UK REGIONAL ELECTRICITY BILL DYNAMICS: Real-time & Scenario-based Time Series Forecasting Models for Large Energy Consumers

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BACKGROUND

Large energy consumers have experienced gradual **increase in electricity expenditures over recent years**[1].The consequent negative impact on their profitability incites them to play a more active role in energy conservation.

However, a **complex billing structure** results from the aggregation of electricity charges set by various stakeholders; as these may vary as a function of **customer attributes** (voltage connection, geographical location or supplier contract) [2].

Together with the influence of **socio-economic, technology or political decisions**, all these factors prevent non-domestic customers from establishing straightforward long-term strategies to mitigate potential losses in revenues.

RESEARCH AIM & OBJECTIVES

The project is part of the **Sainsbury's - Imperial partnership**, developed to both lower the carbon footprint and minimise energy expenditures of the company's retail activities.

This MSc thesis focuses more particularly on capturing current and prospective dynamics within electricity bills of energy-intensive users. The main objectives were:

- To develop a **Real-time electricity bill model**, taking into account locational and temporal variations in tariffs for Financial Year 2017/18.
- To develop a **scenario-based Time-Series Forecasting model** estimating future electricity prices with a 5-year time horizon under uncertainty.

The aim is to pave the way to develop suitable energy savings strategies within the retail sector.

REAL TIME ELECTRICITY PRICE MODEL

METHODOLOGY

Component Classification Fifteen charges compose the electricity bill of Profile Classes 5 and above. These describe singularity in their fluctuations as they may differ **spatially** across the UK, **temporally**, or per **voltage** connection. Furthermore, the targeted consumption attribute include Energy Consumption [kWh], Active Power [kW], Reactive Power [kVArh], Capacity [kVA] or fixed. It was thus necessary to find a way to group the billing components appropriately before recreating the electricity bill. **Table 1** defines the classification established.

Table 1. Tariff Classification for Real-Time Electricity Bill Modelling

Tariff Classification	Components or Tariffs	Charge	Locational Dependence	Intra financial Year Temporal Variations	Voltage Dependence
Stochastic p/kWh charges	MIP, BSUoS	p/kWh	NO	Seasonal, Monthly, day type, HH	Constant
Constant p/kWh charges	RO, CCL, CfD, AAHEDC, Supplier fee, FiT	p/kWh	NO	Constant	Constant
Peaking Charges	TNUoS	£/kW	YES	Seasonal, Monthly, day type, HH	NO
	CM	p/kWh	NO		
Pre-Determined distribution tariffs	DUoS	p/kWh	YES	day type, HH	YES
	Capacity & Exceeded Capacity	p/kVA		Constant	YES
	Fixed charge	p/day		Constant	YES
	Reactive Power	p/kVArh		Constant	YES

Objective Function: The electricity bill of a large energy consumer was taken as the summation of all **tariffs of type** T_i multiplied by the corresponding **customer-specific attribute** A_i it charges (such as energy usage in kWh or power consumption in kW):

$$Electricity\ Bill_{Year_T,DNO_N,VoltageType,DayType,Day,HH} = \sum T_{iY_{ear_T},DNO_N,v_k,dt,d,hh} \times A_{iY_T,DNO_N,v_k,dt,d,hh}$$

with $Year_T$ = Financial Year starting April 1^{st} in Year T and ending March 31^{st} in Year $T+1$
DNO_N = Distribution Network Operator
v_k = Consumer Voltage Connection to the Network (Low Voltage/ Low − Voltage Substation/ High Voltage)
dt or daytype = Week − End (WE) or Week Day (WD), d = Calendar Day, hh = Half − Hour or Settlement Number

Consumer Load Profile and bill aggregation: The aggregation of the electricity bill was done on Python. A large database aggregated every half-hour was created and assigned with the right customer attribute. The energy needs of a 4300 m^2 Sainsbury's superstore was taken as a reference to represent the consumer side.

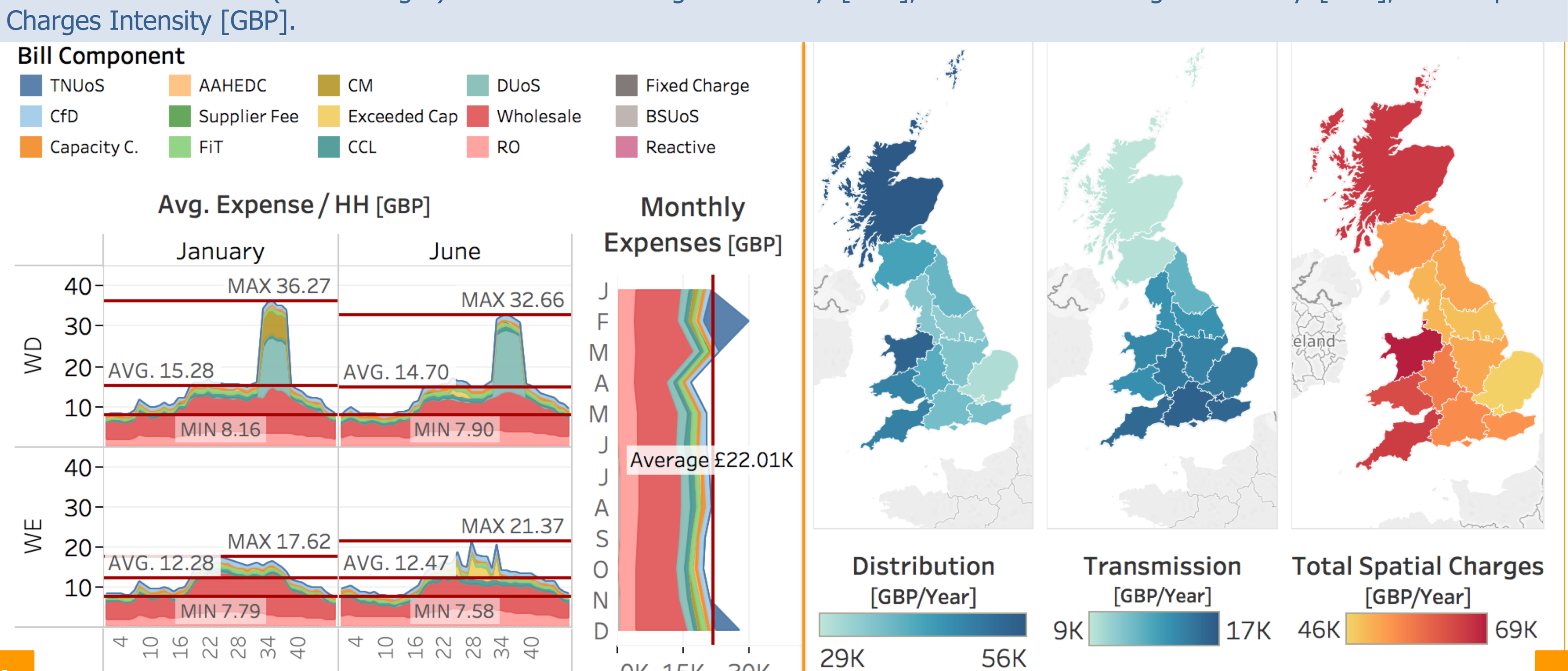
RESULTS

Electricity Bill Profile Total energy expenses were estimated at **£250,152** for the reference store from April 1^{st} 2017 to March 31st 2018. Expenses were dominated by commodity costs(48%), followed by Renewable Obligations(18.9%), and DUoS (8.4%). Prices are highest on week-days and during the winter season, with the occurrence of the punctual triads and Capacity Market.

Spatial Disparities Transmission charges were found to be highest in Northern Scotland and lowest in London. The opposite was true for distribution charges. They appeared to increase proportionally to the distance from the North as indicated in Figure 1. The overall impact of Distribution costs on overall consumer bills were substantially higher as they ranged between **£29K and £56K** against **£9K to £17K** during financial year 2017/18.

Figure 1. Electricity Bill for Year 17/18: Spatial and Temporal Fluctuations

{1}. Temporal disparities in electricity prices. (Left): Average Expense per settlement number and month[GBP]. (Right): Total Monthly Expenses [GBP].
{2}. Spatial Pricing Disparities in electricity prices across the UK per DNO area assuming same load profile than reference grocery store across the UK. (Left to Right): Distribution Charges Intensity [GBP]; Transmission Charges Intensity [GBP]; Total Spatial Charges Intensity [GBP].



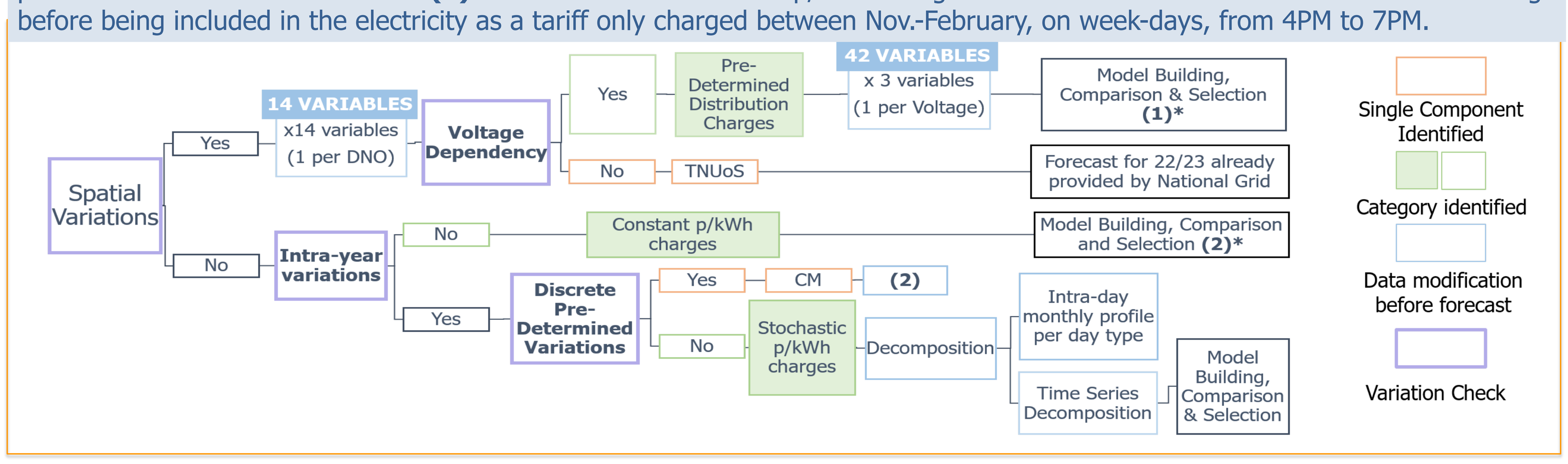
SCENARIO-BASED TIME SERIES FORECASTING MODEL

METHODOLOGY

1. **Quantitative Approach** The time series techniques chosen for the five-year forecast were **component-specific**. The selection resulted from analyses of historical pattern, availability in data but were mainly based on linear or exponential smoothing methodologies integrating various levels of complexity and **seasonality**. The decision tree for method selection is provided through **Figure 2**.

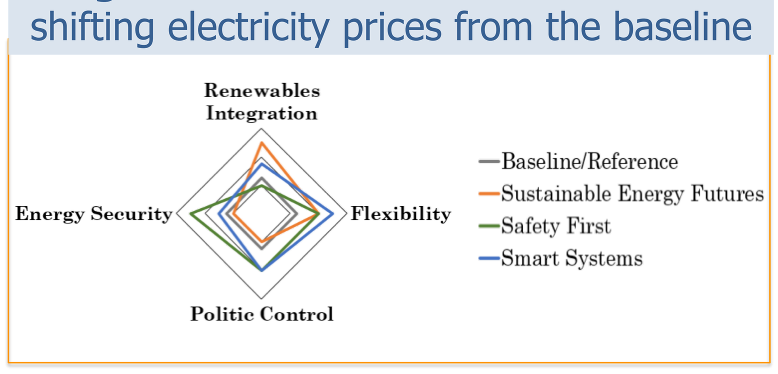
Figure 2. Decision Tree for Electricity Price Forecasting Methodology

(1)* For pre-determined charges, A program was developed to automatically select the suitable forecasting technique upon checking the MSE with test data. Four methodologies were included: 3 exponential smoothing methods with different smoothing parameters and a linear forecast. **(2)*** CM was included in the p/kWh charges forecast in the form of a unit maximum charge before being included in the electricity as a tariff only charged between Nov.-February, on week-days, from 4PM to 7PM.



2. **Qualitative Approach & Scenario Development** Worst and Best case of each component were determined statistically and complemented with the definition of three future energy scenarios shifting from the baseline. These were based upon extensive research and data gathered from major actors of the energy supply-chain. The outlooks were created with various integration of **four drivers:** Renewables Integration, Flexibility and Politic Control.

Figure 3. Definition of three scenarios shifting electricity prices from the baseline

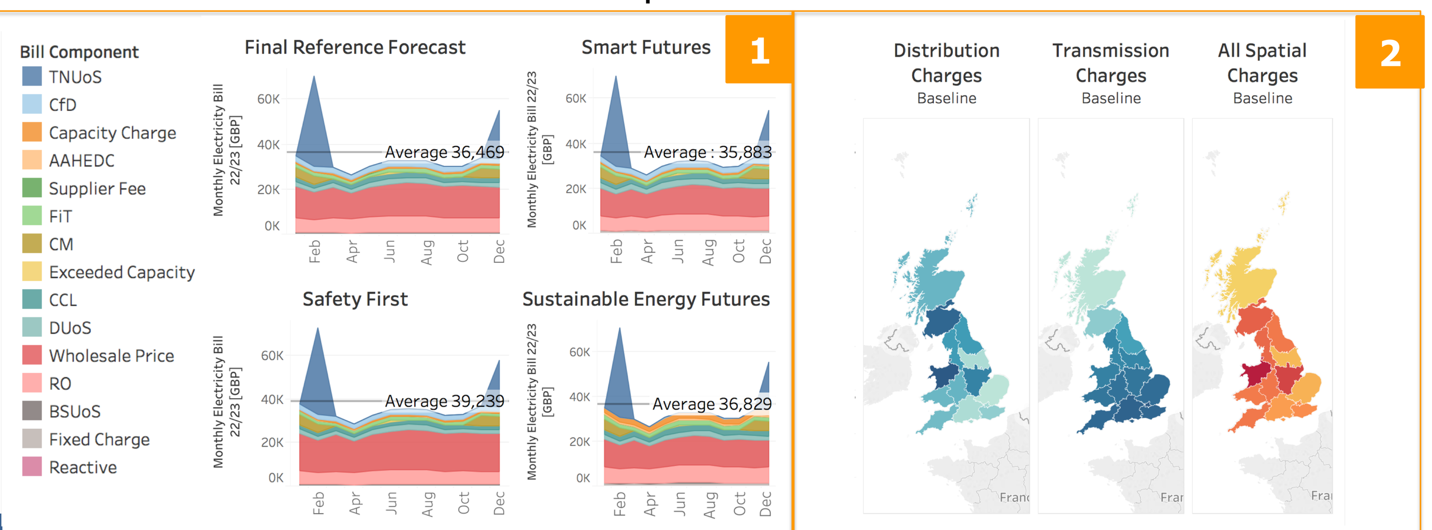


RESULTS

Electricity Bill Profile In all scenarios developed, electricity charges increase significantly for large energy consumers, due to an increase in most tariffs. Bills grow by 67 to 78% within five years depending on the scenario. In the high (or worst) case scenario, policies aim to prioritise security of supply over innovation or clean generation. Commodity costs only account for 38% in the baseline while environmental and social obligation costs climbed up to 34%.

Spatial Disparities The impact of transmission charges across the UK is set to grow substantially within the next five years. The charge intensity as a function of UK region, however, follows the same variations as in 2017/18. DUoS charges have seen their time bands flattening, with the Red Band getting closer to Amber and Green charges. Nonetheless, this does not reduce the price customers pay per year on distribution time-of-use overall, which happen to be rising. Locational charges are to increase by a factor of 2 to 3 in the worst case scenario if prices follow current trends.

Figure 4. 22/23 Electricity Bill. Representation of Spatio-Temporal Fluctuations. Similar Load Profile Reproduced across the UK.
{1}. Monthly Electricity Bill [GBP] for the four composed scenarios.
{2}. Spatial Disparities for Reference Scenario.



CONCLUSIONS

- Findings indicate that **power expenses** should nearly **double** within the next five years for large energy consumers. Prices are highest in winter with the occurrence of triads and capacity market charging at peak times; and on week-days. Time-of-Use Distribution tariffs are **flattening**, reducing the opportunity for companies to implement suitable **demand-side response strategies**.
- The future of the energy market however, is **highly unpredictable**. The interrelation with political decisions and control, energy mix, make it difficult to predict future prices with a fair degree of reliability. The impact of **Brexit** on Interconnection projects is not yet completely understood and may have a significant impact on electricity prices as external policy-makers are involved, although. **Massive EV penetration** could also critically impact the prices and forecasts are systematically revised **upwards[3].** Interviews with various stakeholders of the electricity supply-chain indicate that the market is currently not fit to the purpose.

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