A Sensitivity Analysis of PSO Parameters Solving the P2P Electricity Market Problem

Miguel Vieira
School of Engineering (ISEP)
Polytechnic of Porto (IPP)
Porto, Portugal
1170866@isep.ipp.pt

Ricardo Faia, Fernando Lezama, Zita Vale
GECAD
Polytechnic of Porto (ISEP/IPP)
Porto, Portugal
{rfmfa, flz, zav}@isep.ipp.pt

Abstract— Energy community markets have emerged to promote prosumers' active participation and empowerment in the electrical power system. These initiatives allow prosumers to transact electricity locally without an intermediary such as an aggregator. However, it is necessary to implement optimization methods that determine the best transactions within the energy community, obtaining the best solution under these models. Particle Swarm Optimization (PSO) fits this type of problem well because it allows reaching results in short optimization times. Furthermore, applying this metaheuristic to the problem is easy compared to other available optimization tools. In this work, we provide a sensitivity analysis of the impact of different parameters of PSO in solving an energy community market problem. As a result, the combination of parameters that lead to the best results is obtained, demonstrating the effectiveness of PSO solving different case studies.

***Index Terms*— Local electricity markets, Particle Swarm Optimization, Peer-to-Peer transactions, Sensitivity analysis, Swarm intelligence.**

I. INTRODUCTION

Local electricity markets (LEM) have appeared as a solution to promote the interactions between the end-users (consumers, prosumers, and small producers) at the local level of the energy chain [1]. Different structures for negotiation and organization have been proposed in the literature [2], although those are essentially targeting two types: the community market and the P2P market. Consumers benefit from P2P electricity trading since it allows them to engage in direct trading as buyers and sellers [3]. Typically, these approaches are characterized by resource sharing among its peers to accomplish certain goals. Examples of such objectives include the maximization of energy usage, electricity cost reduction, peak load shaving, network operation, and investment cost minimization [4]. Each member can be a producer, a consumer, or both (the so called prosumer) and can directly communicate with the rest of the network's peers without any intervention of a third-party controller [5].

Due to the complexity of the problem, metaheuristic optimization became an alternative tool to find feasible solutions to the problem [6]. Some studies had proposed the use of metaheuristics for solving P2P scheduling in LEM. For instance, [7] proposes the use of evolutionary computation for obtaining optimal bidding in a local market by using the differential evolution algorithm and its variants.

In this work, we propose the use of particle swarm optimization (PSO), one of the most effective swarm intelligence algorithms proposed to date [8]. This metaheuristic has been used for other power system optimization problems since it shows a good performance when compared with other solving methods for economic dispatch (ED) problems [9]. The PSO algorithm was proposed by Kennedy and Eberhart, in 1995, and it was inspired by the study of group behaviors such as predation of birds [10]. The velocity function of PSO is characterized by three different parameters, which influence the next position of each particle. The first is the inertia term. This decides the importance given to the previous velocity. The second is the local coefficient. In this case, it is a weight applied to the best solution of the particle, the third is the global coefficient that is applied to the best global position [11].

According to [12], the control parameters of the original PSO have an impact on the overall search capabilities of the algorithm. As also stated in [12], PSO suffers from a condition, known as premature convergence, which causes it to fail in obtaining the global minimum and thus converge to a local solution. This issue has been previously studied, for instance in [12], where different mechanisms and methods are introduced to alleviate this effect. In fact, sensitivity analysis methods allow the study of relationships between the uncertainty in the output and output of a model [13]. Other studies regarding the tunning of PSO parameters have been proposed, like the one in [14], where the parameters of the PSO algorithm had been investigated through the use of the design of experiments (DOE) techniques. The DOE techniques can be applied to optimization algorithms, considering the run of an algorithm as an experiment, gaining insightful conclusions into the behavior of the algorithm and the interaction and significance of its parameters.

In this work, the PSO algorithm is used to optimize the P2P electricity market problem. We provide a sensitivity analysis in the PSO parameters, showing how the selection of these parameters contribute to the algorithm performance. The sensitive analyses are performed to obtain the best combination between the number of iterations, number of particles, inertia

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term, local coefficient, and global coefficient. The sensitivity analysis is made by changing the value of a single parameter and seeing the effect produced in the output.

The rest of the paper is organized as follows: the PSO main equations are explained in Section II. An overall model of a P2P market has been described the Section III. The case study and sensitive analysis simulation is explained in Section IV. The main results for each parameter analyzed are described in Section V. Section VI presents the conclusion of the study.

II. Particle Swarm Optimization

Equation (1) represents the velocity function of the PSO algorithm, and equation (2) is the position update function.

$$v_{k+1}^{j} = w_k v_k^{j} + c_k^{j} \times r^1 \times P_{best}^{j} + c_k^2 \times r^2 \times P_{global} \quad (1)$$

$$x_{k+1}^{j} = x_k^{j} + v_{k+1}^{j} \quad (2)$$

where, v_{k+1}^{j} corresponds to the velocity, w_k is the inertia term, c_k^{j} is the personal coefficient term, r^1 is a random term for the personal component, P_{best}^{j} is the personal best position, c_k^2 is the global coefficient term, r^2 is a random term for the global component, P_{global} is the best global position of the swarm and x_{k+1}^{j} corresponds to the particle position. Equation (3) presents the inertia term function updating.

$$w_k = w^{max} - \frac{w^{max} - w^{min}}{N_k} \times k \quad (3)$$

where, w^{max} is the maximum value for the inertia terms, w^{min} is the minimum value for the inertia term, k is the current iteration, and N_k is the total number of iterations. Equation (4) presents the personal coefficient updating function.

$$c_k^1 = c^{1,max} - \frac{c^{1,max} - c^{1,min}}{N_k} \times k \quad (4)$$

where, $c^{1,max}$ corresponds to the maximum value for the personal coefficient and $c^{1,min}$ presents the minimum value for the personal coefficient. Equation (5) presents the global coefficient updating function.

$$c_k^2 = c^{2,min} + \frac{c^{2,max} - c^{2,min}}{N_k} \times k \quad (5)$$

where, $c^{2,min}$ corresponds to the minimum value for the global coefficient and $c^{2,max}$ corresponds to the maximum value for the global coefficient.

Equations to obtain the inertia, personal, and global coefficient values are considered linear according to the iteration number. For equations (3) and (4), the equations are linear decreasing, and equation (5) is linear increasing.

III. Methodology

As mentioned before, a sensitive analysis to select the best combinations of parameters is considered in this paper. The parameters in the study are: the total number of iterations N_k, the total number of particles N_j, values for w^{max} and w^{min}, values for $c^{1,max}$ and $c^{1,min}$, and values for $c^{2,max}$ and $c^{2,min}$.

A. P2P Electricity Market Problem

The P2P electricity market problem consists of determining the best P2P combination to transact electricity. Equation (6) presents the fitness function and guides the PSO search.

$$fit(x) = fob + \sum_{i=1}^{N_i}\sum_{t=1}^{N_t} Balance_{i,j}^{1} + \sum_{t=1}^{N_t} Balance_t^{2} \quad (6)$$

where, $fit(x)$ corresponds to the value of fitness function, fob represents the objective function value, $Balance_{i,j}^{1}$ is the energy balance of each agent, $Balance_t^{2}$ corresponds to the P2P market balance, N_i is the number of agents and N_t is the number of periods.

The fitness function contains three different terms, the objective value obtained by equation (7) the energy balance equation (8) and the P2P balance obtained by equation (9). Both balances values are added to the fitness in order to guide the PSO search for the solution with minimal balances that originates valid solutions.

$$fob = \sum_{i=1}^{N_i}\sum_{t=1}^{N_t}\left(P_{i,t}^{bg} \times c_{i,t}^{bg} - P_{i,t}^{sg} \times c_{i,t}^{bg}\right) \quad (7)$$

where, $P_{i,t}^{bg}$ corresponds to the electricity bought from the grid, $c_{i,t}^{bg}$ is the price of buy electricity from the grid, $P_{i,t}^{sg}$ is the electricity sold to the grid and $c_{i,t}^{bg}$ is the price of sold electricity to the grid. Equation (8) represents each agent's energy balance for each period.

$$Balance_{i,j}^{1} = \left|\left(P_{i,t}^{bg} + P_{i,t}^{gen} + \sum_{l=1}^{N_l} P_{l,i,t}^{bP2P}\right) - \left(P_{i,t}^{sg} + P_{i,t}^{load} - \sum_{l=1}^{N_l} P_{l,i,t}^{sP2P}\right)\right| \quad \forall i \in N_i, \forall t \in N_t \quad (8)$$

where, $P_{i,t}^{gen}$ corresponds to the electricity generated, $P_{l,i,t}^{bP2P}$ correspond to the electricity buy of player l from player i, $P_{i,t}^{load}$ corresponds to the load and $P_{l,i,t}^{sP2P}$ represents the electricity sold of player l to player i. Equation (9) represents the P2P electricity balance.

$$Balance_t^{2} = \left|\left(\sum_{i=1}^{N_i}\sum_{l=1}^{N_l} P_{l,i,t}^{bP2P}\right) - \left(\sum_{i=1}^{N_i}\sum_{l=1}^{N_l} P_{l,i,t}^{sP2P}\right)\right|, \forall t \in N_t \quad (9)$$

This balance is executed for all periods and ensures that the value of total electricity bought in the P2P market equals the electricity sold in the P2P market. Therefore, equations (10) - (12) limit the buy and sell quantity in the P2P market.

$$0 \le P_{l,i,t}^{bP2P} \le \bar{P}_{l,i,t}^{bP2P} \times X_{l,i,t}^{bP2P}, \forall l \in N_l, \forall i \in N_i, \forall t \in N_t \quad (10)$$

$$0 \le P_{l,i,t}^{sP2P} \le \bar{P}_{l,i,t}^{sP2P} \times X_{l,i,t}^{sP2P}, \forall l \in N_l, \forall i \in N_i, \forall t \in N_t \quad (11)$$

$$X_{l,i,t}^{bP2P} + X_{l,i,t}^{sP2P} \le 1, \forall l \in N_l, \forall i \in N_i, \forall t \in N_t \quad (12)$$

where, $\bar{P}_{l,i,t}^{bP2P}$ is the maximum limit for buy electricity in P2P mode, $X_{l,i,t}^{bP2P}$ is a binary variable associated to the to buy action in P2P market, $\bar{P}_{l,i,t}^{sP2P}$ is the maximum limit to sell electricity in P2P mode and $X_{l,i,t}^{sP2P}$ is a binary variable associated to the sell action in the P2P market. Equation (12) limits the buy and sell simultaneously in the P2P mode. Equation (13) - (15) limits the quantity of buy and sell with the grid transactions.

$$0 \leq P_{i,t}^{bg} \leq \bar{P}_{i,t}^{bg} \times X_{i,t}^{bg}, \forall i \in N_i, \forall t \in N_t \tag{13}$$

$$0 \leq P_{i,t}^{sg} \leq \bar{P}_{i,t}^{sg} \times X_{i,t}^{sg}, \forall i \in N_i, \forall t \in N_t \tag{14}$$

$$X_{i,t}^{bg} + X_{i,t}^{sg} \leq 1, \forall i \in N_i, \forall t \in N_t \tag{15}$$

where, $\bar{P}_{i,t}^{bg}$ represents the maximum limit for buy electricity from the grid, $X_{i,t}^{bg}$ is a binary variable associated with buy electricity action from the grid, $\bar{P}_{i,t}^{sg}$ represent the maximum limit for sell electricity to the grid, and $X_{i,t}^{sg}$ is a binary variable associated to the sell electricity action to the grid. Equations (16) and (17) limit the simultaneous action of buy in the grid and sell in P2P mode and sell in the grid and buy in P2P mode.

$$X_{i,t}^{bg} + \sum_{l=1}^{N_l} X_{l,i,t}^{sP2P} \leq 1, \forall i \in N_i, \forall t \in N_t \tag{16}$$

$$X_{i,t}^{sg} + \sum_{l=1}^{N_l} X_{l,i,t}^{bP2P} \leq 1, \forall i \in N_i, \forall t \in N_t \tag{17}$$

B. *Encoding Process*

In this study, to solve the P2P electricity market problem, the PSO will search for the best combinations of transactions between peers. The algorithm will select only transactions between two different peers. The combination theory equation (18) is applied to define the number of possible transactions(18).

$$C_{N_i,2} = \frac{n!}{N_i!\,(n - N_i)!} \tag{18}$$

Regarding the dimension of the problem, for instance, in this study is used 9 agents; then, according to equation (18) for $N_i = 9$, the number of combinations is 36. In this way, in each period, the number of variables is 36 (equal to the number of combinations). For the number of periods equal to N_t the total number of variables is $36 \times N_t$. The solution vector contains only binary variables that are active or not depending on the possible transaction.

$$x = [X_{1,1}^{P2P}, X_{1,2}^{P2P}, X_{1,3}^{P2P}, \dots, X_{N_t,N_c}^{P2P}] \tag{19}$$

where, $X_{t,c}^{P2P}$ represents the binary variable for the transaction combination c of period t, for $X_{t,c}^{P2P} = 1$ the transaction is active and $X_{t,c}^{P2P} = 0$ the transaction is inactive.

Figure *1* presents the encoding process for 1st period with 9 agents. As can see the combination between the same peers (e.g., (1,1)) and repeated combination (e.g., (1,2) and (2,1)) are automatically excluded from the search.

		$c(2)$								
	$t = 1$	1	2	3	4	5	6	7	8	9
$c(1)$	1		$X_{1,1}^{P2P}$	$X_{1,2}^{P2P}$	$X_{1,3}^{P2P}$	$X_{1,4}^{P2P}$	$X_{1,5}^{P2P}$	$X_{1,6}^{P2P}$	$X_{1,7}^{P2P}$	$X_{1,8}^{P2P}$
	2			$X_{1,9}^{P2P}$	$X_{1,10}^{P2P}$	$X_{1,11}^{P2P}$	$X_{1,12}^{P2P}$	$X_{1,13}^{P2P}$	$X_{1,14}^{P2P}$	$X_{1,15}^{P2P}$
	3				$X_{1,16}^{P2P}$	$X_{1,17}^{P2P}$	$X_{1,18}^{P2P}$	$X_{1,19}^{P2P}$	$X_{1,20}^{P2P}$	$X_{1,21}^{P2P}$
	4					$X_{1,22}^{P2P}$	$X_{1,23}^{P2P}$	$X_{1,24}^{P2P}$	$X_{1,25}^{P2P}$	$X_{1,26}^{P2P}$
	5						$X_{1,27}^{P2P}$	$X_{1,28}^{P2P}$	$X_{1,29}^{P2P}$	$X_{1,30}^{P2P}$
	6							$X_{1,31}^{P2P}$	$X_{1,32}^{P2P}$	$X_{1,33}^{P2P}$
	7								$X_{1,34}^{P2P}$	$X_{1,35}^{P2P}$
	8									$X_{1,36}^{P2P}$
	9									

Figure 1 – Encoding Process for 1st period and 9 agents

The process should be repeated for all other periods. After each iteration, the solution of PSO should be repaired to avoid constrains violations. Equation (20) is used to obtain the value for import $P_{i=c(1),t} > 0$ or export $P_{i=c(1),t} < 0$ electricity in each agent, equation (21) is applied if $X_{t,c}^{P2P} = 1$, the value of $X_{t,c}^{P2P}$ is repaired according to the value of $P_{i=c(1),t}$ and $P_{i=c(2),t}$.

$$\begin{aligned} P_{i=c(1),t} &= P_{i=c(1),t}^{load} - P_{i=c(1),t}^{gen} \\ P_{i=c(2),t} &= P_{i=c(2),t}^{load} - P_{i=c(2),t}^{gen} \end{aligned} \tag{20}$$

$$X_{t,c}^{P2P} = \begin{cases} 0 \quad if & \begin{cases} (P_{i=c(1),t} < 0 \;\cap\; P_{i=c(2),t} < 0) \\ \cup \\ (P_{i=c(1),t} > 0 \;\cap\; P_{i=c(2),t} > 0) \end{cases} \\ 1 \quad if & \begin{cases} (P_{i=c(1),t} < 0 \;\cap\; P_{i=c(2),t} > 0) \\ \cup \\ (P_{i=c(1),t} > 0 \;\cap\; P_{i=c(2),t} < 0) \end{cases} \end{cases} \tag{21}$$

After applying equation (21) and the value of $X_{t,c}^{P2P}$ still 1 the value of $P_{l,i,t}^{bP2P}$, $P_{l,i,t}^{sP2P}$, $P_{i,t}^{bg}$ and $P_{i,t}^{sg}$ can be obtained.

$$\begin{pmatrix} X_{t,c}^{P2P} = 1 \\ \cap \\ P_{i=c(1),t} > P_{i=c(2),t} \\ \cap \\ |P_{i=c(1),t}| > |P_{i=c(2),t}| \end{pmatrix} \rightarrow \begin{cases} P_{l=c(1),i=c(2),t}^{bP2P} = |P_{i=c(2),t}| \\ P_{l=c(1),i=c(2),t}^{sP2P} = 0 \\ P_{i=c(1),t}^{bg} = |P_{i=c(1),t}| - |P_{i=c(2),t}| \\ P_{i=c(1),t}^{sg} = 0 \\ P_{l=c(2),i=c(1),t}^{bP2P} = 0 \\ P_{l=c(2),i=c(1),t}^{sP2P} = |P_{i=c(2),t}| \\ P_{i=c(2),t}^{bg} = 0 \\ P_{i=c(2),t}^{sg} = 0 \end{cases} \tag{22}$$

To apply equation (22) the initial condition should be met, meaning that a P2P transaction is proposed, where $P_{i=c(1),t}$ is the buyer, $P_{i=c(2),t}$ is the seller and the quantity of seller is fulfilled.

$$\begin{pmatrix} X_{t,c}^{P2P} = 1 \\ \cap \\ P_{i=c(1),t} > P_{i=c(2),t} \\ \cap \\ |P_{i=c(1),t}| < |P_{i=c(2),t}| \end{pmatrix} \rightarrow \begin{cases} P_{l=c(1),i=c(2),t}^{bP2P} = |P_{i=c(1),t}| \\ P_{l=c(1),i=c(2),t}^{sP2P} = 0 \\ P_{i=c(1),t}^{bg} = 0 \\ P_{i=c(1),t}^{sg} = 0 \\ P_{l=c(2),i=c(1),t}^{bP2P} = 0 \\ P_{l=c(2),i=c(1),t}^{sP2P} = |P_{i=c(1),t}| \\ P_{i=c(2),t}^{bg} = 0 \\ P_{i=c(2),t}^{sg} = |P_{i=c(2),t}| - |P_{i=c(1),t}| \end{cases} \tag{23}$$

In the case of equation (23) the buyer is $P_{i=c(1),t}$, the seller is $P_{i=c(2),t}$ and the quantity of buyer is fulfilled.

$$\begin{pmatrix} X_{t,c}^{P2P}=1 \\ \cap \\ P_{i=c(1),t} < P_{i=c(2),t} \\ \cap \\ |P_{i=c(1),t}| > |P_{i=c(2),t}| \end{pmatrix} \rightarrow \begin{cases} P_{l=c(1),i=c(2),t}^{bP2P} = 0 \\ P_{l=c(1),i=c(2),t}^{sP2P} = |P_{i=c(2),t}| \\ P_{i=c(1),t}^{bg} = 0 \\ P_{i=c(1),t}^{sg} = |P_{i=c(1),t}| - |P_{i=c(2),t}| \\ P_{l=c(2),i=c(1),t}^{bP2P} = |P_{i=c(2),t}| \\ P_{l=c(2),i=c(1),t}^{sP2P} = 0 \\ P_{i=c(2),t}^{bg} = 0 \\ P_{i=c(2),t}^{sg} = 0 \end{cases} \tag{24}$$

In equation (24), $P_{i=c(1),t}$ is the seller, $P_{i=c(2),t}$ is the buyer and the quantity of seller is fulfilled.

$$\begin{pmatrix} X_{t,c}^{P2P}=1 \\ \cap \\ P_{i=c(1),t} < P_{i=c(2),t} \\ \cap \\ |P_{i=c(1),t}| < |P_{i=c(2),t}| \end{pmatrix} \rightarrow \begin{cases} P_{l=c(1),i=c(2),t}^{bP2P} = 0 \\ P_{l=c(1),i=c(2),t}^{sP2P} = |P_{i=c(1),t}| \\ P_{i=c(1),t}^{bg} = 0 \\ P_{i=c(1),t}^{sg} = 0 \\ P_{l=c(2),i=c(1),t}^{bP2P} = |P_{i=c(1),t}| \\ P_{l=c(2),i=c(1),t}^{sP2P} = 0 \\ P_{i=c(2),t}^{bg} = |P_{i=c(2),t}| - |P_{i=c(1),t}| \\ P_{i=c(2),t}^{sg} = 0 \end{cases} \tag{25}$$

In the case of equation (25) the seller is $P_{i=c(1),t}$, the buyer is $P_{i=c(2),t}$ and the quantity of seller is fulfilled. When the $X_{t,c}^{P2P} = 0$ four different conditions should be tested.

$$\begin{pmatrix} X_{t,c}^{P2P}=0 \\ \cap \\ P_{i=c(1),t} > 0 \\ \cap \\ P_{i=c(2),t} > 0 \end{pmatrix} \rightarrow \begin{cases} P_{l=c(1),i=c(2),t}^{bP2P} = 0 \\ P_{l=c(1),i=c(2),t}^{sP2P} = 0 \\ P_{i=c(1),t}^{bg} = |P_{i=c(1),t}| \\ P_{i=c(1),t}^{sg} = 0 \\ P_{l=c(2),i=c(1),t}^{bP2P} = 0 \\ P_{l=c(2),i=c(1),t}^{sP2P} = 0 \\ P_{i=c(2),t}^{bg} = |P_{i=c(2),t}| \\ P_{i=c(2),t}^{sg} = 0 \end{cases} \tag{26}$$

Equation (26) represents the condition when no P2P transactions exist and both players are consumers, so they need to buy energy from the grid.

$$\begin{pmatrix} X_{t,c}^{P2P}=0 \\ \cap \\ P_{i=c(1),t} < 0 \\ \cap \\ P_{i=c(2),t} < 0 \end{pmatrix} \rightarrow \begin{cases} P_{l=c(1),i=c(2),t}^{bP2P} = 0 \\ P_{l=c(1),i=c(2),t}^{sP2P} = 0 \\ P_{i=c(1),t}^{bg} = 0 \\ P_{i=c(1),t}^{sg} = |P_{i=c(1),t}| \\ P_{l=c(2),i=c(1),t}^{bP2P} = 0 \\ P_{l=c(2),i=c(1),t}^{sP2P} = 0 \\ P_{i=c(2),t}^{bg} = 0 \\ P_{i=c(2),t}^{sg} = |P_{i=c(2),t}| \end{cases} \tag{27}$$

In the case of equation (27) both players are sellers, and the variable of P2P transactions is disabled.

$$\begin{pmatrix} X_{t,c}^{P2P}=0 \\ \cap \\ P_{i=c(1),t} > 0 \\ \cap \\ P_{i=c(2),t} < 0 \end{pmatrix} \rightarrow \begin{cases} P_{l=c(1),i=c(2),t}^{bP2P} = 0 \\ P_{l=c(1),i=c(2),t}^{sP2P} = 0 \\ P_{i=c(1),t}^{bg} = |P_{i=c(1),t}| \\ P_{i=c(1),t}^{sg} = 0 \\ P_{l=c(2),i=c(1),t}^{bP2P} = 0 \\ P_{l=c(2),i=c(1),t}^{sP2P} = 0 \\ P_{i=c(2),t}^{bg} = 0 \\ P_{i=c(2),t}^{sg} = |P_{i=c(2),t}| \end{cases} \tag{28}$$

In equation (28) the $P_{i=c(1),t}$ is buyer and $P_{i=c(2),t}$ is seller, but as there is no P2P transaction active, both players transact electricity with the grid.

$$\begin{pmatrix} X_{t,c}^{P2P}=0 \\ \cap \\ P_{i=c(1),t} < 0 \\ \cap \\ P_{i=c(2),t} > 0 \end{pmatrix} \rightarrow \begin{cases} P_{l=c(1),i=c(2),t}^{bP2P} = 0 \\ P_{l=c(1),i=c(2),t}^{sP2P} = 0 \\ P_{i=c(1),t}^{bg} = 0 \\ P_{i=c(1),t}^{sg} = |P_{i=c(1),t}| \\ P_{l=c(2),i=c(1),t}^{bP2P} = 0 \\ P_{l=c(2),i=c(1),t}^{sP2P} = 0 \\ P_{i=c(2),t}^{bg} = |P_{i=c(2),t}| \\ P_{i=c(2),t}^{sg} = 0 \end{cases} \tag{29}$$

By the equation (29), $P_{i=c(1),t}$ is seller and $P_{i=c(2),t}$ is buyer, and both transact electricity with the grid. Thus, the variable of P2P transactions is disabled.

After applying all equations, $Balance_{i,j}^{1}$ and $Balance_{t}^{2}$ can be obtained, and the fob and the value of $fit(x)$ can be calculated.

IV. Case Study

To perform the simulation, 9 agents were used, namely, 3 consumers, 3 prosumers and 3 producers. Figure 2 presents the profiles of load and generation for all players.

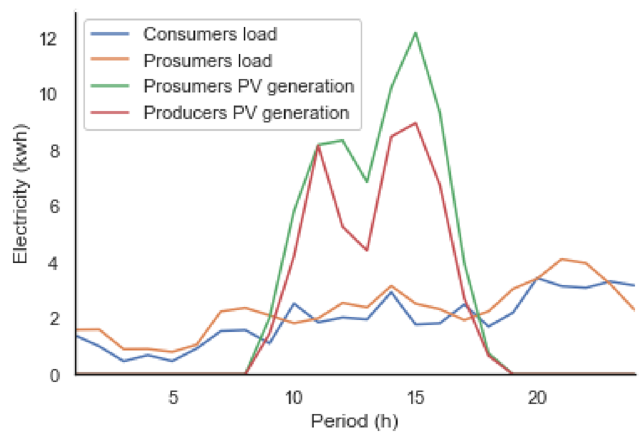

Figure 2 – Load and generation profiles

We assume that consumers can buy electricity from the grid or in P2P mode, the prosumers can buy or sell electricity from the grid or from P2P mode, and the producers can only sell electricity to the grid or in P2P mode. The price of buying electricity from the grid is set to 0.158 €/kWh and for selling to the grid is 0.045 €/kwh.

The sensitive analysis is performed for the total number of particles, the total number of iterations, the minimum and maximum value for inertia, minimum and maximum value for personal coefficient and minimum and maximum value for global coefficient. Table 1 presents the range of values analyzed.

Table 1 – Range of tunned values

Description		Symbol	Range of values
Number of iterations		N_k	[100,200,500,1000,2000]
Number of particles		N_j	[10,20,50,100]
Inertia	Minimum	w^{min}	$[0:2]$in steps of 0.2
	Maximum	w^{max}	$[0:2]$ in steps of 0.2
Personal coefficient	Minimum	$c^{1,min}$	$[0:2]$ in steps of 0.2
	Maximum	$c^{1,max}$	$[0:2]$ in steps of 0.2
Global coefficient	Minimum	$c^{2,min}$	$[0:2]$ in steps of 0.2
	Maximum	$c^{2,max}$	$[0:2]$ in steps of 0.2

As can be seen in Table 1, the analysis is done for five different number of iterations, four different number of particles, and for eleven different values of maximum and minimum inertia, personal coefficient, and global coefficient values (i.e., in the range of 0 to 2 in steps of 0.2). It should be noted that the maximum value must be equal or higher than the minimum value in each of the parameters in analyses.

V. RESULTS

The simulation for the analyses of the results is implemented in Python language using the *Pyticle Swarm*[1] library to run the PSO. Other libraries are also used: *NumPy* to deal with vector and matrix; *pandas* to import data from excel; *itertools* to create the combination of possible P2P transactions; and *matplotlib* to create all plots presented in the paper. 30 trials are performed for each experiment, and the minimum values are stored.

First, the influence of iterations numbers was analyzed. Figure 3 presents the analysis of iteration number parameter.

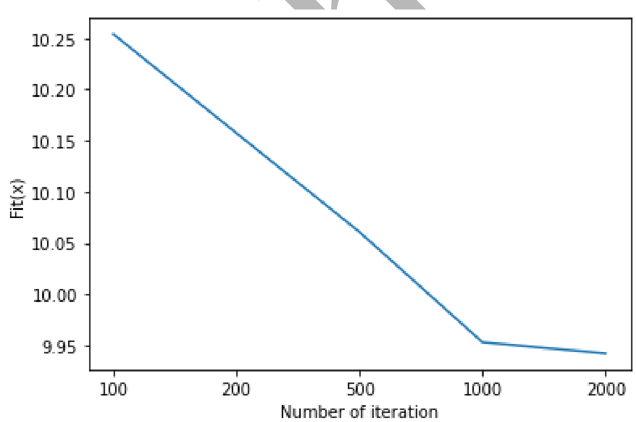

Figure 3 – Iteration number analyses

As can by Figure 3 the result of the fitness function for the different number of iterations changes. As expected, the fitness function value has a great number of iterations. Therefore, the value of 1000 iterations is a good option for this application. A reduction of 0.3 € was obtained when the number of iteration increased from 100 to 1000. However, a reduction of only 0.02 € was obtained when increasing the value from 1000 to 2000. In this sense, the fitness value of 2000 iteration does not bring a significant improvement that justify the large increment in execution time.

Figure 4 presents the analyses for the number of particles. In this case, by the analyses of Figure 4, 50 particles are considered as the best option. This is because, from 20 to 50 particles number, the fitness value decreases by an acceptable degree, whereas from 50 to 100 there is not a significant improvement.

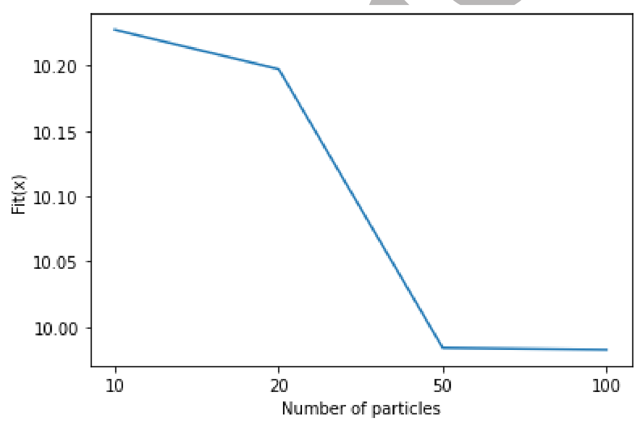

Figure 4 – Particles number analyses

Figure 5 presents the heatmap for the inertia sensitivity analyses. By the analyses of Figure 5, it is possible to verify that the fitness function value varies with respect to the different number of inertia values. For the value of inertia minimum (w^{min}) the number of 0.2 is selected, and the value of 0.4 is selected for the maximum value of inertia (w^{max}). The heatmap shows the best values in the selected range of values for inertia.

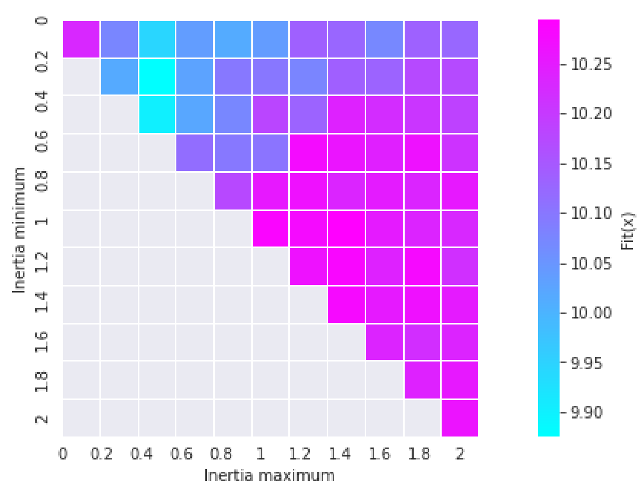

Figure 5 – Maximum and minimum inertia analyses

Figure 6 presents the heatmap for the maximum and minimum value of personal coefficient analyses. By the

[1]Available at https://pyswarms.readthedocs.io/.

analyses of results presented in Figure 6, the values for minimum and maximum of the personal coefficient can be selected. The value selected for minimum personal coefficient ($c^{1,min}$) is 0.4 and for the maximum ($c^{1,max}$) is 1.6.

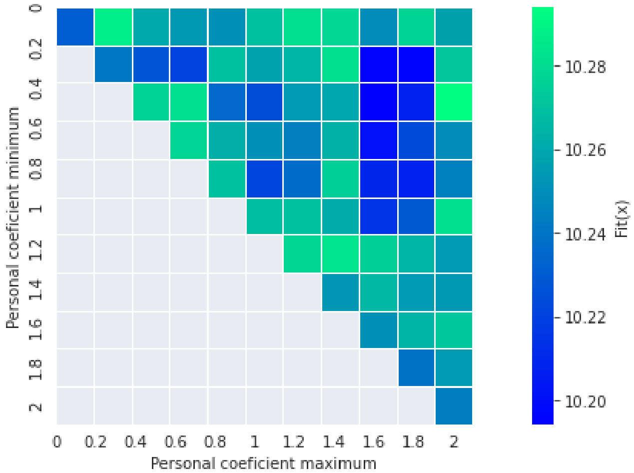

Figure 6 – Maximum and minimum personal coefficient analyses

Figure 7 presents the heatmap for the maximum and minimum value of the global coefficient. Considering the results of Figure 7 the values selected for minimum global coefficient ($c^{2,min}$) is 0 and for the maximum values ($c^{2,max}$) is 1.2.

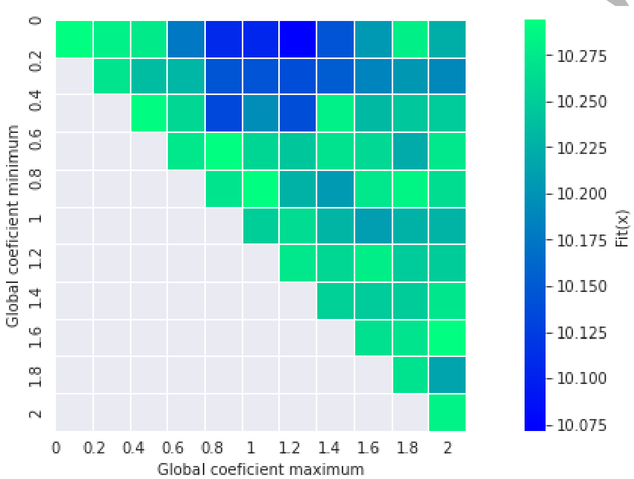

Figure 7 – Maximum and minimum global coefficient analyses

Table 2 presents the summary of the selected parameters to perform the optimization of the P2P electricity market problem.

Table 2 – Parameters values

Description		Symbol	Values
Number of iterations		N_k	1000
Number of particles		N_j	50
Inertia	Minimum	w^{min}	0.2
	Maximum	w^{max}	0.4
Personal coefficient	Minimum	$c^{1,min}$	0.4
	Maximum	$c^{1,max}$	1.6
Global coefficient	Minimum	$c^{2,min}$	0
	Maximum	$c^{2,max}$	1.2

Now, regarding convergency of the tested algorithm, Figure 8 presents the convergence performance of the PSO algorithm with the parameters selected. The solution without P2P transaction is also presented with green color as the baseline of the experiment. The blue line presents the mean value obtained in each iteration for the 30 trails used, and with the orange line, the minimum solution obtained by the PSO is presented. With the blue line is possible to see the performance convergence of the algorithm. In the initial phase, the algorithm starts with a solution of 10.29 €, achiving a final value of 9.29 €, a reduction of around 1 €. Comparing the minimum value (9.036 €) with the value without P2P transactions (10.294 €), the algorithm achieved a reduction of 1.258 €, a reduction that might be significan considering larger time horizons.

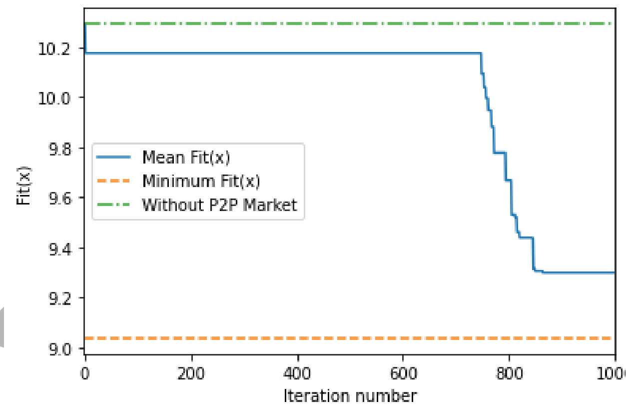

Figure 8 – PSO convergence performance

VI. Conclusion

Premature convergence and sensitivity to initial control parameters are problems that might arise when using the PSO algorithm. Therefore, in this work, we performed a comprehensive sensitivity analysis to investigate the impact of the control parameters and determine the best set of those to solve a P2P market problem. The parameter analysis is done in a constrained optimization problem, and the findings revealed that the inertia weight and acceleration coefficients were the most sensitive parameters of PSO. The best set of parameters was found under different scenarios in the P2P electricity market problem. The verification study demonstrated that PSO achieves acceptable performance after the parameter tuning. It also ensures an extensive sensitivity analysis by studying most of the parameters in the PSO algorithm. Although the present sensitive analyzes fulfils the main goals of the study, it could be improved extending the case study with more agents (e.g., more than 30 agents) and the inclusion of combined heat and power generators to increase the liquidity of the P2P market. The analyses could also be improved by decreasing the value of the steps (e.g., 0.1) thus increasing the resolution of the achieved results.

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