# A New Strategy for Collective Energy Self-consumption in the Eco-Industrial Park: Mathematical Modeling and Economic Evaluation

Hamza Gribiss, Mohammadmohsen Aghelinejad, Farouk Yalaoui

# A new strategy for collective energy self-consumption in the eco-industrial park : Mathematical modeling and economic evaluation

Hamza GRIBISS[1], MohammadMohsen AGHELINEJAD[2] and Farouk YALAOUI[3]

Laboratory of Computer Science and Digital Society (LIST3N), University of Technology of Troyes, France

(hamza.gribiss, mohsen.aghelinejad, farouk.yalaoui)@utt.fr

[1] ORCID ID : 0000-0002-3971-6095

[2] ORCID ID : 0000-0002-9345-4807

[3] ORCID ID : 0000-0001-7360-2932

**Abstract.** Renewable energies are increasingly used around the world to replace fossil energy resources such as gas, coal, and oil sources in order to reduce greenhouse gases. Eco-industrial parks promote the use and sharing of renewable energy sources between factories in a collective self-consumption framework. This article presents a new strategy of photovoltaic self-consumption in an eco-industrial park, that combines collective and individual self-consumption. This strategy has been compared with the classical configuration of self-consumption, in which factories do not share a common photovoltaic installation. Two mathematical models have been proposed and solved for these two configurations, the results show that the new strategy is more efficient than the classical configuration of individual self-consumption.

**Keywords.** Eco-industrial park, Renewable energy, Collective self-consumption, Mathematical modeling.

## 1 Introduction

Energy production is mainly based on fossil energy resources such as gas, coal, and oil sources. According to the UN (United Nations Organization), the use of these resources results in global warming of 1.5 °C due to the emission of greenhouse gases [1]. Among the targets set out in the European Union's (EU) climate and energy framework for 2030, is to reduce greenhouse gases emissions and to increase the share of renewable energy [2].

Energy self-consumption is an important option, which drives to increase renewable energy sources as a result of high energy prices and the emission of greenhouse gases. There are two types of self-consumption :

- The individual self-consumption, that is part of the total energy production consumed by the system. It refers to the process by which a producer consumes its energy production [3].
- The collective self-consumption, that is the case where several consumers share the same energy production. For instance, an industrial park contains several factories that share a photovoltaic production [4]. There is another form of collective self-consumption, particularly in eco-industrial parks. Factories exchange the surplus of energy between themselves, in terms of energy symbioses.

Eco-industrial parks (EIPs) are characterized as a set of factories located in the same geographic area, with the goal of fostering cooperation and resource sharing [5]. EIPs aim to efficiently exchange natural resources, reduce overall environmental impact, and increase economic benefits to participants [6].

This article presents a study, which combines individual and collective self-consumption in an eco-industrial park. In order to minimize energy costs and greenhouse gas emissions. The rest of this article is organized as follows. Section 2 presents the industrial symbioses involving renewable energy. Section 3 presents the problem description and section 4 introduces the mathematical model. Section 5 provides the data generation for testing the model. Section 6 includes a discussion of the results. Section 7 draws conclusions with some directions for future research.

## 2 Related work

The main objective of eco-industrial parks is to facilitate industrial symbiosis between a set of production units that can generate exchanges of waste, materials, and energy. Industrial symbiosis has been defined by Chertow et al [7] as a collective commitment including physical exchanges of materials, energy, and products between factories that have geographical proximity. In this context, Butturi et al [8] proposed a multi-objective optimization to evaluate energy symbiosis, that includes the integration of renewable energy sources within an eco-industrial park and considering both economic and environmental issues. They discuss three scenarios that provide individual company and park managers with relevant information, which support the decision-making regarding the economic sustainability and environmental impacts of energy symbiosis. Jiang et al [9] presented a genetic algorithm to solve a multi-objective optimization, that propose an exchange the electricity between four parks in absence of grid power. Their aim was to minimize a power interruption, storage system cost, and customer dissatisfaction. Heendeniya [10] proposed an agent-based model to exchange energy between prosumers, which have their own PV power generation and a battery storage. Each agent tries individually and collectively to maximize self-consumption of renewable energy.

The economic feasibility of self-consumption in eco-industrial parks and remote areas has been studied in several papers. Among these works, Contreras et al [11] present a cooperative planning framework that integrates long-term planning and short-term operation of an energy collective composed of consumers sharing a photovoltaic and storage system. Their objective was to determine the optimal size of the PV plus storage system, that reduces total costs. Long-term planning gives each consumer an idea of how much they can save, which allows them to decide to join the collective or not. Pedrero et al [12] presented an economic evaluation of shared self-consumption of PV installations between three halls with the addition of the option to sell surplus energy. They prove that the economic feasibility depends largely on the compensation for the electricity fed into the grid.

A study on the integration of renewable energy in eco-industrial parks in the literature has been treated by Butturi et al [13]. The result of this study shows that a few articles have considered the integration of renewable energy. Among the works that have been published after this research [13], we find Jiang et al [9], which discuss in their paper the exchange of renewable energy between four parks with the integration of a storage system. Butturi et al [8] treat the case of renewable energy exchange between factories. In another study, Pedredro et al [12] deal with the case of collective self-consumption with the option of selling the surplus energy between 3 factories that share a photovoltaic installation.

The result of this state of the art shows that there is a lack of articles that deal with the combination of individual and collective self-consumption within an eco-industrial park, as well as few papers have considered in the same study the storage option and the option of selling the surplus energy.

In this paper, a new strategy of energy self-consumption in eco-industrial park is introduced. It allows the merge of both individual and collective self-consumption with the integration of storage systems and the addition of the option of selling surplus energy.

## 3 Problem definition

In this section, the eco-industrial park's strategy and the classic individual self-consumption configuration are presented. The structure of the strategy of the eco-industrial park is as follows:

- Each factory has its own photovoltaic production that provides energy to satisfy the demands. Excess energy is either stored in the factory's battery or sold to the grid.
- In case the factory's self-production is not sufficient to guarantee its energy requirements, the factory relies on the shared photovoltaic production or the shared battery.
- The common photovoltaic production and the common battery provide a percentage of their energy to each factory. This percentage depends on the investment cost of each factory for the creation of the park. The surplus energy from the common production is either stored in the common battery or sold to the grid.

– The appeal to the main grid is made in case of an emergency where the factory's own production, its battery, the common production, and the common battery are not enough to guarantee the energy demands needs in the factories.

The Figure 1 represents the schema of this strategy for a case of three factories.

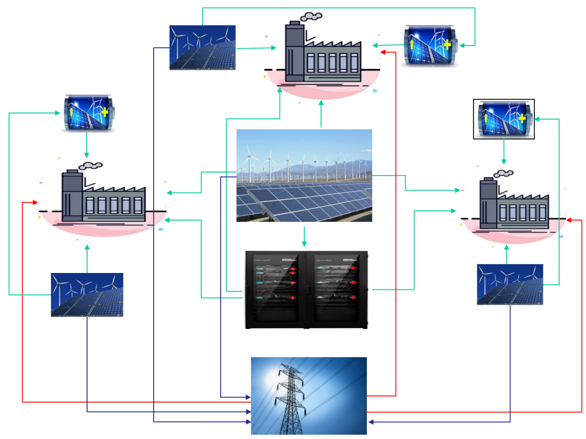

**Fig. 1.** Schema of strategy for a case of three factories.

The objective is to compare this strategy with the classical configuration (individual self-consumption) which is already studied in several articles in the literature. This configuration is very present in residential buildings that use photovoltaic panels with the integration of batteries [3]. As an example to this study, Braun et al [14] used a lithium-ion battery to increase self-consumed photovoltaic energy with the addition of the option of selling the surplus energy.

The structure of this configuration in our study is as follows :

– Each factory has its own photovoltaic production that provides energy to satisfy the demands. Excess energy is either stored in the factory's battery or sold to the grid.
– In case the factory's self-production is not sufficient to guarantee its energy requirements, the factory draws energy from the grid.

The Figure 2 represents the schema of classical individual self-consumption for a case of three factories.

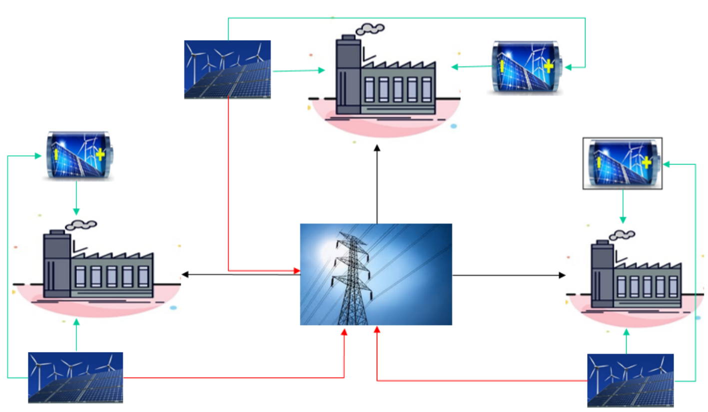

**Fig. 2.** Schema of individual self-consumption for a case of three factories.

## 4 The Mathematical Models

In this section, two mathematical models are addressed to present the strategy of the eco-industrial park and the classical configuration for self-consumption which are presented in the previous section.

### 4.1 Parameters and decision variables

Sets :

$j = \{1, \ldots, J\}$: set of factories in the eco-industrial park
$t = \{1, \ldots, H\}$ : set of the time period (in hours)
$i = \{1, \ldots, I\}$ : set of PV installation in the park

Parameters :

$D_{j,t}[KWh]$: Energy demand of factory $j$ at period $t$
$Q^p_{i,t}[KWh]$: Amount of photovoltaic energy available in the shared source $i$ at period $t$
$Q^f_{j,t}[KWh]$: Amount of photovoltaic energy available in the factory $j$ at period $t$
$P^g_t[€/KWh]$: Price of energy from the grid at period $t$
$P^s_t[€/KWh]$: Price of energy sold to the grid at period $t$
$P^f_t[€/KWh]$: Price of energy drawn from the factory's production at period $t$
$P^p_t[€/KWh]$: Price of energy drawn from the shared production at period $t$
$P^{bf}_t[€/KWh]$: Price of energy drawn from the factory's battery at period $t$
$P^{bp}_t[€/KWh]$: Price of energy drawn from the shared battery at period $t$
$SOC^{max}_j[kWh]$: Maximum state of charge of the factory's battery $j$
$SOC^{min}_j[kWh]$: Minimum state of charge of the factory's battery $j$
$SOCP^{max}[kWh]$: Maximum state of charge of the shared battery
$SOCP^{min}[kWh]$: Minimum state of charge of the shared battery
$\eta^{char}$ : Losses due to the battery's charging
$\eta^{dech}$: Losses due to the battery's discharge
$IC^f_j[€]$ : Investment costs related to the factory $j$ for its own photovoltaic energy and battery during the horizon $H$
$IC^p_j[€]$: Investment costs related to the factory $j$ for the common photovoltaic production and battery during the horizon $H$
$IC^p[€]$ : Total investment costs of the park during the horizon $H$
$Pr^f_j[\%]$ : The contribution rate of the factory $j$ to the construction of the park

Decision variables :

$E^f_{j,t}[KWh]$ : Amount of energy which is drawn by factory $j$ at period $t$ from its PV production
$E^p_{i,j,t}[KWh]$ : Amount of energy which is drawn by factory $j$ at period $t$ from the common source $i$
$E^g_{j,t}[KWh]$: Amount of energy which is drawn by factory $j$ at period $t$ from grid
$E^{dbf}_{j,t}[KWh]$: Amount of energy which is drawn by factory $j$ at period $t$ from its battery
$E^{dbp}_{j,t}[KWh]$: Amount of energy which is drawn by factory $j$ at period $t$ from the common battery
$E^{cbf}_{j,t}[KWh]$ : Amount of produced energy by the factory $j$ at period $t$ stored in its battery
$E^{cbp}_{i,t}[KWh]$ : Amount of produced energy by the common source $i$ at period $t$ stored in the common battery
$E^{sf}_{j,t}[KWh]$ : Amount of produced energy by the factory $j$ at period $t$ that is sold to the grid
$E^{sp}_{t,i}[KWh]$ : Amount of produced energy by the common source $i$ at period $t$ that is sold to the grid
$E^{sp}_t[KWh]$ : Amount of produced energy in park at period $t$ that is sold to the grid
$SOC_{jt}$: State of charge of the factory's battery $j$ at period $t$
$SOCP_t$: State of charge of the common battery $j$ at period $t$
$c^p_t$: $= 1$ if the common battery is charging at period $t$. 0 otherwise
$d^p_t$ : $= 1$ if the common battery is discharging at period $t$. 0 otherwise
$c^f_{j,t}$ : $= 1$ if the factory's battery $j$ is charging at period $t$. 0 otherwise

$d^f_{j,t}$: = 1 if the factory's battery $j$ is discharging at period $t$. 0 otherwise

In the following, the model of the individual self-consumption is presented as model 1 and the model of the individual and collective self-consumption is presented as model 2.

### 4.2 Objective function of model 1

The objective function aims to minimize the energy cost of the factories. It is calculated by subtracting the following two blocks:

- The first is the summation of the variable costs of energy which are: the costs of purchasing energy from the grid, the factories productions, and the factories batteries.
- The second is the sale of the surplus energy to the grid by the factories.

$$\min Z_1 = \sum_{j=1}^{J}\sum_{t=1}^{H}(P^g_t \times E^g_{j,t} + P^f_t \times E^f_{j,t} + P^{bf}_t \times E^{dbf}_{j,t} - P^s_t \times E^{sf}_{j,t}) \quad (1)$$

### 4.3 Constraints of model 1

Constraint (2) ensures that the total demand of each factory $j$ is satisfied by the energy sources available in factory $j$ and the grid at period $t$.

$$E^f_{j,t} + E^{dbf}_{j,t} + E^g_{j,t} = D_{j,t} \quad \forall j,t \quad (2)$$

Constraint (3) ensures that the sum of the quantities of energy drawn by each factory $j$, stored in the factory's battery $j$, and sold to the grid must be equal to the quantity of energy available in the factory's production $j$ at period $t$.

$$E^f_{j,t} + E^{cbf}_{j,t} + E^{sf}_{j,t} = Q^f_{j,t} \quad \forall j,t \quad (3)$$

The constraints (4), (5), and (6) represent the state of charge initial, final, and at period $t$ respectively for the factory's battery $j$.

$$SOC_{j,0} = SOC^{min}_j \quad (4)$$

$$SOC_{j,T} = SOC^{min}_j \quad (5)$$

$$SOC_{j,t} = SOC_{j,(t-1)} + \eta^{char} \times E^{cbf}_{j,t} - 1/\eta^{dech} \times E^{dbf}_{j,t} \quad \forall j,t \quad (6)$$

Constraint (7) ensures that the factory's battery $j$ is protected against accelerated aging.

$$SOC^{max}_j \leq SOC_{j,t} \leq SOC^{min}_j \quad \forall j,t \quad (7)$$

Additionally, the amount of charging and discharging of the factories batteries must also meet the upper and lower bound constraints. Constraints (8) and (9) refer to the maximum to be charged in the factory's battery $j$ at period t and constraints (10) and (11) represent the maximum to be discharged in the factory's battery $j$ at period $t$.

$$E^{cbf}_{j,t} \leq SOC^{max}_j \times c^f_{j,t} \quad \forall j,t \quad (8)$$

$$E^{cbf}_{j,t} \geq c^f_{j,t} \quad \forall j,t \quad (9)$$

$$E^{dbf}_{j,t} \leq SOC^{max}_j \times d^f_{j,t} \quad \forall j,t \quad (10)$$

$$E^{dbf}_{j,t} \geq d^f_{j,t} \quad \forall j,t \quad (11)$$

Constraint (12) ensures the choice between charging or discharging of the factory's battery $j$ at period $t$.

$$c^f_{j,t} + d^f_{j,t} \leq 1 \quad \forall j,t \quad (12)$$

### 4.4 Objective function of model 2

The aim of the objective function of model 2 is the same as of model 1, it minimizes the energy cost of the factories in the park. Equation (13) represents this objective function.

$$\min Z_2 = \sum_{j=1}^{J}\sum_{t=1}^{H}(P_t^g \times E_{j,t}^g + +P_t^f \times E_{j,t}^f + P_t^{bf} \times E_{j,t}^{dbf} + P_t^p \times \sum_{i=1}^{I}(E_{i,j,t}^p) + P_t^{bp} \times E_{j,t}^{dbp} - P_t^s \times (E_{j,t}^{sf} + E_t^{sp})) \tag{13}$$

### 4.5 Constraints of model 2

Constraints (3-12) of model 1 are applied to model 2. In addition, the following constraints have been exclusively applied to model 2.

Constraint (14) ensures that the total demand of each factory $j$ is satisfied by the energy sources available in the park, the factory $j$, and the grid at period $t$.

$$E_{j,t}^f + E_{j,t}^{dbf} + \sum_{i=1}^{I}(E_{i,j,t}^p) + E_{j,t}^{dbp} + E_{j,t}^g = D_{j,t} \quad \forall j,t \tag{14}$$

Constraint (15) ensures that the sum of the quantities of energy demands of all factories is satisfied by the common source $i$, the energy stored in the common battery from source $i$, and the energy sold to the grid from source $i$ must be equal to the quantity of energy available in the shared source $i$ at period $t$.

$$\sum_{j=1}^{J}(E_{i,j,t}^p) + E_{i,t}^{cbp} + E_{t,i}^{sp} = Q_{i,t}^p \quad \forall t,i \tag{15}$$

Constraint (16) represents the total energy sold to the grid by the shared production.

$$\sum_{i=1}^{I}(E_{t,i}^{sp}) = E_t^{sp} \quad \forall t \tag{16}$$

Constraint (17) represents the percentage of energy to be drawn from the common production and the common battery by each factory $j$ during the horizon $H$.

$$\sum_{t=1}^{H}(E_{j,t}^{dbp} + \sum_{i=1}^{I}(E_{i,j,t}^p)) = Pr_j^f \times \sum_{t=1}^{H}\sum_{i=1}^{I}(Q_{i,t}^p) \quad \forall j \tag{17}$$

The constraints (18), (19), and (20) represent the state of charge initial, final, and at period $t$ respectively for the shared battery.

$$SOCP_0 = SOCP^{min} \tag{18}$$

$$SOCP_T = SOCP^{min} \tag{19}$$

$$SOCP_t = SOCP_{(t-1)} + \eta^{char} \times \sum_{i=1}^{I}(E_{i,t}^{cbp}) - 1/\eta^{dech} \times \sum_{j=1}^{J}(E_{j,t}^{dbp}) \quad \forall t \tag{20}$$

Constraint (21) ensures that the shared battery is protected against accelerated aging.

$$SOCP^{max} \leq SOCP_t \leq SOCP^{min} \quad \forall t \tag{21}$$

Additionally, the amount of charging and discharging of the common battery must also meet the constraints of the upper and lower limits. Constraints (22) and (23) refer to the maximum to be charged in the common battery at period t and Constraints (24) and (25) represent the maximum to be discharged in the common battery at period t.

$$\sum_{i=1}^{I}(E_{i,t}^{cbp}) \leq SOCP^{max} \times c_t^p \quad \forall t \tag{22}$$

$$\sum_{i=1}^{I}(E_{i,t}^{cbp}) \geq c_t^p \quad \forall t \tag{23}$$

$$\sum_{j=1}^{J}(E_{j,t}^{dbp}) \leq SOCP^{max} \times d_t^p \quad \forall t \tag{24}$$

$$\sum_{j=1}^{J}(E_{j,t}^{dbp}) \geq d_t^p \quad \forall t \tag{25}$$

Constraint (26) ensures the choice between charging or discharging of the shared battery at period $t$.

$$c_t^p + d_t^p \leq 1 \quad \forall t \tag{26}$$

## 5 Data generation

This section presents how the model data was generated, such as photovoltaic installation, battery size, and investment costs.

### 5.1 Photovoltaic installation in factories

In this study, the maximum size of photovoltaic production will be installed on the roofs of factories is considered. As a hypothesis, the available surface on the roofs of these factories taken into account to install photovoltaic panels is $S^{min} \leq S \leq S^{max}$ where $S^{min} = 800m^2$ and $S^{max} = 1200m^2$ Based on [15] a 1.9 $m^2$ monocristallin solar panel can produce 365 $W$, so the maximum size of the photovoltaic installation that can be placed in a surface $S$ is $\alpha = \frac{S \times 365}{1,9}$

To calculate the amount of energy $Q_{j,t}^f$ produced with a PV installation $\alpha$, in each period t during the horizon H, the European Commission's Photovoltaic Geographic Information System (PVGIS) [16] is used. The PVGIS-SARAH radiation database is chosen, it can offer PV load profiles with a resolution of one hour between 2005 and 2016, which in turn were used to generate an average annual PV load profile for each factory roof.

To summarize, for each factory $j$ of surface $S_j$, it is possible to install a PV production size $\alpha_j$ that gives an amount of energy $Q_{j,t}^f$ at each period $t$.

### 5.2 Photovoltaic installation in the park

The size of the PV installation in the park is chosen with the following method:

- Calculating the difference between the total demand and the total energy produced by all factories in one year, which is defined by $R = \sum_{t=1}^{8760} \sum_{j=1}^{J} D_{j,t} - \sum_{t=1}^{8760} \sum_{j=1}^{J} Q_{j,t}^f$
- Using PVGIS, the determination of the size of the PV installation that produces a percentage k of R, i.e : $\sum_{t=1}^{8760} \sum_{i=1}^{I} Q_{i,t}^p = k \times R$. This size is used to calculate the amount of energy produced in the park over 4 horizons (1 month, 1 season, 2 seasons, and 4 seasons).

In this study, the cases where $k$ is 20% 40%, 60%, and 80% are compared.

### 5.3 Battery size in the factories and in the park

In a study of PV self-consumption by Luthander et al [3], they report that PV self-consumption can be increased by 13-24% by using a battery capacity of 0.5-1 kWh for each KW of PV power installed. In this case study, a 1 kWh lithium battery is installed for every 1 kW of PV power installed.

### 5.4 Investment cost of the factories

For each factory, there are two types of investment costs :

- Fixed investment costs for its own photovoltaic energy and battery during the horizon $H$.
- Fixed investment costs for the shared photovoltaic production and battery during the horizon $H$.

To calculate the investment costs in the factories and in the park, the data of Pedrero et al is used [12], represented in tables 1 and 2.

**Table 1.** PV installations reference costs

| PV Power | Reference Cost [€/$W$] |
|---|---|
| $\leq 10kW$ | 1.5 |
| $10kW - 100kW$ | 0.9 |
| $100kW - 1MW$ | 0.75 |

**Table 2.** Economic parameters for the calculation of investment costs

| Parameter | Value |
|---|---|
| PV modules service life | 25 (year) |
| Inverter service life | 15 (year) |
| Inverter cost | 0.2€/$W$ |
| Maintenance cost | 0.02€/$(W \times year)$ |

To calculate the contribution cost for each factory, table 3 is relied upon.

**Table 3.** Percentage of contribution for each factory

| | Total demand | Percentage of contribution |
|---|---|---|
| Factory $j$ | $\sum_{t=1}^{H} D_{j,t}$ | $Pr_j^f = \frac{\sum_{t=1}^{H} D_{j,t}}{\sum_{t=1}^{H} \sum_{j=1}^{J} D_{j,t}}$ |

### 5.5 Different energy costs

The variation in electricity prices over the optimisation horizon can affect the total energy cost. In this paper, time-of-use (TOU) pricing is put to use to balance electricity supply and demand. The purchase price of the electricity grid is the most expensive and the price of the energy from the factory is the cheapest. The prices are classified in this order :

$$P_t^f \leq P_t^{bf} \leq P_t^p \leq P_t^{bp} \leq P_t^g \quad \forall t$$

## 6 Numerical study

In this section, illustrative examples are considered to validate and evaluate the presented models, which are solved by CPLEX on an Intel Core i5 with 2.7 GHz and 8 GB RAM.

To compare the results between the proposed new strategy and the classical configuration of individual self-consumption, the ratio between the investment and the price paid by all factories at the end of the horizon H is calculated.

$X = \frac{IC1}{G1}$ and $Y = \frac{IC2}{G2}$ represent this ratio in the case of individual self-consumption and the strategy respectively

with :

- $IC1$ : Total investment cost of the factories during the horizon H for the case of individual self-consumption.
- $G1$ : Total cost paid by the factories during the horizon H for the case of the individual self-consumption.
- $IC2$ : Total investment cost of the factories during the horizon H for the case of the strategy.
- $G2$ : Total cost paid by the factories during the horizon H for the case of the strategy.

In the rest of this paper, four different cases of the eco-industrial park are used. The first one contains 3 factories, the second 6 factories, the third 9 factories, and the fourth 15 factories. Each case is tested over 4 horizons (1 month, 1 season, 2 seasons, and 4 seasons) which are presented in hours. The values represented in the following tables are the average value of the gap between X and Y over the 4 horizons.

The gap can be calculated by $\frac{Y-X}{X} \times 100$ . For example, the value 235.4 presented in table 4 represents this gap in the case of 3 factories and $k = 40\%$. It was calculated using the previous gap formula with $X = 0,1184$ and $Y = 0,39712$. The more this gap is greater, the considered strategy is more performed.

**Variation of the size of the photovoltaic installation in the park**

Table 4 represents the average values of the gap during the four horizons for each case of the eco-industrial park by varying the percentage $k$ of the photovoltaic installation of the park As a

**Table 4.** Variation of the size of the photovoltaic installation in the park

| | 3 factories (%) | 6 factories (%) | 9 factories (%) | 15 factories (%) | average (%) |
|---|---|---|---|---|---|
| $k = 20\%$ | 105,50 | 105,51 | 102,60 | 102,59 | 104,05 |
| $k = 40\%$ | 235,40 | 235,44 | 228,65 | 228,62 | 232,03 |
| $k = 60\%$ | 398,19 | 386,38 | 386,16 | 386,08 | 389,20 |
| $k = 80\%$ | 608,16 | 603,25 | 588,69 | 588,58 | 597,17 |
| average | 336,81 | 332,64 | 326,52 | 326,47 | |

result, it can be concluded that :

- In each instance, the use of the proposed strategy model is better than the individual self-consumption model.
- Despite the increase in the number of factories, there is a small decrease of the gap, which gives the possibility to add several factories in the same park without having the problem of decreasing the gap.
- By increasing the energy of the park by 20% the gap increases between 52,44% and 123,14%.

**Variation in the selling price of surplus energy**

Due to low feed-in tariffs [10] especially for large installations, three categories of energy selling price are considered such as : $P_t^s = 1/10 \times P_t^g$, $P_t^s = 1/5 \times P_t^g$ and $P_t^s = P_t^g$ where $P_t^s$ :Price of energy sold to the grid at period t and $P_t^g$ : Price of energy from the grid at period t.

Table 5 represents the average values of the gap during the four horizons for each case of the eco-industrial park by varying the selling price of the surplus energy.

It is concluded that :

- The proposed strategy is more efficient than the individual self-consumption in each case.

**Table 5.** Variation in the selling price of surplus energy

| | 3 factories (%) | 6 factories (%) | 9 factories (%) | 15 factories (%) | average |
|---|---|---|---|---|---|
| $P_t^s = 1/10 \times P_t^g$ | 231 | 231,04 | 224,28 | 224,25 | 227,64 |
| $P_t^s = 1/5 \times P_t^g$ | 235,40 | 235,44 | 228,65 | 228,62 | 232,02 |
| $P_t^s = P_t^g$ | 298,99 | 299,00 | 291,13 | 266,79 | 288,97 |
| average | 255,13 | 255,16 | 248,13 | 239,89 | |

- The increase in the selling price of surplus energy increases the gap between the proposed strategy and the classical configuration of individual self-consumption.

The proposed strategy gives better results than the classical configuration of individual self-consumption even in the months when there is little photovoltaic production such as January.

## 7 Conclusion

This paper develops two mathematical models, the first one represents a new strategy of self-consumption in eco-industrial parks and the second one defines the classical configuration of individual self-consumption. In both models, the option of storage and sale of surplus energy have been addressed. This study represents a step forward in the under-investigated field regarding the integration of renewable energy in eco-industrial park [13]. The two models were tested and compared, the results show that with this new strategy the factories can reduce the price of electricity compared to the classical configuration of individual self-consumption.

According to [17] the necessary condition to justify the creation of an eco-industrial park, is to prove that the benefits achieved by working with a collective strategy of factories are superior to the benefits achieved by working as a single factory. This study shows that investing collectively among the factories is more efficient than investing alone.

With this strategy, several factories can be in the same park because the results show that despite the increase in the number of factories, there is a small decrease in the gap and the results obtained by this new strategy are still more efficient.

## References


1. Nations unies, https://www.un.org/fr/, accessed on : 2021-01-12.
2. European unions, https://europa.eu/, accessed on : 2021-02-24.
3. Rasmus Luthander, Joakim Widén, Daniel Nilsson, and Jenny Palm. Photovoltaic self-consumption in buildings: A review. *Applied energy*, 142:80–94, 2015.
4. Daniele Menniti, Nicola Sorrentino, Anna Pinnarelli, Stefano Mendicino, Pasquale Vizza, and Gaetano Polizzi. A blockchain based incentive mechanism for increasing collective self-consumption in a nonsumer community. In *2020 17th International Conference on the European Energy Market (EEM)*, pages 1–6. IEEE, 2020.
5. Mathilde Le Tellier, Lamia Berrah, Benoit Stutz, Jean-François Audy, and Simon Barnabé. Towards sustainable business parks: A literature review and a systemic model. *Journal of cleaner production*, 216:129–138, 2019.
6. Zhe Liu, Michelle Adams, Raymond P Cote, Yong Geng, Jingzheng Ren, Qinghua Chen, Weili Liu, and Xuesong Zhu. Co-benefits accounting for the implementation of eco-industrial development strategies in the scale of industrial park based on emergy analysis. *Renewable and Sustainable Energy Reviews*, 81:1522–1529, 2018.
7. Marian R Chertow. Industrial symbiosis: literature and taxonomy. *Annual review of energy and the environment*, 25(1):313–337, 2000.
8. Maria Angela Butturi, Miguel A Sellitto, Francesco Lolli, Elia Balugani, and Alessandro Neri. A model for renewable energy symbiosis networks in eco-industrial parks. *IFAC-PapersOnLine*, 53(2):13137–13142, 2020.
9. Youhua Jiang, Jinwan Yang, Chunji Wang, and Yilong Cao. Electricity optimal scheduling strategy considering multiple parks shared energy in the absence of grid power supply. *International Transactions on Electrical Energy Systems*, 30(12):e12634, 2020.
10. Charitha Buddhika Heendeniya. Agent-based modeling of a rule-based community energy sharing concept. In *E3S Web of Conferences*, volume 239. EDP Sciences, 2021.
11. Jesus E Contreras-Ocaña, Arshpreet Singh, Yvon Bésanger, and Frédéric Wurtz. Integrated planning of a solar/storage collective. *IEEE Transactions on Smart Grid*, 12(1):215–226, 2020.
12. Juan Pedrero, Patxi Hernández, and Álvaro Martínez. Economic evaluation of pv installations for self-consumption in industrial parks. *Energies*, 14(3):728, 2021.
13. MA Butturi, F Lolli, MA Sellitto, E Balugani, R Gamberini, and B Rimini. Renewable energy in eco-industrial parks and urban-industrial symbiosis: A literature review and a conceptual synthesis. *Applied Energy*, 255:113825, 2019.
14. Martin Braun, Kathrin Büdenbender, Dirk Magnor, and Andreas Jossen. Photovoltaic self-consumption in germany: using lithium-ion storage to increase self-consumed photovoltaic energy. 2009.
15. Pv surface, https://fr.electrical-installation.org/, accessed on : 2021-03-01.
16. Pvgis, https://re.jrc.ec.europa.eu/, accessed on : 2021-03-15.
17. Marianne Boix, Ludovic Montastruc, Catherine Azzaro-Pantel, and Serge Domenech. Optimization methods applied to the design of eco-industrial parks: a literature review. *Journal of Cleaner Production*, 87:303–317, 2015.