Conclusions from the DEePRED project – distributional impacts of flexible electricity tariffs

Timur Yunusov; Jacopo Torriti

School of Built Environment, University of Reading, UK.

Abstract

Whilst flexible electricity tariffs, such as Time-of-Use (ToU) and real-time, play an important role in motivating the shift of electricity demand away from the peak period and progressing towards the Net Zero, their widespread implementation for residential customers may have an adverse effect on some groups of consumers. The objective of research work within the DEePRED (Distributional Effects of dynamic Pricing for Responsive Electricity Demand) project is to evaluate the distributional impact of flexible tariffs and identify groups of consumers who might be advantaged or disadvantaged based on by their socio-demographic parameters. As the project comes to its conclusion, this paper presents key findings , appraises the impact of ToU on smart meter data and explores the application of such findings in the context of transition to Net Zero. The key findings are as follows: (i) bottom-up (clustering) impact analysis method clearly identifies the most affected household groups; (ii) there is no clear set of socio-demographic parameters that can describe these groups; (iii) grouping by household composition demonstrates that the presence of children increases the probability and intensity of energy-related activities at peak-time and hence increases the likelihood of adverse impact of ToU; and (iv) the impact on consumer groups who do not change their behaviour in response to ToU is defined by the peak to off-peak price ratio, which is confirmed by analysis of ToU impact on smart meter profiles.

Introduction

In the GB, the electricity distribution networks and electricity generation plants are traditionally designed to cater for peak demand, which diminishes the utilization and hence cost-effectiveness of the energy system. In addition to increasing the need to reinforce networks, growing peak demand also contributes to rising prices and CO2 emissions associated with the operation of typically fossil-fuel-based peaking generation plants. Decarbonisation of infrastructures and residential sector, including the uptake of electric vehicles and heat pumps, would increase the electricity system peak demand in the long-term under all Future Energy Scenarios developed by NG ESO (National Grid 2021) if left unmanaged, but could also provide up to 17.7GW of flexibility from residential sector alone by 2050. Introduction of price-based incentives, like flexible tariffs, has a role to play in enabling and motivating flexibility from residential consumers However, the distributional impacts of these tariffs have not been analysed in detail.

Previous studies on flexible tariffs focus on the extent to which tariffs - especially ToU - cause changes in electricity consumption, including temporary reductions in electricity demand during peak periods and absolute net conservation effects. More recently, the distributional effects of these tariffs on different types of residential consumers have been analysed as it was recognised that changes in tariffs may create advantages to some socio-demographic groups, but also disadvantages to others (Hledik et al., 2017, CEPA 2017, Frontier Economics. (2012)).

The introduction of ToU tariffs may affect residential electricity consumers differently depending not only on their financial but also time availability. Understanding how different socio-demographic groups may financially gain from the introduction of ToU tariffs calls for analyses which look simultaneously at highly granular metered electricity consumption data, socio-demographic information about consumers and timing of activities carried out in their homes. This paper sets out to address this research challenge by matching electricity demand profiles to time use activities and assessing the distributional effects of ToU on different income groups.

Previously, authors have reported the outcomes of distributional impact analysis comparing top-down and bottom-up approaches (Torriti, J., & Yunusov, T. 2020) and analysis on differences between socio-demographic groups with modelling of demand from activity data (Yunusov, T. and Torriti, J. 2021). This paper presents the finding from applying the range of ToU tariffs on smart meter data and, building on previous publications, explores how the project findings could inform the transition to Net Zero.

Methodology

Throughout the project, the several methodological approaches based on Time Use activity data analysis were used to understand the distributional impact of ToU tariffs. First approach applied clustering of households according to similarities in energy related activities during peak periods and analysis of peak-to-off-peak ratios for energy related activities (Torriti, J., & Yunusov, T. 2020). Second approach applied extrapolation of analysis of synthetic demand, created by matching smart meter data and time use activity data for income groups, to other socio-demographic groups (Yunusov, T. and Torriti, J. 2021). In this paper, complementing the analysis on time-use data, authors explore the distributional impact of the time of use tariffs from the literature and commercially available real-time price tariffs when applied to smart meter data.

Data

Smart Meter profiles

Smart meter data sets chosen for the analysis were collected as part of two innovation projects and offer composite socio-demographic grouping. First, the Customer-Led Network Revolution (CLNR) was carried out over 2011 to 2014 by Northern Power Grid (Sidebotham & Powergrid, 2015), which is based on 13,000 electricity customers in the North East of England to develop an understanding of electricity use patterns. For domestic customers this included a control set of basic demand profiling with Mosaic consumer segmentation (Experian 2009[1]), and customers with Low Carbon Technologies, such as Air Source Heat Pumps and Electric Vehicles. Second, Low Carbon London (LCL) was a UK Power Networks project encompassing

[1] Experian Mosaic Consumer segmentation 2009 Consumer Types, https://www.experianintact.com/content/uk/documents/productSheets/MosaicConsumerUK.pdf

energy consumption readings from 5,567 London households between 2011 and 2014 with the associated CACI's Acorn[2] consumer segmentation of the customers (Sun et al., 2016). Data is available for a control group and a group that were subject to dynamic ToU tariffs in 2013.

LCL split into control group and group exposed to a number of incentives targeting peak demand reduction and demand turn-up at different trial periods (J. Schofield et al 2014). When split by consumer segmentation groups, CLNR incentive groups had insufficient number of profiles across all groups to be included in the analysis. Applying the chosen tariffs on a year worth of smart meter data from LCL and CLRN assumes no changes in behaviour, which corresponds to the control groups of customers in both projects. The resultant costs from ToU tariffs are compared against the cost if a flat tariff is applied, that correspond to the ToU, matching the time period and location.

Tariffs

To assess the impact of ToU tariff on each socio-demographic group two types of tariffs were chosen: standard flat tariff and static ToU tariffs. The tariff schedules and ratios of price levels for the tariffs were based on two studies by Centre for Sustainable Energy (2014) and by Hledik et al. (2017). The third tariff is a commercially available Real-Time Pricing (RTP) tariff Agile from Octopus Energy (Octopus Energy 2021), representing prices from 2018 and 2019. Unlike, tariffs referenced by CSE and Brattle group, RTP tariffs are linked to the wholesale prices and hence vary throughout the day. Furthermore, consumers have only visibility of the prices for 24 hours in advance.

Table 1 presents the timings and the price levels of the tariffs and Figure 1 compares the shape of the tariffs from literature against the mean Winter month prices for Octopus Agile.

Table 1 - Flat and static ToU tariffs applied to assess the impact on bill costs

Source	Tariff	Peak period	Peak price P/kwh	Middle period	Middle price P/kwh	Off-peak period	Off-peak price P/kwh	Peak to off-peak price ratio
CSE	ToU-1	everyday 16:00-20:00	22.9	-	-	Everyday 20:00 -16:00	10.6	2.160
CSE	ToU-2	everyday 16:00-20:00	23.4	everyday 14:00 - 16:00 20:00 - 23:00	11.7	Everyday 20:00 -16:00	7	3.343
CSE	ToU-3	weekday 16:00-20:00	27.1	Weekday 14:00 - 16:00 20:00 - 23:00	13.7	weekday 20:00 -16:00; weekend all day	8.1	3.346
CSE	Flat	-	-	All time	13.6	-	-	-
Brattle	Tou-1	weekday 16:00-20:00	18	-	-	weekday 20:00 -16:00; weekend all day	6	3.000
Brattle	Flat	-	-	All time	12	-	-	-
Octopus Agile	London 2018	16:00 - 19:00	29.16	All day excl. 16:00 - 19:00	12.81	4 cheapest hours	9.5	3.5804[3] 3.069[4]

---

[2] CACI's Acord Consumer Classification, https://acorn.caci.co.uk/what-is-acorn

[3] Daily ratio of highest and lowest prices.

[4] Daily ratio of average highest and lowest 4 hours everyday.

Octopus Agile	Yorkshire 2018	16:00 – 19:00	29.18	All day excl. 16:00 - 19:00	12.81	4 cheapest hours	9.5	3.701[3] 3.071[4]
	London 2019		25.29		9.4		6.69	6.885[3] 3.7803[4]
	Yorkshire 2019		25.3		9.4		6.69	7.1797[3] 3.7818[4]
Flat tariff	2018	-	-	All time	15.4	-	-	-
	2019	-	-	All time	16.7	-	-	-

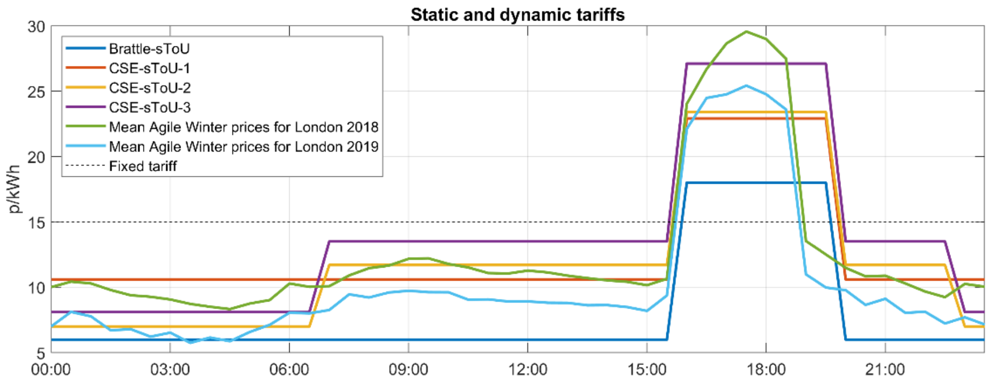

Figure 1: Visual comparison of static ToU tariffs from literature against the 2018 and 2019 Octopus Agile Tariff for London.

A key feature of all tariffs is high price period corresponding to the evening peak demand, starting at 16:00 and finishing at 19:00 for Agile tariff and 20:00 for tariffs from the literature. Being a real time tariff, prices for the Agile vary across the day and year, typically achieving lowest at night between 03:00 and 05:00. Compared to the tariffs from literature, Agile tariff in 2019 tend to be lower for most of the time except for the evening peak demand period.

In addition to the Table 1, distribution of daily peak-to-off-peak ratio are presented in Figure 2. The range of peak-to-off-peak prices between two years, particularly in 2019 where prices reached near zero values on several occasions pushing the average daily peak-to-off-peak price ratio almost twice as in 2018,

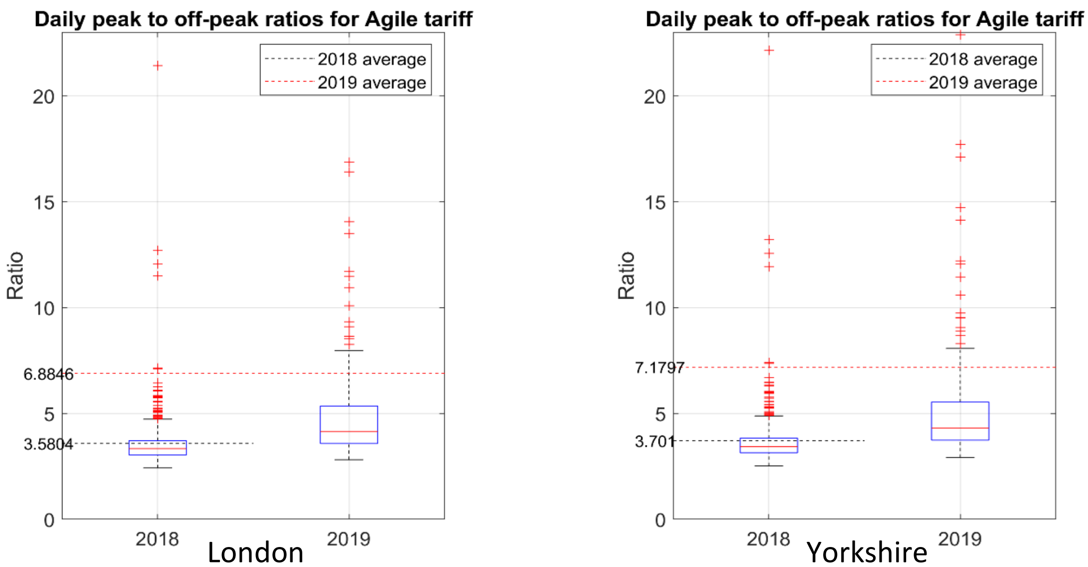

Figure 2: Daily Peak-to-Off-Peak price ratio for Octopus Agile tariff.

Distributional impact

Both LCL and CLNR smart meter data sets include commercially available customer segmentation provided by CACI's Acorn and Experian's Mosaic respectively. These customer segmentation mechanisms are based on a composite of a multitude of parameters and are aimed at evaluating commercial, financial (Acorn) and marketing preference (Mosaic) features of the population by postcode areas. Although income is only one of the parameters in the segmentation, both segmentation approaches can be broadly mapped to income groups based on distribution of national household incomes (ONS 2019) Table 2.

Table 2: Mapping of consumer segmentation groups from LCL and CLNR to income groups.

Consumer income group	Acorn Groups (LCL)	Mosaic Groups (CLNR)
Low (<£19k)	Q	IJKLN
Lower middle (£20k – £26k)	NI	DEFGHMO
Middle (£27k – £35k)	KLMOP	
Upper middle (£36k -£49k)	FGHJ	ABC
High (£49k -£60k)	CDE	
Very High (>£60k)	AB	

Results and Discussion

Smart meter data analysis

Applying the Agile tariff and the tariffs from the literature on the two smart meter data sets demonstrate that the bill reduction across all consumer segmentation groups is mainly driven by the tariff design (i.e. ratio of peak-to-off-peak prices and weekend prices) and the corresponding flat tariff being compared against. Figure 3, particularly shows that potential bill reductions from switching to ToU tariffs from literature or the Agile tariff across all groups is broadly uniform. Comparing Agile 2019 prices against the 2019 average flat tariff of 16.7p/kWh on average all groups achieve around 30% bill reduction. Whilst the 2018 prices, average bill reduction is around 3% and some households in the 90% range of each group could be worse off by up to 8%, particularly those in group E Active Retirement. Similar story is visible when fixed tariffs from literature are applied. All three tariffs from CSE have on average no effect on the bill, however, within each Mosaic group households are split between achieving bill reduction of up to 8% (e.g. C Rural Solitude and E Active retirement) and bill increase by up to 13% (e.g. E Active retirement and M Industrial Heritage). The tariff from the Brattle group report, on average delivers 25% of bill reduction for all groups, however, group E Active Retirement is again having the lowest reduction compared to other groups.

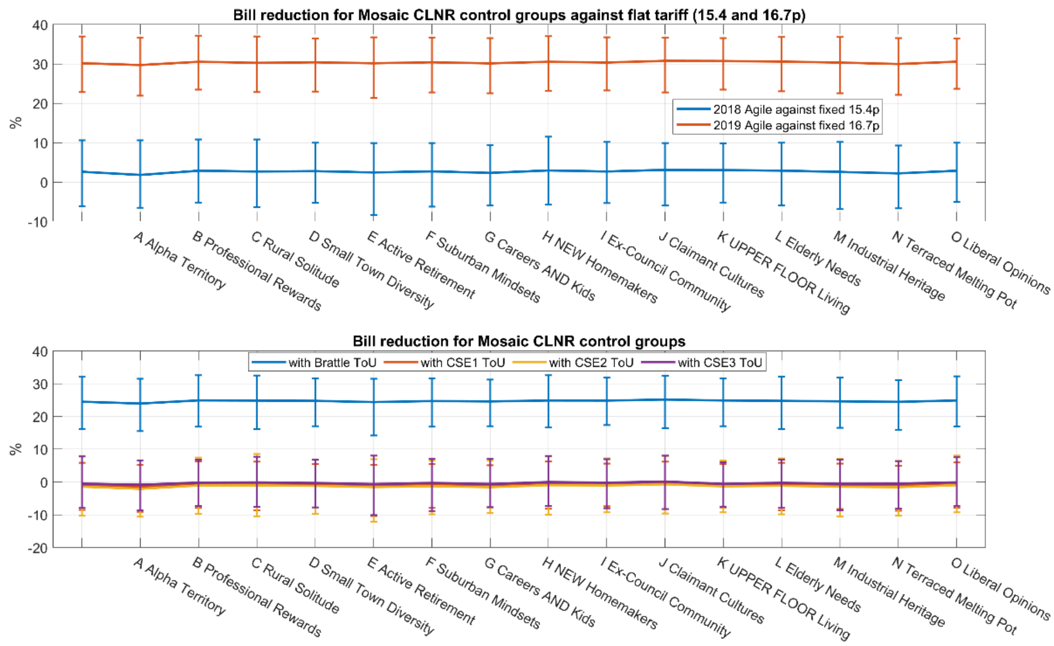

Figure 3: Centre 90% of bill reductions for CLNR control group per Mosaic consumer segmentation for each of the chosen ToU tariffs against the corresponding flat tariff.

From the LCL project, the variability of impact across different groups is more pronounced compared to the CLNR. Figure 4 shows the centre 90% of bill reductions for LCL control and ToU groups with 2018 and 2019 Agile tariff applied. Similarly to the CLNR project, the impact of Agile tariffs on control group tend to have on average same effect across all groups, hovering between 3% and 8% for 2018 prices and between 30% and 35% of bill reduction for 2019 prices. However some groups had much broader spread in the savings up to 25 percentage points

In the LCL project all of the households in the ToU group received a mix of incentives throughout the duration of the trial. At different periods incentives were designed to trial constraint management (i.e. to shift demand away from the evening peak) and also to trial the response to incentive to follow generation (e.g. increase the demand during the day) through high and lower prices in both trials. However ever, not all Acorn groups responded equally and hence the impact of Agile tariffs is also different between the consumer segment groups but also between the control and incentive groups of trial participants. Without disaggregating the ToU incentive group by trial objectives, the households in the ToU incentive group actually reduced the spread of bill reductions from Agile tariffs.

Returning to the households in the control group several the Acorn consumer segmentation groups exhibited distinctive impact compared to other groups and the CLNR results:

- Acorn P (High Rise hardship) average bill savings of 9.2% and the spread between -1.7% (increase in bill) and 26% saving
- Acorn J (Prudent Pensioners) average bill savings of 8% and the spread between -1.2% (increase in bill) and 24% saving

- Acorn O (Burdened Singles) average bill savings of 7% and the spread between -2.6% (increase in bill) and 16% saving
- Acorn I (Settled suburbia) average bill savings of 4.5% and the spread between -5.57% (increase in bill) and 11% saving

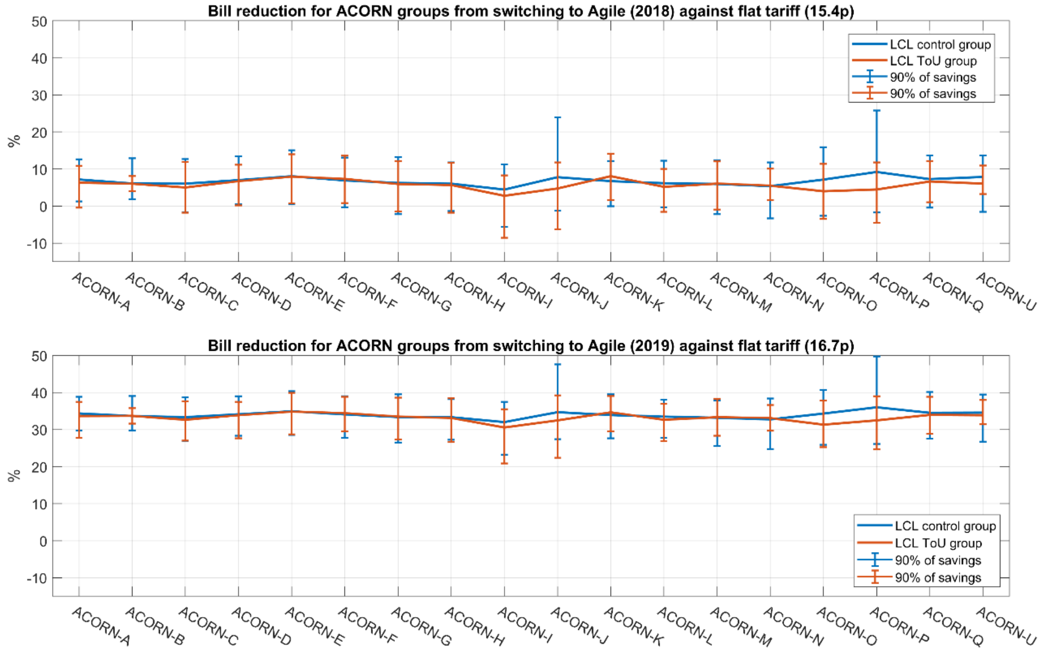

Figure 4: Distribution of bill reduction per Acorn consumer segmentation group compared to the flat tariff for the corresponding year.

Comparison with activity-based analysis

Difference between the impact of Agile tariffs on the households in the LCL and CLNR projects is only visible in the four Acorn consumer segmentation groups, highlighted above and one Mosaic group. Whilst the exact socio-demographic definition for both consumer segmentation methods is not publicly available, description of the segments and the estimated mapping to income groups allows us to compare the impact from smart meter data analysis and the findings from previous publications analysis on ratio of activity probabilities during the peak time to probability in non-peak time as shown in Figure 5 and Figure 6.

Mosaic group E Active Retirement in the group with lowest bill savings in CLRN which corresponds to middle and lower middle-income groups, whilst in LCL Acorn I Settled Suburbia consumer group has the lowest average bill saving and the highest increase in bill within the 90% range also can be mapped to the lower middle-income group. Broadly this aligns with the findings from the analysis of activities: two income groups with highest product of peak-time ratios for energy related activities are the lower middle- and very high-income groups.

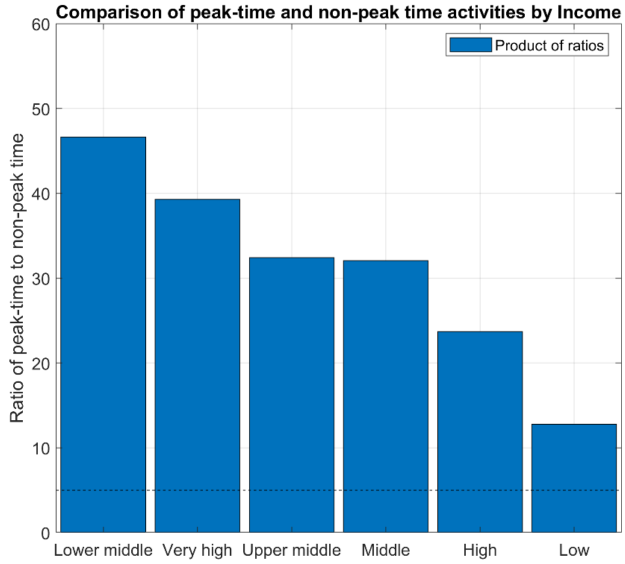

Figure 5: Product of peak-to-off-peak probabilities for energy related activities (cooking, laundry, TV watching and ironing) and active occupancy for households grouped by income.

Consumer group Acorn O (Burdened Singles) has the second lowest average saving of 7% and second highest increase in bill. The highest product of ratio of peak-time activities also falls on the single parent with one child. Whilst it is not a direct link with the Acorn Group O, Burdened Singles also includes single parents offers another link between high peak-to-off-peak ratio for energy activities and the likelihood of negative impact of ToU tariffs compared to other consumer groups.

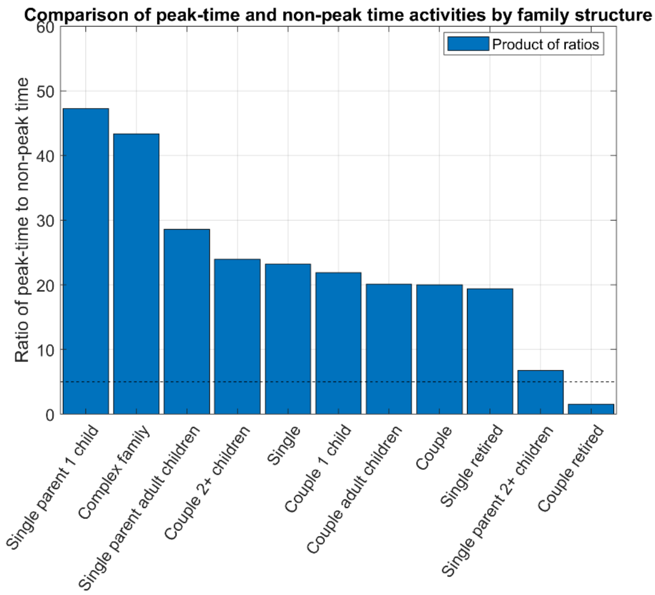

Figure 6: Product of peak-to-off-peak probabilities for energy related activities (cooking, laundry, TV watching and ironing) and active occupancy for households grouped by family structure.

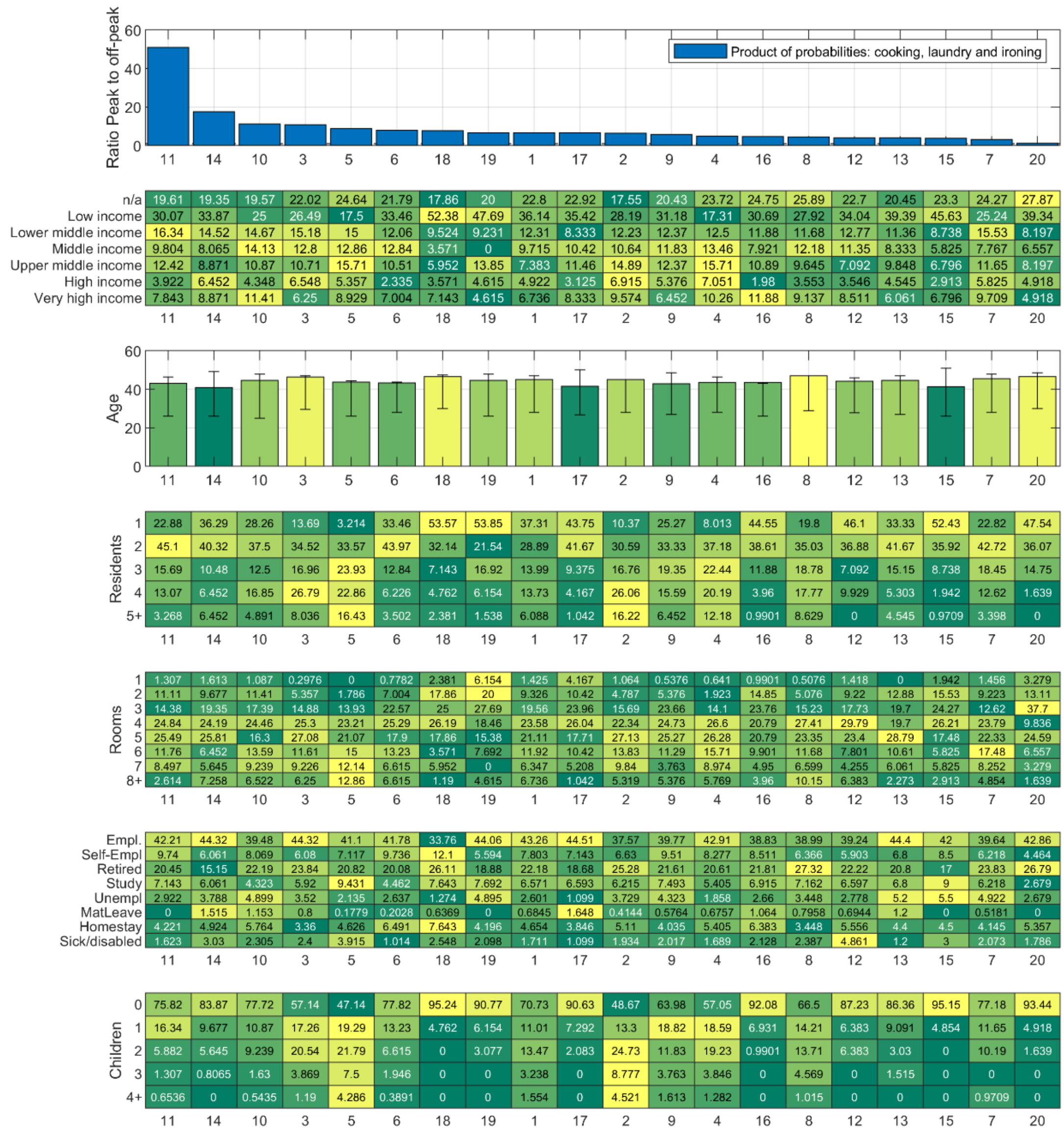

Figure 7: Comparison of peak to off-peak ratios by cluster and distribution of socio-demographic parameters for cluster composition (income group, age, number of residents, number of rooms, employment status and number of children). Clusters and corresponding socio-demographic information in descending order of product of peak to off-peak ratios of energy intensive activities.

Bottom-up clustering of households using pattern of energy related activities at peak-time offers a clear indication of households that are likely to be worse off, however, as discussed in (Torriti, J. and Yunusov, T. 2020) cluster cannot be defined by a single set of socio-demographic parameter. Similarly with the method of using smart meter data alone, it may not be practical for guiding the policy makers in identifying groups of customers requiring protection from adverse impacts of time-varying tariffs.

Extrapolation to impacts under Net Zero

Scarcity and security of fossil fuel required for power generation and the intermittent nature of the renewable generation may increase the frequency of wholesale prices and costs of operating balanced energy system, which will have an adverse effect on the consumers through rising bills. As suppliers are encouraged by Ofgem to offer innovative products to customers, including Time of Use tariffs, more customers at risk of being exposed to tariffs that may not be suitable. Particularly, customers who are not flexible and are unable to take advantage of lower prices outside of peak-time periods would be negatively impacted. As the proportion of customers on time-varying tariffs grows and the demand is successfully moved away from the peak-time, those on fixed tariff could be benefiting in the long-term from the system-wide lower peak demand at times when the wholesale prices are high.

Transition to Net Zero will increase the proportion of intermittent generation but it will also create an opportunity for households to user their flexibility from low carbon technologies, such as heat pumps and EVs, to take advantage of time-varying tariffs. However, on the other hand, electrification of cooking would increase the consumption of electricity at peak time disadvantaging those who do not have technical ability to shift demand (e.g. battery storage) or resources to avoid cooking at peak time (e.g. time to prepare meals before peak time or to outsource cooking). Increasing popularity and ability to work from home, would be beneficial in this case and also allows to move other energy intensive activities, such as laundry, away from peak time. However, not all professions and trades can be done at the place of residence and the question of distributional impacts still stand.

Conclusions

The comparison of three methods for assessing distributional impacts of Time of Use tariffs (including real-time price tariffs) highlighted the complexity of the process and lack of sufficiently granular data to derive a definitive outcome. The three methods used in the this research project consist of: 1) top-down grouping of households by socio-demographic information (household income and family structure) for analysis of peak-time activity probability; 2) bottom-up clustering of households by the pattern of activities at peak demand periods; and 3) applying a selection of time of use tariffs on smart meter profiles. The top-down method offers the simplicity by defining the groups by a single socio-demographic parameter, however, the impact from time-of-use tariffs may not be clearly defined since the households in the same, for example, income group could have a range of the sizes of the household or the energy efficiency of appliances in each household. The bottom-up approaches using activity data and smart meter profiles for individual households are harder to implement in the context of policy despite giving a more accurate understanding of the effect from ToU tariffs.

The peak-to-off-peak ratio of activity distribution has proven useful when contrasting the worst-case impacts between smart meter data with consumer segmentation information and the analysis on the intensity of peak-time activities for two socio-demographic parameters (income and household structure) . However, the same ratio does not provide the degree of impact in financial terms as it only indicates the possibility of negative impacts on average for the group.

Fully understanding peak-time activities and their implications for distributional impacts -as discussed in previous publications- will grow in importance due to the electrification of services, such as cooking and heating, which are considered to be key for transition to Net

Zero. As such, the distributional impact of time-of-use tariffs will also change with changes in households and behaviour of residents.

References

Cambridge Economic Policy Associates (CEPA). (2017) "Distributional Impact of Time of Use Tariffs - Final Report."

Frontier Economics. (2012) "Domestic and SME Tariff Development for the Customer - Led Network Revolution.

Hledik, R., Gorman, W., Irwin, N., Fell, M., Nicolson, M. & Huebner, G. (2017), The Value of TOU Tariffs in Great Britain : Insights for Decisionmakers, Technical Report.

National Grid ESO, Future Energy scenarios, July 2021, https://www.nationalgrideso.com/future-energy/future-energy-scenarios

Torriti, J. and Yunusov, T. (2020) It's only a matter of time: flexibility, activities and time of use tariffs in the United Kingdom. Energy Research & Social Science, doi: https://doi.org/10.1016/j.erss.2020.101697

Sidebotham, L., & Northern Powergrid (2015). 'Customer-led network revolution project closedown report. Customer Led Network Revolution', http://www.networkrevolution.co.uk.

J. Schofield, R. Carmichael, S. Tindemans, M. Woolf, M. Bilton, G. Strbac, "Residential consumer responsiveness to time-varying pricing", Report A3 for the "Low Carbon London" LCNF project: Imperial College London, 2014.

Sun, M., Konstantelos, I., & Strbac, G. (2016). 'Analysis of diversified residential demand in London using smart meter and demographic data', in 2016 IEEE Power and Energy Society General Meeting (PESGM) (pp. 1-5).

Yunusov, T. and Torriti, J. (2021) Distributional effects of Time of Use tariffs based on electricity demand and time use. Energy Policy, doi: https://doi.org/10.1016/j.enpol.2021.112412

Keywords

Energy Consumer – Domestic; Energy Demand; Clustering; flexibility; peak demand Time-of-Use tariffs; Time use.