Modelling Real-Time Pricing of Electricity for Energy Conservation Measures in the UK Commercial Sector

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Abstract — Electricity bills in the UK are increasing year after year due to power market conditions and they will most likely continue to rise. These high costs are reducing the profitability of businesses and thus efforts on understanding and mitigating these charges are a key concern for companies in order to improve their bottom line. This paper focuses on detailing a comprehensive bottom-up model of electricity commercial bills that generates real-time price curves; thus allowing customers to comprehend the true cost of electricity over time for different UK regions across various seasons. Such insights provide clarity and are valuable because they can be used to inform efficiency programs; thus allowing decision makers to evaluate more accurately the return on investment their initiatives can have. Results overall show Yorkshire has the highest rates, while the South West has the most expensive peaks. Meanwhile, London and Southern England have the cheapest rates.

Index Terms — energy markets, modelling electricity tariffs, network charges, real-time pricing

I. INTRODUCTION

Electricity bills in the UK are among the most expensive in Europe for non-domestic consumers [1]. Although after the liberalization of the power sector in the 1990's costs dropped, this trend has radically changed in the past decade. The average commercial customer rates from 2004 to 2015 rose by 264% (from 4.02 p/kWh to 10.62 p/kWh) [2]. The needs to invest in both new conventional and renewable power plants as well as in transmission and distribution infrastructure are the main reasons behind surging electricity costs [3]. Due to the existing power system challenges, costs will continue to rise in the foreseeable future [4]. These high costs are reducing the profitability of energy intensive businesses and hence efforts on understanding and mitigating these charges are a key priority for UK companies if they wish to remain competitive. As a consequence, businesses are becoming more conscious and proactive in terms of energy management [5]. However, due to the complex billing structure and diverse procurement strategies an accurate representation of the true cost of electricity in real-time is difficult to portray [6]. This

fact has the perverse effect of distorting energy efficiency programs as consumers do not fully understand at what time of the day and in which periods of the year they are paying the most or the least for electricity consumption.

Based on this energy context, UK businesses that are energy savvy need taking decisive actions to:

- Keep updated on energy markets and policy;
- Learn in detail how energy is used;
- Comprehend electricity billing structure;
- Identify best times to reduce energy use;
- Understand most suitable technologies to reduce demand;
- Make investments enhancing bottom line while reducing market exposure

Based on context explained, there is a necessity to develop decision support tools for proactive consumers to improve the way they use energy. Accordingly, this paper focuses on detailing a bottom-up model of electricity commercial bills that generates real-time price curves; thus allowing customers to comprehend the true cost of electricity over time for different UK regions across various seasons. Such modelling insights provide clarity to decision makers as it allows them to evaluate more accurately the return on investment their energy efficiency initiatives can achieve. Therefore, it may help trigger initiatives ranging from demand side management up to on-site generation investments. The paper has the following structure: a) the current UK electricity bill for commercial customers is defined and explained, b) key stakeholders and data sources are outlined, c) the modelling approach is described, c) real-time cost profiles are illustrated for different day types and across different UK regions, d) the paper concludes by highlighting the knowledge contribution of this work as well as discussion of key results while also outlining next steps of further work in this exciting research field.

II. UK ELECTRICITY BILL BREAKDOWN

Table I details each tariff component found in UK commercial electricity bills for the financial year 2015-16. Figure 1 shows the role each component has on total cost.

TABLE I. UK TARIFF COMPONENTS

Element	Description
<i>Energy</i>	Cost of the electricity purchased on the wholesale market usually set via bilateral contracts and representing about 48% of total energy cost [7].
<i>DuoS</i>	Use charges covering the costs of operating distribution systems; at about 15% of the bill they are reviewed annually. Charges vary within the 14 distribution network operators (DNOs) based on voltage connection and time of use [8].
<i>TNuoS</i>	Use charges covering the costs of operating transmission networks represent around 5% of the bill and fees are revised annually. The charge varies across 14 zones and is set based on user's average half-hourly demand over three Triad periods taking place every winter season [9].
<i>Dloss</i>	Distribution losses are set through Line Loss Factors (LLFs) by DNOs and are time and season dependent; they represent about 3% of the bill [8].
<i>Tloss</i>	Transmission loss multipliers (TLMs) are used to set charges for transmission losses, which are calculated every half-hour (1% of the bill) [9].
<i>BSUoS</i>	Balancing charge that recovers the cost of day to day operation of the transmission system through half-hourly settlements (3% of the bill) [10].
<i>RO</i>	The renewables obligation addresses the cost of supporting renewable projects. This scheme forces suppliers to purchase varying renewable energy quotas each year and has no temporal or spatial dependency (14% of the bill) [11].
<i>FiT</i>	Complementing ROs, the Feed-in-Tariff scheme is a program from the government to promote the use of small-scale low-carbon generation technologies (less than 5MW); making 4% of the bill [12].
<i>CCL</i>	The climate change levy is a tax on business energy use. The final recipient of supplies of electricity generated from certain renewable sources and combined heat and power enjoy exemptions (6% of the bill) [13].
<i>Others</i>	Procurement management fees and assistance for areas with high electricity distribution costs (AAHEDC) are negligible [14]. Meanwhile, recent market reform initiatives contracts for difference (CfD) and the capacity mechanism (CapM) still have no palpable impact on consumers [15, 16].

Figure 1. 2015 electricity bill breakdown for commercial UK consumers.

III. UK POWER MARKET FEATURES

Once the tariff components that determine the cost of electricity have been comprehended, it is necessary to understand the intrinsic features of the cost data available and how frequent these are updated. By identifying the dynamics each billing component has it makes possible to envisage the influence they have in shaping the cost profiles of consumers. Therefore, when such interactions are accounted for and aggregated it is possible quantify the cost of electricity in real-time; providing rich temporal and spatial information.

A. Data Sources and Review Periods

Table II outlines the data sources in setting tariffs and how often these are reviewed.

TABLE II. UK POWER MARKET COSTING FEATURES

Element	Data Sources & Features	Review Period
<i>Energy</i>	Half-hourly settlement periods based on market index price (MIP) available at the Elexon portal [7].	Long term contracts are norm, but trading can be done up to 1 hour before gate closes
<i>DuoS</i>	Three time band rates on weekdays (red, amber, green), while green band applies on weekends. Fixed and variable costs vary on rate and voltage connection. Reactive power is charged too. Info is published separately by each DNO [8].	Fixed annually - updated February and effective from 1 st April
<i>TNuoS</i>	Based on Triad days (system peaks) measured each year between 16 to 19 hours November to February. Data released by National Grid; the system operator [9].	Tariffs published by 31 st January and take effect from 1 st April
<i>Dloss</i>	DNOs calculate the LLFs and provide these factors to Elexon. Info is published separately by each DNO [8].	Fixed annually - updated February and effective from 1 st April
<i>Tloss</i>	ELEXON, through the Balancing and Settlement Code (BSC) sets out the rules for how transmission network users pay for losses [9].	Calculated for each settlement period (half hour)
<i>BSUoS</i>	National grid provides a monthly forecast of BSUoS; generators and suppliers are liable for these charges and has no spatial variability [10].	Half hour settlement periods
<i>RO, FiT, CCL, CfD, CM</i>	Tariff set by government and enforced by Ofgem; it has no temporal or spatial dependency [11, 12, 13].	Fixed annually - taking effect on 1 st April

B. Regional Pricing

As explained in the previous sections, within the UK there are differences in costs per kWh delivered between geographical locations due to varying DuoS and TNuoS charges. This is due to the fact that delivering power to different parts of the country is costed based on efficiency; which is influenced by topology and asset management. There are 14 DNOs, spread across 6 companies, and similarly there are 14 transmission demand tariffs [17]. Accounting and identifying these areas is highly relevant to develop an accurate representation of real-time costs of electricity. Figure 2 and Table III showcase the DNO regions in the UK.

Figure 2. UK Electricity distribution map [18].
Note: Northern Ireland has been omitted from this study as its costing mechanisms are not similar to the ones in mainland Britain [19].

TABLE III. UK ELECTRICITY DISTRIBUTION MAP

Numbers	Operator Details
10, 12, 19	UK Power Networks (UKPN) [20]
11, 14, 21, 22	Western Power Distribution (WPD) [21]
15, 23	Northern Power Grid (NPG) [22]
13, 18	SP Energy Networks (SPEN) [23]
16	Electricity North West (ENW) [24]
17, 20	Scottish and Southern Energy (SSE) [25]

IV. MODELLING METHODOLOGY & SCOPE OF ANALYSIS

This section focuses on explaining the approach employed to develop UK real-time cost profiles of electricity. Particular emphasis is put on the considerations taken in order to model half-hourly prices of electricity for 4 typical days of the year. Hence, the spatial and temporal features of the various tariff elements need to be comprehended.

A. Seasonal Scenarios

Since TNuoS are charged based on the Triad consumption metered between November to February it was decided to “cost” this element in this particular time period. Therefore, in this work we make a distinction between days from March to October and those from November to February. More specifically, since Triads are bound to occur between 4 to 7 p.m. the allocated TNuoS charges in this model were applied within this time frame; particularly between 5 and 6.30 p.m. as the historical data shows this is the time most likely Triad measurements are to occur [26].

B. Day Type Scenarios

Two day types are simulated in this work: weekdays (WD) and weekends (WE). This consideration arise because the wholesale market prices are quite distinctive from Monday to Friday when compared to Saturday and Sunday; primarily because on weekends only base block clips can be purchased [27]. In addition, red, amber, and green DuoS charges only apply during weekdays, while in the weekend only green charges apply. Such dynamics justify distinguishing separately cost profiles of weekdays and weekends.

C. Spatially Fixed Tariffs

This section outlines how tariff data which is fixed for the whole of UK (albeit some these may be time dependent) was processed for modelling purposes.

- *Energy*: varies half-hourly, most expensive in winter (*i.e.* high demand) and least expensive in summer (*i.e.* low demand). 2014 representative average data was calculated for 4 typical days from data collected in the Elexon portal [7].
- *BSUoS*: varies half-hourly and is most expensive in winter. 2014 representative average data was obtained from National Grid [10].
- *Tloss*: varies half-hourly and spatially using TLMs and transmission loss factors (TLFs). Data was obtained from the Elexon portal [9].
- *RO/FiT/CCL/CfD/CM*: since tariffs are set in advance they have been evenly distributed across each half-hourly interval, except for the Capacity Mechanism which is applied at the same period as TNuoS charges [11, 12, 13, 14, 15, 16].

D. Spatially Variable Tariffs

This section outlines how tariff data which varies across DNO regions in the UK (and usually is time dependent too) was processed for modelling purposes.

- *DuoS*: charges are composed of 3 key groups – fixed, variable, and reactive power [8]. *Fixed* fee is set by DNO based on local capacity and voltage connection daily rates, this cost was distributed evenly across each half-hourly intervals. *Variable* rates come from DNO charging statements specifying time bands. These were applied for each region assuming a low voltage substation HH metered connection (*i.e.* commercial user). *Reactive* charges are applied across each half-hourly intervals based on kVARh measured at 0.98 power factor.
- *Dloss*: DNOs set LLFs for a region into different periods (similar to red, amber, green bands). These were applied for each region assuming a low voltage substation HH metered connection (*i.e.* commercial user) [8].
- *TNuoS*: National Grid’s HH Demand Tariffs were revised to set a rate for DNO regions and applied in weekdays from November to February [9].

E. Methodology

The total cost of electricity in £/kWh for each half-hourly interval in a particular DNO region is calculated using the following expression:

$$Cost_{(s, d, t)} = Fixed\ Tariffs_{(s, d, t)} + Variable\ Tariffs_{(s, d, t)} \quad (1)$$

The cost of electricity is hence a function of the season (s), day type (d) and interval in time (t) being assessed. The *fixed tariffs* are the ones described in Section IV-C while the *variable tariffs* are the ones outlined in Section IV-D.

V. REAL-TIME ELECTRICITY COST PROFILES

The modelling approach described in the previous section was used to simulate the 14 UK DNO regions. From the simulations 56 electricity profiles for 2015-16 were produced.

A. Day Types

The capacity to simulate prices in half-hourly intervals offers very relevant insights into how the cost of electricity varies across different day types. Figures 3 to 6 illustrate the 56 electricity profiles generated; meanwhile Table IV details statistical results of each day type. Results clearly show weekdays have the highest level of fluctuation with distinctive peaks in the early evening, while weekend profiles are a bit more flat in nature. From the figures it is evident that November to February is the more expensive period.

Figure 3. March to October weekday electricity cost profiles.

Figure 4. November to February weekday electricity cost profiles.

Figure 5. March to October weekend electricity cost profiles.

Figure 6. November to February weekend electricity cost profiles

TABLE IV. BASE, AVERAGE, AND PEAK COSTS (P/KWH)

Period	Minimum	Average	Peak	Peak to Base Ratio
March-October WD	6.50	9.73	29.36	4.52
November-February WD	6.26	12.11	73.56	11.75
March-October WE	6.11	6.98	8.62	1.41
November-February WE	6.24	8.40	11.69	1.87

The results allow us to reach the following understanding:

- Average annual electricity cost is 9.63 p/kWh.
- Minimum electricity costs do not vary substantially; averaging 6.28 p/kWh and occur mostly in the early hours of weekdays as well as some hours in the weekend.
- Average prices vary considerably between day types and seasons. March – October weekdays are 39% more expensive than weekends, while November – February weekdays are 44% more expensive than weekends.
- Peak charges during March – October weekdays are 3 times the average cost, while for November-February weekdays this value is 6.

B. Regional Rankings

This section goes in more depth in analyzing the subtleties between UK regions in terms of average cost and peak costs. By combining the datasets presented in the previous section a normalized annual weighted average was calculated as the March to October cost profiles are more frequent (245 days) than the November to February period (120 days). Figure 7 illustrates the UK DNO map in which the red circles indicate most expensive areas and the green circles indicate lower cost areas, meanwhile Table V ranks each region by average cost from most expensive to least expensive.

Figure 7. Most (red) and least (green) expensive regions in the UK.

TABLE V. 2015-16 AVERAGE UK ELECTRICITY COSTS

Region	DNO	Cost (p/kWh)
23	NPG Yorkshire	10.29
13	SPEN Merseyside & Northern Wales	10.16
15	NPG North Eastern England	10.13
22	WPD South Western England	9.90
16	ENW North Western England	9.87
18	SPEN Southern Scotland	9.81
21	WPD Southern Wales	9.62
19	UKPN South Eastern England	9.51
17	SSE Northern Scotland	9.49
14	WPD West Midlands	9.47
10	UKPN Eastern England	9.36
11	WPD East Midlands	9.33
20	SSE Southern England	8.99
12	UKPN London	8.92

Table VI ranks each region by most expensive peaks for the periods of November to February and March to October.

TABLE VI. 2015-16 PEAK UK ELECTRICITY COSTS

Region	Nov-Feb (p/kWh)	Nov-Feb Ranking	Mar-Oct (p/kWh)	Mar-Oct Ranking
10	59.56	3	18.70	9
11	56.62	9	19.89	5
12	56.87	7	12.09	14
13	59.15	4	24.37	2
14	58.13	6	19.73	7
15	36.72	13	19.15	8
16	52.64	10	18.63	10
17	35.84	14	13.26	13
18	49.32	12	21.05	3
19	63.18	2	20.00	4
20	58.63	5	16.46	12
21	56.77	8	19.79	6
22	73.56	1	29.36	1
23	51.89	11	18.29	11

As Tables V and VI show, it is abundantly clear that regions with the highest peaks of electricity are not a precursor for high annual costs. This means other factors such as DNO fixed and variable tariffs (*e.g.* green and amber rates) as well as *Dloss* and *reactive* power have a relevant weight when compounded across a year to shift the costs the ranking. For example, the region NPG Yorkshire has the most expensive rate over a year in the UK, but its peak values of electricity are ranked 11th for both seasonal periods assessed in this study. Meanwhile, WPD South Western England has the most expensive peaks but ranks 4th when average cost is calculated.

VI. CONCLUSION

UK electricity prices have risen substantially in the last few years and they are projected to continue to rise. These spiraling high costs are reducing the profitability of businesses and hence efforts on understanding and mitigating these charges are a key priority for UK companies so they can improve their profit margins. This paper has focused on detailing a bottom-up model of electricity commercial bills generating real-time price curves; thus allowing customers to comprehend the true cost of electricity over time for different UK regions so more effective energy efficiency programs can be devised. Results have shown the valuable insights customers can achieve in identifying at what moments in time they pay the most for electricity. Hence, companies should employ this type of information to devise more innovative and accurate business cases that provide more certainty in the rate of return that can be achieved.

The methodology presented in this work has focused in explaining all the tariff elements and how when these are combined real-time cost electricity profiles can be generated. In this paper results focused on showcasing and comparing 4 typical days of the 2015-16 year in half-hourly intervals for the 14 DNO regions.

Analysis of the results show weekdays have the highest level of fluctuation in prices with distinctive peaks in the early evening, while weekend profiles are a bit more flat in nature. Also it is evident electricity from November to February is the most expensive period overall with very expensive peaks. The most drastic example is the WPD South Western England region which charges 73.56 p/kWh in a winter weekday evening. Nonetheless, expensive peaks do not correlate clearly with most expensive rates over the year. NPG Yorkshire was determined the most expensive region in the UK with a rate of 10.29 p/kWh, however its evening peaks ranked 11th place. Meanwhile the London area has the lowest rates in the country. Further research on network charges and analysis on the weight of each tariff component is required in order to identify more insights into the subtleties of commercial electricity bills.

It is important to stress that due to the nature and dynamics of the UK power market the methodology presented here needs to be frequently updated as it's subject to change to policy initiatives and market externalities. We expect the output from this work will allow decision makers to take a step forward into developing valuable costing models that can diffuse a broad range of economic research into energy systems within a commercial context.

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