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***Abstract*—The challenges raised by new energy technologies, clean energy sources and energy efficiency led us to reconsider the way we manage energy in electricity grids and the way the stakeholders are involved. To tackle these issues, the focus should emphasize not solely the technical side, but also the sociological and economic issues related to the development of these new energy solutions. This paper presents an Energy Management System (EMS) addressing the following question : *how to take into account, from the grid point of view, a stakeholder willing to be involved in the grid* ? Involvement-profiles amongst stakeholders, particularly the households, in terms of electricity consumption/production can be defined by a socio-economic approach, and we chose to use a potential game approach from the game theory to integrate those profiles and imagine the possible interactions among them, incorporating their sensitivities and objectives.**

***Index Terms*—Demand Side Management, Game Theory, Consumer Preferences.**

I. Introduction

Today's environmental preoccupations led to a growing part of renewable energies in the energy production, thus challenging the equilibrium of the entire electrical grid between the energy produced and the energy consumed. This key point affecting the stability of the grid, new ways of managing electricity should therefore be considered [1]. These issues bring the research to investigate the potential of smarter grids : the smart grids. Over the past 13 years, more than 950 European projects (demonstrators as well as R&D projects) tackling these challenges have been identified by the Joint Research Center (JRC) [2].

Emerging from all these projects, beyond the technical difficulties (equipment, communication protocols, ...), are precisely the problems of regulation and involvement. Described as the most significant setback, role definition of the various stakeholders raises concern as it is often unclear. This leads to uncertainties in terms of cost sharing (financial as well as risks in a more general way) and benefit sharing, impeding investment and involvement in these new grid models. It should also be noted that the two main objectives of these studies are often oriented towards residential consumers : to understand their functioning and to encourage their involvement [3]. As the most complex grid stakeholders to apprehend, due to the multiplicity of profiles and to the human nature, households are the focus of this paper : the methodology is however to be replicated for other consumers (industry and services sector) but also power producers or the grid system operator.

To tackle the presented issues, demand side management (DSM), aiming to involve the consumer in the equilibrium of the grid, is the second funded domain among smart grid projects [2]. The approach is most often technical, practises and involvement in the residential sector are then only observed a posteriori. A framework is therefore required in order to take into account those questions not exclusively technical, but that involve other domains such as social sciences. For this purpose, the proposed approach seeks to investigate at the crossroads of electrical engineering, economics and sociology. The aim is to develop an effective grid management allowing to pass these barriers by ensuring that the objectives and the sensitivities of each stakeholder are met.

The used methodology is presented in Fig. 1, where the three steps are providing an answer to each of the following questions : 1. *What are the existing involvement-profiles in terms of electricity consumption/production* ? 2. *How to model these profiles* ? 3. *How to use these models in an energy management strategy* ? We present briefly how the socio-economic approach helps to determine involvement profiles to model the sensitivities of an household. However, the main focus of this paper is the modelling of these profiles using a game theory approach including those sensitivities in the game of the different grid stakeholders. The last part introduces the interaction between the different profiles using Dynamic Programming before presenting the corresponding results for each household and the grid.

II. Proposed Approach

A. Prior socio-economic study

Economy is the starting point of many study on electricity consumption : To enhance a consumer to delay his consumption, the most common leverage used in DSM is indeed the price. Various possibilities exist, but the four mains tariff

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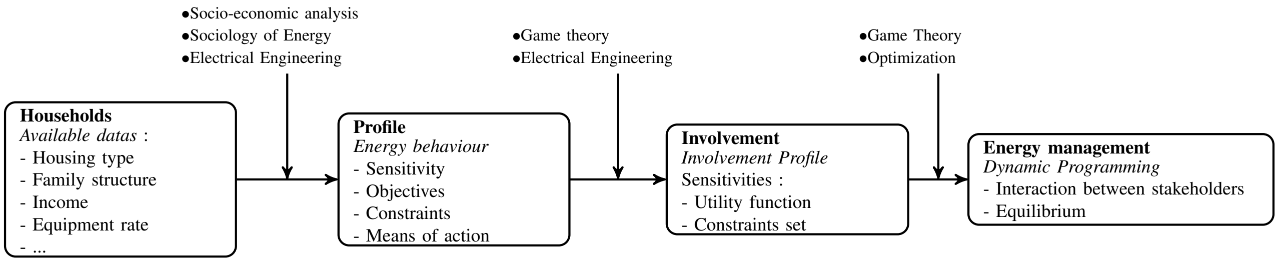

Fig. 1. Proposed methodology of this study for the residential sector

strategies are [4]: Time Of Use pricing (TOU), Critical Peak Pricing (CPP), Real Time Pricing (RTP), Peak Time Rebates (PTR). An overview of different studies analysing the impact of these models shows that the CPP model is the most efficient and can allow up to 30 % of peak reduction [5]. Best results are obtained when the loads are automatically controlled but the effectiveness of these solutions depends on the actor's involvement in their definition and on the freedom he has to take back control at any time.

The economy may help further as it is necessary to succeed in cutting out the profiles present in a given population, in order to devise adapted solutions and thus promote acceptance and involvement. For this purpose, the micro-economy rely on discrete choice models : these models describe the behaviour of an individual facing a set of actions. The approach used here is the one advocated by the standard micro-economy (namely neoclassical economy) and many models have resulted from it. They are based on the search for *demand functions* (linking consumption to the price of the good, market prices, and individual incomes) to include consumer expectations that influence their self-reliance [6]. Briefly, it considers that the choices are intrinsically deterministic : it requires therefore to find the relevant parameters to be taken into account in order to model these choices precisely. This analyse enable to determine the energy consumption of a given population under observable variables.

On the other hand, the consumption of electricity is also a matter of everyday decisions and reactions to social stimulation. Therefore, the sociology of energy helps to understand a human decision through the theories of human behaviour. These concepts seek to determine the commitment of a consumer through his own perceptions. As for the smart-grid, [7] evaluate the following exogenous criteria influencing these perceptions : compatibility, understanding, reliability, economics, ecology, data protection, EMR[1]. Accordingly, those aspect should be considered during the development of management of the electricity.

Involving user is therefore one of the key in the future smart-grids. However, it emerges from [8] that each individual has an inherent rationality and that if money is often the driving force of change, it is not the only lever. Two decisive factors are the return of utility and the behaviours in his environment (neighbours, friends, ...). Interaction can thus rely on the competitive spirit, on cooperation, or on the feeling of control and appropriation by the consumer. These non-economical aspects are also studied in [9] or [10]: The influence of feedback (within a home, between households or between households and suppliers, and the form of these feedbacks) on daily social practices has therefore been studied, and consumption reductions of the same order as for a price increase between 11 and 20% are observed. It is shown that the rebound effect may even be limited by suitable non-economic measures. The example of the Accenture's survey on Fig. 2 sums up the diversity of profiles and the objectives or constraints that different residential actors may embody [11].

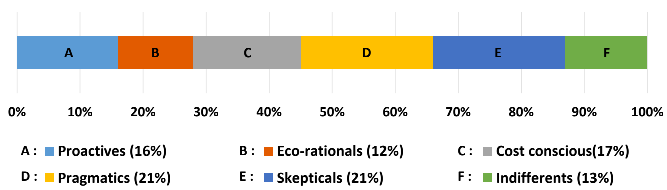

Fig. 2. Average distribution of residential consumer over the world [11]

All of these observations underline that informations and other forms of stimulation (beyond economics) would enable different sensitivities to be considered while managing the grid. Based on these results, the purpose of the socio-economic approach is to list the different profiles in term of electricity consumption, to synthesize the key points that need to be taken into account in the management of the energy. Thus answering the following question : which are the sensitivities and the constraints representing the consumer? This study is important to shift the paradigm to actively engage the consumer in the smart grid equilibrium, and to enhance acceptance.

The results of the socio-economic analysis is summarized through the example of one consumer profile in Table I. The objective is to be able to use these profiles for a better management of the electricity in the grid considering the sensitivities of the household - and later the other stakeholders - in order to enable involvement.

B. Potential Game approach

In this study, the game theory provides a framework for the interaction between stakeholders to ensure, under certain conditions, the existence and uniqueness of equilibrium points in the sharing of the electricity. This framework is mathematical and dictates the form of the functions used to model

[1] Electromagnetic Radiation

TABLE I
EXAMPLE OF A SYNTHESIZED PROFILE

Objective	Means of action	Constraints
To reduce the bill	Electricity supplier	Electricity price
	Heater	Technical feature Desired comfort
	Hot water tank	Water availability Technical feature
	Electrical vehicle	Vehicle availability Technical feature
	Other loads *(Oven, washer,..)*	Social constraints

the different involvement profiles, as well as the the form of the constraints representing the technical limits and the preferences of the players. The notations for the following section are :

- Each step of time will be noted $k \in [1, K]$;
- a player (household) is identified using subscript $i \in [1, N]$;
- $x_{k,i}$ is the consumed power by the player i at the time step k;
- $\ell_\mathrm{m} = \frac{\sum_{i=1}^{N}\sum_{k=1}^{K} x_{k,i}}{K}$ is the mean value of the total load over a day.

1) Introduction to game theory: Game theory is the study of conflict and cooperation among intelligent rational decision-makers, which has been used and proved useful in smart grid [12], [13], [14]. The limit of these studies is that they rely exclusively on automated loads in an household and are not enable to represent the diversity of consumption profiles. The idea in this paper is to use the game theory approach to ensure the grid equilibrium while setting a path for the consumption of each stakeholder, regarding of their objectives and sensitivities.

The concept used here is the following : the interactions between the consumer is formulated as a non-cooperative game between the households willing to take part in the grid equilibrium. This game is represented as followed :

- Player set : The players are the N households;
- Strategy set : For a player i, X_i represent the set of all the possible strategies, depending on the constraints mentioned previously. His strategy vector is then noted $\mathrm{x}_i \in X_i$ with $\mathrm{x}_i = [x_{1,i}, x_{2,i}, \cdots, x_{k,i}, \cdots, x_{K,i}]$. x_{-i} is then the strategy vector representing all the other players' strategies.
- Utility function (or pay-off function) : represents the pay-off of the player i for a chosen strategy, noted $U_i(\mathrm{x}_i)$.

Each player will try to maximize its pay-off and therefore optimizes its utility function to reach his so called *best reply* x_i^*. Given the type of utility function used here, this game is named *best-response potential game*. The game theory studies the various equilibrium that exist in the process of utility optimization. From definition 1, the Nash equilibrium used in this paper is defined as a strategy vector $[\mathrm{x}_i^*, \mathrm{x}_{-i}^*]$ in which no player can improve its payoff by unilaterally deviating from its equilibrium strategy x_i^* [15]. As proved by the authors, such game converges to a Nash equilibrium if players choose their best responses (maximize their payoff) in a sequential and asynchronous way.

Definition 1: A strategy vector $[\mathrm{x}_i^*, \mathrm{x}_{-i}^*]$ is a Nash equilibrium if and only if $\forall i \in N$ and $\forall \mathrm{x}_i \in X_i$

$$U_i(\mathrm{x}_i^*, \mathrm{x}_{-i}^*) \geq U_i(\mathrm{x}_i, \mathrm{x}_{-i}^*) \quad (1)$$

The conditions for the existence of a Nash equilibrium in this game are the following [12]:

- The player set is finite;
- The strategy sets are closed, bounded, and convex.
- The utility functions are continuous and quasi-concave in the strategy space

2) Modelling the consumer: In this study, the hypothesis is that each household is able to manage his consumption either manually or automatically though smart home appliance. The objective is to set the best path (in terms of electricity consumption) for the stakeholder to follow in order for him to reach his objective while respecting his constraints (both technical or social). Furthermore, it is assumed that with the new smart metering technology, it is possible to forecast the energy consumption a day in advance regarding of the profile, as it is done today with profiling though data mining.

The crucial point of the model is the possibility of implementing parameters to simulate the attitude of a stakeholder in terms of his participation to the grid. To design a solution, the basis utility function (2) is taken from [15], whose goal is to reduce the peaks on the grid. It manages the consumption to flatten the global load in order to bring it closer to the mean load over a day. With this function, if the consumption of the player i enables to reduce the total distance between the total load and its average value, his utility increase and vice versa.

$$U_i(\mathrm{x}_i, \mathrm{x}_{-i}) = -\sum_{k=1}^{K}\left((x_{k,i} + \sum_{j=1, j\neq i}^{N} x_{k,j}) - \ell_\mathrm{m}\right)^2 \quad (2)$$

Starting from this function, the representation of the participation will have the form of a parameter in the utility function of each player. In further development, this parameter will be accounted for participation, price or environmental sensitivities as presented in section II-A, and be itself a function depending on time : the interesting part in this paper is above all the used methodology and the opportunities that opens. The introduction of this parameter must not alter the mathematical form of the utility function in order to stay in the availability domain required to converge to the Nash equilibrium.

Assuming that the daily household consumption profile (x_i^d) is forecasted one day ahead (or directly defined by the user) and using D_k as the distance between the average load and the total load at a step of time k (3), the involvement parameter $\alpha \in [0.5, 1]$ is introduced in (4). A value of 1 indicates the non-participation of the household to the equilibrium mechanism, a value of 0.5 indicates a full commitment, and a value in between stands for the different involvement profiles.

$$D_k = -\sum_{j=1}^{N} x_{k,j} + \ell_{\mathrm{m}} \tag{3}$$

$$u_{k,i} = -\left(x_{k,i} - [(1-\alpha)\cdot D_k + \alpha \cdot x^{\mathrm{d}}_{k,i}]\right)^2 \tag{4}$$

This approach enables to convert the results of the socio economic approach into a usable form for the grid management. Each player will be modelled by a utility function but also by a set of constraints representing both the technical and the social constraints (as synthesized in Table I). This set of constraints will determine the set of possible strategy available X_i for the player in order for him to optimize its pay-off. For example, the constraints related to an electrical vehicle using on–off-control can be :

- Technical : $x(t) = 0$ or P_{charger}, the power of the charger in kW;
- Social : $\int_{19:00}^{7:00} x(t)dt = E_{\text{daily commute}}$, the required energy to complete the daily commute without recharging in kWh.

III. Algorithm

As privacy is indeed amongst the main concerns of the grid stakeholders (Section II-A), the advantage of such method is that each player do not receive private data from other player, but only the aggregated load of all the consumer of the grid. The aggregator receives the information of consumption from each consumer, and then communicates with each one of them sequentially at each update. Each player will then adjust his consumption according to the new total load in order to maximize their utility function. This decentralized approach also saves the aggregator an intensive computational optimization, thus not limiting the number of household in the considered grid.

The main algorithm applied by the aggregator can be broke down as follows :

1) Each consumer sends his consumption for the next day (desired or forecasted x_i^{d}) to the aggregator who then compiles it and adds it to the other forecasted load of the rest of the grid (noted ℓ_k for the step of time k). The total power profile over the day is $\lambda = [\lambda_1, \lambda_2, \cdots, \lambda_k, \cdots, \lambda_K]$ with $\lambda_k = \sum_{i=1}^{N} x_{k,i} + \ell_k$;
2) This global profile is sent to the first consumer who recalculates his consumption for the day using dynamic programming (presented below) to maximize his utility function and sends back his new consumption to the aggregator;
3) The aggregator then recalculates the total power profile and sends it to the second consumer, who will also adjust its consumption accordingly by maximizing its utility and return it;
4) The aggregator thus proceeds with all consumers and starts again until none of them changes its consumption profile anymore.

As long as the criteria on the utility function and the strategy set are met (Section II-B1), stopping the algorithm indicates that the Nash equilibrium is reached. Each actor having shifted (or not) his consumption according to his sensitivities, he benefits the maximum pay-off of its consumption, and can only decrease it if he decides to derogate unilaterally from the obtained power profile.

The optimization problem is solved by the household using Dynamic Programming. This method enables to find the best path between various proposition, by breaking it down into simpler and smaller sub-problems. When a household receives the global load profile on the grid and if it has changed since the last communication, the algorithm performs the optimization of the strategy x_i as follows :

1) The algorithm is set to shift the power consumption over the day but to let the consumer consume the same amount of energy. Therefore, the consumed energy at the first time step is worth 0 and it must reach $E_{i,total} = \sum_{k=0}^{K} x_{k,i}^{d}$ at the last time step K. The set of all possible paths (reachable energy level) over the day is then determined by the constraints.
2) For the first time step, it evaluates each possible path using the utility function it has been assigned, and stores this information for each case.
3) At the second time step, it evaluates the paths between all the energy level reached previously and the reachable levels, using once again the utility function, and taking into account the previous score of each path.
4) It then proceeds for each step of time, storing for each reached energy level : the best way to get there and the score attributed to this path. At each time step k, it stores therefore for each possible level of arrival the path which maximizes the utility function.
5) At the last step of time ($k = K$), it has stored the best path to reach the forecasted amount of energy. The obtained power profile is then the optimal strategy, and is sent to the aggregator.

IV. Simulation and Results

The goal of the simulation is to study the possibility of integrating different involvement in the management of electricity in the grid. The simulated grid is represented on Fig. 4, where the 6 profiles are modelled with different values of the α-parameter (Table II). To perceive the influence of this parameter, each household will be given the same forecasted power consumption profile $\mathrm{x}_i^{\mathrm{d}}$. Additionally, an arbitrary load ("other load") will be added to the simulation, representing either consumer unwilling to participate or a load that can not be shifted. For a step of time k, this power will be noted ℓ_k.

TABLE II
Value of α-parameter for each simulated profile

Profile	1	2	3	4	5	6
α	0.50	0.70	0.80	0.90	0.93	1.00

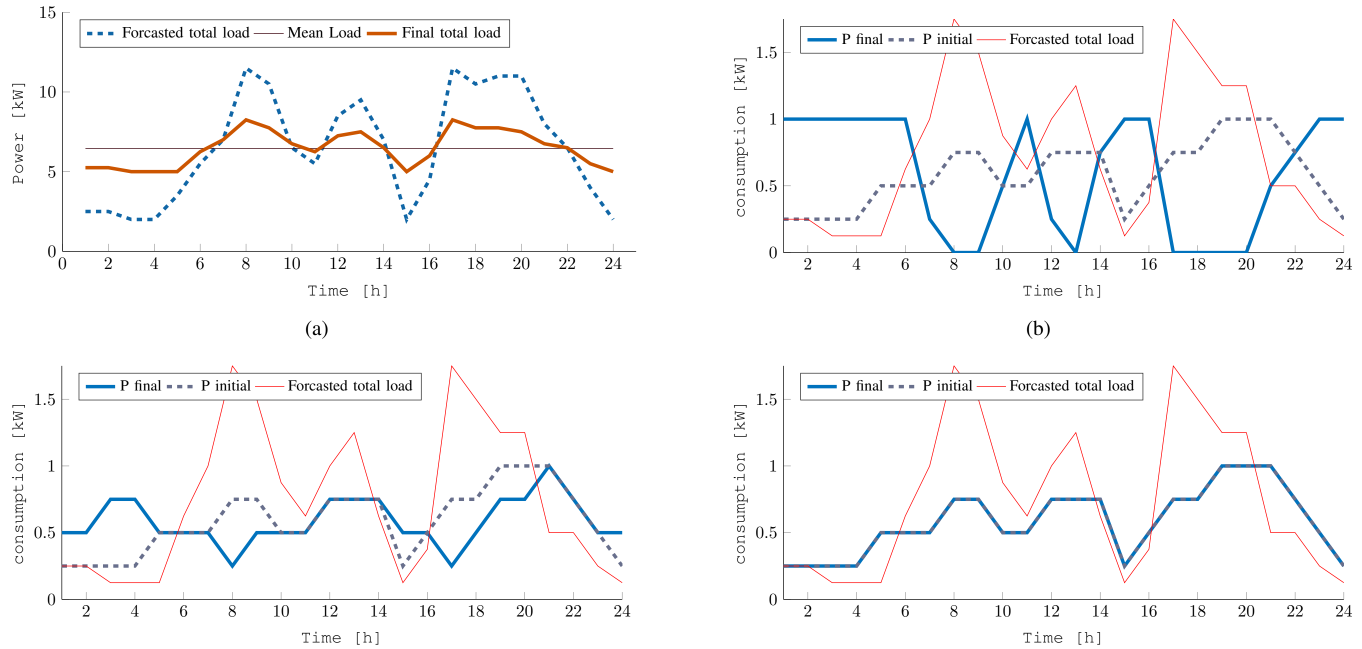

Fig. 3. Simulation results : (a) Evolution of the total load of the grid, (b) Shifting results for the profile $\alpha = 0.5$, (c) Shifting results for the profile $\alpha = 0.9$, (d) Shifting results for the profile $\alpha = 1$.

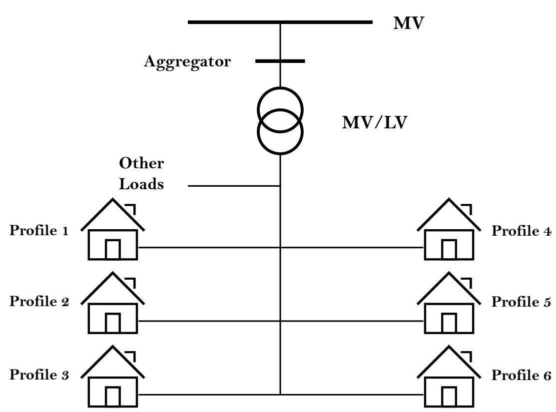

Fig. 4. Simulated grid

As a first step, the associated constraints defining the strategy set for each households are as follows :

- Power: $0 \leq x_{i,k} \leq 1$ with $x_{i,k} = 0.25j$, $\forall j \in [0, 1, 2, 3, 4]$;
- Energy: $\tau \sum_{k=1}^{K} x_{i,k} = \sum_{k=1}^{K} x_{i,k}^{d} = E_{i,total}$, with τ the time step duration (1 hour here).

This set of constraints is closed, bounded, and convex. The definition of the constraints is where the modelling of the profiles will be performed in a future simulation, by first introducing the technical constraints, then adding the constraints related to the use required by the consumer. This set, imposed by the different stakeholders, represents with the utility function the interesting part of this work : if they are correctly defined, then the interaction of the players will allow to meet each stakeholder's objectives while participating in the grid's balance. It thus enables to ensure a framework that will be respected for those who want to participate, and to have a way to ensure balance for the grid manager.

The results of the simulation are illustrated in the Figure 3. In Figure 3(a), presenting the evolution of the total load on the grid, it is logically observable that once all the actors have shifted (or not) their consumption, the global objective to decrease the peaks towards the average load is met. In the other figures (3(b), 3(c) and 3(d)) are presented for three profiles an image of the total forecasted load on the grid, the forecasted -or stated- consumption profile ("*P initial*", the strategy x_i^{d}), and the shifted consumption profile resulting from the optimization of the utility function ("*P final*", the strategy x_i^{*}). The simulation confirms the possibility of using the presented approach to model various profiles. A fully involved household (Fig. 3(b)) uses indeed his strategy set at its maximum to compensate the peaks by not consuming. On the contrary, a profile unwilling (or unable) to take part in the global objective (Fig. 3(d)) is observed to not shift his consumption over the day. In between, the α-parameter enable to model different involvement : in the Fig. 3(c) for example, the household accepts to participate and shift partially his consumption only during critical times of the day where the two biggest peaks are observed.

The last part of this work is the use of indicators, allowing to evaluate the effort and the gain for each profile regarding the associate objectives. As the objective in this simulation is grid-oriented, a relevant indicator for the grid manager is the peak reduction I_{peak} (5): calculated as the percentage decrease of the difference between the total load and the average load (Table III).

$$I_{\text{peak}} = \frac{D_{\text{peak final}} - D_{\text{peak intial}}}{D_{\text{peak intial}}} \quad (5)$$

with :

$$\begin{cases} D_{\text{peak intial}} = \sum_{k=1}^{K} |\sum_{i=1}^{N} x_{k,i}^{d} + \ell_k - \ell_m| \\ D_{\text{peak final}} = \sum_{k=1}^{K} |\sum_{i=1}^{N} x_{k,i}^{*} + \ell_k - \ell_m| \end{cases}$$

Furthermore, the produced effort by each household , I_e, can be extract from the simulation according to (6), by calculating the percentage of the shifted energy amount. Future developments of this indicator could differentiate the consumption shift requiring a binding effort from those who do not (e.g. Heating vs. Hot water tank). The results for each profile are compiled in table III, illustrating the correlation between the involvement and the effort made.

$$I_e = \frac{100}{E_{\text{total}}} \cdot \sum_{k=1}^{K} \tau \cdot (x_k^* - x_k^-) \quad (6)$$

with :

$$x^- = \begin{cases} x_k^d & \text{if } x_k^d > x_k^* \\ x_k^* & \text{if } x_k^d \leqslant x_k^* \end{cases}$$

TABLE III
CALCULATED INDICATORS FOR EACH PROFILE

Profile	1	2	3	4	5	6	Grid Manager
I_e (%)	50	50	43	29	11	0	/
I_{peak}	/	/	/	/	/	/	-56.2

This first simulations remain succinct, but shows that one can imagine the interaction between different profiles in this way. It will of course be necessary to push the reflection further, studying the influence of different parameters, the most relevant way to introduce them, and the interaction between them. In addition to that, we plan to introduce different type of constraints coming from different stakeholders, while respecting the presented framework.

V. Conclusion and perspectives

This paper proposes a way to introduce parameters from a socio-economic analysis, a study that is essential to understand, involve, and consider stakeholders of a smart grid in the management of the electricity. The presented simulation shows that it is possible to model different profile using a game theory approach and thus taking them into account in order to respect their objectives while managing the smart-grid more efficiently. This preliminary work opens the way of numerous amelioration, especially for the utility functions and the parameters. Simulations are being therefore conducted to study on the one hand the use of parameters such as the price or the renewable energy consumption, and on the other hand how these parameters might interfere with each other. A reflection on the mathematical function to use must be therefore also conducted. Once a relevant function is found, the next challenge is to correlate this function with real profiles : future research using fuzzy logic is planned to link the prior socio-economic study to the mathematical reasoning presented in this paper.

In the long run, we are convinced that this approach will be useful for the prediction - by modelling as accurately as needed the different profiles in a given population in terms of electricity consumption and sensitivities - and the definition of consumer contracts - which then requires an economical model to define the financial benefits for those who take part in the grid equilibrium. In the first case, a learning loop, using neuronal network for example, is required to constantly adapt the parameters to fit the profiles among a given population. In the second case, such approach gives a path to those with a given sensitivity to follow, parallel to a more dynamic pricing mechanism, so that both the stakeholder - by getting closer to his goal - and the grid system operator - by reducing the equilibrium uncertainties - may benefit from it.

References

[1] B. Robyns *et al.*, *Energy Storage in Electric Power Grids*. Wiley-ISTE, 2015.

[2] F. Gangale *et al.*, *Smart grid projects outlook 2017: facts, figures and trends in Europe*. EUR 28614 EN, 2017.

[3] F. Gangale, A. Mengolini, and I. Onyeji, "Consumer engagement: An insight from smart grid projects in Europe," *Energy Policy*, vol. 60, pp. 621–628, 2013.

[4] S. Moser, "Optimisation of small customer network tariffs for smart grids," in *8th International Conference on Energy Efficiency in Domestic Appliances and Lighting – EEDAL'15*. European Commission Joint Research Centre - Institute for Energy, 2015.

[5] G. Newsham and B. Bowker, "The effect of utility time-varying pricing and load control strategies on residential summer peak electricity use: A review," *Energy Policy*, vol. 38, no. 7, pp. 3289–3296, 2010.

[6] P. Taube and D. MacDonald, "A Dynamic Almost Ideal Demand System Incorporating Consumer Expectations," *Managerial and Decision Economics*, vol. 12, pp. 197–206, 06 1991.

[7] C. Park, H. Kim, and Y. Kim, "A study of factors enhancing smart grid consumer engagement," *Energy Policy*, vol. 72, pp. 211–218, 2014.

[8] G. Verbong, S. Beemsterboer, and F. Sengers, "Smart grids or smart users? Involving users in developing a low carbon electricity economy," *Energy Policy*, vol. 52, pp. 117–125, 2013.

[9] H. Allcott, "Social norms and energy conservation," *Journal of Public Economics*, vol. 95, pp. 1082–1095, 2011.

[10] J. Naus *et al.*, "Smart grids, information flows and emerging domestic energy practices," *Energy Policy*, vol. 68, pp. 436–446, 2014.

[11] Accenture, "Understanding Consumer Preferences in Energy Efficiency," *Accenture end-consummer observatory on electricity management*, 2010.

[12] B. Chai *et al.*, "Demand response management with multiple utility companies: A two-level game approach," *IEEE Transactions on Smart Grid*, vol. 5, no. 2, pp. 722–731, 2014.

[13] A. Loni and F. A. Parand, "A survey of game theory approach in smart grid with emphasis on cooperative games," in *2017 IEEE International Conference on Smart Grid and Smart Cities (ICSGSC)*, Jul. 2017, pp. 237–242.

[14] W. Saad *et al.*, "Game-theoretic methods for the smart grid: An overview of microgrid systems, demand-side management, and smart grid communications," *IEEE Signal Processing Magazine*, vol. 29, no. 5, pp. 86–105, 2012.

[15] H. K. Nguyen and J. B. Song, "Optimal charging and discharging for multiple phevs with demand side management in vehicle-to-building," *Journal of Communications and Networks*, vol. 14, no. 6, pp. 662–671, 12 2012.