tools	Case Study
Rysanek and Choudhary [21]	✓	-	✓	✓	✓	✓	✓	✓	Economic & Technical	Robust decision-making BEM	office building in the United Kingdom
Tan et al. [28]	✓	-	-	✓	-	-	✓	-	-	CPLEX 12.1 solver with MATLAB	university campus in Istanbul
Fan and Xia [20]	✓	✓	✓	-	-	-	✓	-	-	Genetic Algorithm with MATLAB	Existing building
Jafari and Valentin [29]	✓	✓	✓	-	-	✓	✓	-	-	MATLAB & eQuest simulation software	The house constructed in 1964
Wu et al.[30]	✓	✓	✓	-	-	-	✓	-	-	Weighted-Sum method	A commercial building & an office building
Liu et al. [31]	✓	✓	✓	-	-	✓	-	-	-	Simulation Tool?	Existing building constructed in 1988
Wang et al. [32]	✓	✓	✓	-	-	-	✓	-	-	DE Algorithm	Replacing facilities in a building
Malatji et al. [33]	✓	✓	-	-	-	✓	✓	-	-	GA algorithm	Replacing facilities in a building
Nottrott et al. [22]	✓	-	✓	-	-	✓	✓	✓	Load uncertainty	LP system is solved in MATLAB.	-
Wang et al. [24]	-	-	-	-	✓	✓	✓	✓	Power output uncertainty	HOMER	A smart home integrated with a PV system
Mulder et al. [35]	✓	-	-	-	-	✓	✓	-	-	?	German tariffs
Ascione et al. [36]	-	✓	-	✓	-	✓	✓	-	-	MATLAB & Energy Plus	building located in South Italy
Pratama, Purwanto [37]	-	-	✓	✓	-	-	✓	-	-	GAMS	6 regions in Indonesia
Wang and Xia [12]	✓	✓	✓	-	-	✓	✓	-	-	MPC & DE algorithm (Simulation Tool)?	Actual building retrofitting project
Balaban and de Oliveira [38]	-	-	-	✓	-	-	-	-	-	-	Building in Tokyo
Radhi [39]	-	-	✓	✓	-	✓	-	-	-	BEES (Design-Builder)	UAE university campus
Fetanat and Khorasaninejad [40]	-	-	✓	-	-	✓	✓	-	-	MATLAB	Numerical example
Akbari et al. [25]	✓	-	✓	✓	✓	✓	✓	✓	uncertainties in distributed energy	GAMS & Energy Plus	-
Hosseinalizadeh et al. [13]	-	-	✓	-	-	✓	✓	-	-	MATLAB	Four regions in Iran with a steady demand of 10 kW.
Shakouri et al. [41]	✓	-	✓	-	-	✓	✓	-	-	GAMS & BCS19	New building in Iran
Carpinelli et al. [23]	-	-	-	-	-	✓	-	✓	Load & power production uncertainty	Monte Carlo simulation	4 different cases
This study	✓	✓	✓	✓	✓	✓	✓	✓	Uncertainty in solar irradiance and demand load	Simphony	Solar irradiance of Tehran, Iran

Methodology

The methodology utilized in this research is base on a simulation-optimization approach that applied with Simphony software to simulate the behavior of solar panels in two scenarios to choose the optimum type of photovoltaic panel to be installed on an industrial building's rooftop. In this paper, the most fitting probabilistic distribution that applied to the irradiation data of Tehran and real demand load data of a certain factory is presented by simulation. The goal of the proposed model is to determine the optimum type of panel to satisfy the profit of the overall system by considering panels decadence, maintenance costs, and carbon tax simultaneously as well as introduce the more suitable governments subsidy among two scenarios .Moreover, another objective of the model is to reach the lowest payback period while maximizing the rate of solar energy consumption. Therefore, we determined the number of each type of solar panels, considering constraints of the available rooftop area and the area of the solar panels included in this paper. Then, we put all the obtained data into our simulation model to estimate the objective function parameters.

As mentioned in Table 1, several studies in similar fields employed GAMS for solving multi-objective models [25,37,41,42] . In this paper, the Simphony software is chosen since defining the most fitted probability function for Tehran's irradiation based on the real data, and considering the outcome uncertain value of yearly irradiation in all steps of calculations. The Simphony software made the integration of probabilistic uncertainty with mathematical modeling possible and accurate. Applying this kind of uncertainty in GAMS software requisite the replacement of the probability function with only a mean value of probability function, which provokes an inaccurate result. In all steps of simulation, for including uncertainty, Simphony takes a sample from the fitted distribution of irradiance and demand load.

Two scenarios are defined which investigate the government incentive scheme policy on producing energy from solar panels. The first scenario (Fixed Tarriffs) examines the current incentive scheme of Irans' policy. In the second Scenario, unsubsidized electricity price and FiT is investigated, as the government intends to gradually raise electricity tariffs in the following years. In this situation, the feed-in tariff will stay fix, and the electricity tariff will increase to be equal to its export price. In this study, the environmental and monetary consequences of both having incentive schemes and unsubsidized feed-in tariff are investigated. In a multi-objective optimization with inconsistent objective functions, there is no unique optimization solution. Therefore, the goal is to find the most appropriate solution among all the optimal solutions. According to the trade-offs made among the objectives, we cannot confirm to obtain the complete Pareto front, so it is helpful to find the most preferred solution to the original multi-objective problem.

Uncertainty

Uncertainty in solar irradiance

Due to the increase of solar generators usage for generating electricity and variation in the amount of solar radiation, the determination of the output power of units has a stochastic nature. Uncertainty is applied for unstable parameters using fuzzy methods or probabilistic approaches. Solar radiation is predicted by numerical prediction of weather conditions as an effective tool to enhance the operation of an electronic system connected to a large-sized solar generator. As a result, an investigation is made to develop a new empirical method for predicting the uncertainty in solar radiation based on a numerical forecast of the weather. Many models have been formed to predict the probable prediction of solar radiation, such as linear regression models, neural network models, and different scenarios [26]. The important point to notice, considering any approach is to regard this fact that, planning of power distribution systems for long, medium, and short term operating systems (i.e., one day before the operation) is significantly affected by uncertainty [23].

To consider the uncertainties in daily radiation, we used real data of solar radiation from Tehran meteorological station from 2018 to 2019. The information of Tehran meteorological synoptic station with the longitude of 51.23N and latitude of 35.44E with a height of 1419 meters from the sea level used [43]. Afterward, by using the Simphony simulation software, we fitted the probabilistic distribution on the data. As it is observable in Table 2, the data is best fitted to the beta distribution. The goodness of fit of distributions is tested by least squares, maximum likelihood, and moment matching methods.

Table 2. The goodness of fit for determining the distribution in Tehran

Least Squares			Maximum Likelihood			Moment Matching		
Distribution	K-S	X^2	Distribution	K-S	X^2	Distribution	K-S	X^2
Beta	0.03628	16.61	Beta	0.03659	15.99	Beta	0.03659	15.99
Weibull	0.05862	66.59	Weibull	0.07454	68.36	Normal	0.08023	80.12
Normal	0.08688	71.06	Normal	0.08023	80.12	Logistic	0.09440	115.41

Beta pdf is described as [27] :

$$f_I(x) = \begin{cases} \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} * I^{(\alpha-1)} * (1-I)^{(\beta-1)}, & for\ 0 \leq I \leq 1 \\ 0, & otherwise \quad \alpha \geq 0, \quad \beta \geq 0 \end{cases}, \tag{1}$$

where I is the solar irradiance, kW/m^2; $f_I(x)$ is the Beta distribution function of I, and α, β are the parameters of the Beta distribution function.

In each method, the goodness of fit is evaluated by K-S and Chi-Squared tests and the best distribution for Tehran irradiation data is recommended. The beta distribution is obviously the most appropriate one among the other probabilistic distributions. Due to the sample size which is 365, because of the number of days in a year, if test results are lower than 0.071 in the K-S test and 18.3 in the Chi-Square test with a 95% confidence level, the probabilistic distribution is completely suitable. The results in Tables 2 and 3 explicitly indicate the aptness of the Beta distribution.

Therefore, we will use this distribution to continue our calculations in this paper. The distribution parameters are α =1.534, β =1.143 for Tehran and the probability density function, (PDF) cumulative probability function (CDF) of distribution, and the real data are explicitly depicted in Figs. 1 and 2.

Demand load uncertainty

Probabilistic nature of demand load fluctuation can be evaluated by a Normal distribution. Probability function of demanding load is depicted as follows [44]:

$$f\big(EC(t)\big) = \frac{1}{\sqrt{2\pi(\sigma^{dl})^2}} \exp\left(-\frac{\left(EC(t)-\mu^{dl}\right)^2}{2(\sigma^{dl})^2}\right), \tag{2}$$

where μ^{dl} and σ^{dl} are mean value and standard deviation of the normal distribution of demand load based on observed value (the case used in the numerical applications of thispaper). The average of the factory's electricity demand is 243736.2 kW with standard deviation of 16220.44 kW. Probability density function (PDF), cumulative probability function (CDF) of Normal distribution, and the goodness of fit of real data are explicitly depicted in Figs. 3 and 4.

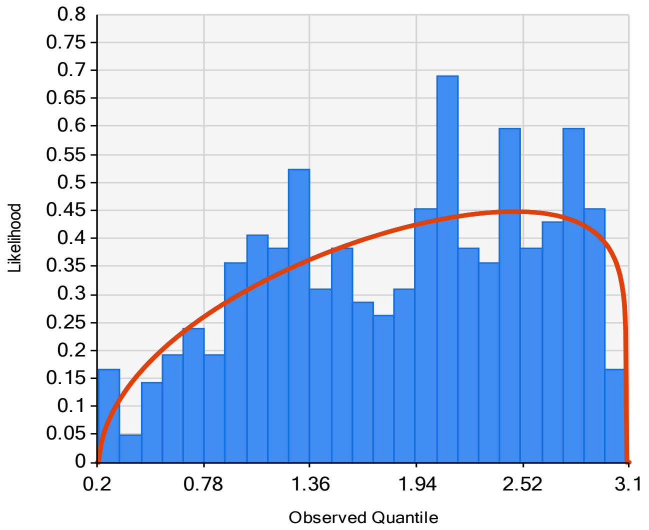

Fig. 1. Probability Density Function of Tehran (PDF)

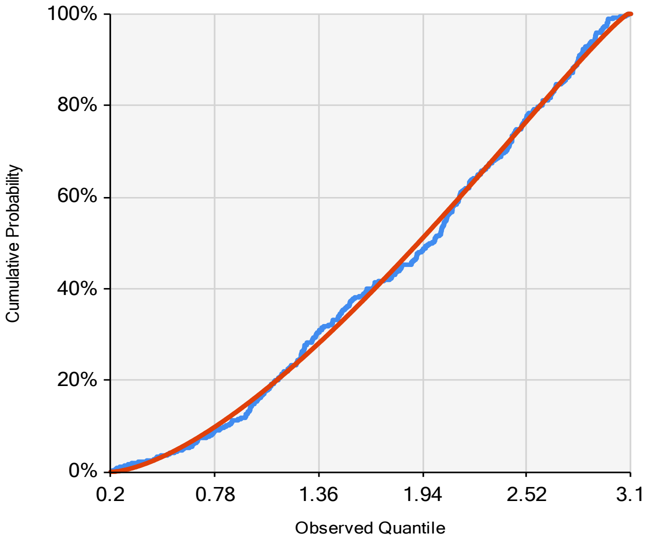

Fig. 2. Cumulative Probability function of Tehran (CDF)

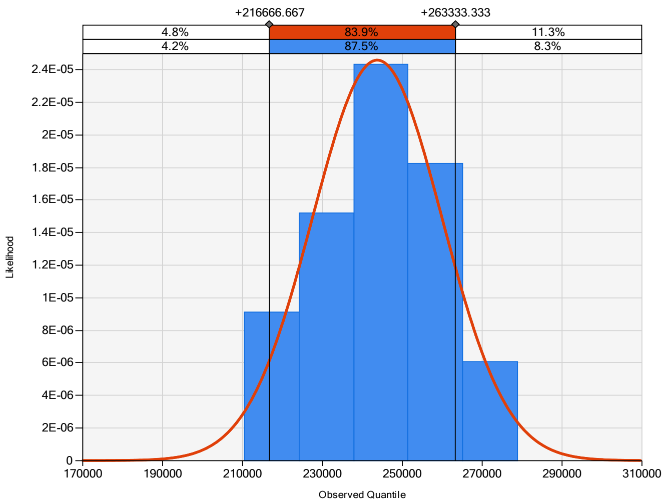

Fig. 3. Probability Density Function of Demand Load (PDF)

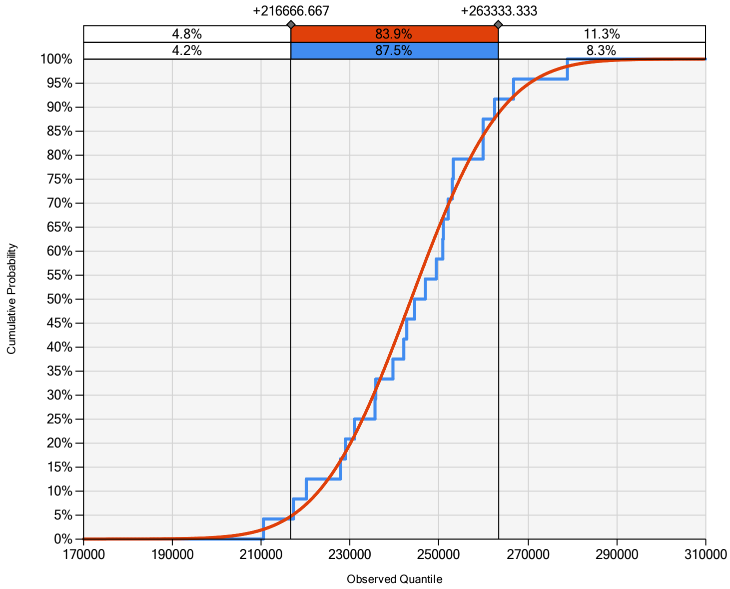

Fig. 4. Cumulative Probability function of Demand load (CDF)

Nomenclature

Parameters	
t	PV panels lifetime years $t = 1 \ to \ 24$
l	PV panels type $l = 1 \ to \ 7$
$L(t)$	Reliability function and life function distribution (Weibull distribution)
$V(t)$	Number of solar panels installed at the beginning of the project that still works properly at the end of the t-th
$M(t)$	Number of panels installed during maintenance and T_m is the maintenance interval
A_{eff}	Effective and usable area of the roof
$E_{PV}(t)$	Energy produced by the installed solar panel power supply system in the t-th year
δ_l	Efficiency of the l-th type solar panel
δ_{PV}	Average solar to electrical power conversion efficiency, taking into account losses due to temperature, etc.
I_{PV}	Solar irradiation (kW h/m^2-year)
A_l^{pv}	Area of one solar panel of type l (m^2)
$EC(t)$	Demand load in the t-th year
$c_M(t)$	Maintenance cost for the solar panel power supply system in the t-th year
$c_{RI}(t)$	Risk insurance cost for the solar panel power supply in the t-th year
c_r	Initial cost of solar panels installation
r	Interest rate
$P_t^{Off-peak}$	Electricity tariff in off-peak hours in the t-th year
$P_t^{Mid-peak}$	Electricity tariff in mid-peak hours in the t-th year
$P_t^{Peak-load}$	Electricity tariff in peak load hours in the t-th year
P_{EXP}	Exported electricity tariff
FIT	Feed-in-tariff
ψ_1 , ψ_2, ψ_3	Energy consumption rate in peak-load, mid-peak and off-peak hours respectively
$e_{l,t}$	CO_2 savings achieved at the end of period t by using technology l
ie	increasing rate of electricity
F^{pv}	CO_2 emission from the production of silicon PV modules

CES	CO_2 emission saving
CF	Capacity factor
CTS	Carbon tax saving
ct	Carbon tax for per Kg emissioned carbon
E_N	Amount of energy the PV system would have produced at full capacity
NPV	Net present value obtained by installing and maintaining solar panels considering risk insurance
PBP	Payback Period
$SECR$	Solar energy consumption rate
$\overline{NPV}$	maximum value of net present value
$\overline{PBP}$	maximum value of the payback period
$\overline{SECR}$	maximum value of Solar energy consumption rate
N_l^0	Number of solar panels installed at the beginning of solar panel installation
Decision variables	
x_l^{pv}	1, if the l-th type of the solar panels is chosen; otherwise 0

Mathematical formulation

In this paper, the solar energy production system is modeled to show the amount of energy demand in a factory. Besides, the panel's decay, which causes a reduction in solar energy production, is also taken into account. To obtain an accurate estimate of the energy generation system in the study, the maintenance program for the failed solar panels is considered. One of the constraints confines the available area of the rooftop installing photovoltaic panels.

The photovoltaic system considered in this study has very high reliability in its 24 - year lifespan but its performance will be reduced over time. As the results of simulations presented by the Simphony software indicate, the number of properly functioning panels will be decreased over time, and consequently, the performance will decrease. The system lifetime, the reliability of the system can be easily estimated by the Weibull distribution, and following the number of properly functioning panels would be calculated. The notations are introduced in Appendix. The general pattern of reduction in the number of solar panels can be estimated by the following equation [20]:

$$L(t) = e^{-(\frac{t}{\varphi})^3} \tag{3}$$

where $L(t)$ represents the survival rate of solar panels at time t, φ is a scale parameter. Hence, with a given Ł, which in this study is considered 24, the lifespan of solar panels, the value of the coefficient φ can be obtained by solving the following equation [32,45]:

$$L(Ł) = 0.5 \tag{4}$$

consequently, $\varphi = 28.4$ is obtained.

The number of solar panels installed at the beginning of the project that still works properly at the end of the t-th year is equivalent to:

$$V(t)=N_l^0 *L(t) \tag{5}$$

where k is a positive integer, T_M is maintenance interval.

$$M(t)=\begin{cases}N_l^0-V(t) & t=kT_M\\ 0 & otherwise\end{cases} \tag{6}$$

Produced energy from healthy solar panels in the t-th year equals $E_{PV}(t)$ (kW h/year) [46,47]:

$$E_{PV}(t)=\sum_{l=1}^{L}\left(x_l^{pv}\delta_l\right)\sum_{l=1}^{L}\left(x_l^{pv}A_l^{pv}\right)I_{PV}\delta_{PV}V(t) \tag{7}$$

$$c_M(t)=M(t)\left(\sum_{l=1}^{L}x_l^{pv}\,c_{m_l}^{pv}\right) \tag{8}$$

$c_M(t)$ is the maintenance cost for the solar panel system in the t-th year ($), the initial cost of solar panels installation calculates as follows:

$$c_r=N_l^0\sum_{l=1}^{L}x_l^{pv}\,c_l^{pv} \tag{9}$$

$$C_{tot}=c_r+\sum_{t=1}^{T}c_M(t)+\sum_{t=1}^{T}c_{RI}(t) \tag{10}$$

C_{tot} includes initial cost for solar panels installation, maintenance cost and risk insurance cost during the lifetime of solar panel power supply system.

$$CES=\sum_{t=1}^{T}e_{l,t}E_{PV}(t)-\sum_{l=1}^{L}N_l^0x_l^{pv}\,F_l^{pv} \tag{11}$$

$$CTS=CES\times ct \tag{12}$$

Maximize NPV
Minimize PBP (13)
Maximize SECR

CES is the total CO_2 emission prevention considering the amount of emitted CO_2 while producing the process of solar panels in a factory. Producing electricity from Solar panels is generally considered to be a non-emission process altogether. But through conducting a deeper study on solar panels, we will find that in the course of the solar panels production process, fossil fuel consumption will produce CO_2. Ideally, the amount of emissions emitted during the generation of solar panels should decrease, and after this decrement, the remaining small amount will be offset by the use of panels in order to generate electricity [48,49]. CTS is the carbon tax saving due to CO_2 emission prevention.

The NPV method is usually used in capital budgeting to analyze the profitability of a projected investment or project. In this study, the NPV method is used to evaluate the overall value obtained by installing and maintaining solar panels considering risk insurance and carbon tax. The payback period (PBP) is a critical indicator of how soon an investment returns its initial cost considering the time value of money. This is usually important because help decision-makers to compare various investment opportunities. It is defined as the period after which NPV turns and stays non-negative and can be obtained by the following equation. As we are seeking for the highest profit, so if the electricity tariffs are less than feed-in-tariff (FiT), it leads to using grid energy instead of solar-generated power. The third objective function intends to maximize the solar energy consumption rate ($SECR$)[50].

Subject to:

Following equations are physical constraints of the proposed model:

$$\sum_{l=1}^{L} x_{l,t}^{pv} A_{pv}^{l} N_l^0 \ll A_{eff} \tag{14}$$

$$\sum_{l=1}^{L} x_l^{pv} = 1 \quad for\ x_l^{pv} \in \{0,1\}, \forall\ l\ \in \{1,2,\dots,L\} \tag{15}$$

Scenario I: Fixed tarrifs

Medium-scale solar PV systems are not commonly installed in the country. The financial progressive of these medium systems in factories are influenced by the investment incentives and tariff policy of the country. In many countries around the world, incentive plans have been put in place by the government and the grid utility to expand the use of renewable energy sources in factories. One of these incentives is purchasing surplus electricity from factories which have equipped with renewables with fixed feed-in-tariff in the long term. The building sells electricity to the grid utility at a higher price than the users purchase it from the grid that which may cause the profitability of the owner. Therefore, due to Iran's qualifications, electricity feed-in-tariff is four times higher than purchasing power from the grid. The electricity tariff is assumed steady over the solar panels lifetime. $NPV, PBP, SECR$ are defined to evaluate the amount of profitability in order to choose the most suitable photovoltaic panel to invest. NPV is the difference between the present values of cash inflows and cash outflows over a while.

Under the feed-in tariff policy, industrial proprietors that are installed rooftop solar PV systems are paid by utilities a tariff rate determined by authorities and guaranteed for a specific period of time. [51,52].Feed-in tariff payments could be fixed-price or premium-price payments [51]. Feed-in tariff schemes are attractive to industrial consumers since it offers guaranteed payment, grid access, and stable and long term contracts.

$$NPV = \begin{cases} \sum_{t=1}^{T} \frac{\left(E_{pv}(t) - \psi_1 EC(t)\right) * FiT - c_m(t) - c_{RI}(t)}{(1+r)^t} + CTS - c_r & for\ E_{pv}(t) > \psi_1 EC(t) \quad (16) \\ \sum_{t=1}^{T} \frac{\left(\psi_1 EC(t) - E_{pv}(t)\right) * P_t^{Peak-load} - c_m(t) - c_{RI}(t)}{(1+r)^t} + CTS - c_r & for\ E_{pv}(t) < \psi_1 EC(t) \quad (17) \end{cases}$$

$$NPV = \sum_{t=1}^{T} \frac{\left(E_{pv}(t) * FIT - \psi_2 EC(t) * P_t^{Mid-peak}\right) * FiT - c_m(t) - c_{RI}(t)}{(1+r)^t} + CTS - c_r \tag{18}$$

$$NPV = \sum_{t=1}^{T} \frac{\left(E_{pv}(t) * FIT - \psi_3 EC(t) * P_t^{Off-peak}\right) * FiT - c_m(t) - c_{RI}(t)}{(1+r)^t} + CTS - c_r \tag{19}$$

$$X_1 = \begin{cases} \sum_{t=1}^{T} (E_{pv}(t) - \psi_1 EC(t)) * FiT * (1+ie)^t & for\ E_{pv}(t) > \psi_1 EC(t) \quad (20) \\ \sum_{t=1}^{T} (E_{pv}(t) - \psi_1 EC(t)) * P_t^{Peak-load} * (1+ie)^t & for\ E_{pv}(t) < \psi_1 EC(t) \quad (21) \end{cases}$$

$$X_2 = \sum_{t=1}^{T} (E_{pv}(t) * FiT - \psi_2 EC(t) * \ P_t^{Mid-peak}) * (1 + ie)^t \tag{22}$$

$$X_3 = \sum_{t=1}^{T} (E_{pv}(t) * FiT - \psi_3 EC(t) * \ P_t^{Off-peak}) * (1 + ie)^t \tag{23}$$

$$PBP = \frac{c_r}{(X_1+X_2+X_3)/T} \tag{24}$$

$$SECR = 1 - \frac{\sum_{t=1}^{T}\left(E_{pv}(t)-\psi_1 EC(t)\right)}{\sum_{t=1}^{T} E_{pv}(t)} \tag{25}$$

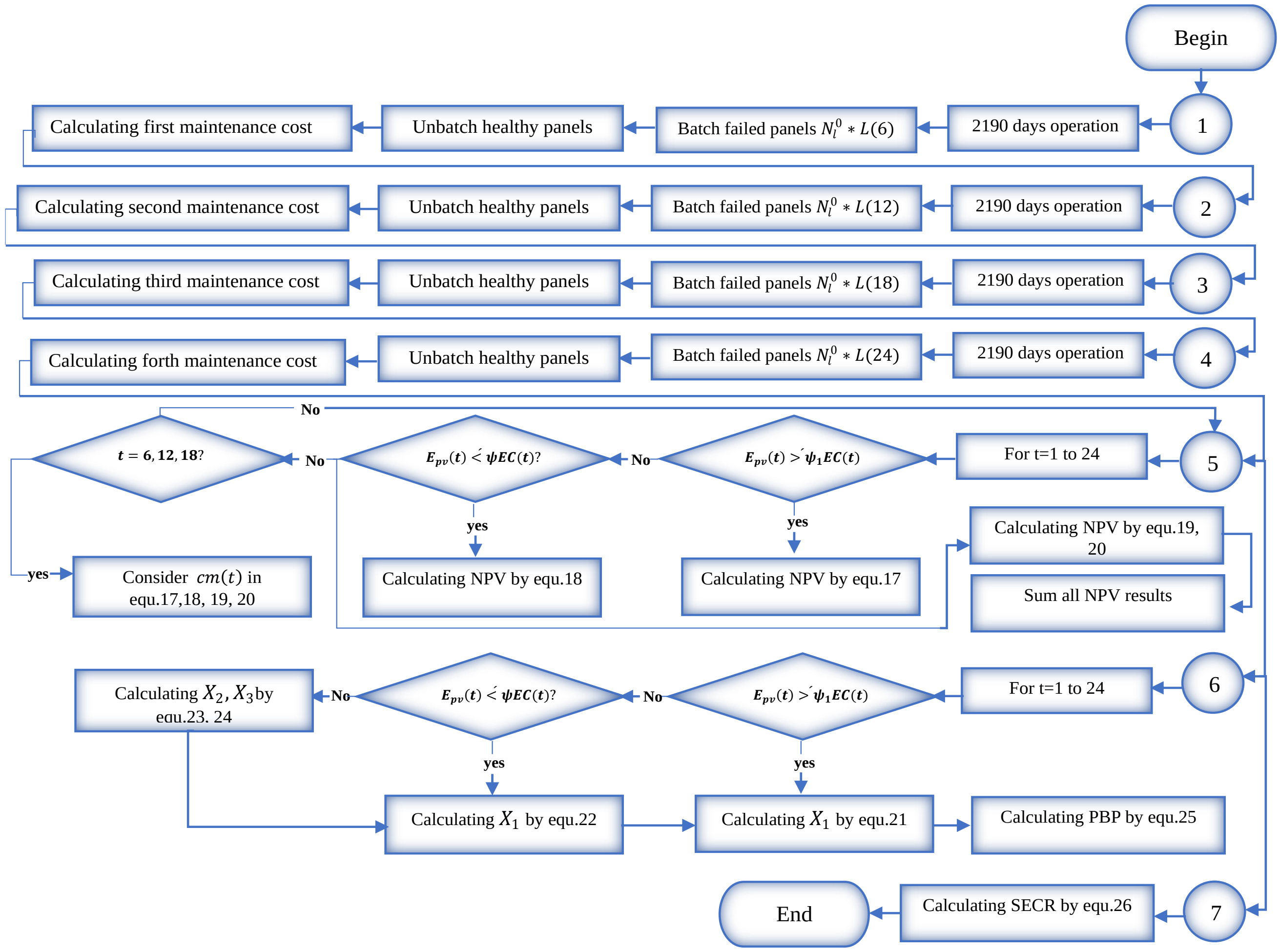

Fig. 5. Simulation process in scenario *I*

In capital budgeting, the NPV method is utilized to estimate the cost-effectiveness of an investment. In this study, the NPV method is applied to analyze the overall profit obtained by installing photovoltaic panels considering maintenance costs, risk insurance, and carbon tax. In this study, the assumption is in peak-load hours the factory must use solar-generated power with $P_t^{Peak-load}$. In case if there will be surplus energy, it would be sold to the utility. In off-peak and mid-peak hours, to gain more value, the generated electricity would be sold to the utility and the demand load power supplies from the grid with related tariff. The detailed information of the first scenario simulation is depicted in Fig. 5. Under the feed-in tariff policy, industrial proprietors who installed rooftop solar PV systems, are paid by the utility with a tariff rate determined by authorities and this rate is guaranteed for a specific period of time by the government [51,52]. Feed-in tariff payments could be fixed-price or premium-price payments [51]. Feed-in tariff schemes are attractive to industrial consumers since it offers guaranteed payment, grid access, and stable and long term contracts. Consequently, the probability of profitability will increase. In this study, the case study is considered Tehran, so the electricity tariff of this city is considered in calculations as well.

One of the objectives of this study is to explore how photovoltaic systems increase NPV, to what extent the expenses of owners of photovoltaic systems will decrease, and how much will spend on installing these panels. First, we need to consider the costs and revenues resulting from installing panels connected to the grid. The total cost entered in this study includes installation costs, maintenance costs, and risk insurance cost. The total income obtains from selling the photovoltaic system's surplus power. If there is no surplus power, the installation fees will not return [48]. In this case, the NPV is calculated considering the problem assumptions with Eqs. 16 to 19. The third objective function to gain more environmental benefits forces the factories to use more solar-generated electricity than grid power but NPV tries to use solar energy to earn a monetary profit. The plan considered seven alternatives of solar panels to choose from for installation in the simulation and optimization process. Details of these alternatives and used up input data are presented in Tables 3 and 4, respectively.

Table 3. Information on solar panels.

l	Description	c_l^{pv}($)	δ_l(%)	A_l^{pv}(m2)
1	SPR-A400-G	1388	21.5	1.864
2	LG370Q13-V5	1184	21.4	1.7272
3	REC380AA	1400	21.8	1.7485
4	VBHN335SA17	1055.7	20	1.57427
5	SLA-320M-HC	1036.8	19.5	1.655
6	VBHN 340 SA17	1105	20.3	1.6724
7	LG NEONR 35001C	1230	20.8	1.8321

Table 4. Used data for simulation

$P_t^{Off-peak}$	$ 0.042 per kW
$P_t^{Mid-peak}$	$ 0.048 per kW
$P_t^{Peak-load}$	$ 0.06 per kW
P_{EXP}	$ 0.226 per kW
FiT	$ 0.168 per kW
T_M	6 years
ψ_1 , ψ_2, ψ_3	0.25, 0.6, 0.15 (%)
$EC(t)$	~Normal [243736.2, 16220.44] kW
I_{PV}	~ Beta [1.53, 1.14, 0.21, 3.08] kW/m2

In the real world, we observe different amounts of radiation every day, so we are unable to extract a fixed amount of energy from solar PV panels. As a result, considering the solar-generated energy, regardless of climate variables uncertainties will lead to an unreliable result. In the present study, the solar irradiance obeys the probabilistic distribution and the energy generated from panels follows the irradiance uncertainty, so it directly affects NPV, PBP, $SECR$, capacity factor, and carbon tax. On the other side, in the real situation, we face demand load uncertainty. To cope with this issue, we consider the load demand with Normal distribution. The reliable simulation results indicated in Table 5. Table 5 summarize some basic statistics of the model outputs for Tehran: mean, standard deviation (SD), minimum (min), and maximum (max).

Table 5. Simulation results in Tehran

l	Parameter	Min	Max	Mean	SD	value
1	NPV ($\$M$)	-1.13	7.54	3.83	2.23	-
	$PBP(year)$	1.97	25.5	4.73	4.43	-
	$SECR$ (%)	5.2	80.2	11.7	8.6	-
	$Epv\ (t)(MWh)$	6.36	93.91	56.4	22.68	-
	$C_r(\$M)$	-	-	-	-	1.354
	N_l^0	-	-	-	-	976
2	NPV ($\$M$)	-1.04	7.6	3.9	2.23	-
	$PBP(year)$	1.825	22.789	4.425	4.267	-
	$SECR$ (%)	5.3	80.1	11.9	8.7	-
	$Epv\ (t)(MWh)$	6.36	93.4	56.1	22.5	-
	$C_r(\$M)$	-	-	-	-	1.246
	N_l^0	-	-	-	-	1053
3	NPV ($\$M$)	-1.24	7.56	3.796	2.27	-
	$PBP(year)$	2.092	27.772	5.027	4.741	-
	$SECR$ (%)	5.1	78.6	11.6	8.5	-
	$Epv\ (t)(MWh)$	6.56	95.17	57.41	22.85	-
	$C_r(\$M)$	-	-	-	-	1.46
	N_l^0	-	-	-	-	1040
4	NPV ($\$M$)	-1.052	7.011	3.566	2.076	-
	$PBP(year)$	1.915	28.558	4.676	4.619	-
	$SECR$ (%)	7.2	91.1	13.8	12.1	-
	$Epv\ (t)(MWh)$	6.02	87.4	52.57	20.96	-
	$C_r(\$M)$	-	-	-	-	1.22
	N_l^0	-	-	-	-	1156
5	NPV ($\$M$)	-0.983	6.88	3.513	2.033	-
	$PBP(year)$	1.837	25.913	4.483	4.364	-
	$SECR$ (%)	5.8	88.4	13	9.6	-
	$Epv\ (t)(MWh)$	5.85	85.15	51.22	20.47	-
	$C_r(\$M)$	-	-	-	-	1.14
	N_l^0	-	-	-	-	1099
6	NPV ($\$M$)	-0.937	7.253	3.75	2.112	-
	$PBP(year)$	1.858	25.996	4.509	4.412	-
	$SECR$ (%)	5.6	84.9	12.6	9.3	-
	$Epv\ (t)(MWh)$	6.06	88.68	53.35	21.35	-
	$C_r(\$M)$	-	-	-	-	1.2
	N_l^0	-	-	-	-	1088
7	NPV ($\$M$)	-1.013	7.18	3.57	2.117	-
	$PBP(year)$	1.735	22.127	4.321	4.034	-
	$SECR$ (%)	5.5	85.1	12.5	9.1	-
	$Epv\ (t)(MWh)$	6.02	88.66	53.31	21.34	-
	$C_r(\$M)$	-	-	-	-	1.122
	N_l^0	-	-	-	-	993

Scenario II: Unsubsidizing electricity price and FiT

Electricity tariffs inside Iran are subsidized. A new governmental policy has been put forward to increase tariffs on its exportation price and phase out subsidies in Iran. For this scheme, the government plans to increase electricity tariffs in subsequent years gradually. The electricity tariff will be equal to the feed-in tariff over the next five to six coming years. Following, according to the tariff increase rate, the feed-in tariff would be lower than tariffs. In this case, economic examining would be different from the first Scenario.

In the second scenario, when the FiT is higher than the electricity tariffs, the objective functions are calculated as the first scenario. So, all the generated power transfers to the utility and the demand supplies from the grid. When the tariff proceeds above the FiT, we encounter a different strategy to earn a greater profit. The changes in tariffs are depicted in Fig. 6. If the solar-generated energy is more than the demand load, the surplus power will be sold to the grid and otherwise, the factory must purchase the shortage of demand load from the utility with a related tariff. In this case, like the first scenario, the factory is forced to supply its peak-load hour demand with solar-generated power. All the simulation process is presented in Fig.7 in detail. All results of the second scenario for seven-panel types, after 50000-time runs of software, concerning the uncertainty of radiation and demand load in a factory in Tehran, are presented in Table 6. As Tehran is the capital of Iran and the amount of pollution is greatly high, so using renewables is highly recommended. Indeed, one can verify that if a suitable type of panel is used, the factory will gain profit.

Table 6. Simulation results in Tehran

l	Description	Parameter	Min	Max	Mean	SD
1	SPR-A400-G	NPV ($\$M$)	-1.36	2.99	1.13	1.12
		$PBP(year)$	2.88	31.97	7.36	8.47
		$SECR$ (%)	23.4	91.3	41.7	17.4
2	LG370Q13-V5	NPV ($\$M$)	-1.26	3.07	1.22	1.12
		$PBP(year)$	2.66	32.23	6.83	7.74
		$SECR$ (%)	23.6	91.7	41.1	17.5
3	REC380AA	NPV ($\$M$)	-1.46	2.95	1.07	1.14
		$PBP(year)$	3.05	41.55	7.84	8.98
		$SECR$ (%)	23.2	91.6	41.3	17.4
4	VBHN335SA17	NPV ($\$M$)	-1.26	2.79	1.06	1.04
		$PBP(year)$	2.8	44.1	7.3	8.8
		$SECR$ (%)	24.7	92.2	44	17.7
5	SLA-320M-HC	NPV ($\$M$)	-1.18	2.76	1.08	1.015
		$PBP(year)$	2.680	31.795	7.043	8.694
		$SECR$ (%)	25.2	92.5	44.7	17.7
6	VBHN 340 SA17	NPV ($\$M$)	-1.14	2.97	1.21	1.05
		$PBP(year)$	2.7	32.5	7.08	8.5
		$SECR$ (%)	24.4	92.6	44.3	17.7
7	LG NEONR 35001C	NPV ($\$M$)	-1.15	3.07	1.18	1.08
		$PBP(year)$	2.47	32.06	6.9	7.57
		FCR (%)	23.8	92.2	40.7	17.5

$$P_t^{Off-peak} = P_{t-1}^{Off-peak}(1+\lambda)^t \tag{26}$$

$$P_t^{Mid-peak} = P_{t-1}^{Mid-peak}(1+\lambda)^t \tag{27}$$

$$P_t^{Peak-load} = P_{t-1}^{Peak-load}(1+\lambda)^t \tag{28}$$

$$P_t^{Off-peak} \leq P_{EXP}^{off-peak} \tag{29}$$

$$P_t^{Mid-peak} \leq P_{EXP}^{Mid-peak} \tag{30}$$

$$P_t^{Peak-load} \leq P_{EXP}^{Peak-load} \tag{31}$$

$$\eta_1 = \{t| \quad P_t^{Off-peak}, \quad P_t^{Mid-peak}, \quad P_t^{Peak-load} \leq FiT \} \tag{32}$$

$$\eta_2 = \{t| \quad P_t^{Off-peak}, \quad P_t^{Mid-peak}, \quad P_t^{Peak-load} \geq FiT \} \tag{33}$$

$$NPV = \begin{cases} \sum_{t=1}^{T} \frac{\left(E_{pv}(t) - \psi_1 EC(t)\right) * FiT - c_m(t) - c_{RI}(t)}{(1+r)^t} + CTS - c_r & for\ E_{pv}(t) > \psi_1 EC(t) \quad (34) \\ \sum_{t=1}^{T} \frac{\left(E_{pv}(t) - \psi_1 EC(t)\right) * \quad P_t^{Peak-load} - c_m(t) - c_{RI}(t)}{(1+r)^t} + CTS - c_r & for\ E_{pv}(t) < \psi_1 EC(t) \quad (35) \end{cases}$$

$$NPV = \begin{cases} \sum_{t=1}^{T} \frac{\left(E_{pv}(t) - \psi_2 EC(t)\right) * FiT - c_m(t) - c_{RI}(t)}{(1+r)^t} + CTS - c_r & for\ E_{pv}(t) > \psi_2 EC(t) \quad (36) \\ \sum_{t=1}^{T} \frac{\left(E_{pv}(t) - \psi_2 EC(t)\right) * \quad P_t^{Mid-peak} - c_m(t) - c_{RI}(t)}{(1+r)^t} + CTS - c_r & for\ E_{pv}(t) < \psi_2 EC(t) \quad (37) \end{cases}$$

$$NPV = \begin{cases} \sum_{t=1}^{T} \frac{\left(E_{pv}(t) - \psi_3 EC(t)\right) * FiT - c_m(t) - c_{RI}(t)}{(1+r)^t} + CTS - c_r & for\ E_{pv}(t) > \psi_3 EC(t) \quad (38) \\ \sum_{t=1}^{T} \frac{\left(E_{pv}(t) - \psi_3 EC(t)\right) * \quad P_t^{Off-peak} - c_m(t) - c_{RI}(t)}{(1+r)^t} + CTS - c_r & for\ E_{pv}(t) < \psi_3 EC(t) \quad (39) \end{cases}$$

$$X_1 = \begin{cases} \sum_{t\in\eta_1,\eta_2} (E_{pv}(t) - \psi_1 EC(t)) * FiT * (1+ie)^t & for\ E_{pv}(t) > \psi_1 EC(t) \\ \sum_{t\in\eta_1,\eta_2} (E_{pv}(t) - \psi_1 EC(t)) * \quad P_t^{Peak-load} * (1+ie)^t & for\ E_{pv}(t) < \psi_1 EC(t) \end{cases} \tag{40}$$

$$X_2 = \quad \sum_{t\in\eta_1} (E_{pv}(t) * FiT - \psi_2 EC(t) * \quad P_t^{Mid-peak}) * (1+ie)^t \tag{41}$$

$$X_2 = \begin{cases} \sum_{t\in\eta_2} (E_{pv}(t) - \psi_2 EC(t)) * FiT * (1+ie)^t & for\ E_{pv}(t) > \psi_2 EC(t) \\ \sum_{t\in\eta_2} (E_{pv}(t) - \psi_2 EC(t)) * P_t^{Mid-peak} * (1+ie)^t & for\ E_{pv}(t) < \psi_2 EC(t) \end{cases} \tag{42}$$

$$X_3 = \quad \sum_{t\in\eta_1} (E_{pv}(t) * FiT - \psi_3 EC(t) * \quad P_t^{Off-peak}) * (1+ie)^t \tag{43}$$

$$X_3 = \begin{cases} \sum_{t\in\eta_2} (E_{pv}(t) - \psi_3 EC(t)) * FiT * (1+ie)^t & for\ E_{pv}(t) > \psi_3 EC(t) \\ \sum_{t\in\eta_2} (E_{pv}(t) - \psi_3 EC(t)) * \quad P_t^{Off-peak} * (1+ie)^t & for\ E_{pv}(t) < \psi_3 EC(t) \end{cases} \tag{44}$$

$$PBP = \frac{c_r}{(X_1+X_2+X_3)/T} \tag{45}$$

$$SECR = \begin{cases} 1 - \dfrac{\sum_{t=1}^{T}\left(E_{pv}(t) - \psi_1 EC(t)\right)}{\sum_{t=1}^{T} E_{pv}(t)} & t \in \eta_1 \quad (46) \\ 1 - \dfrac{\sum_{t=1}^{T}\left(E_{pv}(t) - EC(t)\right)}{\sum_{t=1}^{T} E_{pv}(t)} \quad for\ E_{pv}(t) > EC(t) & t \in \eta_2 \quad (47) \\ 1 \quad for\ E_{pv}(t) < EC(t) & \end{cases}$$

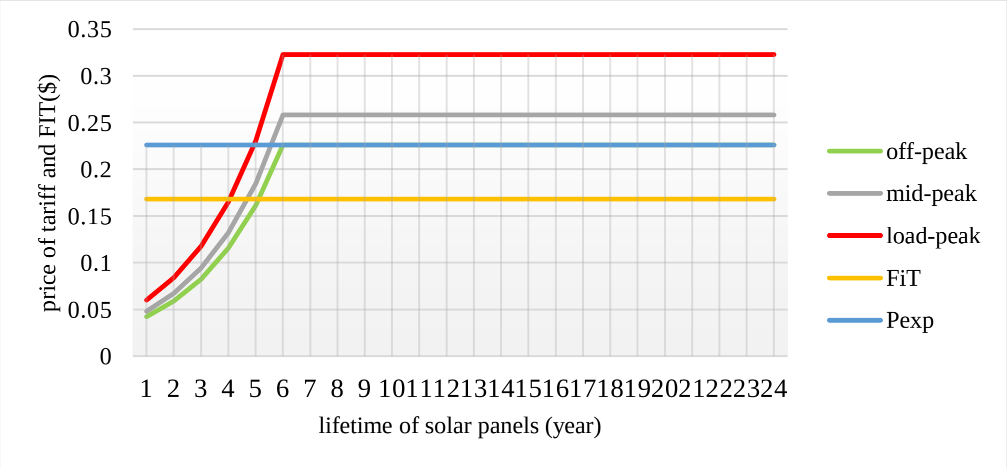

Fig.6. Tariffs and Feed-in-Tariff in scenario *II*

Optimization

Since Simphony software is unable to do the optimization, this process should be done separately from the simulation. Meanwhile, the best option among the introduced solar panels is chosen. In this paper, the full maintenance process is done every $T_M = 6$ years. During each maintenance process, failed solar panels are all substituted with new ones. The available area of rooftop for installing solar panels assumed 1820 m^2. In the first step, we obtain the possible numbers for each panel based upon the available area, then the initial cost of installation is calculated for each panel. The corresponding results are displayed in Table 5. The simulation includes seven scenarios, each designed to specify a certain type of the panel in Table 3. The statistical reports of simulations are shown in Table 5.

In a multi-objective optimization with a trade-off between objectives, there is no individual optimal solution that can optimize all the objective functions at once. So, the purpose is to achieve the most adopted solution among the optimal solutions. While we cannot ensure to obtain the complete Pareto front, it is helpful that can find a solution to the original multi-objective problem, according to the trade-offs made among the objectives. The trade-off between objective functions for each scenario is depicted in Figs. 8 and 9.

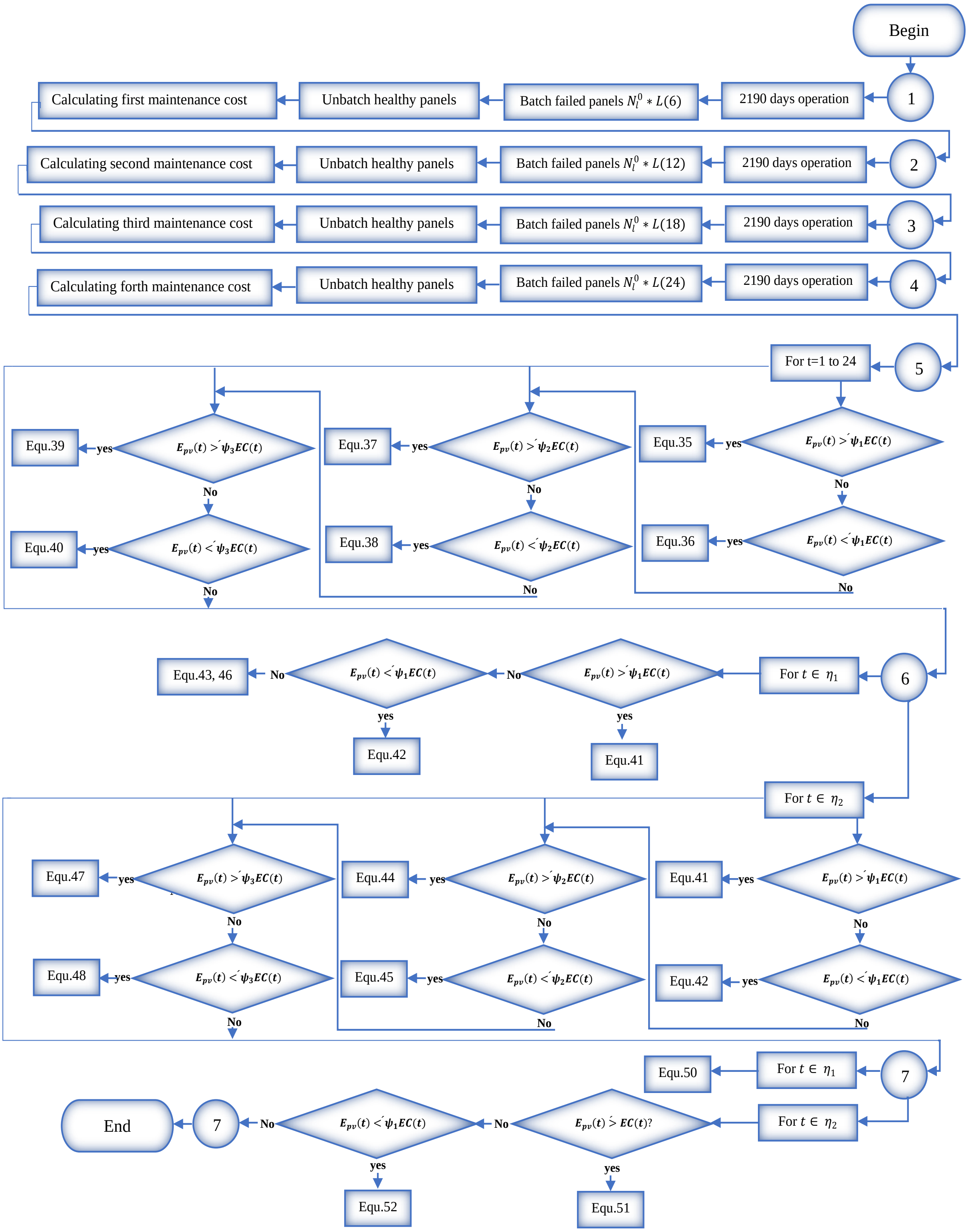

Fig. 7. Simulation process in scenario II

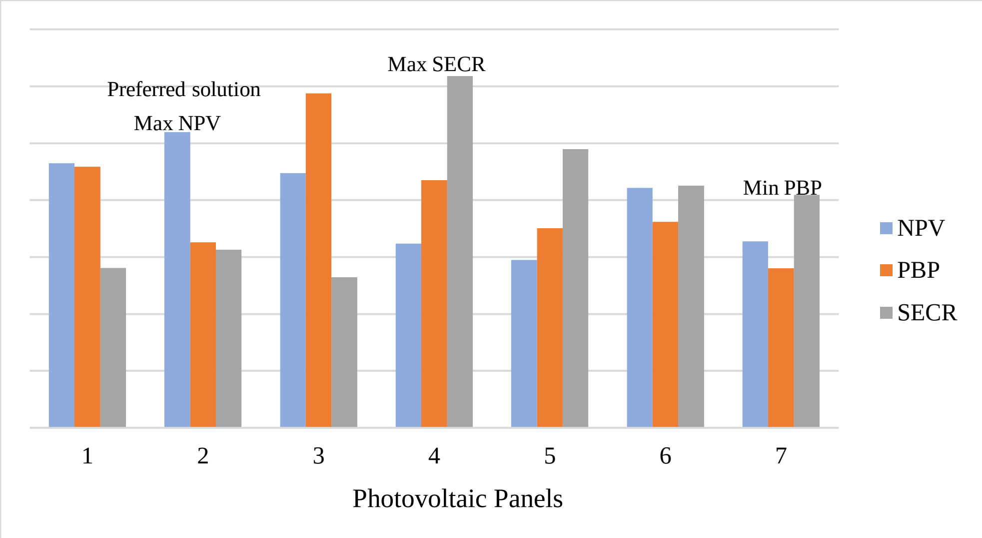

Fig. 8. Trade-off between objective functions in the first scenario

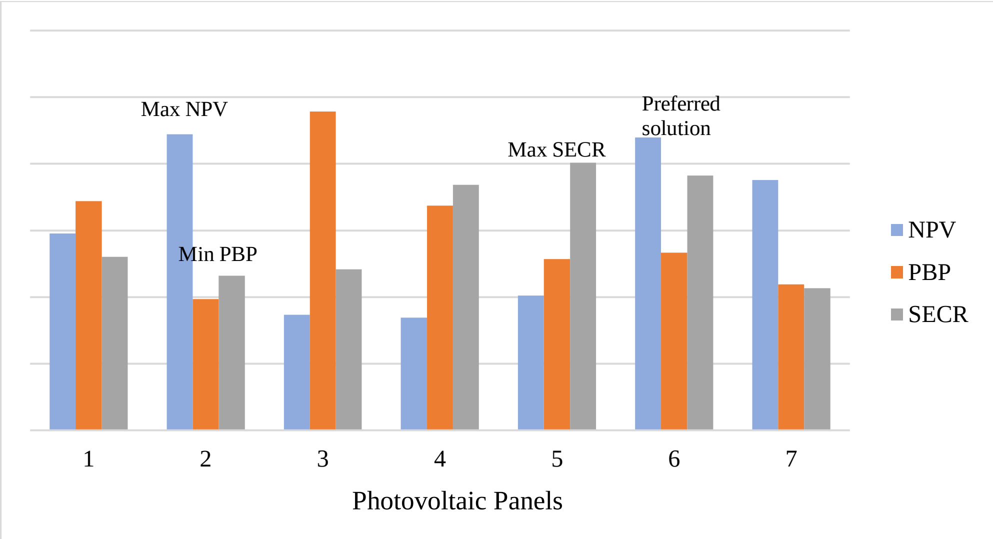

Fig. 9. Trade-off between objective functions in the second scenario

In the first scenario with a more stable tariff policy, when we set all concentration on NPV, the results represent the second panel (LG370Q13-V5) as an optimum panel. In addition, while the highest attention belongs to PBP, the seventh panel (LG NEONR 35001C) is preferred. Likewise, by focusing on the third objective function, the fourth panel (VBHN335SA17) is the best option to be chosen. In this scenario, with unsteady electricity tariffs, the results almost fluctuate between the second (LG370Q13-V5), fifth (SLA-320M-HC) and sixth (VBHN 340 SA17) photovoltaic panel. Entirely, by giving all priority to NPV, PBP, and $SECR$ respectively, the second type of solar panel (LG370Q13-V5) and the fifth (SLA-320M-HC) panel would be the optimum one.

The analysis of the trade-off solutions shows that for each objective function separately, there is a different optimum photovoltaic panel. The second type of solar panel has a reasonable compromise between the objective functions in the first scenario (Fig. 8), and therefore, it is preferred. It has the highest NPV, its PBP is the second minimum one, and the $SECR$ in this panel is mediocre among other photovoltaic panels. This panel achieves a 10% increase in NPV with only a 2% increase in PBP relative to the optimal PBP (panel 7). In the second scenario (Fig. 9), with only a 0.2% decrease in NPV and a 3% increase in PBP, the preferred alternative (panel 6) attains a 7% increase in the amount of SECR with respect to panel 2 with the lowest PBP and highest NPV which prevents 10236 kg CO_2 emission.

Capacity Factor

The optimal size for the PV system is determined through optimization solutions providing the desired availability with minimum cost. The optimal size of the system leads to the optimal capacity factor of the system. The capacity factor is the ratio of actual output of a power plant over a period of time to the possible energy generation if the panels were exposed to sun irradiation all the time in that period. This ratio is critical as it shows how fully a system's capacity is utilized [53]:

$$CF = \frac{E_{pv}(t)}{8760 * E_N} \tag{48}$$

where 8760 is the number of hours of the solar panels' lifetime and E_N is the nominal installed panel capacity. As the solar irradiance follows the probabilistic distribution and this uncertainty, directly affects the solar-generated power, so the capacity factor is mainly affected by the uncertainty factor. After running the simulation process 50000 times, results show the minimum value of capacity factor 6.2%, the maximum of 21.3%, the average of 14.9 % for Tehran that which reported in Table 7.

Table 7. Simulation results of *CF*

Parameter	Min	Max	Mean	SD
CF (%)	6.2	21.3	14.9	3.9

Fig. 10 shows the results of the desired panel's capacity factor. As indicated in the mentioned figure, 76.1% of results, the capacity factor is between 10% and 20%, 14.1% of the results of the are less than 10 percent and 9.8% of results of capacity factor simulation fluctuates between 20% and 22%.

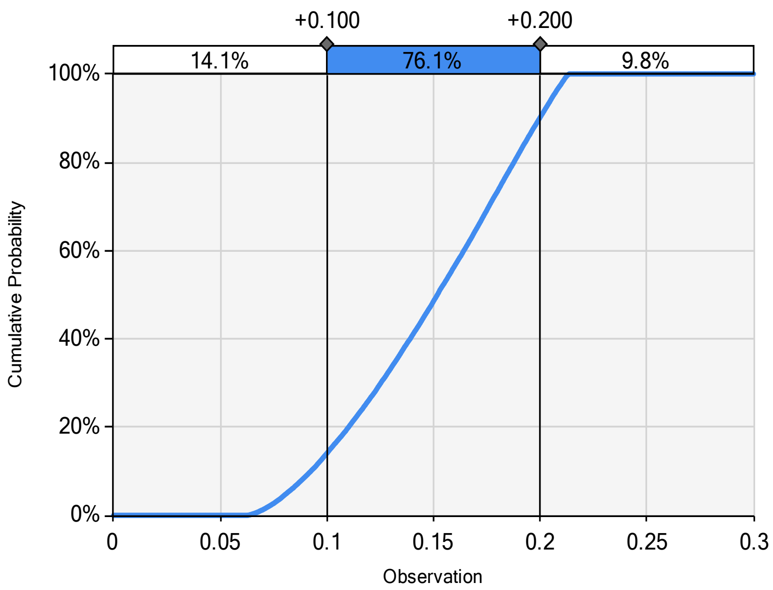

Fig. 10. Capacity Factor due to irradiance uncertainty

Managerial insights

In the first scenario considering the stable situation and low electricity tariffs, the consideration is put on selling the solar panels' produced energy in off-peak and mid-peak. However, due to higher tariffs and electricity consumption rates in the peak load, the demand load is supplied by the generated electricity by solar panels. In the second scenario, considering the high electricity tariff and fixed FiT, the electricity consumption strategy would be different. In this scenario, the electricity sells only if there is a surplus generated energy except for peak load time. In the peak load, the demand supplies by the solar panels' generated energy. The numerical results received from the implementation of the models' simulation, the comparison between two scenarios, lead to some managerial insights listed below:

- If FiT is higher than the electricity tariff, to reach higher monetary benefits, the most suitable strategy is selling the generated electricity to the grid in the off-peak and mid-peak and using it in the peak load.
- If the electricity tariff is equal to or higher than FiT, the best strategy is to supply the plants' energy demand from the panels' produced energy, and only the surplus energy would be sold.
- Considering the obtained result, in the first scenario compared to the second scenario, the monetary benefits would be higher; consequently, the payback period of the initial investment is lower.
- In the second scenario, in choosing each type of panels, about 40 to 45 percent of generated electricity by solar panels is consumed by the plant, so the adverse environmental impacts of grid electricity are considerably reduced. In contrast, in the first scenario, as the consideration is on the electricity sale, only 11 to 14 percent of the produced energy is consumed, and the remainder is sold to the grid.
- choosing the best scenario is highly related to the situation. If the environmental aspects are the priority, the strategy of the second scenario would be the best choice, while if the monetary benefits are preferred, the first scenario can be an optimal choice.

Conclusion

In the present study, a multi-objective optimization for the factory photovoltaic system investigated. This study aims to increase the energy efficiency of existing factories with a certain budget and eventually maximize profits for investors and the environment and the best payback time. In the process of this research, decadence, and maintenance of solar panels are considered to increase energy production which could lead to economic benefits. The optimization model results help decision-makers to become aware of their investment opportunities and risks in factories. Thus, we have investigated the most significant economic indicator, including NPV, PBP in two scenarios for two different electricity tariff policy.

Although the fourth panel has a smaller area than others, and therefore more PV panels are needed to cover the available rooftop area, due to its suitable price and efficiency, it is one of the optimal options when a stable tariff policy is in place. Additionally, when the focus is on more use of solar-generated energy, either all three objective functions to the same extent, this type of panel appears as an optimal option. The second panel, in addition to its high efficiency, is more affordable than relatively similar efficiency PV panels. As a result, the panel is more effective when electricity tariffs are stable and also while concentrating on profitability. Since the seventh panel has the lowest area and needs the lowest number of panels to cover the rooftop, we can select it as the optimal choice when considering the shorter payback period.

In the absence of electricity tariff instability, when the focus is primarily on profitability or simultaneously taking into account the payback period, the second panel is considered the most optimal choice. In the second scenario, when the focus is on less use of grid power and more use of the power produced by the panels, we can choose the fifth panel as an optimum. The sixth panel is the most preferred solution in this scenario, with a little decrease in NPV and PBP, the environmental benefits will increase considerably.

The simulation and optimization in two different scenarios due to installing, maintenance, risk insurance, and carbon tax costs were carried out for a specific factory in Tehran seeing uncertainty in irradiance and demand load beside comprehensive economic considerations, and it shows that among different photovoltaic panels, the sixth panel type in most simulation results is more cost-effective for the unstable economic situation and the second type when the tariff will not change considerably over time. To sum up, as the results are shown, considering uncertainty in all steps of the simulation process, this model can be regarded as an appropriate model to choose the most appropriate panel among all panels considering the economic situation.

There are several ways to extend this study that can be suggested as future research directions. At first, we can use other types of renewable energies in factories like wind turbines while considering uncertainty in wind speed to cover the weakness of the PV system. Besides, future researchs can attend to taking all the factors of retrofitting such as walls, windows, roof and air-conditioning system into account in order to optimize energy consumption in factories. Furthermore, addressing other characteristics of sustainability, like using passive systems in the factory is the latest direction.

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