Economic Impact of Dynamic Electricity Pricing Mechanisms Adoption for Households in Sweden

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Global smart metering market growth has increased significantly over the past few years and the trend is expected to continue. Smart metering technology enables energy consumption feedback and the adoption of dynamic pricing mechanisms that encourages users to shift power consumption from peak-use times to lower-use times, in order to help balance the load in the power system. In Sweden particularly, the introduction of the new legislation and adoption of remote meters in 2009, in combination with more flexible pricing schemes, offer a great opportunity for users to reduce energy consumption during peak times, increase their energy efficiency and therefore reduce their overall cost. More recently, in 2012, Swedish energy providers started offering hourly spot-based electricity price to homeowners in order give them access to pricing mechanisms that are closer to the real cost of electricity supply. Additionally to hourly pricing, other dynamic pricing contracts are available for consumers all across the country; however, conventional agreements that use fixed-rates for electricity are still the most common. This paper analyzes the economic impact for consumers, if dynamic pricing, enabled through smart metering technologies, is adopted. To achieve this, electricity costs from a large group of households were calculated, using users' hourly consumption data with both conventional fixed rates and real time pricing, in order to understand their impact on customers' bills. Obtained results suggest that real time pricing has great savings potential, especially for years where summer rainfall and winter conditions are within average. However, in order to increase savings and have them consistent year after year, changes in user time-of-use consumption profile are required. Moreover, this research work leads to further analysis on dynamic pricing combined with demand response in order to optimize electricity costs.

1. INTRODUCTION

The electrical grid allows energy to be transferred from the generators (supply) to the end-users (load). In order for the system to run properly, the amount of power produced has to equal the consumed power plus the losses in the system. Energy storage could be used as a buffer to help keep the system balanced under unexpected rapid changes between supply and demand; current technologies, however, provide with limited storage capacity and financial benefits are yet not fully understood [1].

For the supply to equal the load consumption, different power sources have to be used and dispatched according to demand fluctuations. Each power source has a different cost structure and run on different operation conditions; the system's operator has to decide which power sources to include in the system at any given time, based on several parameters, for instance: running costs, electricity demand forecast, weather conditions and reservoir capacities.

This operation principle leads to a variable operation cost for the electrical system as a whole. How to charge end-customers from a variable pricing product has been debated since the beginning of the electric power industry (early- to mid-1890s). Utilities defined the optimal pricing regime for this service: Hopkinson's differentiated rates based on time-of-day use [2]. Additional dynamic pricing schemes have been developed since then and current methods include critical peak pricing (CPP), critical peak rebate (CPR), demand-based tariff and real time pricing (RTP) [3], [4], [5], [6].

The Nordic Power system is based on a mixture of generation sources with a total installed capacity of 97 622 MW. Over half of the production capacity comes from renewable power sources, with hydropower accounting for more than half of the total production. Combined Heat and Power (CHP) is the second largest generation source with a contribution of 31% of the total production share. Nuclear Power is used only in Sweden and Finland and accounts for 12% of the total Nordic generation capacity. Wind power currently accounts for 7% of the total production capacity, but has increased significantly over the last few years [7].

The Swedish electricity market was deregulated after January 1, 1996. This means that both electricity production and retail have been subject to competition after the reform. Network operation is a regulated monopoly. Since the reform, the electricity price is determined by supply and demand in an hourly basis on NordPool's spot market (Elspot) for the next 24-hour period. Due to physical transmission restrictions between countries, the Nordic electricity market is divided into bidding areas (Elspot areas) [8].

For each hour of the following day, the players in the spot market specify the amount of electricity they wish to sell or buy. All the bids are aggregated both in price and quantities and the demand curve is built from the sum of all purchase bids. The combination of price and quantities where supply and demand curves match, establish the market price as shown in figure 1 [8].

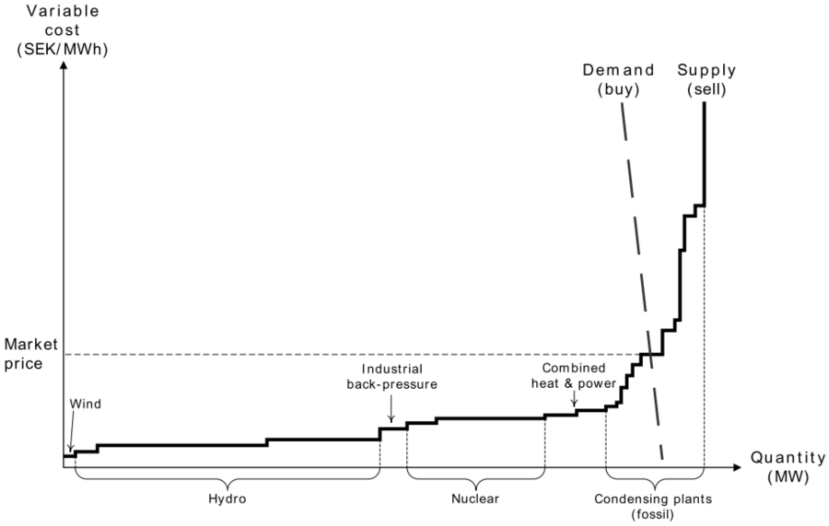


Figure 1. Price formation in the Nordpool Spot Market

In 2011, NordPool Spot's market share of all the electricity consumed in the area was 297 TWh, about 75% of the total electricity consumed. Almost all electricity generated and consumed in Sweden was traded through NordPool Spot [9].

For household users in Sweden, total electricity cost comprises the cost of electricity supply itself, electricity transmission and energy taxes and VAT. The share of the electricity supply price has increased over the last decade and in January 2012 it made up to 49% of the user's electricity bill. 15% corresponded to the network tariff and 36% to energy tax and VAT [9].

One of the main advantages for residential users of a deregulated market together with smart metering technology, is the contract flexibility and options provided by electricity suppliers [10]. In 2012, over 1.6 million households users changed electricity suppliers or entered a new contract, corresponding to 37% of the total amount of residential users in the Swedish electricity market [9].

Even with a residential sector highly active on the electricity market, users still prefer fixed-price contracts over variable-price ones. The majority (42% of all users) chooses to have a fixed-price electricity supply contracts at fixed-term, while only 27% choose to have variable-price electricity supply. Of all users, 24% still have open-ended contracts, and 7% have other type of agreements [9].

Open-ended contracts' customer base is declining rapidly, since users are becoming aware of available flexible options and this type of agreement offer the most expensive price per kWh. Users choosing fixed-term contracts at a fixed price are moving from three-year contracts to one- and two-year contracts, showing a shift towards shorter-term commitments between users and their service providers. Variable-price contracts, however, remain stagnant since most users are yet not willing to move from the conventional fixed-price electricity supply to a variable price scheme, where unexpected weather changes may induce price fluctuations.

In this paper, the impact on electricity bills of switching to a real-time pricing (RTP) electricity supply contract is studied on 400 households in the central region of Sollentuna, near Stockholm in Sweden. Electricity consumption series for 8 years, between year 2000 and 2007 were obtained from the smart metering infrastructure available in the area. The annual electricity supply cost was calculated using the regular fixed-price and was also calculated for a RTP using Nordpool's spot price. The results were compared for each individual user for each year of study in order to establish the advantages and limitations for household users to switch to market price based electricity supply contracts.

2. MATERIAL AND METHODS

400 residential users from the municipality of Sollentuna, in central Sweden, were selected for this study. The region of Sollentuna has 65,891 inhabitants and is situated 15 km north of Stockholm. Out of the 400 users, 200 users were connected to the district heating (DH) network and 200 used electricity as the main source of heating.

Electricity consumption data was provided as raw text directly from the local utility's database. File contained 3 columns: meter ID, time-stamp (YY:MM:DD HH:MM format) and electricity use value (in kWh). Additionally, for each user ID, information about their main energy source used for heating was also provided. Users could be either connected to the district heating (DH) network, or could use electrical heating.

Fixed electricity prices per kWh were obtained from the Swedish Central Bureau of Statistics both for users with and without electrical heating. Hourly market price per kWh was obtained from Nordpool's electricity prices database.

All the hourly data entries were formatted into MATLAB time-series for processing. Missing values in electricity consumption data were linearly interpolated. Each user time-series was adjusted for daylight saving time (DST) for each corresponding year. Data entries were indexed using a common time-vector. This vector was formatted in serial format; it represents, in a single number, the amount of days that have passed since 01/01/0000.

User data was organized into two main groups: users with DH and users with electrical heating. In order to eliminate potential non-residential users, for the first group of users, those with electricity consumption over 20000 kWh per year were filtered. In the second group, the filter was applied for users with annual electricity consumption over 40000 kWh.

Hourly electricity price supply cost matrices were obtained for each filtered group for both pricing schemes. Time-of-use (TOU) matrices and annual matrices were also obtained from the hourly cost matrices. In Addition, highest priced hour was extracted for each day of every year.

3. RESULTS AND DISCUSSION

All the resulting matrices from the user electricity consumption data and its electricity supply costs for both fixed- and RTP schemes were analyzed and plotted for each year to compare its impact on users' electricity bills based on market price fluctuations.

3.1. Annual Electricity Consumption and Supply Costs

Nordic countries' electric supply is very sensitive to environmental changes, specially due to the large use of hydropower and strong connection between temperature and electricity consumption during winter season [11]. It is therefore, a clear connection between this factors and the electricity price.

Mild winters resolve in stable prices and just above average for the first months of the year. Out of the 8 years of study, years 2000, 2002, and 2004 fall within this category. Year 2000 is shown in Figure 2 as an example.

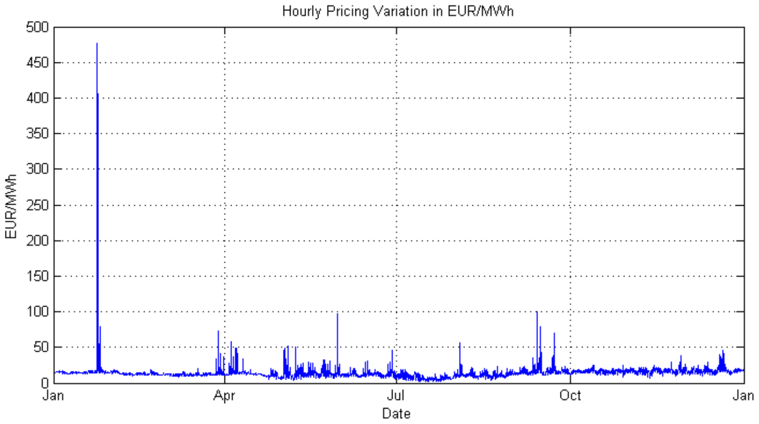


Figure 2. Hourly price variation in year 2000.

Cold winters produce the opposite pattern, higher than average prices during the first 3 to 4 months of the year. Years 2003 and 2006 experienced this behavior; year 2003 market price is shown in Figure 3.

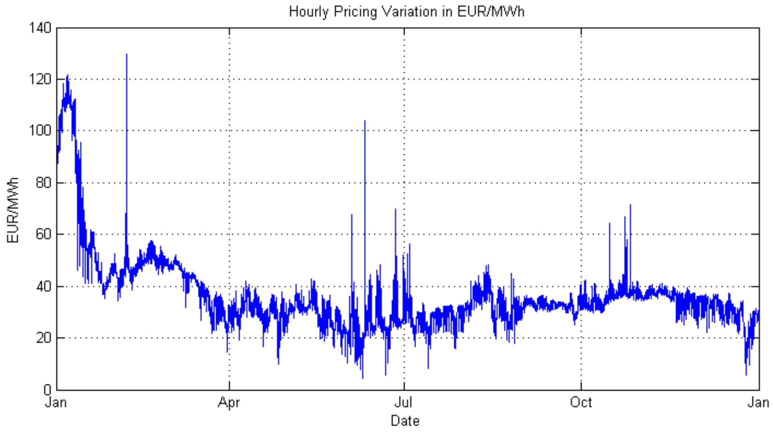


Figure 3. Hourly price variation in year 2003

Other years presented fluctuations over the winter period, but maintaining a price range within average.

Abundant summer rainfall is usually followed by low market prices through the rest of the year, with particularly low prices during the months from June to August. Year 2001 experienced this phenomena and its hourly market price is shown in Figure 4

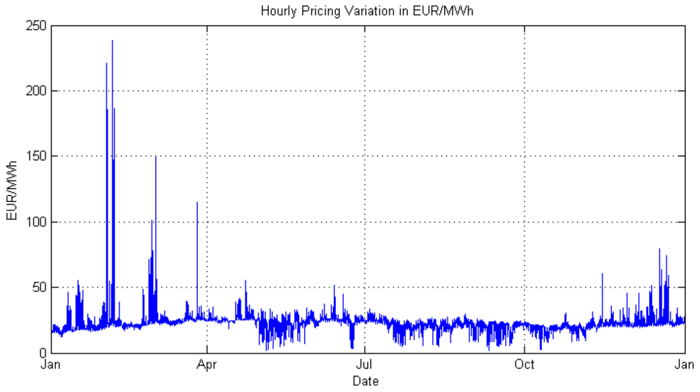
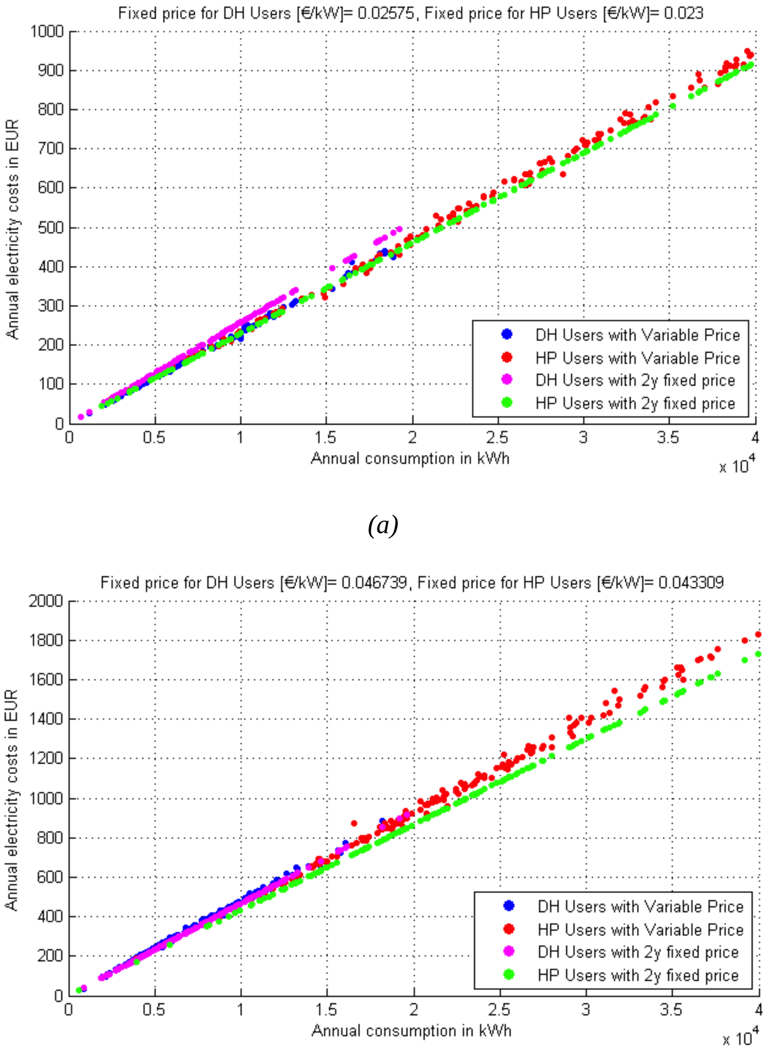


Figure 4. Hourly Electricity Price variation for year 2001

3.2. Annual Electricity Supply cost

Annual electricity supply costs were calculated using both fixed and variable prices for each user for the two groups every year of the study. Both pricing schemes were compared calculating the annual costs vs. annual consumption.

Annual electricity supply costs for users with fixed price contracts were highly affected by the weather conditions of the year before, and can be compared with fluctuations on the spot price market. For those where the year before presented low average prices and small price fluctuations at the end of the year, the fixed price was low. If the upcoming year presented low fluctuations, annual supply costs were very close between the two pricing schemes. This phenomena con be appreciated in years 2001 and 2006 and the results are shown in Figure 5.

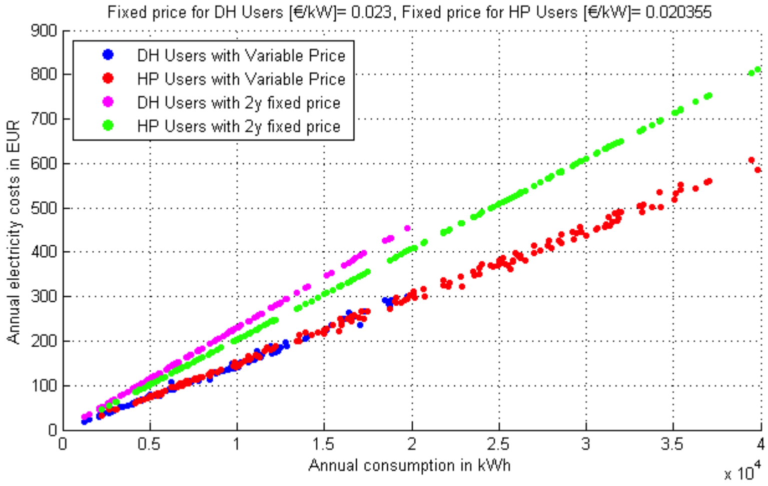


(a)

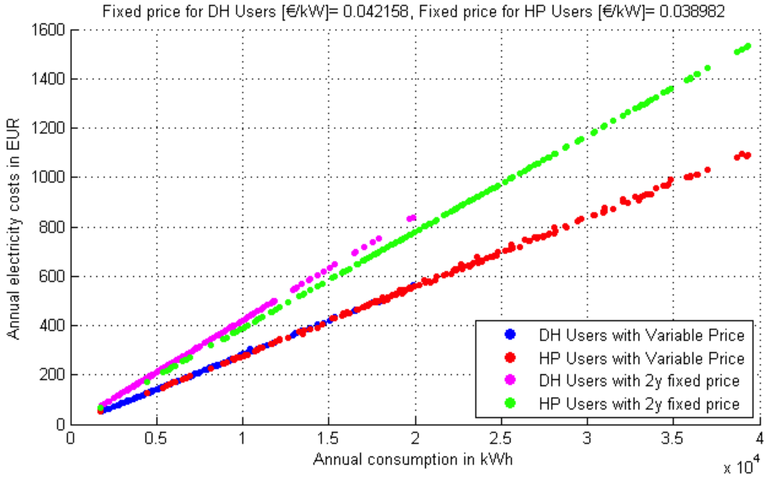
(b)

Figure 5. Annual Electricity Supply Cost vs Annual Electricity Consumption for years with low average market prices and low fluctuations. (a) 2001, (b) 2006

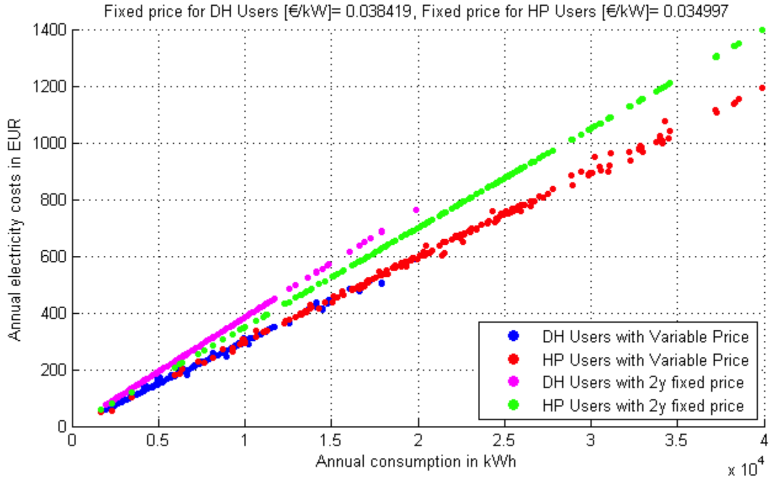
Years with low average price and small fluctuations, offered both user groups with lower annual electricity supply costs for RTP contracts. If the previous year had experienced high prices, the running year ended with fixed-price based contracts paying more than users with RTP contracts. This phenomenon was experienced in years 2000, 2004, 2005 and 2007 and results are shown in Figure 6.


Fixed price for DH Users [€/kW]= 0.023, Fixed price for HP Users [€/kW]= 0.020355
Annual electricity costs in EUR
Annual consumption in kWh
x 10^4
0
100
200
300
400
500
600
700
800
900
0
0.5
1
1.5
2
2.5
3
3.5
4
● DH Users with Variable Price
● HP Users with Variable Price
● DH Users with 2y fixed price
● HP Users with 2y fixed price

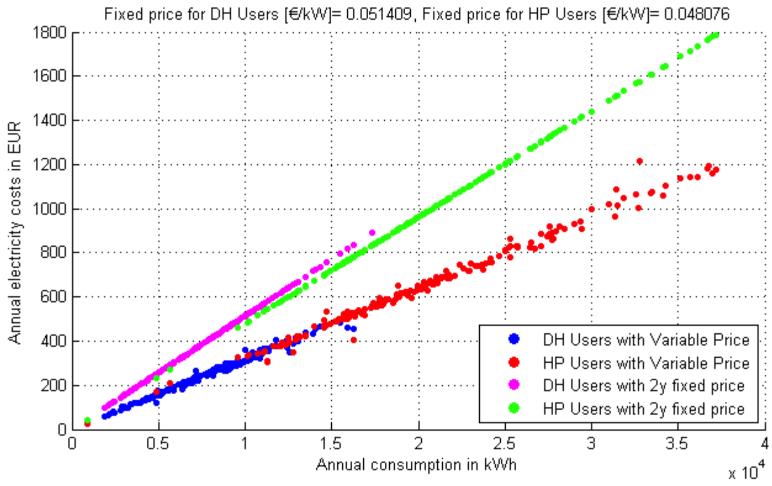
(a)


Fixed price for DH Users [€/kW]= 0.042158, Fixed price for HP Users [€/kW]= 0.038982
Annual electricity costs in EUR
Annual consumption in kWh
x 10^4
0
200
400
600
800
1000
1200
1400
1600
0
0.5
1
1.5
2
2.5
3
3.5
4
● DH Users with Variable Price
● HP Users with Variable Price
● DH Users with 2y fixed price
● HP Users with 2y fixed price

(b)


Fixed price for DH Users [€/kW]= 0.038419, Fixed price for HP Users [€/kW]= 0.034997
Annual electricity costs in EUR
Annual consumption in kWh
x 10^4
0
200
400
600
800
1000
1200
1400
0
0.5
1
1.5
2
2.5
3
3.5
4
● DH Users with Variable Price
● HP Users with Variable Price
● DH Users with 2y fixed price
● HP Users with 2y fixed price

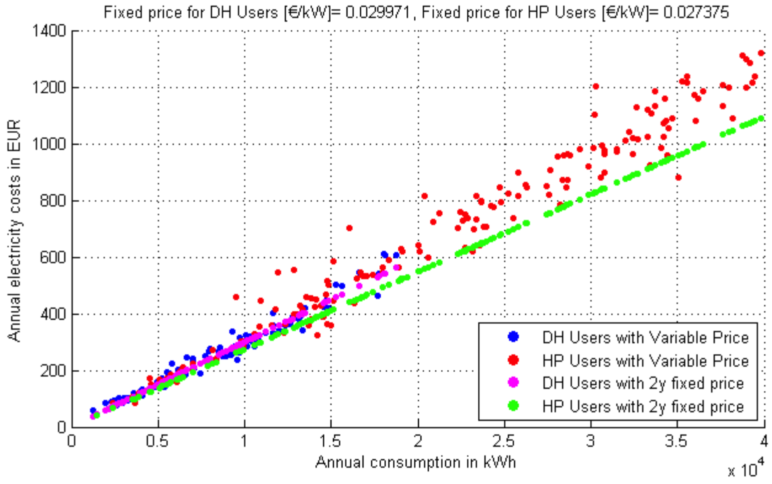
(c)



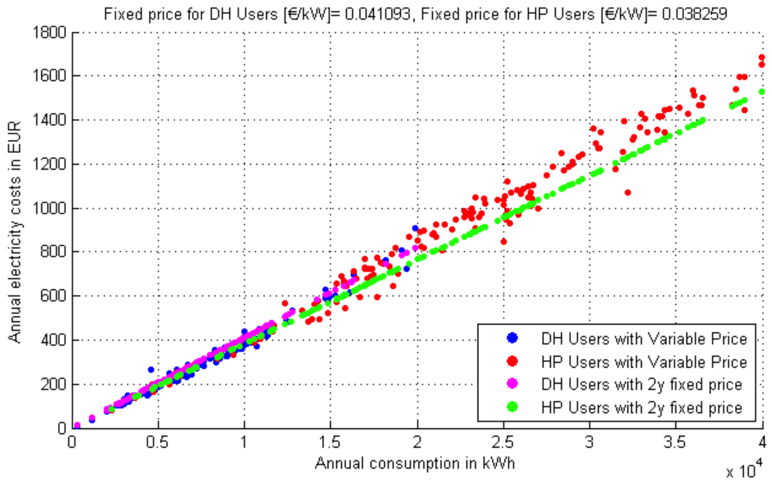
(d)

Figure 6. *Annual Electricity Supply Cost vs Annual Electricity Consumption for years that experienced higher average market price on previous year. (a) 2000, (b) 2004, (c) 2005, (d) 2007*

Finally, in years where high weather fluctuations were experienced, electricity supply costs for RTP contracts were significantly higher. The winter season of 2002-2003, experienced the lowest temperatures of the 8 years of study [11]. Its impact on RTP contracts is shown in Figure 7.



(a)



(b)

Figure 7. Annual Electricity Supply Cost vs Annual Electricity Consumption for years with significant weather fluctuations. (a) 2002, (b) 2003.

3.3. Time of day price analysis

A histogram of the time of the day (TOD) where the highest daily price took place was obtained for each year, together with the average hourly price for the whole year, in order to establish a relationship between the frequency of the most expensive hour of the day and its price.

Five out of the eight years of study (62%) experienced the highest price of the day at 9:00 am, 2 years (25%) at noon and one year (12.5%) at 18:00. However, when analyzing the annual average hourly price of the day, for 4 years (50%) the highest price was recorded at noon, for three years (37.5%) at 09:00 and one year (12.5%) at 11:00, all the results are shown in Table 1.

Table 1. Time of Day Electricity Price Analysis

Year	*TOD with the highest daily price*	*Days of occurrence*	*TOD with the highest annual average price*	*Avg Price [EUR/kWh]*
2000	*09:00*	*81*	*09:00*	*0.0184*
2001	*12:00*	*70*	*09:00*	*0.0277*
2002	*09:00*	*86*	*12:00*	*0.0305*
2003	*09:00 / 18:00*	*67 / 67*	*12:00*	*0.0396*
2004	*9:00*	*109*	*12:00*	*0.0300*
2005	*9:00*	*81*	*9:00*	*0.0325*
2006	*18:00*	*67*	*12:00*	*0.0516*
2007	*9:00*	*67*	*11:00*	*0.0336*

When analyzing electricity consumption profiles for both users group, it was found that the morning consumption patterns were similar, peaking at 9:00 am. Regarding the afternoon peak, for users connected to the district-heating network, this peak took place at 20:00 for 5 years of the study (62.5%) while it took place at 21:00 (37.5%) for three years, however, electricity consumption was very similar during those two hours. The result was the same for users with electric heating, but the peak hour time differed between years, when compared to the other users group. Complete results are shown in Table 2.

Table 2. Electricity consumption peak times analysis

Year	*Users with District Heating*		*Users with Electric Heating*	
	TOD for the morning consumption peak	*TOD for the afternoon consumption peak*	*TOD for the morning consumption peak*	*TOD for the afternoon consumption peak*
2000	*9:00*	*20:00*	*9:00*	*20:00*
2001	*9:00*	*20:00*	*9:00*	*20:00*
2002	*9:00*	*20:00*	*9:00*	*20:00*
2003	*9:00*	*20:00*	*9:00*	*20:00*
2004	*9:00*	*21:00*	*9:00*	*20:00*
2005	*9:00*	*21:00*	*9:00*	*21:00*
2006	*9:00*	*21:00*	*9:00*	*21:00*
2007	*9:00*	*20:00*	*9:00*	*21:00*

Excluding year 2001, for users with electric heating, the afternoon peak was higher than the morning one in all cases.

When comparing the two tables, the morning consumption peak becomes critical, because it happens during the time when the chance of having the most expensive price of the day is the highest. The afternoon consumption peak happens about three hours shifted from the afternoon price peak, and therefore it does not cause as great impact.

3.4. CONCLUSIONS

A mature smart metering infrastructure in Sweden, has provided residential users with new opportunities to access dynamic pricing mechanisms that could encourage them to change energy consumption patterns in order to use electricity when the production costs are lower, providing them with a chance of saving on utility bills.

The economic impact of adopting electricity supply real-time-pricing contracts for residential users in Sweden was analyzed and presented on this paper. Hourly electricity consumption data from 400 users in the central region of Stockholm was gathered and used for comparing the annual electricity supply costs between fixed-price and RTP contracts.

Results showed that there is a strong dependency on weather patterns and electricity supply costs. Years with predictable conditions, like normal rainfall in summer and mild winters, provided users using RTP with an economical advantage over users with fixed-price contracts. On the contrary, years with strong winters and with changes on summer rainfall provided with price spikes that severely affected users with RTP, ending it higher annual electricity supply costs compared with users with fixed-price contracts.

Users with electrical heating experienced the largest differences between the two types of contracts, however, in general, savings achieved through adopting RTP alone will not be enough to encourage users to shift, unless time-of-use consumption patterns are changed, since the savings are not consistent and without proper electricity time-of-day usage profile, it cannot be guaranteed that RTP will provide with savings every year.

In order to do so, effective feedback strategies should be adopted that would allow users to understand their electricity usage patterns and thus, increase their consumption awareness. Electricity retailers could also provide users with information about the economic impact of adopting different dynamic price mechanisms based on their own historical electricity consumption profiles, rather than just the total annual consumption.

Finally, home-automation and home energy management technologies should work together with dynamic pricing strategies to provide users with large savings through automated demand response in order to reduce the payback period of the required investments for the adoption of these technologies.

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