Needs of Energy Storage to Supply the Urban Services in Peripheral Areas
Approach to Sustainability Cities

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ABSTRACT

The energy transition towards the change of the current energy model into a new distributed model based on renewable energies is a growing public demand in a social environment. To ensure that cities and human settlements are inclusive and sustainable, it is necessary to bring shared self-consumption into their industrial states, where normally most city's energy is consumed. Nevertheless, current laws in most countries, such as Portugal or Spain, does not exploit shared self-consumption in full potential nor do they know the methodology to apply and carry out the energy transition model in cities.

This thesis will present an optimization problem of shared energy for applying in industrial states of cities based on the study of the electricity and water consumption pattern of enterprises and the use of shared self-consumption combined with a hybrid system (PATs and PV Solar), with the aim of reducing the total bill of every energy community during the year. This optimization is not only in the energy storage systems, but is important in water distribution networks as well. These pipes consume large amounts of water resources that need to be recovered energetically, using innovative solutions as small and micro-hydropower systems (particularly pump working as micro-turbine). The final scenario and analysis showed interesting values related to environmental reductions of CO2 emissions and economic indicators. Consequently, according to the criteria developed in this research project and the results obtained from the analysed models, the first step would be to use On-Grid systems for the industrial energy communities with the highest consumption and for those that generate less, Off-Grid systems.

Keywords: energy community, hydraulic energy, hybrid system, photovoltaic, self-consumption.

1. Introduction

The world's population is constantly increasing. To accommodate everyone, we need to build modern and sustainable cities [2] (**Global Goals, 2020**). For this reason, in this report, a model or pattern will be designed for the search of potential companies and industries, capable of entering to the project of energy communities' creation and industrial states transformation, towards the energy transition.

2. Background

The research will be focused on the city of Granollers, located in the province of Barcelona, within the region of Catalonia and eastern Spain.

This city has seven industrial estates with a useful surface of 273 hectares and more than 650 business activities where approximately 4000 million of turnover is generated per year. These companies provide employment for 12,000 workers in the area, being the second city in Catalonia with the highest percentage of employment in the sector.

In this project, the impulse towards the energy transition will be evaluated for the specific cases of the two industrial areas of the city with the highest altitude; Coll de la Manya and Font del Ràdium. The main objective is to implement energy solutions through renewable energies (hydraulic and photovoltaic) in order to improve the circular economy among the companies of these industrial areas and to give a solution that permits to reduce the electrical consumption and the CO_2 emissions to the atmosphere.

Table 2.1: Location of industrial states studied.

During the research, all the meteorological information available at Servei Meteròlogic de Catalunya[1] has been collected, such as average wind speed, global horizontal irradiation and temperature. In addition, the renewable resources available in the area have been analyzed to validate the solar and hydraulic solution.

Also, the databases of the Industrial Estate Associations registered in the city have been used to obtain basic data of companies such as the NIF, location, name and contact email. The remaining information is based on databases posted on the Internet, such as SABI's[2] database on economic issues (invoicing, number of workers, expenses, etc.) and tools used by some institutions such as the IDAE[3] for energy topics.

As part of this research, a sample for electricity and water consumption was obtained from 50 companies located in the Coll de la Manya and Font del Ràdium industrial estates in the city of Granollers. In this way, relevant information such as the annual electricity consumption has been requested through a form sent to companies and checked through a data download kit for electricity meters.

3. Understanding water and electricity consumption

In order to create a pattern for assessing companies on industrial estates, it is necessary to deal with the variables for which information has been collected from 50 enterprises. These are the surface area of the industrial building, the company's turnover, the number of workers, the hours worked during a year by all workers, the annual water consumption, the annual thermal consumption, the money spent on salaries annually and the following ratios:

$$R1 = \frac{number\ of\ workers}{water\ consumption}$$

$$R2 = \frac{number\ of\ workers}{water\ bill}$$

[1] Meteorological institute of the Catalonia's region, Spain. Provides information about weather and meteorological phenomena.
[2] "Iberian Balance Sheet Analysis Systems" - a tool that contains information on the balance sheets presented by more than 1.2 million Spanish companies and 400,000 Portuguese companies
[3] Institute for Energy Savings and Promotion.

Firstly, it is necessary to carry out a correlation study of these variables to rule out those that are considered statistically equal.

	M_2	turn	n_work	hor_work	Cons_H2O	Cons_Term
turn	0,561					
n_work	0,573	0,782				
hor_work	0,573	0,782	1,000			
Cons_H2O	0,615	0,568	0,575	0,575		
Cons_Term	0,246	0,177	0,185	0,185	-0,057	
Salaries	0,525	0,814	0,865	0,865	0,633	0,133

Table 3.1: Analysis of the variables' correlations.

Subsequently, with the resulting variables, a PCA (Principal Component Analysis) analysis was performed using Minitab software to reduce the number of variables to make the data easier to analyze.

Finally, to start working on the energy transition of an industrial state, it is necessary to understand which factors, treated in the previous step, can influence the consumption of company resources and which data are relevant for each study case. In this section, a statistical study of the variables has been carried out based on a first proposal based on the study of this topic by several authors. In which, it is concluded that the variables total area of the establishments [1] (**Dwiegielewski, 2000**), the turnover of the company [4] (**Worthington, 2010**), the average number of hours worked per day per worker and the number of workers [3] (**Hobby, 2011**), are the biggest factors in the water and electricity consumption.

The models analysed and proposed for each demand (water and electricity) by industrial building and entire year:

$$\mathrm{Log}(\mathrm{Cons}_{El}) = -0{,}042+1{,}1834\cdot\mathrm{Log}(M_2)-0{,}06\cdot\mathrm{Log}(\mathrm{turn})+0{,}000282\cdot n_{work}-0{,}0056\cdot\mathrm{Cons}_{Term} \quad (3.1)$$

$$\mathrm{Log}(\mathrm{Cons}_{H2O}) = 0{,}857+0{,}489\cdot\mathrm{Log}(M_2)+0{,}167\cdot\mathrm{Log}(\mathrm{turn})+0{,}174\cdot\mathrm{Log}(n_{work})-0{,}112\cdot\mathrm{Cons}_{Term} \quad (3.2)$$

4. Shared Projects

To create an energy community, a thorough study of the standards and laws that make up the technical guides of the country where the installation will be located is required. For this reason, the steps to be taken to do so have been broadly defined in accordance with the professional guide for self-consumption [8].

In this section, a statistical study is carried out to determine in which points or areas of the industrial estates it is more feasible to act and more likely to create energy communities. To do this, it is necessary to determine the number of potential customers who generate energy (Generating Leads), the consumers interested in improving their energy system and finally to determine the optimal groups to apply the possible improvements.

The main potential customers will be chosen to be the generators of renewable energy and sell it to nearby companies, to form energy communities. They will also be the main actors who will help promote the solution with their neighbours and potential energy sharing partners.

Consumer leads are considered those who will obtain most of their energy from the Generating Leads, although they may also generate some energy for distribution or self-consumption. Their aim is to reduce the costs of the electricity bill based mainly on a need to reduce costs.

To define the groups of companies studied, a clustering has been applied focused on the number of observations in the sample and taking into account restrictions defined with the variables of minimum supply pressure (p_{k_T}) and cost electricity per capita (P_{k_n}).

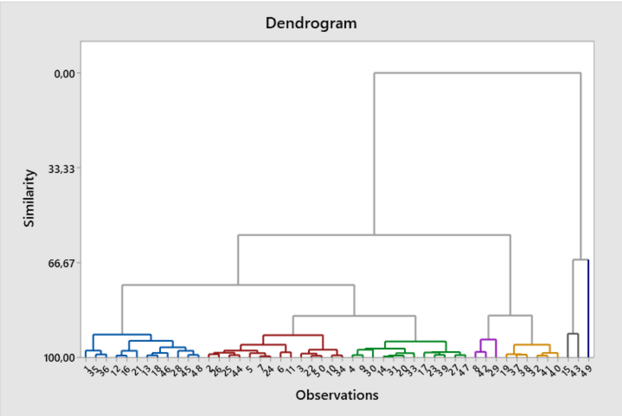

Figure 4.1: Dendogram study with the clustered observations.

In each group or conglomerate, one generating lead and several consumers leads will be chosen according to several indexes and restrictions based on distance between companies, electricity and water bills, company turnover, number of workers, expenses in salaries, annual electricity consumption and solar capacity of the company.

5. Optimization Problem

To apply what has been studied previously to the field, an optimization problem has been developed with software Matlab to evaluate energetically and economically every case of an energy community in industrial areas.

The purpose of the function to solve the optimization problem is to minimize the costs of the electricity bill for all consumers separately in the energy community. It is defined as Eq. 5.1 by system surpluses and consumer costs:

$$\min \sum_{t=1}^{T} \left(C_D(t) \cdot \sum_{k=1}^{K} d(k,t) - C_E(t) \cdot e(t)\right) \quad (5.1)$$

In addition, these equations and restrictions are present in the problem:

$$G(t) = g_{PV,b}(t) + g_{TB,b}(t) + g_{PV,e}(t) + g_{TB,e}(t) + \sum_{k=1}^{K} g_{PV,k}(k,t) + \sum_{k=1}^{K} g_{TB,k}(k,t) \quad (5.2)$$

$$d(k,t) = D(k,t) - g_{PV,k}(k,t) - g_{TB,k}(k,t) - \eta \cdot b_k(k,t) \quad (5.3)$$

$$b(t) = b(t-1) + \eta \cdot g_{PV,b}(t) + \eta \cdot g_{TB,b}(t) - \sum_{k=1}^{K} b_k(k,t) - b_e(t) \quad (5.4)$$

$$e(t) = g_{PV,e}(t) + g_{TB,e}(t) + \eta \cdot b_e(t) \quad (5.5)$$

$$\mu \cdot B < b(t) < B \quad (5.6)$$

Due to the complexity of the problem, useful approach could be that the initial battery charge, $b(0)$ is negligible.

Parameters	Description
k	Consumer index
t	Time index [h]

Table 5.1: Parameters of Equations. (5.1) – (5.6)

Inputs	Description
K	Number of consumers.
T	Number of hours.
$D(k, t)$	Consumption of consumer k at hour t.
$G(t)$	Total generation at hour t.
$C_D(t)$, $C_E(t)$	Cost of electricity demand and surplus at hour t.
B	Battery capacity.
η, μ	Battery efficiency and depth of discharge.

Table 5.2: Constants of equations (5.1) – (5.6)

Consequences	Description
$b(t)$	Battery charge at hour t.
$d(k, t)$	Demand of consumer k at hour t.
$e(t)$	Global system surplus at hour t.

Table 5.3: Results of Equations. (5.1) – (5.6)

Variables	Description
$b_e(t)$	Electricity from battery to surplus at hour t.
$b_k(k, t)$	Electricity from battery to consumer k at hour t.
$g_{PV,b}(t)$, $g_{TB,b}(t)$	PV and Turbine generation to battery at hour t.
$g_{PV,e}(t)$, $g_{TB,e}(t)$	PV and Turbine generation to surplus at hour t.
$g_{PV,k}(k, t)$, $g_{TB,k}(k, t)$	PV and Turbine generation to consumer k at hour t.

Table 5.4: Variables of Equations. (5.1) – (5.6)

6. Analyzed Particular Case

The previous optimization problem are analysed in a particular case consisting on four industrial factories or warehouses (demands), a micro turbine, a photovoltaic panel and a battery. To simplify the problem, the set of buildings is considered an energy community and later, it will be extrapolated to the other cases of the industrial estates.

This study is located in Granollers (Spain) and specifically in two industrial states of this city. Solar data for this city (Lat. 41.60º, Lon. 2.27º), for the years 2018 and 2019 has been taken from Meteorological Service of Catalonia. To evaluate the solar capacity of the selected companies, a photovoltaic solar viewer is available, provided by the Granollers City Council (**ICGC Sostenibilitat**[4]). It allows evaluating the roofs of the companies by using information such as inclination, orientation and thermal map of the irradiation in the area. The maximum yearly power of the photovoltaic panel is **0.25 kWp**.

Electricity price data has been taken from operating company in this place. The industrial factories' demand is extracted of equations defined in the section Consumption Definition and them variables for each consumer, from various databases such as SABI or Spanish property registration. The average yearly consumption about the study of 50 enterprises in these industrial states is **85527 kWh** and then, the range of 274780 kWh to 412170 kWh is considered good for any energy community with 4 consumers (K). The hours worked during the year by every company are between 2178 and 2222, considered like hours in its average consumption.

The hydraulic model to implement consists a solution with microturbines in the main water pipe of consumer companies of each energy community, taking advantage of the energy obtained from the pumping head from the main tank to the turbine. The generation of the micro turbine is calculated with software WaterGems, where it is used the hydraulic map and altitude of the zone. To simplify the scheme slightly, an equal hourly demand pattern has been inserted for all companies where the hours with maximum consumption are between 9 am and 7 pm.

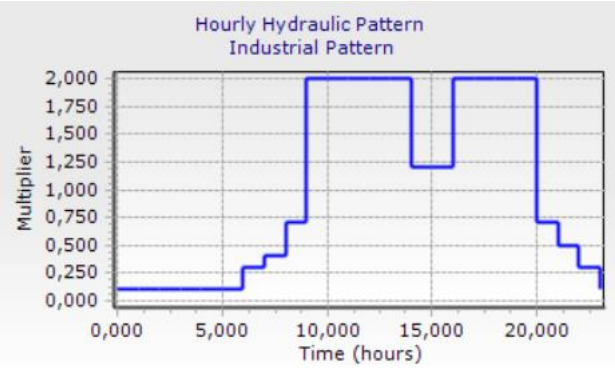

Figure 6.1: Hourly demand pattern for water consumption of industrial building.

For a hydraulic flow of 3.03 L/s and a pressure drop of 6 mWc (difference between point pressure and minimum pressure) in the C-99 pipe, a **0.178 kW** turbine is chosen for the grid-connected model and stand-alone system. The pressure drop is given by the difference between the pressure drop from the tank to the pipeline (31 mWc) and the minimum required consumption pressure (25 mWc).

To choose the size of the battery, it is necessary to evaluate a set of basic parameters such as the nominal capacity according to the maximum daily discharge (C_d) and the nominal capacity according to the seasonal discharge (C_e). Finally, the battery's depth of discharge is considered µ=0.80 and its efficiency ratio η=0.94. The particular case of on-grid system is illustrated in Figure 6.2, and the off-grid, could be the same figure without Electric Grid and surpluses (green lines).

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[4] https://visors.icgc.cat/sostenibilitat/#/visor

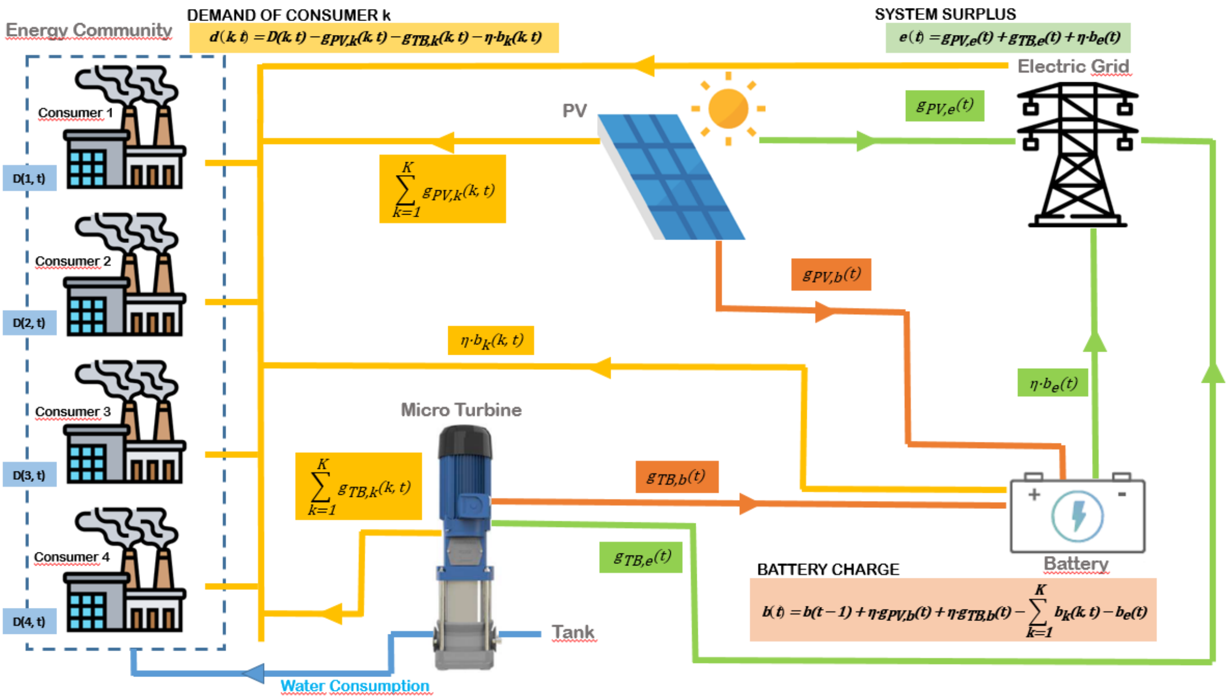

Figure 6.2: Optimization model illustrated in particular case of four companies sharing energy.

To simplify the model, all cases and results are evaluated in one period (year).

7. Results

The results obtained could be analyzed separately by two energy policies:

(i) Demand-dependent exchange: related to the optimization of the demand for electricity and therefore the total saving of the system is shared equally among all consumers k.

(ii) Proportional distribution of the energy: all consumers receive the same amount of energy per hour and energy savings are distributed proportionally and separately.

In the results are used the energy policy of Demand-dependent exchange and this one is compared with No-Sharing and no Self-consumption. In addition, different price options could be assessed for the sale of surplus energy, always including the next restriction $C_E < C_D$. Moreover, the self-consumption's retribution must be also examined. Three schemes are proposed here: net metering, in which the electricity surplus is priced at the retail electricity price ($C_E = C_D$); net billing, in which the electricity surplus is priced at the retail electricity price and exclusive self-consumption, in which electricity surplus has no value (C_E=0). In Spanish legality, is not possible that net metering work in any energy system, so it will not be analysed. Nevertheless, five well-differentiated cases will be examined in order to obtain optimal conclusions:

1- Sharing & Connected to grid: In this case, we will have the model of energy community by which the companies will be able to share energy among themselves and all of them will be connected to the electric grid for the sale of the surplus energy. The benefits of the surplus energy will be distributed according to the policies considered by the community and the legislation.

2- Sharing & Self-consumption: This case is the same as the previous one but it will not have the connection to the electricity grid, so it will not be profitable if it generates extra energy. It will have a regulator that will stop the production of renewable energy at the peaks of less demand.

3- No sharing & Connected to grid: This energy methodology is based on the sale of surpluses to the electricity company on an individual basis, i.e. each company will have the profits separately.

4- No sharing & Self-consumption: In this case, each company will have an autonomous system adapted and disconnected from the electricity network, where the cost of electricity will be zero.

5- No sharing & no Self-consumption: In this case, the companies will be connected to the electricity grid as in the traditional system and without the sale of surpluses.

To evaluate every case studied is important to do this double analysis, economic and environmental.

In the case of **environmental analysis**, as indicated in Real Decreto 616/2017[5], of 16th June, which sets out the direct granting of subsidies to unique projects of local entities that promote the transition to a low-carbon economy, a bonus is set for the reduction of CO_2 emissions of approximately 0.19 euros per tonne.

Therefore, for the self-consumption options, the benefit for the reduction of emissions will be directly the consumption of the companies by the amount of the module type of the previous section, i. e:

$$g_{CO2} = \sum_{k=1}^{K} D \cdot 0{,}428 \frac{kg}{kWh} \cdot \frac{1\,Tm}{1000\,kg} \cdot \frac{0{,}19€}{1\,Tm} \tag{7.1}$$

For grid-connected options, the benefit will be according to the difference in energy generated with renewable energies:

$$g_{CO2} = \left[\sum_{k=1}^{K} D - \sum_{k=1}^{K} d(k,t)\right] \cdot 0{,}428 \frac{kg}{kWh} \cdot \frac{1\,Tm}{1000\,kg} \cdot \frac{0{,}19€}{1\,Tm} \tag{7.2}$$

[5] Real Decreto 616/2017: Decree published by the organ of the Ministry of Industry, Energy and Digital Agenda of Spain.

In the **economic analysis**, it is included turbine costs, photovoltaic installation costs and battery costs.

The cost of the turbine can be calculated approximately according to the following equation obtained from the source [5] (**D. Novara, 2019**), and depends exclusively on the power used:

$$c_{TB} = P[kW] \cdot 826{,}42 \cdot P[kW]^{-0{,}292} \tag{7.3}$$

Using this equation, you can approximate the total cost of installing the turbine, including the generator.

According to a market study of PV installations, it was decided to estimate the price of the installations according to euros per installed watt peak using the following criteria:

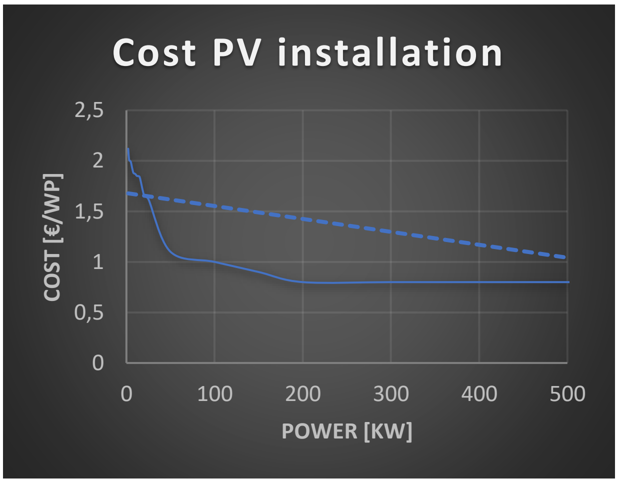

Figure 7.1: Costs of PV installation by Power

a) Installations of **12,5 kW** → 1,85€/Wp
b) Installations of **25 kW** → 1,62 €/Wp
c) Installations of **50 kW** → 1,1 €/Wp
d) Installations of **100 kW** → 1 €/Wp
e) Installations of more than **200 kW** → 0,8 €/Wp

Each case explained has been economically analysed with a mathematical optimization software and from the defined optimization system. From this, variables such as the first year's profit, the initial investment, the payback and the rate of return on investment (IRR) have been evaluated.

The benefits of the installation (g_{ins}) are calculated from two main factors, depending on the function to be optimized. These are the sale of surplus energy to the electric company ($c1$) and the net benefit of the energy generated from renewables that will no longer be paid to the supplier ($c2$).

$$c1 = \sum_{t=1}^{T} (C_E(t) \cdot e(t)) \quad (7.4)$$

$$c2 = [\sum_{k=1}^{K} D - \sum_{k=1}^{K} d(k, t)] \cdot C_D \quad (7.5)$$

In these factors the environmental benefit or subsidy for the reduction of CO_2 emissions, evaluated in the previous section, will be added (g_{CO2}). This profit will increase approximately 1% per year due to the increase in the cost of electricity (C_D) and will form the cash flow.

$$g_{ins} = c1 + c2 + g_{CO2} \quad (7.6)$$

The initial investment or total costs (c_{ins}) will be the costs of the photovoltaic installation (C_{PV}) added to the costs of the installation of the turbine (C_{TB}) and the battery costs (C_{Bat}).

With these comparisons, it is expected to obtain a criterion on the net energy price of the energy community where it should not vary in any model and an acceptance of the use of batteries clearly providing economic advantages to consumers. Finally, it is necessary to demonstrate that the use of a hybrid system with micro-turbine in the general pipe, adds value to the solution.

8. Conclusions

The main estimated conclusions of this project are based on promoting changes in the peripheral areas of industrial cities by proving that the energy system can be improved by means of hybrid models and energy sharing between the companies that are the main consumers. They can be summarized as follows:

(i) Need to establish the creation of the energy management role in local administrations to promote the energy transition in industrial areas. In this project, it has been shown that obtaining information on consumption by companies has been a difficult milestone to achieve, due to the lack of time they spend on external factors such as improvements in their energy systems.

(ii) The statistical study carried out will facilitate an extrapolation of the results to new peripheral areas of similar cities and will also serve as a guide to follow for the study of the creation of energy communities. At present, the technical and legal resources provided by the administration are ambiguous and not sufficiently accurate to carry out this important energy transformation that must be applied in the real world.

(iii) Confirmation of the option of self-consumption is the best solution at an environmental scale in the long-term, although in the case of industrial areas or peripheral zones with large consumers, at a technical scale it could be a complex step in energy transformation.

(iv) Identifying that the use of micro turbines always improves the investment return because their installation cost is significant compared to the energy generated [5]. It is a good model to implement, because it takes advantage of an energy that is implicit in any industrial area and uses the resources of others to contribute to all (Circular Economy).

(v) According to the criterion developed in this project, it is important to move towards energy transition step by step and not to want to take huge steps to obtain milestones quickly and without coherence. Thus, we should start by connecting those energy communities with large consumption, such as industrial companies, to the electricity network. Saving the cost of batteries will allow companies to have a sufficiently consistent payback period to initiate changes towards energy transition. The total disconnection would be a good incentive for communities of neighbours or administrative buildings of daily use that consume much less energy than the industry sector.

(vi) Enhancing energy Sharing, renewable energies are also promoted together with the implicit market and, in fact, it helps in the contribution towards a more sustainable world with the help of the reduction of CO_2 emissions in the current processes of electricity generation.

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