**DUEBE: AN AGENT BASED SIMULATOR FOR SMART RETAIL POWER MARKETS**

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## Overview

Power systems are witnessing a set of disruptions that have been widely described in several research works. Power market liberalization has started in the ‘90s and much progress and understanding has been achieved at the wholesale level. However, at the retail level, not much progress has been made and the understanding of retail market mechanisms is still limited. There are different proposals of such mechanisms but there is no consensus around them. Retail power markets are highly complex and difficult to be modelled and understood, an adequate approach for studying such complexity is therefore needed. In this research project, we developed a data-driven, Python-based Agent-Based Model (ABM) through which potential future retail market mechanisms can be simulated and tested. Our model capabilities contribute to a better understanding of the impact of market designs as well as market imperfections on retail competition. Our quantitative results are based on per-hour household data (consumption and generation from PV panels for 25 households) [1] from Austin, TX, USA, and hourly wholesale market prices from the Electric Reliability Council of Texas (ERCOT), for the full year of 2018. Since one of the main concerns of governments is to define the support schemes to be used in retail power markets and how to combine them in the most effective manner [2], we here present an example to showcase the capabilities of our Digital Urban Energy Business Ecosystem (DUEBE) model and provide some insights on the impact of different combinations of Feed-in Tariffs (FITs) and metering modes on retailers’ profits and customers’ bills.

## Methods

In this work, we present one example to showcase the capabilities of our DUEBE ABM model in studying retail power markets. ABM is an approach to modeling complex systems composed of autonomous agents that can sense their environment and engage with each other in some prescribed manner. Specifically, agents’ behaviors are described by simple rules, they interact with other agents and react to others’ actions. Agents are modeled individually, and their interaction gives rise to the behavior of the system as a whole. Therefore, patterns, structures, and behaviors not explicitly programmed into models emerge. ABM is a means to inquire about all the multi-factor and component interactive subtleties appearing in smart grids [3]. As our focus is on retail competition, in this research project we study the interaction between two groups of smart agents. Namely, retailers and their customers.

Retailers aim at profit maximization. Each retailer is specialized in a specific tariff structure and proposes a single tariff at each time-step. They can choose among Time-of-Use (ToU), Real-Time Prices (RTP), and some related variants. At each time-step, computing customers’ weekly energy costs for each tariff (considering demand response potential) and anticipating their switch, retailers propose a tariff that corresponds to their best-response assuming that competitors will propose the same tariff as in the previous time step.

Customers aim at cost minimization. Each customer browses through the tariffs offered by retailers at each time-step and computes her best option. This is the lowest estimated energy bill considering her demand response potential.

In order to test different future scenarios, the model allows us to set a series of parameters: i. *The default retailer*: it simulates the power utility in a non-competitive regulated retail market that typically exists before market liberalization. The tariff offered by the default retailer (which is set at the beginning of the simulation and does not vary) also forms a ceiling that constrains the profits of other retailers. Prosumers are always free to choose the default tariff over competing retailers’ tariffs. The role of the default tariff is an essential element of the simulation, given that at the beginning of a simulation all customers are subscribed to the default retailer; ii. *Errors in forecasting:* some prediction errors can be set to simulate real-world uncertainties, these affect the following per-hour forecasts for each agent: wholesale market prices (only retail-side), generation and consumption; iii. *Number of retailers*: the number of retailers offering the same tariff structure can be set; iv. *Elasticity to prices*: it models how extensively customers modify their consumption behaviors depending on how the change in prices compares to the default tariff; v. *Excess energy selling price*: Feed-in tariff, wholesale market price, same tariff as buying tariff; vi. *Metering mode*: net- and gross-metering.

Setting of the simulation:

1. The default retailer: 0.20 $;
2. Length of the simulation: 100 weeks;
3. Errors in forecasting: we apply a Normal distribution with SD:1 and MEAN:0 to measured data;
4. Number of retailers: 1 per tariff structure (ToU, RTP, and RTPprop);
5. Elasticity to prices: - 0.3;
6. Excess energy selling price: FIT 0.20 $, FIT 0.10 $, and FIT 0.05 $;
7. Metering mode: net-metering, gross-metering;
8. PV penetration: 76% of customers generate from PV.

In our analyses, we assume a scenario where digital technologies and Building Energy Management Systems (BEMs) systems allow for automated and fully rational individual decisions. Very little or no human interaction is assumed.

**Results**

In this work, we tested alternative design features of support schemes for distributed renewable electricity, namely gross-FITs (i.e. buy-all, sell-all) and net-FITs (i.e. net-billing). Some of our results are summarized in Figure 1 and Figure 2, which we will briefly review here.

a) *Tariff level*: retail tariffs offered under gross-FIT are more expensive than tariffs offered under net-FIT, a higher FIT results in more expensive retail tariffs under both gross-FIT and net-FIT; b) *Aggregate consumption*: a higher FIT results in lower aggregate consumption under both gross-FIT and net-FIT, aggregate consumption under gross-FIT is lower than under net-FIT; c) C*osts:* aggregate customers’ cost and per kWh cost are higher under net-FIT than under gross-FIT at any FIT level, a lower FIT results in a lower per kWh cost in 5 out of 6 scenarios tested, a lower FIT results in a smaller gap between aggregate customers’ costs under gross-FIT and net-FIT; d) *Profit: a* lower FIT results in lower aggregate profit for the retailer offering RTP under both net-FIT and gross-FIT, the default retailer subsidizes prosumption under net-FIT (negative profit), a lower FIT results in a smaller gap between aggregate retailers’ profit under both gross-FIT and net-FIT; e) *Market and profit share*: fully dynamic tariffs reach a market share (i.e. fraction of customers) that is at least 73% under all scenarios tested, and generate profits that are never lower than 68% of the aggregate retailers’ profit, the flat tariff offered by the default retailer reaches the lowest market share under all scenarios tested (i.e. 0%-4%) and it provides negative returns under net-FIT scenarios.

Figure 1 - Aggregate consumption of the entire pool of customers under net-FIT and gross-FIT and different FIT levels

Figure 2 - Aggregate cost for the entire pool of customers and aggregate retail profit under net-FIT and gross-FIT and different FIT levels

**Conclusions**

Understanding retail power markets is a key factor for a successful energy transition towards decentralization, decarbonization, and digitalization. Due to the complexity of the system and its techno-economic nature, we believe this problem can be effectively studied using an agent-based model approach. This is why in this project we do so by accurately modelling the dynamic interaction among rule-based agents (i.e. retailers and customers), considering their objective functions, and a set of market mechanisms. In this work we showcase our model with one example in a specific setting. In this example, we find that FIT has an important influence on consumption, customers’ costs, and retail profits; the higher the FIT, the higher the influence. In our model, retailers have two cost items: wholesale market price and FIT. Therefore, a high penetration of PV and a high FIT can create distortions as they have a significant impact on retailers’ costs. This is emphasized under gross-FIT as the whole PV generation is remunerated at FIT. Because of higher costs, retailers propose more expensive tariffs and customers provide more demand response reducing their consumption. As we said and as can be seen in Figure 1, this effect is more pronounced under gross-FIT. Despite tariffs being more expensive under gross-FIT, customers’ cost is higher under net-FIT as customers react reducing consumption to a lesser extent than under gross-FIT and they receive a payment from the retailer only for the excess energy imported to the grid, and not the whole generation. The same rationale works for retail profits as well. Retail profits are higher under net-FIT despite the tariffs proposed being less expensive than under gross-FIT. This is because under net-FIT, consumption is higher and FIT payment concerns only excess energy. This work aims at presenting to the reader some of the capabilities of our DUEBE ABM model. In the future, we will integrate battery storage and the possibility for prosumers and consumers to trade among themselves. This will expand the capabilities of our model and will allow us to perform more complex tests and identify more suitable retail and local market designs.

## References

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