ODD PROTOCOL

DEMAND-SIDE ELECTRICITY MANAGEMENT APPLICATION IN SPAIN (MADRID)

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Introduction

For the last years, there has been an increasing pressure on developing demand-side electricity management policies that reduce the global consumption of electricity across countries. There are several measures that have been put in place to increase the social welfare from a demand perspective such as price-time sensitive tariffs which drive consumption towards valley hours reducing the required investments in the grids while fostering the principles of prosumer. New algorithms and user-friendly applications have been developed in less regulated electricity commercialization household markets based on behavioral nudging.
In this sense, the monthly consumption of a household (measured in KWh) is compared to the average consumption of its neighbors and scaled to see the position of everyone compared to the average consumption.
From an ABM perspective, there are several models that consider the interaction of the different agents in the system (generation, distribution and demand) [2], [4],[5] and the introduction of hybrid and electric cars considering their impact on demand and the grid [1]. Furthermore, there are studies that consider the behavioral side of the introduction of electric cars and its adoption [1][3]. In this sense, there are not a lot of studies (ABM models) related to demand-side electricity consumption management that place households at the core of the system [5].

Overview

Purpose and patterns

The **purpose of this model** is to see the influence of this measure on the electricity consumption on a residential area in Spain (Madrid) to determine if behavioral nudging has an overall lowering impact on the consumption of electricity in the household market.
The expected **pattern** to be seen is that as the adoption and use rate of the application (which compares consumptions) increases the overall electricity consumption should decrease. A threshold should be established based on previous studies related to electricity demand regarding the consumption decrease and increase of the adoption rate. Only decreases over 10% in the overall electricity consumption [7] will be considered as satisfactory through the adoption of this app. Although the adoption and the use of the application are not necessarily the same, the adoption (through download of this application) will be considered as a good proxy of its use.

Entities, state variables and scales

The entities of the model entities are **block of apartments** (spatial) that build a neighborhood powered by one substation (excluding malls and public spaces which will have their own feeding substation). The blocks of apartments will be represented in a grid following the blueprint of a neighborhood in the outskirts of Madrid and all of them will have smart meters that will allow the total consumption of the block to be merged and compared to the individual consumption. **Households** (agent) that will vary from 1 to 4 (considering the average number of members per household in Spain) and can be digital or not depending on the use of the application. Households will be linked into **Communities** based on the spatial distribution of the households within each block. The environment will be the season of the year, considering only two seasons (from an electricity consumption perspective: winter and summer).

A concise definition of each entity is as follows:

Entity: **block of apartments**	Type: Spatial
Number of apartments	The number of apartments within the block.
Average size	The average size of the apartment considering the total living area of apartments in a block divided by the number of apartments discretized in three different bins < 90 m^2, 90-120m^2 >120 m^2.
Occupancy	The occupancy of the building raging from 0% to 100% depending on the number of families that live in the apartment.
Type of heating system	Heating system in the building accepting central, individual or both. Central heating will be considered as gas heating so it will not increase the total amount of electricity consumed. When both is selected then the % of individual heating apartments must be specified.
Individual heating	Individual heating is electricity based and the total amount of electricity will be increased due to the use of electricity (heating system and hot water). A factor of 1.25 will be applied to the total consumption
Type of kitchen	“Gas” or “electric” kitchen increasing the consumption of electricity required for the apartment. The use of electric kitchens will increase by 1.15 the total electricity consumption.
Energy Certification	The average isolation of the building/block corresponding to the averaged individual energy certification according to the energy certificates registration.

Entity: Household	**Type: Agent**
Size of the family	Number of people occupying an apartment ranging from 1-4
Type of occupancy	The occupiers of the apartment are “tenants” or “owners”.
Application adoption	The use of the application “Yes/no”.
Age range	The average age of the occupiers of the apartment ranging from 30-85
Income bracket	The income bracket for the household binned in three categories (low, medium, high).
Electricity usage	Smart/not smart users that will try to reduce the electricity bill by adapting to the dynamic tariffs in place for each season.
Amount of Electricity	The total amount of electricity that the household uses per month.

Entity: Community	Type: Collective
Max number of households	Max number of linked agents (households) in an apartments block that build up the community.
Digital households	The number of households within an apartments block that has installed the app. Lower or equal to the max number of households.

Entity: Environment	Type: Environment
Season	From an electricity consumption perspective only two seasons will be considered: Winter (Oct-Mar) and Summer (April-Sept)
Size of the neighborhood	Numeric variable representing the total population of the neighborhood

Scales

Besides the scales defined for each variable of the entities, the following will be considered:

- **Location:** The grid will represent the blueprint of an average neighborhood powered by one substation equating to 4 km^2 (2000 m x 2000m) where each grid cell will represent 2 m^2.
- **Time:** The time span will be four years (time in which tariffs structure remains unchanged in Spain) with a time step of a month (when electricity bills are received).
- **Electricity consumption:** represented by the color of the patch giving a heatmap and will be representing values between 0 kWh (no apartment in the grid, a street), 20 MWh – 100 MWh (best- and worst-case scenarios regarding electricity consumption per block of apartments).

Process overview and scheduling

The entity block of apartments are placed in the blueprint of the neighborhood with random occupancies starting from 75% onwards. Households remain in the block of apartments for at least one year maintaining the occupancy of the block of apartments stable during that period. **See occupancy submodel.**

Entities receive the electricity consumption at the end of each time step (month) and an initial amount (random within each community) have the application that compares consumption. There is no relationship outside of the communities between households regarding the application and at the end of each month the number of households with the application installed changes. As the number of “digital” households increases within a community consumption decreases. **See Community submodel**

For those that have the application installed, the electricity consumption decreases in a period of three months up to 10% while others will not use it and continue with the same level of consumption per season with monthly fluctuations. **See application usage submodel.** Electricity consumption will be naturally increased from summer to winter **(see seasonal variation submodel).** The observer may include half-year price changes increasing and decreasing the price and consumption will vary accordingly **(see price strategy submodel).**

The total consumption per block of apartments, as well as its relative decrease/increase, will be registered in a monthly basis with a cumulative total per season natural year. The relative difference will be shown in different colors as a heatmap and through a comparison chart.

Design Concepts

Emergence

Communities will see how the electricity consumption of the block decreases when the number of "digital" households (households using the application) increase. This will be a cumulative decrease during the months until it stabilizes around an annual 10% decrease due to the better usage of electricity (appliances, etc.).
It is expected to see the decrease of consumption first in those households which have a smaller income bracket and therefore the electricity bill represents a higher percentage of their income.

Objectives

The objective of the households is to reduce the electricity price within the budget within a certain range (not more than 3%). The objective of the community is to maximize the number of households that have the app to achieve the 10% annual decrease of electricity consumption.

Adaptation

Households adapt their behavior during the year due to the price changes and the season. Communities adapt their behavior, and the decrease becomes significant when the number of households with the app increases.

Learning

After the first complete year, households that remain in their apartments learn the way to keep the electricity consumption within budget irrespective of the use of the application. Within the year, the seasonal increase of prices will reduce the consumption to keep it within the desired budget.

Prediction

Communities can predict prices and will modify their behavior based on the potential prices to come after the first year.

Sensing

Households in one block of apartments will know that there are certain households that have installed the application after three months as they will know the overall consumption of their block or apartments (but not from other blocks). Households will have perfect knowledge of the electricity price schemes and their previous month consumption.

Interaction

There are direct interactions between the households of the block of apartments when there are digital households. Within the community, there are interactions between digital and non-digital households. There are indirect interactions between the environment (seasonal consumption and price changes) and the households and communities as the increase of consumption and price will change the behavior of the households to reduce their consumption and will also leave some room to the communities to decrease theirs.

Stochasticity

The initial values of block of apartments and households are taken from real life data. The initial number of digital households within the community are stochastically assigned and updated during the simulation. The occupancy is stochastically updated at the beginning of each year and with it the community. The use of the application of the agent is updated stochastically.

Collectives

Communities are initially (stochastically) assigned in the model and are emergent during the simulation. There is a difference in behavior between strong and mild collectives depending on the number of households within the community that have installed and kept the app for a reasonable amount of time.

Observation

The observations from the model are the following:

- The expected consumption of electricity per block of apartments in a monthly and cumulative way
- The increase and decrease of number of members within a community in each block of apartments
- The price variation and consumption each month for each block of apartments
- The variation of occupancy against the electricity consumption of the block each year

Details

Initialization

The model is initialized taking real data from the neighborhood under study. The blueprint of the neighborhood will be taken from the public information digitally available in https://www.sedecatastro.gob.es/ for Madrid.

The data for the block of apartments and households will be taken from studies and databases as described in *Input Data*. Household variables such as "application adoption" and "electricity usage" will be applied randomly with values following a normal distribution within the communities and values for the former between 10%-20% and 30%-40% for the latter. The year will be initialized as the 1st of January and will follow natural months per steps so the environment "season" will be set to winter.

Input Data

The input data of the variables for the entities of the model will be done in the following way:

- Block of apartments:
    - "Number of apartments", "average size", "type of heating system", if it has "individual heating", "type of kitchen" and "energy certification" are publicly available data on https://www.idealista.com/en/. The values will remain static during all the time steps and the whole simulation

- "Occupancy": It will be initialized considering the number of apartments for rent and sale in the abovementioned webpage (https://www.idealista.com/en/).

- Household:
    - "Size of family", "type of occupancy" will derived from the number of bedrooms per apartment and type of occupancy in https://www.idealista.com/en/
    - "Age range" and "income bracket" will be taken from Madrid's census for the neighborhood https://www.ine.es/en/ and will be compared against data on https://www.citypopulation.de/en/spain/madrid/madrid/28079__madrid/ as it has data that is recently updated.
    - "Amount of electricity" per apartment will be taken as an average considering the installed power (KW) and the equivalent average hours (h) of usage per apartment size and season from https://www.ree.es/en

The data not described here will be part of the initialization process to see how with different values in the rate of adoption and smart usage of electricity the communities and neighborhood consumption evolves.

Submodels

The purpose of the submodels used in the model is to update the parameters for the model to simulate "close to real" conditions. The submodels will work as follows:

- **Occupancy submodel** will update the level of occupancy per year following anormal distribution with occupations that will randomly oscillate around the central value from the input data given to the model for time step 0.
- **Community submodel** simulates the adoption of the application within the blocks of apartments. The number of households using the application will be updated at the end of the month amongst the households that have the highest consumption and randomly consider a 10% adoption. Every 3 months there will be households that stop using the application.
- **Application usage submodel** will take into consideration the effective impact on electricity consumption per household once the application is used. In this case, if the application is in use for more than three months there will be a steady decrease of the electricity consumption and will also incentivize at a lower rate the use of the application by other households of the block of apartments. Effective decrease will be noticeable from the third month onwards (time steps to update the value)
- **Seasonal variation submodel** will consider the seasonal variation increasing by a factor of 1.16 in winter compared to summer [6] and updated throughout the months following a Weibull distribution that will be evolving each month based on the previous month consumption to moderate the impact of the season as it advances.
- **Price strategy submodel** will include four price of electricity changes (one per quarter). To simplify the model the price will be calculated as the total price per KWh irrespective of the KW that the apartment can have. The effect of different prices per power will be factored in when calculating the equivalent hours of electricity usage. The results of this submodel will be updated once every quarter of four steps.

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