MODIFICATION OF THE 'TIME OF USE' PRICING PERIOD: FIRST RESULTS FROM AN EXPERIMENT ON RESIDENTIAL CUSTOMERS IN BELGIUM

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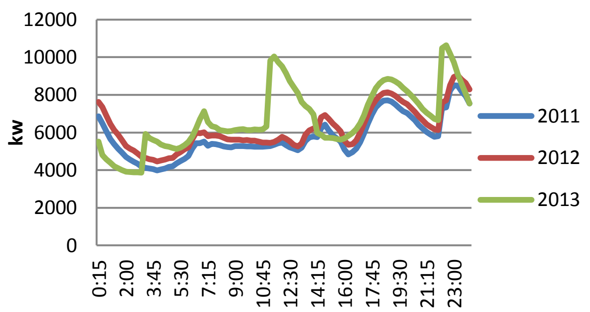
INTRODUCTION

The development of decentralised production of electricity is steadily rising and its integration into the grid is a major challenge for the DSO. And this is why the main DSO in southern Belgium, ORES, decided to start an experiment on two electrical substations S1 and S2. Since July 2013 and until the end of March, residential clients experience a modification of the off-peak period with discounted prices. The three sub-periods: 10pm to midnight, 3am to 7am[1] and 11am to 2pm replace the continuous period of time from 10pm to 7am. The period between 11am to 2pm is aimed to promote consumption during the higher period of photovoltaic production.
The goals of this study are to detect if a significant modification in consumption behaviours has taken place and to determine if there is an impact on the level of global electricity consumption.
The paper will be divided in three sections. The first one presents the results from a qualitative evaluation of the data sets thanks to some graphs; the second, the results from two quantitative methods: the first method is a high frequency forecasting model and the second one is based on two control substations; and in the third section we will conclude. To find a relevant result, the convergence between these three methods is needed.

QUALITATIVE EVALUATION

The qualitative evaluation uses the historical data from the two reference substations to identify structural patterns of consumption and their significant modifications during the experiment. It is illustrated with some graphs.
We will first explain the data use to produce them.
The first data set is the consumption from the two experienced substations minus the consumption from the large companies to only analyse the residential consumption. The set begins in 2011 and the unit is the average power demand by quarter in kW. Its name is 'Infeed – AMR'
The second set is the production from photovoltaic panels for each substation. Because the exact data are unavailable, we set working hypotheses based on the cumulative installed power of photovoltaic facilities (expressed in kVA) and their monthly frequency. The first hypothesis is about the production profile. We used the average profile of seven producers who don't live in the substations area. The second hypothesis is the equality between 1kVA and 1kW. And the last hypothesis is that the production from photovoltaic panels is consumed by the producer or someone else in the substation. This data set is 'PV'
In every graph of this section, the load profiles are the sum of these two data sets to obtain the total consumption on each substation, and are an average week day of the studied month.

Graph 1: Load profiles (Infeed – AMR + PV) in November in S1.

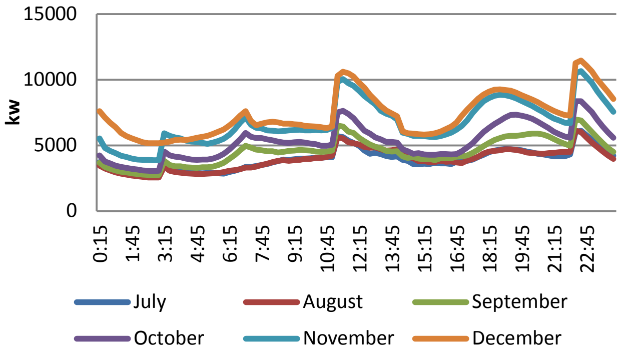


Graph 1 is an example, for the month of November, of the load profiles for three years but the conclusions are quite similar for each month of the experiment and for the two substations.
First of all, it appears clearly on the graph that the experiment involves modifications in the residential client's loads profiles.
In the first sub-period, from 3am to 7am, we notice, in 2013, a consumption peak at the beginning of the period but this one is resorbed before 7am.
For the second sub-period, from 11am to 2pm, the same phenomenon appears in 2013 at the beginning of the period but the peak is bigger in an absolute and relative basis. Note that in July and August, this peak is at the same place than a structural one.
And for the last sub-period, from 10pm to midnight, we note that the consumption at the beginning of the period in 2013 is higher than before, except for July and August. But it also decreases more and quicker until 3am than in 2011 and 2012. This can be partly

1 Since the 20th November, the night period is from 22pm to 7am without interruption to guarantee the same level of comfort to the clients and because of electric heating.

explained by the fact that all trigger signals, for the off-peak period with discounted prices, are no longer sent progressively but all at the same time.

Graph 2: Load profiles (Infeed – AMR + PV) in S1 in 2013.



Graph 2 is an example, for 2013, of the load profiles in S1 for each month from July to December.
The main lesson from it is the evolution between the months. In July and August, the levels of consumption and the load profiles are similar. In September and October, the levels increase slowly and we can notice two modifications on the curves. The first one is at 7am where a new peak of consumption appears because holidays are over and people go back to work or to school and the second one is around 7pm where the increase in consumption is higher than in previous months. For November and December, the level of consumption is still increasing and the peaks at 7am and 7pm are reinforced. Note that the peaks consumption at 11am are the biggest in absolute and relative terms despite the fact that the photovoltaic production is weaker during these months. This indicates that a differentiated policy according to the season could be more effective.

QUANTITATIVE EVALUATION

The quantitative evaluation consists of two methods. The first one is a high frequency forecasting model and the second is based on two control substations.

Forecasting model

The high frequency forecasting model is based on the Synthetic Load Profiles (SLP) from the Belgian Federation of Electricity and Gas network administrators – Synergrid. For each quarter of an hour of a year, SLP calculates a percentage of gas or electricity consumption. Inside this forecasting model, there is a climatic forecasting model (temperatures, wind, nebulosity…).
There are two SLP's for residential electricity consumption, S21 (consumption night/day < 1,3) and S22 (consumption night/day ≥ 1,3). We use a maximum likelihood regression analysis with autoregressive error of order 12 to determine the allocation among SLP S21 and S22 between clients on S1 and S2.

The model is:

$$\% \, C_{ti} \;=\; \alpha * SLP\ S21_{ti} + \;\beta * SLP\ S22_{ti} + u_{ti} \text{ [1]}$$

with α + β = 1;
$\% \, C_{ti}$, the part of daily consumption in substation *i* at quarter of an hour *t*;
$SLP\ S21_{ti}$, value of SLP S21 corrected for real temperatures in substation *i* at quarter of an hour *t*;
$SLP\ S22_{ti}$, idem for SLP S22;
$u_{ti} = -f_1 u_{ti-1} - f_2 u_{ti-2} \ldots - f_m u_{ti-m} + \varepsilon_{ti}$
and ε_{ti}~IN (0, σ^2);
i, substation S1, S2.

After simplifications, we assume that:

$$\% \, C_{ti} - SLP\ S22_{ti} = Y_{ti} \quad [2]$$
$$SLP\ S21_{ti} - SLP\ S22_{ti} = X_{ti} \quad [3]$$

We have, for each substation:

$$Y_t = \alpha X_t + u_t \quad [4]$$

The results of the regressions are summarized in Table 1.

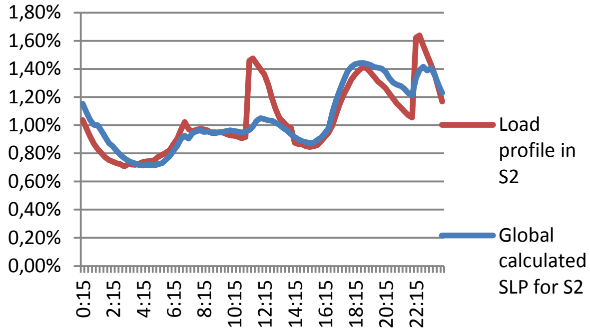
Table 1: Results from the regressions.

	S1	S2
α	0,7394	0,7368
Standard error	0,004400	0,004198
Value of the *t* test	168,05	175,50
Approx of Pr > |t|	< 0,0001	< 0,0001
Durbin-Watson	2,0005	2,0011
Regress R-Square	0,4466	0,4681
Total R-Square	0,9776	0,9776

Thanks to Table 1, we can assert that the alpha value is robust. For S1, the part of SLP S21 and S22 are, 0.7394 and 0,2606 respectively and for S2, 0,7368 and 0.2632. We can now calculate the global SLP for each substation.

In Graph 3, an example for December 2013, the data sets 'Global calculated SLP' or counterfactual load profile and 'Infeed – AMR + PV' are quarter hourly data expressed as a percentage of the total average week day.

Graph 3: Global calculated SLP and load profile (Infeed – AMR + PV) in S2 in December 2013.



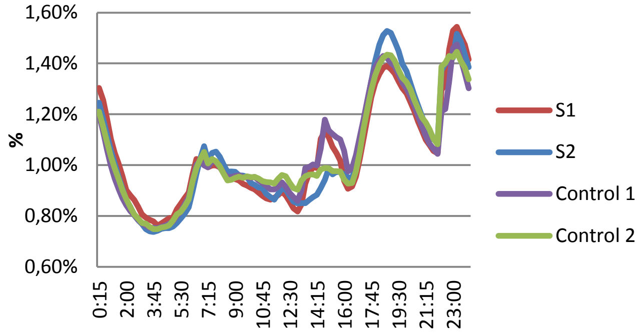
As we can see, the global calculated SLP is a good predictor for the load profile. For each month and substation, we notice an increase in consumption for the period 11am to 2pm, when the photovoltaic panels produce the most. In S1, this increase is, on average of the six studied months, + 2,46% and for the substation S2, +1,86%.
We are still working to transform the percentages in level of consumption (kW). Thanks to the second quantitative method, we will have a first idea of it.

Control substations

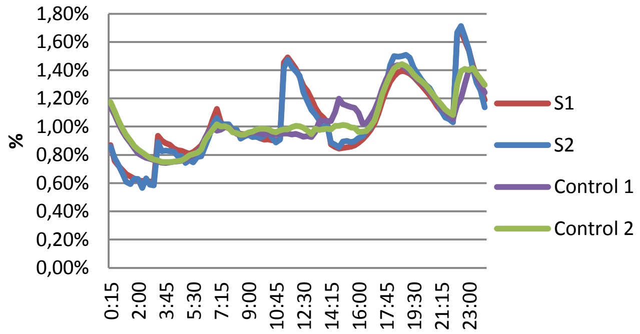
For this method, we will use two control substations. They were both chosen because of their geographic proximity with the reference substations, and so their similar climatic conditions; because they have a comparable volume of consumption and because the same data sets are available from 2011.
The main objective by using control substations is to be sure that the observed effects on reference substations are not caused by external and independent events. The second objective is to use the load profiles from the control substations to predict the 'counterfactual' load profiles for the reference substations during the experiment. The condition for this is that they should have comparable load profiles.

Graphs 4 and 5 represent an average week day of a month, November, in which every quarter is expressed as a percentage of the all-day consumption. Thus, the comparison between the reference and the control substations is easier.

Graph 4: Load profiles (Infeed – AMR) in November 2012.



Graph 5: Load profiles (Infeed – AMR) in November 2013.

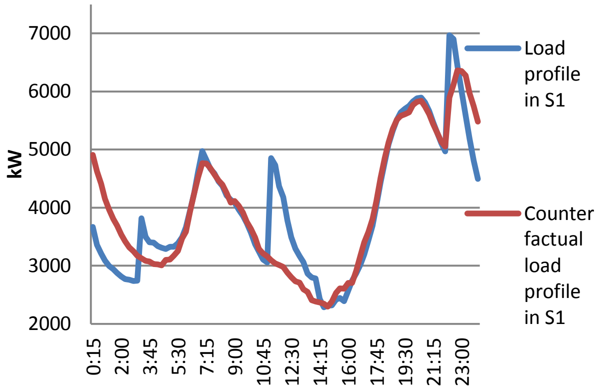


When we compare graphs 4 and 5, we can clearly notice the impact of the policy and especially at the beginning of the new off-peak periods with discounted prices. The first objective of the control substations is so fully achieved.

For the second objective, we need comparable load profiles between the reference and the control substations. Thanks to Graph 4, we can conclude positively. In fact, for example in November 2012, S1 and control 1 and S2 and control 2 are similar and so, control substations can be used to predict 'counterfactual' load profiles.
To build them, we used the data set 'Infeed – AMR' because we don't have to predict the photovoltaic production. Because the control and the reference substations don't have the exact same level of consumption, we need to use coefficients of adjustment to rectify this. For each month of the experiment, the coefficient data set is constructed with the data 'Infeed – AMR' for the same month from the year before. It is an average week day in which the consumption value by quarter of the reference substation is divided by the corresponding value of the control substation. There are so ninety-six data for each month and for each reference substation. These data are then, for each month of the

experiment, multiplied by the average week day of the control substation to obtain the 'counterfactual' load profile.
Graph 6 is an illustration of the results for September 2013.

Graph 6: Counterfactual and observed load profiles (Infeed – AMR) in S1 in September 2013.



In Table 2, we can find a summary of the results for each month of the experiment.

Table 2: Results from the control substations method.

Months	Differences in % of electricity consumption between the observed and the counterfactual load profiles in S1 for an average week day	Differences in % of electricity consumption between the observed and the counterfactual load profiles in S2 for an average week day
July	-2,85%	-2,38%
August	-4,95%	-7,61%
September	-0,01%	-3,10%
October	2,58%	5,23%
November	6,40%	-1,92%
December	6,79%	-0,95%

One of the conclusions from Table 2 is that the policy doesn't have the same impact everywhere and in any time. However, for the sub-period from 11am to 2pm, during which the photovoltaic production is higher, there is an increase of consumption in the two reference substations and for each month. This increase is in average for the six months of the experiment, for S1 and S2 respectively, +3,15% and +2,47%.

CONCLUSION

Even at this early stage of the research, we can conclude from the qualitative evaluation that a seasonal policy should be more effective than a global one (see Graph 2).
One of the experiment goals is to promote consumption during the higher period of photovoltaic production, the period from 11am to 2pm. Thanks to the quantitative evaluation; we can argue that this aim is fulfilled. Even if the percentages of increase in substation S1 and S2 are not exactly the same if we use forecasting model method or control substations method.

In the future, we have to work on the forecasting model based on SLP's to convert percentages of load profiles into kW. We have also to evaluate the error linked to the counterfactual load profiles and develop our own forecasting model based on historical data of substations by using a vector auto regression model.