The Value of TOU Tariffs in Great Britain: Insights for Decision-makers

Volume I: Final Report

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Glossary of Acronyms

BAM	Brattle Annual Model
BEIS	Department for Business, Energy & Industrial Strategy
CBT	Irish Consumer Behaviour Trial
CLNR	Customer Led Network Revolution
CONE	Cost of New Entry
CPP	Critical Peak Pricing
CPR	Critical Peak Rebate
DNO	Distribution Network Operator
EV	Electric Vehicle
GB	Great Britain
HP	Heat Pump
iTOU	Inverted Time-of-Use
LCL	Low Carbon London
NPV	Net Present Value
PRISM	Price Impact Simulation Model
RTP	Real-time Pricing
TOU	Time-of-Use
UCL	University College London
WPD	Western Power Distribution

Executive Summary

Introduction

New developments are changing the way households consume electricity in Great Britain (GB). A market for smart home appliances is emerging, electric vehicles (EVs) are expected to become more prevalent, and a nationwide rollout of smart meters is underway. Retail tariff structures may also evolve as part of this trend. A possibility that is receiving particular interest is the provision of time-of-use (TOU) retail tariffs to domestic customers.

TOU tariffs more accurately reflect the time-varying nature of electricity costs than current tariff offerings. Rather than charging customers a flat price regardless of when electricity is consumed, prices in TOU tariffs vary by time of day. The price signal can be static (i.e., the same every day) or dynamic (i.e., changing in response to system conditions).

The price signal in TOU tariffs gives customers an incentive to shift their electricity consumption to lower-priced hours, providing bill savings opportunities and an associated potential reduction in overall power system costs. TOU tariffs are also often discussed as an important enabler of the adoption of new home automation technologies.

While some prior studies have quantified the potential value of TOU tariffs to the power system, and other studies have explored the value of TOU tariffs to consumers, there has been little research that has systematically combined these considerations into a comprehensive view of the overall value of TOU tariffs. To fill that research void, Citizens Advice commissioned The Brattle Group and University College London (UCL) to conduct a study on TOU value. This study addresses two key topics: (1) quantifying the system value of TOU tariffs in GB and assessing the market conditions under which that value will materialise, and (2) exploring consumer preferences for TOU tariffs.

Methodology

There are several novel features of the study design:

Our assumptions about customer enrolment and price responsiveness are informed by a comprehensive evidence review and additional primary market research. Enrolment assumptions are based on a "rapid review" which drew on an initial pool of more than 4,000 studies to identify the existing research on the consumer appeal of TOU tariffs. Price response assumptions are derived from a review of the results of more than 40 domestic pricing field trials and over 20 meta-studies on consumer price response. To supplement this review, we surveyed 3,000 domestic energy bill-payers in GB to assess preferences for TOU tariffs in further detail.

System benefits are quantified through detailed modelling of the drivers of marginal costs and the ability of TOU tariffs to avoid those costs. We utilized a sub-hourly power generation dispatch model to capture the energy market dynamics that are driven by different demand and supply scenarios (e.g., growth in adoption of renewables or electrification of heating and transportation). The ability of TOU tariffs to provide capacity value was modelled in a way that accurately accounts for operational constraints associated with the tariffs (e.g., a fixed window of peak hours). TOU value was assessed under four different plausible future market scenarios: Current Trends, High Renewables, Electrification, and Electrification with Automation.

The analysis includes conventional and emerging TOU tariff designs. We analysed a range of tariff designs, including conventional options, such as static TOU and critical peak pricing (CPP) as well as emerging options such as critical peak rebates (CPR), inverted static TOU tariffs (iTOU), and a half-hourly Smart Home Rate (SHR). We explore the potential value associated with both opt-in and opt-out TOU offerings.

The methodological framing and assumptions are informed by interviews with key industry stakeholders. To account for a diverse range of perspectives on the issue of TOU value, we conducted phone and in-person interviews with Ofgem, distribution network operators (DNOs), suppliers, academics, and demand response aggregators.

THE VALUE OF TOU TARIFFS

Under future market conditions that are similar to those that exist today, we estimate annual savings of opt-in TOU offerings to be around £20 to £25 million/year. This equates to roughly £1 per GB household per year. If those savings were captured entirely by participants, with a nationwide participation rate of around 20%, the savings to participants would be roughly £5 per household per year. By comparison, the typical domestic customer's annual electricity bill in GB is between £500 and £600 per year. For reasons discussed in Section III of the report, similar results were observed for a market scenario with significantly higher adoption of renewable generation.

It is important to note that these savings estimates are associated only with load shifting. Savings estimates will vary by participant depending on the participant's size and degree of price responsiveness. Additionally, it is the case that the portion of the population with a flatter-than-average load profile would see additional bill savings from these tariffs, by virtue of enrolling in a tariff that better accounts for the lower costs that they impose on the power system. Further, these estimates do not reflect the non-monetary or difficult-to-quantify benefits of TOU tariffs discussed throughout this report.

In a system with increased capacity costs, electrified heat and transport, and/or adoption of smart home appliances, our estimates of TOU value are roughly in the range of £150 to £250 million/year. Achieving savings of this magnitude would likely require higher capacity prices (e.g., driven by electrification of heating and transport), adoption of automating technologies, and/or opt-out deployment of TOU tariffs. These aggregate savings amount to roughly between £5 and £10 in savings per year per GB household. In the specific instance where the benefits are being driven by a relatively small share of customers with automating technologies, savings per participant could be between around £30 and £90 per year.[1]

A summary of the TOU system value estimates for each tariff design and market scenario is presented in Table ES-1. Twelve key insights related to the value of TOU tariffs are summarized in Section III of the report.

Table ES-1: TOU System Value (£ million/year)

	Current Trends	High Renewables	Electrification	Electrification with Automation
Static TOU (opt-in)	£19	£20	£54	£103
CPR (opt-in)	£22	£25	£76	£126
CPP (opt-in)	£24	£27	£81	£131
SHR (opt-in)	£3	£3	£10	£272
iTOU (opt-in)	N/A	£4	N/A	N/A
Static TOU (opt-out)	£47	£48	£131	£183
CPR (opt-out)	£40	£45	£137	£190

The Consumer Appeal of TOU Tariffs

The evidence review conducted in this study identified a number of important insights regarding the appeal of TOU tariffs to consumers, as summarized in Table ES-2.

[1] This is based on a relatively simple algorithm to simulate automated price response. A more detailed assessment of the price responsiveness of a fully-equipped "smart home" would be a valuable extension of this research. Some automated appliances could also potentially provide ancillary services, a benefit which is not captured in this analysis.

Table ES-2: Factors Associated with Customer Uptake of TOU Tariffs

Factor	Key takeaways	Strength of findings
Recruitment method (opt-in versus opt-out)	Biggest driver of differences across reviewed studies. 83% average enrolment with opt-out versus 26% with opt-in. On average, customers who are enrolled on TOU tariffs through opt-out policies reduce their peak electricity consumption by less than those who actively opt-in. However, aggregate peak reductions under an opt-out policy will likely be higher than opt-in due to higher opt-out enrolment rates.	High
Financial incentive (e.g. gift card)	Statistically significant impact in comparison across studies, with 35% enrolling when offered incentive versus 20% enrolling when not offered	High
Tariff type	Static TOU (35% average uptake) is more popular than dynamic, particularly hourly RTP (18%). Limited data makes it difficult to detect significant differences in uptake across individual tariff designs like CPP, CPR, etc.	Moderate
Automation	Comparison across studies finds no statistically significant difference in uptake associated with automating technologies. However, individual studies that have tested this experimentally find that automation increases uptake, possibly to a greater extent for dynamic tariffs than static TOU.	Moderate
Bill protection	Comparison across studies finds higher uptake with bill protection (35%) than without (27%) though the difference is not statistically significant. However, one survey study from Australia which tested the impact of bill protection experimentally (assigned participants to the same tariff but randomly varied whether it was accompanied with bill protection) found that bill protection had a modest positive impact on uptake.	Moderate
Messaging (e.g. "sign up to save money")	There is limited research on this issue since most studies emphasise the potential financial savings, making it hard to find a control for comparison. Results, where available, are largely conflicting though suggest a modest effect from promoting environmental benefits.	Inconclusive
Type of customer (e.g. low income, region)	This was not included in the analysis because the reviewed studies did not break down uptake by participant or customer type. Two survey studies which tested this explicitly found no correlation between various socio-economic and demographic factors and willingness to switch to a TOU tariff.	Inconclusive

Additionally, through the review of TOU studies we found that customers who enrolled in TOU tariffs largely have had a positive experience. About four out of five customers expressed satisfaction with their TOU tariff, and similar numbers would participate again or recommend the tariff to others. This suggests that initial skepticism regarding TOU tariffs may eventually be overcome as customers gain experience with the tariffs.

The TOU study review also found that field trials and full scale deployments across the globe have consistently detected customer response to the TOU price signals in the form of peak demand reductions. Trials in GB and Ireland are at the mid- to lower-end of the range and have typically included up to 10% average peak demand reduction across tariff offerings.

The evidence review also identified a number of gaps in the industry's understanding of key issues related to consumer preferences for TOU tariffs. Primary market research conducted in this study was designed to address these research gaps. Highlights of the primary market research findings include:

- On average, roughly one-quarter (26%) of customers indicate that they would switch to a TOU tariff. This is generally higher than the expectations of several stakeholders with whom we spoke in the context of this study.
- Research on the relative differences in likely uptake across individual TOU tariff designs detects little difference. This is a somewhat surprising finding, given potentially significant different value propositions that the tariffs present to customers. This finding should be explored further through alternative forms of market research (e.g., focus groups).
- Age is related to the likelihood that a customer will enrol in a TOU tariff, with younger consumers being more likely to sign up than those older than 65.
- Our results hint that offering TOU tariffs could have negative implications for trust in the electricity supply industry, although this effect is small. Our findings also suggest that trusted non-governmental organizations could be best placed to mitigate such concern.
- Tailored messaging was effective at boosting demand for a static TOU amongst EV owners (a group that is potentially more likely to save money on TOU tariffs). Additionally, the perceived opportunity to save money on the tariff and "ease of use" both contribute to an increased likelihood of uptake. If suppliers could design and market TOU tariffs suited to the lifestyles or consumption patterns of particular consumer groups, this may provide a potential avenue for increasing uptake to TOU tariffs whilst helping consumers to beneficially switch to tariffs that will save them money.

RECOMMENDATIONS

The findings of this study lead to a number of recommendations for policymakers, network operators, suppliers, and other industry stakeholders that are exploring the possibility of a transition to TOU tariffs.

Focus on customer engagement and communication, as they will be critical considerations in any tariff transition. The estimates of TOU value established in this study essentially scale linearly with enrolment. At low levels of TOU enrolment, value will be very limited. But if a significant number of domestic customers enrol in well-designed TOU tariffs in the future, the benefits could be on the order of tens or hundreds of millions of pounds per year. It will therefore be critical to explore innovative options for engaging with customers about the potential benefits of the TOU tariffs, if they are offered in the future.

Take a holistic view of the value of TOU tariffs that extends beyond simple monetary value. There is limited variation in value across the core TOU tariff designs (i.e., TOU, CPP, and CPR). This similarity in system value estimates across the TOU options means that non-monetary considerations (such as simplicity, ease-of-use, distributional bill impacts, and cost-reflectivity), could be as or more important as monetary considerations in future TOU deployment decisions.

Give CPR tariffs serious consideration and test them through an opt-out field trial. CPR tariffs have received relatively little attention as a tariff option in GB thus far. Their customer-friendly design and proven impact on peak demand makes CPR tariffs a potentially attractive candidate for cost-effectively tapping into the demand response potential of the domestic sector. CPR tariffs could be particularly interesting to explore through a field trial that is deployed on an opt-out basis, given the no-lose proposition the tariff presents for participants.

Ensure charging and settlement processes facilitate the provision of economically efficient TOU design. If suppliers are to be expected to offer TOU tariffs in the future, they will need to have a financial incentive to do so. Current settlement processes and network charging structures do not fully reward suppliers for cost savings associated with reductions in the peak demand of their customers. Half-hourly settlement and network charges which accurately reflect the time-varying nature of the cost of delivering power are necessary in this regard, though the costs of improving the settlement and charging processes should be compared to the benefits of doing so (work which is underway in part through Ofgem's ongoing Mandatory Half Hourly Settlement business case analysis).

In the near- to medium-term, TOU design should focus primarily on avoiding capacity costs. In our analysis, across a range of market scenarios, avoided generation capacity cost drives the bulk of TOU value. Exploring opportunities to avoid the capital costs associated with new generation, transmission, and possibly distribution capacity is likely to continue to be more productive than chasing energy value. Given the finding in this study that there is significant interest in TOU tariffs among customers, it will also be important to consider the extent to which future TOU tariff designs which appeal to customer preferences but do not produce system benefits (e.g. through a peak period that does not align with the system peak) may shift costs to non-participants.

Voluntary Smart Home Rate tariffs may help to solve the "chicken and egg" problem that is perceived to limit the adoption of automating technologies. There is a perception among some industry stakeholders that automating technologies will not achieve significant market traction until there are granular retail price signals to which the technologies can respond. A cost-based, voluntary SHR tariff could provide this opportunity.

Explore options available for making automating technologies accessible to low income customers. This study has demonstrated that there is significant TOU tariff value to be unlocked by automating technologies. Maximizing the net societal value of automating technologies – and ensuring that there will not be negative distributional impacts associated with their adoption – will likely require facilitating widespread uptake of the technology. As such, it will be important to examine options that are available to extend these opportunities to all types of customers and not just those with higher incomes.

I. Introduction

New developments are changing the way households consume electricity in Great Britain (GB). A market for smart home appliances is emerging, electric vehicles (EVs) are expected to become more prevalent, and a nationwide rollout of smart meters is underway. Retail tariff structures may also evolve as part of this trend. A possibility that is receiving particular interest is the provision of time-of-use (TOU) retail tariffs to domestic customers.

Time-of-use (TOU) tariffs more accurately reflect the time-varying nature of electricity costs than current tariff offerings. Rather than charging customers a flat price regardless of when electricity is consumed, prices in TOU tariffs vary by time of day. The price signal can be static (i.e., the same every day) or dynamic (i.e., changing in response to system conditions).

The price signal in TOU tariffs gives customers an incentive to shift their electricity consumption to lower-priced hours, providing bill savings opportunities and an associated potential reduction in overall power system costs. TOU tariffs are also often discussed as an important enabler of the adoption of new home automation technologies.

Some evidence already suggests that TOU tariffs are capable of delivering on this promise. Field trials conducted in GB, Ireland, and to a much larger extent in other jurisdictions have consistently found that consumers reduce peak demand in response to time-differentiated price signals. In Europe, a large share of domestic customers in France, Italy, and Spain are enrolled in TOU tariffs. In GB, roughly 13% of customers are enrolled in a TOU tariff known as Economy 7 and suppliers have begun to introduce new tariffs with a time-varying element.[2,3] In parts of North America, the peak demand reductions from domestic TOU tariff offerings are sold directly into the wholesale capacity market.[4] These benefits are passed through to consumers in the form of reduced electricity rates and direct incentive payments for load reductions.

While there is some international experience with TOU tariffs, there is still significant potential for increased uptake of new and innovative offerings. In the longer term, some imagine that the use of TOU tariffs could extend beyond encouraging system peak demand reductions to additionally facilitate around-the-clock balancing of supply and demand. These

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2 While 13% of customers are enroled in the tariff, this number has been declining over the past several years. The tariff was designed specifically for customers with thermal storage heating systems. It is a static TOU design; only one of the many types of time-varying tariff designs considered in this study. For further discussion of the Economy 7 tariff, see Citizens Advice, "Take a Walk on the Demand-Side," August 2014. https://www.citizensadvice.org.uk/about-us/policy/policy-research-topics/energy-policy-research-andconsultation-responses/energy-policy-research/take-a-walk-on-the-demand-side/

3 British Gas's "HomeEnergy FreeTime" tariff and Green Energy UK's "Time of Day Tariff" are two examples.

4 In Pepco's service territory, this is translating into $20 to $40 million per year in avoided capacity costs. See Direct Testimony of Karen Lefkowitz Before the Maryland Public Service Commission, April 2016.

tariff designs could be in the form of sub-hourly real-time prices that reflect fluctuations in supply from intermittent renewable generation resources, prices that vary across locations on the distribution system to encourage more beneficial siting and operation of distributed energy resources, or "inverted" TOU tariffs that encourage on-site electricity consumption during daytime hours when rooftop solar PV systems would otherwise produce net excess electricity.

In spite of growing interest in the value of full-scale TOU deployments in GB, there has been relatively limited research to quantify the value of such an offering. While some prior studies have quantified the potential value of TOU tariffs to the power system, and other studies have explored the value of TOU tariffs to consumers, there has been little research that has systematically combined these considerations into a comprehensive view of the overall value of TOU tariffs. To fill that research void, Citizens Advice commissioned The Brattle Group and University College London (UCL) to conduct a study on TOU value. Citizens Advice is the statutory advocate for energy consumers. Part of its role is to provide perspective on important emerging consumer issues. As such, this study addresses two key topics: (1) quantifying the system value of TOU tariffs in GB, and (2) exploring consumer preferences for TOU tariffs. Brattle led the assessment of the system value of TOU tariffs and UCL led the research on consumer preferences.

Unique Study Features

Our assumptions about customer enrolment and price responsiveness are informed by a comprehensive evidence review and additional primary market research. To develop the participation rate assumptions, we relied on a "rapid review" methodology which drew on an initial pool of more than 4,000 studies to identify the existing research on the consumer appeal of TOU tariffs. Development of price response assumptions included a review of more than 20 meta-studies encompassing over 40 domestic pricing field trials with a focus on consumer price response. To complement this research, we surveyed 3,000 domestic energy bill-payers in GB to assess preferences for TOU tariffs in more detail. In contrast, prior assessments of TOU tariff value have largely relied on illustrative assumptions about participation rates and the share of "flexible load" that will respond to price.

System benefits are quantified through detailed modelling of both the drivers of marginal costs and the ability of TOU tariffs to avoid those costs. We utilized a sub-hourly power generation dispatch model to accurately capture the energy market dynamics that are driven by different demand and supply scenarios (e.g., the impacts of an increase in market penetration of renewables or an increase in electricity demand due to adoption of electric vehicles and heat pumps). Further, the ability of TOU tariffs to provide capacity value was modeled in a way that accurately accounts for operational constraints associated with the tariffs (e.g., a fixed window of peak hours) rather than relying on commonly encountered simplistic assumptions that linearly relate demand reductions to cost savings.

The analysis includes both conventional and emerging TOU tariff designs. Tariff designs such as static TOU and critical peak pricing (CPP) have already received interest in GB. Other tariff designs are only beginning to become part of the conversation, including critical peak rebates (CPR), inverted static TOU tariffs (iTOU), and a half-hourly Smart Home Rate (SHR). Our study analyses each of these tariff designs (further descriptions are provided in Section II). We also explore the potential value associated with an opt-out TOU offering.

The methodological framing and assumptions are informed by interviews with key industry stakeholders. To account for a diverse range of perspectives on this issue, we conducted phone and in-person interviews with Ofgem, DNOs, suppliers, academics, and demand response aggregators.[5]

IMPORTANT CONSIDERATIONS

It is important to clarify the terminology being used in this report. In GB, it is common for the term "TOU" to broadly refer to time-varying tariffs of all types, including both static and dynamic pricing options. Alternatively, the term "static TOU" commonly refers to a specific type of tariff design that has pre-defined peak and off-peak prices which do not change on a dynamic basis. Thus, CPP, CPR, and static TOU tariff designs are all different types of TOU tariffs. While this terminology is fairly GB-specific and different than in other jurisdictions, it has been adopted for this report.

Estimates of value are reported for the year 2030 (in real 2016 GBP). It is expected that smart meters will have been deployed across GB by that time, leaving enough time for metering and settlement barriers to be removed and for suppliers to develop full-scale TOU offerings. But there is considerable uncertainty associated with such projections of the future. We have analysed a number of scenarios to account for a range of potential future states of the GB energy market, though it is important to acknowledge this inherent uncertainty.

Under the current regulatory framework, whether or not TOU tariffs are offered in the future will depend on if they are offered by competitive retail suppliers; there is no regulatory mandate to do so. Our analysis does not account for the likelihood that suppliers choose to offer TOU tariffs in the future. Rather, we assume that, in the future, the tariffs are being offered widely to consumers, and develop realistic enrolment rates that are consistent with that assumption. Participation rates are based on empirical research and well-subscribed international tariff offerings.

Finally, it is worth noting that this study focuses exclusively on retail electricity tariffs for domestic customers. We do not analyse tariffs for the natural gas sector or non-domestic customers. Further, we do not assess the costs and benefits of a broader range of pricing options that are not time-varying (e.g., fixed bill, pre-payment, inclining block tariffs) nor do we consider the broader range of non-price based demand-side response options.

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5 See Appendix A for further details.

Organization of the Report

The remainder of this report is organized as follows: Section II discusses the methodological framework for assessing the value of TOU tariffs. Section III summarises 12 key findings from the TOU value assessment that are important considerations for decision-makers. Section IV presents a review of the international literature on customer acceptance of TOU tariffs. Section V summarises new primary market research conducted specifically for this study on consumer preferences for TOU tariffs. Section VI concludes the report with policy recommendations based on the findings of this study.

II. TOU Valuation Methodology

Overview

The focus of this study is on the system value of TOU tariffs (also sometimes referred to as "societal value"). Specifically, we quantify the total power system costs that could be avoided when customers respond to the introduction of time-varying price signals. The result is an estimate of the total monetary savings that could be achieved through a TOU tariff offering. How these benefits are shared among stakeholders such as customers, suppliers, and grid operators would depend on how the tariff is designed and rolled out.

The approach to quantifying TOU value in this study involves four steps. This approach is derived from widely-used industry practices for valuing demand-side resources.[6]

The first step is to identify the costs that can potentially be avoided as customers change their consumption patterns in response to TOU tariffs (e.g., generation capacity costs, energy costs). These are referred to as "marginal costs." Marginal costs vary depending on supply and demand conditions in the energy market. We have relied on a review of historical cost data and a detailed production cost model (known as the Brattle Annual Model, or "BAM") to develop these marginal cost estimates.[7]

The second step is to define the TOU tariff designs being analysed. This involves first allocating marginal costs to hours of the year in a manner that is proportional to the drivers of those costs (i.e., allocating peak-capacity related costs to peak load hours). The resulting aggregate hourly price profile is used to define the pricing periods in each TOU tariff and to establish the relationship between peak and off-peak prices in the retail tariff.

The third step is to simulate customer response to the new TOU tariffs. We have established estimates of price responsiveness based on an international literature review. A suite of tools for modelling customer price response known as "PRISM" was used to calibrate the estimates of price response to TOU tariffs with various peak-to-off-peak price ratios assumed for this study.[8]

The fourth step is to quantify the aggregate system value of TOU tariffs. This begins with the development of achievable enrolment assumptions, based on a literature review and supplemented with primary market research. The enrolment rates are combined with the estimates of per-participant impacts developed in the third step (above) to establish aggregate

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6 For further discussion, see Ryan Hledik and Ahmad Faruqui, "Valuing Demand Response: International Best Practices, Case Studies, and Applications," prepared for EnerNOC, January 2015. http://www.brattle.com/system/publications/pdfs/000/005/343/original/Valuing_Demand_Response_-_International_Best_Practices__Case_Studies__and_Applications.pdf?1468964700

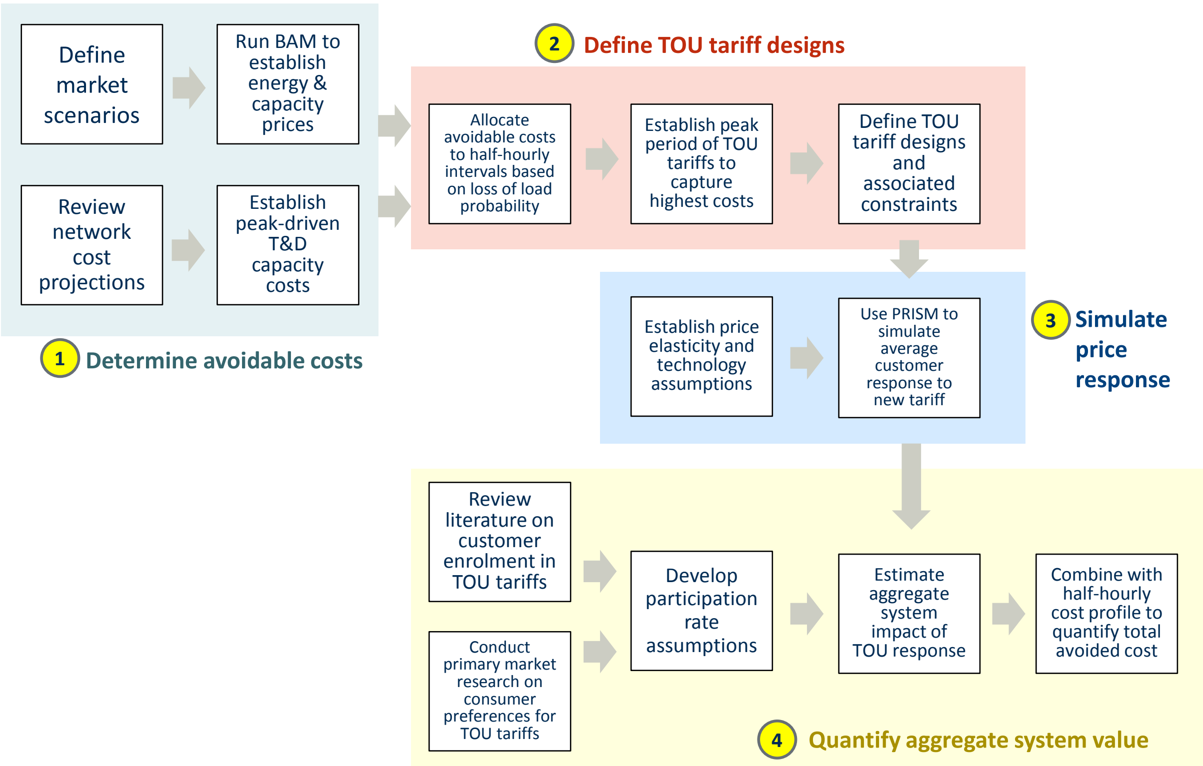
7 For more information about BAM, see Appendix B.

8 For more information about PRISM, see Appendix C.

changes in the system load shape. These changes in the half-hourly system load shape are combined with the half-hourly aggregate cost profiles (developed in the first step) to estimate the total change in system costs.

Figure 1 illustrates each step of the methodological framework. Detail behind each step is discussed further in the remainder of this section.

Figure 1: TOU Valuation Methodology Overview



DETERMINANTS OF TOU SYSTEM VALUE

Many factors determine the potential value of TOU tariffs to the power system. For instance, the average peak demand reduction from TOU participants is one important factor driving TOU value. The magnitude of the average participant's peak demand reductions is a function of the strength of the price signal in the TOU tariff (i.e. the peak-to-off-peak price ratio), the price responsiveness of customers (i.e., "price elasticity"), the nature of the price signal in the tariff (i.e., higher charge versus rebate), the tariff deployment method (opt-in versus opt-out), and the market saturation of automating technology (e.g., smart thermostats).

The timing of the load reduction also impacts TOU value. This is determined by the number of high priced events that are permissible under the tariff rules and the breadth and timing of the peak period window (e.g. 4 pm to 8 pm, 3 pm to 9 pm, etc.).

The participation rate is also a key driver of TOU value. Enrolment is a function of the bill savings opportunity the TOU tariff presents to customers, the appeal of the design of the TOU tariff, the effectiveness with which it is communicated to customers, and the extent to which customers have experience with the tariff and/or have been educated about its implications.

The magnitude and timing of marginal costs are also critical factors to determining TOU value. Avoided capacity costs, for instance, will be determined by the urgency of the need for new capacity and the alignment (or "coincidence") of various capacity cost drivers with the timing of load reductions. Avoided energy costs will be a function of the load shape and the mix of generation resources, which determine a marginal generation costs profile (largely fuel costs).

The methodological approach used in this study accounts for this array of considerations.

Market Scenarios

The future state of the UK power sector is uncertain. Four illustrative scenarios were developed to account for this uncertainty.[9] The definition of the four scenarios is informed by conversations with industry stakeholders and reference to National Grid's Future Energy Scenarios reports.[10] All scenarios are developed for the year 2030. The scenarios span a range of assumptions around the adoption of renewable generation, the electrification of heating and transport, and the proliferation of smart home technologies which would automate response to TOU tariffs. They are illustrative of plausible future conditions rather than a prediction of what is likely to happen.

Current Trends Scenario

In the Current Trends scenario, the market reflects current conditions with the exception of a few commonly expected future changes. Those changes include retirement of all remaining coal generation capacity, a modest escalation of natural gas prices, and the addition of renewable generation capacity (mostly wind).

The Current Trends scenario is characterised by reserve margins that continue to be fairly tight (i.e., around 10%). In spite of the low reserve margin, capacity prices remain modest - this is discussed further below. The supply mix is dominated by natural gas, renewables (mostly wind and solar), and nuclear. We assume little future adoption of smart home appliances and electric heating and transport in this scenario.

High Renewables Scenario

The High Renewables scenario builds off of the Current Trends case, with the only difference being a significant increase in the market adoption of wind and solar generation. In the High Renewables case, wind generation accounts for 32% of all installed capacity and solar PV accounts for 17%. That is relative to future wind and solar capacity of 23% and 13%, respectively, in the Current Trends case and only 14 and 10% today. In terms of the share of

[9] For further information on the assumptions behind each scenario, see Appendix D.

[10] 2016 National Grid Future Energy Scenarios (FES). See website: http://www2.nationalgrid.com/uk/industry-information/future-of-energy/future-energy-scenarios/

total 2030 electricity supply, the wind and solar share increases from 30% in the Current Trends scenario to nearly 50% in the High Renewables scenario.

The High Renewables scenario is characterized by capacity prices that are similar to those in the Current Trends scenario. While the High Renewables scenario includes a significant amount of new wind and solar capacity, the output from those resources is relatively low during the time of the system peak, thus providing limited capacity relief.[11] Additional transmission costs would be associated with connecting remotely-located generation to the system rather than meeting peak demand related needs that are incremental to the Current Trends case. Peak-related distribution costs are assumed to be unaffected in a similar manner, though as is discussed later in this report there may be an opportunity to reduce distribution capacity needs arising from constraints related to excess output from distributed generation.

Electrification Scenario

The Electrification case differs from the Current Trends case in that it assumes significant load growth due to the adoption of electric vehicles (EVs) and electric heat pumps (HPs). Specifically, we assume the addition of 8 million EVs (representing 27% market share) and 6 million HPs (22% market share). This leads to an increase in system peak demand of roughly 9 GW, or 16% relative to the Current Trends Scenario.

The Electrification scenario is characterised by higher capacity prices, as accelerated load growth would increase the need for new capacity. This assumption applies not only at the bulk system level, but also to the distribution system where an increase in domestic load would likely increase the number of locations on the grid experiencing congestion.

Electrification with Automation Scenario

The Electrification with Automation scenario differs from the Electrification scenario only in that it additionally assumes that customers have adopted technologies that automate load reductions in response to TOU price signals. Specifically, we assume that of those customers with a HP, half own a smart thermostat. Similarly, of the customers with an EV, half are assumed to own some type of smart charging technology (which could range from a simple timer to a charger than can remotely receive real-time signals to manage charging).

Among industry stakeholders, there generally tends to be a view that an acceleration of renewables adoption is more likely to occur than widespread adoption of EVs and HPs. Similarly, there seems to be an industry perception that electrification of transport is more likely than electrification of heating. The extent to which these or other developments will occur is, of course, highly uncertain and is the reason for analysing each of these scenarios. A summary of the scenario descriptions is provided in Table 1.

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[11] The difference in capacity price in the High Renewables scenario relative to the Current Trends scenario is attributable to lower energy profits that would be earned by the marginal generator in the High Renewables scenario, thus necessitating a slightly higher capacity price to provide the necessary financial incentive to keep the unit online.

Table 1: The Four Market Scenarios

Market Scenario	Description
Current Trends	**Market reflects current conditions with modest changes** - Fairly tight reserve margins, but with relatively low capacity prices - Supply mix dominated by nuclear, gas, some wind - Little adoption of smart appliances
High Renewables	**Aggressive investment in renewable generation** - Wind and solar represent 32% and 17% of installed capacity, respectively - Peak-related generation and transmission capacity needs mostly unchanged due to lack of coincidence in wind output and system peak - Some local distribution constraints due to output from embedded gen - Negative wholesale energy prices in some hours
Electrification	**Significant load growth** - Electrification leads to adoption of 8 million EVs and 6 million heat pumps - Accelerated load growth leads to higher capacity prices - Energy prices increase but the price profile flattens to some degree
Electrification with Automation	**Additional demand-side advancements** - Same definition as Electrification case, with the additional assumption that the adoption of smart appliances (smart thermostats, EV charging control) facilitates a greater degree of price response

Avoided Costs

This study quantifies four sources of TOU value: avoided energy costs, generation capacity costs, transmission capacity costs, and distribution capacity costs. See the sidebar later in this section of the report for discussion of other potential sources of value that are not quantified in this study.

Avoided Energy Cost

Avoided peak energy costs are commonly recognised as a source of value associated with TOU tariff offerings. As load is shifted from higher-priced hours to lower (or negatively) priced hours of the day, there is a net reduction in fuel costs.

Future energy prices are simulated in this study using a production cost model known as the Brattle Annual Model (BAM).[12] BAM uses linear optimisation to minimise the cost of dispatched electricity across a year, taking account of the demand specified in the model and constraints imposed by the availability of plants and other relevant considerations such as emissions limits. The model includes both forced plant outages as well as scheduled maintenance. It stochastically accounts for the variability of load and intermittent (renewable) generation in order to accurately represent the impacts of this variability on market prices. BAM has been used for many long-term forecasting studies in GB and other European markets.[13]

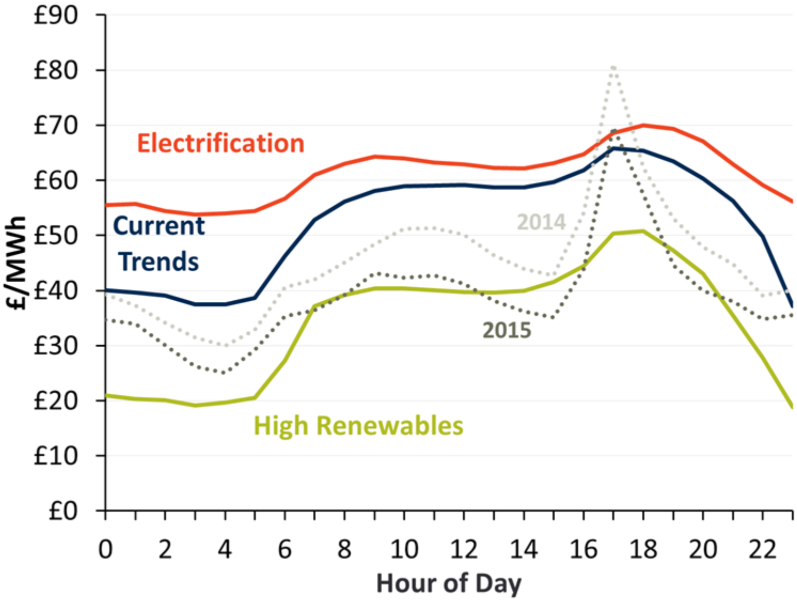
12 For more information about BAM, see Appendix B.

13 See, for instance, Serena Hesmondhalgh, Gill Owen, Maria Pooley, and Judith Ward, "GB Electricity Demand – 2012 and 2025. Impacts of Demand Reduction and Demand Shifting on Wholesale Prices and Carbon Emissions, Results of Brattle Modelling," prepared for Sustainability First, January 2014.

Continued on next page

The hourly energy price profile across the four scenarios developed for this study is illustrated in Figure 2. Historical prices in 2014 and 2015 are shown for comparison.[14] Prices are higher on average in the Current Trends case than in historical conditions due largely to a projected increase in fuel costs. Relative to the Current Trends case, average prices increase in the Electrification scenario due to a tightening of supply and demand. Prices are lower in the High Renewables case due to the introduction of a significant amount of low-variable cost generation. In the High Renewables case, the energy price is negative during around 1% of hours annually.

Figure 2: Average Hourly Winter Energy Prices by Market Scenario



Source: Historical prices from Nordpool. Projections (coloured lines) modelled by Brattle using BAM.

It is important to note that avoided energy costs (i.e., fuel, variable O&M) are different than reduced wholesale prices (i.e. market prices clearing at a lower level due to reduced demand). We focus only on reduced energy costs associated with response to TOU tariffs in this analysis. Reductions in wholesale market prices could be considered a short-term benefit to consumers (and a loss to generators), but as the supply-and-demand balance returns to equilibrium to account for the change in demand, we would expect this impact to diminish over time.

Continued from previous page
http://www.sustainabilityfirst.org.uk/images/publications/gbelec/Sustainability%20First%20-%20Paper%209%20-%20Updated%20Brattle%20Modelling%20-%20GB%20Electricity%20Demand%202012%20&%202025.%20January%202014.pdf

14 While a variety of factors affect future energy prices relative to historical prices, one explanation for the reduced volatility observed in the projections is the introduction of a capacity market, which would reduce pressure for generators to recover fixed costs through the energy market and could therefore lead to a dampening of energy price volatility. The impact of the capacity auction would not yet be observed in 2014 and 2015 historical energy prices.

Avoided Generation Capacity Costs

Reductions in demand in response to peak prices in TOU tariffs can address reliability concerns related to generation supply shortages and avoid or defer the need for investment in new generation capacity. Avoided generation capacity costs have been the primary driver of TOU system value in most international case studies.

In GB, prices in National Grid's capacity auction have only ranged between £18 and £22.50/kW-yr since its inception in 2014.[15] These prices appear low in contrast to the levelized cost of a peaking generation unit (which can sometimes be in excess of £100/kW-yr). This is a particularly puzzling contrast given recent concerns about capacity shortages and single-digit reserve margins.[16]

There are several theories to explain this perceived inconsistency between capacity need and auction results. One is that the steep demand curve in the capacity auction results in capacity prices that are very sensitive to minor changes in expected supply. Another possibility is that current system conditions do not reflect the expected conditions in the future years of the capacity auction (which is a four-year forward-looking auction). It is also possible that the unexpected participation of small-scale embedded diesel generators dampened prices; policy changes have the potential to reduce the amount of this type of capacity that clears in the auction in the future. There is also the possibility that concerns about supply shortages have been simply overblown and/or based on misinterpretation of National Grid's estimates of available reserves.

In the long-run, capacity prices should theoretically approach the net cost of new entry (CONE), which in the UK market is estimated at £50/kW-year.[17] To establish a reasonable assumption for the Current Trends scenario, and in recognition of the currently low market prices, we assume a value of £35/kW-year which is roughly the average of recent market prices and net CONE. A similar assumption is used in the High Renewables scenario, with an adjustment to account for the lower energy margins that would be earned by the marginal unit due to lower energy prices. In the Electrification scenario, the marginal cost of generation capacity is assumed to be the full net CONE value of £50/kW-year due to tighter reserve margins and a greater need for new capacity, as discussed above.

Avoided Transmission Capacity Costs

Similar to generation capacity, transmission capacity could potentially be avoided through peak demand reductions. Avoided transmission costs are sometimes, but not always, included

15 National Grid, "Provisional Capacity Market Results," 2014-2016.

16 See, for instance, Kiran Stacey, "UK Turn to Diesel to meet Power Supply Crunch," *Financial Times*, November 3, 2015.

17 Capacity Market Auction Guidelines, National Grid, July 2016, pg. 5. Gross CONE is the total cost of installing new marginal generation capacity. It is typically determined as a bottom-up engineering estimate or through a survey of recent power plant additions, and ultimately vetted through a public stakeholder process. Net CONE is gross CONE less the energy and ancillary services profits that would be earned in the market by the marginal generation unit.

in assessments of TOU value. This is partly because only a portion of transmission capacity expenditures are driven by peak demand. Transmission is also built to address local congestion issues or to access remotely located sources of renewable generation, neither of which is necessarily related to system peak demand.

For the typical domestic customer, transmission costs represent only 5% of the total bill (£25/year, or £26/kW-yr). A review of avoidable transmission costs in other regions suggests a range of £10/kW-yr to £50/kW-yr. In the Current Trends and High Renewables scenarios, we have assumed a marginal transmission capacity cost of £15/kW-yr, which is within this range. The Electrification scenarios assume a marginal transmission cost of £20/kW-year to better reflect the added stress that load growth would place on the transmission system.

Avoided Distribution Capacity Costs

Stress on the distribution system could potentially be lessened if the peak demand reductions from TOU tariffs are coincident with the timing of local peaks on the distribution system.

The use of demand response and other distributed resources to reduce distribution costs is an area of significant emerging interest among utilities, regulators, policymakers, and stakeholders internationally. Regulatory initiatives in California and New York, for example, have specifically directed utilities to identify locations on the distribution system where capacity upgrades could be deferred through the use of demand response. The deferral of a $1.2 billion substation upgrade in the Brooklyn area of New York through the use of distributed resources is one commonly cited example.[18]

Conversations with DNOs suggest that similar efforts to identify these distribution upgrade deferral opportunities are underway in GB. A prevailing view is that this will be best achieved through targeted demand response programmes with fully automated load reductions. Retail tariffs with prices that vary locally on the distribution system are technically a possibility, though most stakeholders consider that possibility to be particularly far beyond the industry's current capabilities. One stakeholder suggested that GB's Economy 7 tariff had historically led to significant deferrals in the need for distribution infrastructure, though a specific study quantifying this impact could not be identified.

In this study, we have considered the possibility that TOU tariffs could lead to modest incremental distribution capacity avoidance through a broad, average system-wide reduction in peak demand. A review of the Low Carbon London field trial, in which UK Power Networks explored distribution cost avoidance opportunities, and a review of Ofgem's most recent Price Control Review, suggests that peak-driven distribution costs could be up to around £10/kW-year on average.[19] This forms the basis for our assumption in the Current Trends and High Renewables scenarios.

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[18] Robert Walton, "The non-wire alternative: ConEd's Brooklyn-Queens pilot rejects traditional grid upgrades," Utility Dive, August 2016.

[19] Distribution costs represent roughly 20% of the average customer's bill (£100/yr, or £110/kW-yr), but it appears that only 5% to 10% of this is directly related to load growth

Marginal distribution capacity costs are assumed to be significantly higher in the Electrification scenarios, at £30/kW-year. Significant adoption of heat pumps and EVs among domestic customers has the potential to create local constraints due the possibility of "clustered" adoption and the significant impact that these technologies can have on an individual household's peak demand (a single HP could increase the class-average domestic customer's peak by around 90%; an EV could increase it by around 30%). The £30/kW-year assumption is within the range of marginal costs observed in other international jurisdictions.

It is important to note that these marginal distribution capacity cost assumptions are an average across the system. Costs could be significantly higher in portions of the grid that are constrained and lower (or zero) in areas where there is significant excess distribution capacity. An assessment of the potential for distributed resources to avoid distribution costs is highly system specific and, while the distribution assumptions in this study are a reasonable starting point, this is an area of the analysis with considerable uncertainty and would significantly benefit from further research.

Allocating Capacity Costs over Time

Capacity costs are allocated to hours of the year proportional to the likelihood that those hours will drive the need for new capacity. This is a proxy for the reliability risk for insufficient capacity that each hour represents. Capacity costs are allocated to the top 100 half-hourly load intervals of the year.[20] The allocation is proportional to each interval's share of total load in the top 50 hours (i.e., more capacity cost is allocated to the top load hour than the 50th).

This approach has the advantage of accurately accounting for the constraints that exist in a TOU tariff offering, or any demand response offering for that matter. For instance, if the peak period in a TOU tariff is from 4 pm to 8 pm and there is a 10% probability that the system peak will occur outside this window, the capacity value of the TOU tariff is effectively reduced by 10%. A similar implicit reduction accounts for the limited number of high-price events that could be called in a dynamic pricing tariff.

Generation and transmission capacity costs are allocated to the 100 half-hourly increments with the highest system load, reflecting the bulk system-level drivers of these costs. Distribution capacity costs, on the other hand, are allocated proportional to peak domestic load intervals rather than system load. This reflects the geographical clustering of different customer types, and the fact that portions of the distribution system therefore commonly serve one type of customer.

The allocation of capacity costs to hours of the day is illustrated in Figure 3. The highest costs – including most of the capacity costs - are concentrated in the four-hour window of time between 4 pm and 8 pm during the winter.

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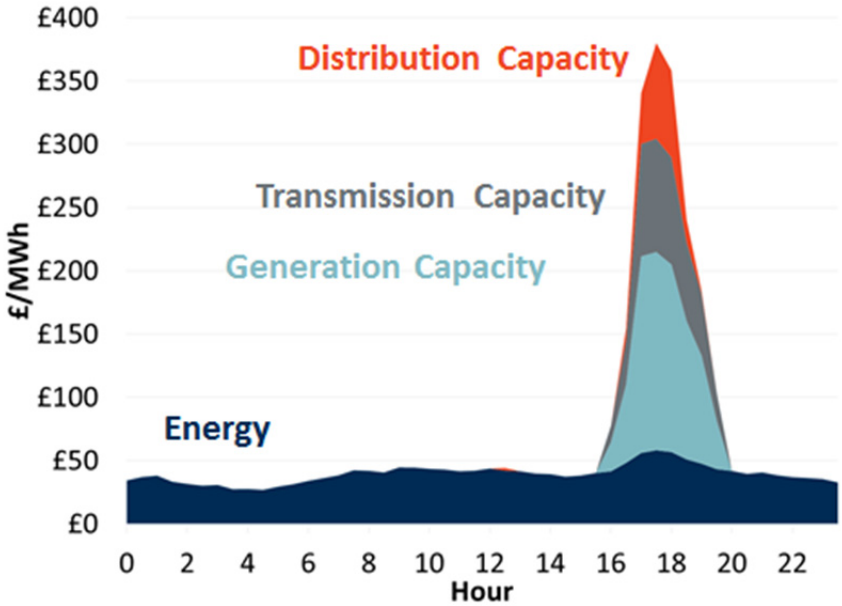
[20] Capacity costs are allocated based on net load (i.e., load net of solar and wind generation). This accounts for the impact that inflexible generation resources would have on system planning.

Figure 3: Allocation of Marginal Costs Over Winter Days (Current Trends Scenario)



Notes: Capacity costs are illustrated only for those days with peaking risk. Costs shown are averages across GB during winter months (Dec, Jan, and Feb). Avoidable distribution costs will be significantly higher in areas of the network with localized constraints.

Under current conditions, the system peak and domestic class peak are relatively well aligned, though there is some divergence in the Electrification scenarios. A summary of capacity prices and load characteristics of each scenario is provided in Table 2.

Table 2: Market Scenario Cost and Load Characteristics

	Current Trends	High Renewables	Electrification
Marginal costs (£/kW-yr)			
Generation capacity	£35	£39	£50
Transmission capacity	£15	£15	£20
Distribution capacity	£10	£10	£30
Peak demand (GW)	55	54	64
Reserve margin	10%	10%	8%
Timing of system peak	5:00 PM	5:00 PM	6:00 PM
Timing of domestic peak	5:30 PM	5:30 PM	6:30 PM

Sidebar: Non-quantified sources of potential TOU value

There are additional potential sources of value from TOU tariffs which are not quantified in this analysis. These tend to be non-monetary, difficult to assign a monetary value, or theoretically possible but largely unproven thus far in the context of TOU tariffs.

Ancillary services: It is theoretically possible to extend ancillary services price signals to domestic retail customers, though thus far this is largely an unproven concept.

Reduced wholesale market prices: A reduction in demand during high-priced hours could (temporarily) reduce wholesale market prices – a benefit to consumers.

Improved fairness in retail pricing: More cost-reflective tariffs would remove the large subsidy from "flat load" customers to "peaky load" customers that is present in the current tariff offerings.

Environmental benefits: If TOU tariffs reduce consumption or shift it to hours when power plants with lower emissions rates are on the margin, this can potentially result in a net environmental benefit. This will depend on the specific characteristics of the system in which the time-varying rates are being offered. For most TOU tariffs, the environmental impact is very modest due to a limited number of peak pricing events and limited change in total electricity consumption.

Facilitating the adoption of distributed energy resources: TOU tariffs can improve the economic attractiveness of certain types of distributed resources such as energy storage and electric vehicles.

Reduced hedging costs: Suppliers must hedge against price and volume risk in order to provide customers with a flat-price tariff. Shifting some of this risk to the customer in the form of a time-varying price in a TOU tariff could warrant a lower average price for participants in the tariff.

Conservation: Some studies have suggested that TOU pricing could lead to a net reduction in overall energy consumption (e.g. by promoting adoption of energy efficient appliances). That would, in particular, enhance energy cost savings. In this study, we have quantified only the value of load shifting and have assumed no net change in total annual consumption.

TOU Tariff Designs

This study modelled five TOU tariff designs: Conventional static TOU, inverted static TOU (iTOU), critical peak pricing (CPP), critical peak rebate (CPR), and a half-hourly "Smart Home Rate" (SHR).

Each of the tariffs is designed to be revenue neutral for the domestic class as a whole. This means that, in the absence of a change in customer load shape, each TOU tariff would collect the same revenue from the domestic class as the current tariff offerings. This assumption isolates the impact of the tariff design on customer behaviour, without also getting into the separate issue of the impacts of an overall rate increase or decrease.

Static TOU: Static TOU tariffs charge customers a higher price during peak hours of the day and a lower price during off-peak hours. The tariff is static in the sense that the price schedule is known to customers and does not change. In this study, we have assumed that the peak period applies from 4 pm to 8 pm on weekdays. Based on a review of tariff deployments and GB marginal costs, the static TOU has a peak-to-off-peak price ratio of 2-to-1 in the Current Trends and High Renewables scenarios, and 4-to-1 in the Electrification scenarios. The ratio is higher in the Electrification scenarios due to higher capacity costs being allocated to the peak period of the tariff.

Inverted TOU (iTOU): An iTOU charges lower prices during mid-day hours and higher prices during other hours. The lower-priced period is set to align with the hours of maximum solar PV output, to encourage self-consumption and reduce distribution constraints due to net excess generation from distributed solar. This tariff design was tested recently with customers in Western Power Distribution's (WPD's) service territory.[21] We assumed an iTOU design for this study that was similar in concept to the one tested by WPD. The peak period of the rate analysed in our study is from 11 am to 3 pm during summer months only.

Critical peak pricing (CPP): CPP tariffs charge significantly higher peak period prices during a limited number of peak events per year, and lower prices during all other hours. The peak price signal is dynamic, with customers being notified of a peak price event one day in advance. We have assumed that the tariff would include a limit of 15 peak price events per year. The peak-to-off-peak price ratio is 6-to-1 in the Current Trends and High Renewables scenarios and 10-to-1 in the Electrification scenarios, for the same reasons discussed above.

Critical Peak Rebate (CPR): A CPR is the "mirror image" of a CPP tariff. Rather than charging a higher price during peak events, rebates are paid to customers for load reductions relative to an estimated baseline consumption level. The underlying tariff design itself does not change; customers are simply awarded a rebate payment if they reduce consumption. As such the CPR effectively is a no-lose proposition for customers. The modelled number of peak events and the implied price ratio in the CPR are the same as in the CPP tariff.

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21 Final reports for the Sunshine Tariff Field Trial can be found on the RegenSW website: https://www.regensw.co.uk/sunshine-tariff

Smart Home Rate (SHR): The price in a SHR varies on an hourly or 30-minute basis. This hourly variation reflects not only changes in energy price but also the time-specific allocation of generation, transmission, and distribution capacity costs (as discussed above). While there are cases of domestic customers being enrolled in hourly tariffs (e.g., Spain's default domestic tariff), those tariffs typically only reflect hourly variation in energy costs, as opposed to including the allocation of capacity costs. The idea of a SHR has begun to attract interest in some jurisdictions internationally as the adoption of smart home appliances has grown.[22]

A summary of the five modelled tariff designs is provided in Table 3.

Table 3: The Five Modelled Tariff Designs

Category	Tariff Designs	Description	Examples
Static (Encourages permanent re-shaping of load)	1. Conventional TOU	Higher daytime (peak period) price and lower price during all other hours.	Economy 7, Arizona Public Service, Ontario (Canada)
	2. Inverted TOU (iTOU)	Lower peak period price and higher off-peak prices. The peak period is set to align with the hours of maximum solar PV output, to encourage self-consumption and reduce distribution constraints due to net excess generation.	WPD Sunshine Tariff, being tested in Hawaii and California
Event-based (Encourages temporary, targeted increases or decreases in load)	3. Critical peak pricing (CPP)	Significantly higher price during a limited number of peak events per year, lower price during all other hours.	Piloted in LCL field trial; offered by PG&E (California)
	4. Critical peak rebates (CPR)	Rebates are paid for load reductions relative to an estimated baseline level of consumption during a limited number of peak events. The underlying tariff design itself does not change; customers are simply awarded a rebate payment if they reduce consumption.	BGE and Pepco (Maryland)
Realtime (Encourages around-the-clock, near-instantaneous load response)	5. Smart Home Rate (SHR)	The price varies on a 30-minute basis. Hourly variation reflects not only changes in energy price but also the allocation of generation, transmission, and distribution capacity costs to the hours that are driving capacity investment needs.	Only conceptual at this point; discussed in NY and CA

ENROLMENT RATES AND PER-PARTICIPANT IMPACTS

Enrolment rates are derived from a comprehensive literature review on consumer preferences for TOU tariffs, as well as subsequent primary market research, both of which are discussed in detail in Sections IV and V of this report. Where the findings of that research were inconclusive, assumptions were made based on experience designing and evaluating TOU field trials and full-scale offerings internationally.

22 See, for instance, Devi Glick, Matt Lehrman, and Owen Smith, "Rate Design for the Distribution Edge," Rocky Mountain Institute report, August 2014. The concept of a SHR-like tariff is also referenced in the European Commission's 2016 Clean Energy Package, which calls for customer access to a dynamic tariff which is "an electricity supply contract between a supplier and a final customer that reflects the price at the spot market, including at the day ahead market at intervals at least equal to the market settlement frequency."

Table 4 summarises the participation rate assumptions in this study. Participation rates are shown both for a case where tariffs are offered on an opt-in basis (where customers must proactively enroll) and a case where the offering is on an opt-out basis (where customers are defaulted on to the tariff with the option to opt-out to a different tariff). Enrolment in opt-out offerings is commonly significantly higher than in opt-in offerings. The support for this and other assumptions is discussed further throughout the remainder of this report.

Table 4: Participation Rates by TOU Design

	Opt-in	Opt-out
Static TOU	20%	80%
iTOU	6% [1]	N/A
CPP	20%	N/A
CPR	25%	90%
SHR	5%	N/A

Notes:
[1] We assume 20% enrolment in the iTOU tariff among eligible customers, but that only 30% of customers are offered the tariff (i.e., those in areas with high distributed solar adoption)
[2] Participation rates are the same across all market scenarios except for SHR in the Electrification w/Automation case, in which we assume 15% enrolment due to the high uptake of automating technologies and the significant associated benefits in that scenario.

Estimates of the price responsiveness of domestic customers in GB were developed based on a review of studies on TOU field trials that have been conducted in GB, Ireland, and internationally. The results of this review are discussed in detail in Section IV of this report. The review found that customers in GB have responded to TOU price signals, measuring average peak demand reductions of up to 10% among trial participants. While customers in GB consume significantly less electricity than those in North America (where many of the international field trials have been conducted), on percentage basis the price responsiveness observed in GB and Ireland field trials is fairly consistent with that observed elsewhere.

Generally, the average peak demand reduction among TOU tariff participants increases as the peak-to-off-peak price ratio increases.[23] This relationship has been captured in a suite of tools developed by Brattle called the Price Impact Simulation Model (PRISM). The estimates of price responsiveness in GB that were established in the literature review described above were tailored to the specific tariffs and price ratios being analysed in this study using the PRISM tools. Resulting estimates of average peak reduction per participant are summarized in Table 5 below.

23 Ahmad Faruqui and Sanem Sergici, "Arcturus: International Evidence on Dynamic Pricing," *The Electricity Journal* August/September 2013.

Table 5: Per-Participant Peak Demand Impacts of TOU Tariffs

	Current Trends	High Renewables	Electrification	Electrification w/Automation [1]
Static TOU				
Opt-in	5%	5%	7%	8%
Opt-out	3%	3%	4%	N/A
iTOU				
Opt-in	N/A	10% [2]	N/A	N/A
CPP				
Opt-in	10%	10%	14%	16%
CPR				
Opt-in	8%	8%	11%	12%
Opt-out	4%	4%	5%	N/A
SHR				
Opt-in	3%	3%	5%	Varies [3]

Notes:
[1] Electrification w/Automation impacts are reported as a weighted average of customers with automating tech and those providing only behavioural response. Impacts for customers with automating tech are higher than those shown in the table. Impacts from EVs are accounted for separately.
[2] iTOU impact is % of load shifted to lower priced peak period.
[3] SHR response varies by hour with a maximum load reduction of 25%.
[4] Unless otherwise noted, reported impact is average across all participants and all peak hours of the TOU tariff.

III. The Value of TOU Tariffs

Twelve Key Findings

The result of the modelling described in Section II is a range of estimates of the total annual system costs that could be avoided through a full scale rollout of TOU tariffs in GB. The results span five possible tariff offerings and four market scenarios. This section of the report is organized around 12 key findings from the TOU value assessment.

Finding #1: Customers do respond to TOU price signals

There is a perception among some industry stakeholders that domestic customers in GB will not respond to TOU price signals. This is typically in spite of the findings of field trials and full-scale deployments which have shown that customers do respond to price, under a range of conditions and in the absence of automating technology (a review of those field trials is presented in Section IV).

The perceived lack of domestic customer price responsiveness is commonly due in part to extrapolating from one's own experience or preferences for TOU tariffs. It is also often attributed to a view that domestic customers have relatively little flexible load.

Behind these views, there tends to be an underappreciation for the significant heterogeneity in the domestic segment. While it is efficient to extrapolate from one's own experience as a customer, the domestic customer base is simply too diverse for this extrapolation to be broadly applicable to the class as whole.

For instance, field trials have anecdotally found that 70 to 80% of the aggregate peak demand reduction from a TOU tariff can come from only 20 to 30% of the TOU participants. In other words, some customers will not respond to TOU tariffs at all, some will respond a little, and some will respond a lot. Since it is ultimately the aggregate response that matters when determining the system value of TOU tariffs, it is important to recognize that populations of TOU participants have always included a group of customers who do not respond. The tariffs have produced meaningful impacts in spite of this.

This diversity in the domestic class also makes it very difficult to construct a bottom-up estimate of those individual loads that are likely to respond to price signals. It can be difficult for TOU participants to articulate the specific actions that led to peak demand reductions, partly because customers often do not have a strong sense of the electricity intensity of various appliances. Further, while some TOU impact evaluations have identified air-conditioning as a driver of flexibility, it is also the case that field trials in winter peaking regions or regions with low market penetration of central air-conditioning have detected significant levels of price response.

There is a broad variety of ways that customers could go about reducing peak load beyond delaying the use of their washer and dryer (commonly perceived to be the likely sources of load flexibility). For instance, lighting is commonly characterised as "inflexible load" but it is not difficult to imagine a customer who becomes more conscious about not leaving the lights on in unattended rooms during peak pricing hours after enrolling in a TOU rate. Customers may also choose to upgrade "inflexible" end-uses to more energy efficient models and achieve permanent peak demand reductions as a result.

There has also been some skepticism that the findings of TOU field trials cannot be extrapolated to the broader population of customers. The view is that this is partly due to self-selection bias[24] among participants in the trials and partly due to an unusual amount of information and "attention" that the customers receive as participants. In contrast to this view, however, field trials that were conducted on an opt-out basis have detected a statistically significant level of price response, thus addressing the concern about self-selection bias.[25] It is also the case that full-scale TOU offerings have produced significant peak reductions even at modest peak-to-off-peak price ratios, suggesting that the impacts observed in field trials can also be observed on a full-scale basis.[26]

Rather than attempting to model the plethora of ways in which a diverse group of customers may respond to TOU tariffs, we have relied on a review of studies reporting the average impacts that have been observed across hundreds of thousands of participants in TOU tariffs in GB and internationally. These results implicitly account for the breadth of ways in which customers respond (or do not respond) to TOU tariffs.

With opt-in offerings in the Current Conditions scenario, we find that behavioural response to TOU tariffs alone could produce 300 to 600 MW of system peak demand reduction in GB (the equivalent of at least four mid-sized peaking units). Under more extreme price conditions, with electrification of heating and transport, and with adoption of automating technologies, we estimate that TOU tariffs could potentially reduce system peak demand by more than 1,000 MW. Fully automated whole-home response, and/or opt-out TOU tariff offerings have the potential to increase this estimate further.

Finding #2: Under current market trends, voluntary TOU tariffs can provide modest but meaningful cost savings

Under Current Trends, and with opt-in deployment, the value of TOU tariffs ranges from £19 to £24 million/year.[27] Averaged across all households in GB, this equates to roughly £1 per domestic GB customer per year. It is roughly £5 of annual savings per TOU participant.

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24 In other words, there is a view that customers who choose to participate in the field trials are likely to be more engaged and price responsive than the typical customer.

25 Potter, Jennifer, Stephen S. George, and Lupe R. Jimenez, "SmartPricing Options Final Evaluation," prepared for the U.S. Department of Energy, September 2014.

26 Ahmad Faruqui et al, "Analysis of Ontario's Full Scale Roll-out of TOU Rates – Final Study," prepared for the Independent Electric System Operator, February 3, 2016.

27 A summary of estimates of system value for all market scenarios and tariff designs is provided later in this section of the report.

These values are gross savings in the form of avoided resource costs that could be shared between suppliers, network operators, TOU participants, and possibly TOU non-participants. How those savings would be allocated would depend on the specific design of the TOU tariff offering.

Looking across the individual TOU designs, the total value of static TOU, critical peak pricing (CPP), and critical peak rebate (CPR) tariffs is surprisingly similar in magnitude. It is generally the case that the relative strengths and weaknesses of each tariff design are offset to some degree. For instance, while CPR may have higher enrolment rate than the CPP tariff, this advantage in participation is offset by a slightly lower average per-participant peak reduction in the CPR due to differences in the nature of the price signal. Similarly, while the static TOU produces a lower average peak impact, the price signal applies on a daily basis and therefore captures value on many more days than the CPP or CPR tariffs.

Finding #3: Customer participation in TOU tariffs will be a key driver of system benefits

In a transition to TOU tariffs, a policy decision will need to be made regarding whether the tariffs will be offered on an opt-in or opt-out basis (sometimes also referred to as a "default" offering). With an opt-in offering, customers must proactively leave their current tariff to sign up for new TOU tariff. With an opt-out offering, customers are automatically moved to the TOU tariff, with the option to switch to a different (and possibly non-time-varying) tariff.

Some regions of the world are transitioning to domestic TOU tariff deployments on an opt-out basis. All four million households in the province of Ontario, Canada have been defaulted to a static TOU, with the option to choose a different rate offered by retail supplier. TOU pricing is the default domestic tariff across Italy for 25 million customers.[28] In Spain, roughly half of all domestic customers remain on the standard tariff, in which the energy charge varies by hour. Ireland is expected to transition to a default domestic TOU tariff following the completion of its smart metering deployment. In the United States, Baltimore Gas & Electric and Pepco Holdings have transitioned all of their domestic customers in Maryland and Delaware to a default CPR. The major utilities in California will transition their domestic customers to default static TOU tariffs in the next few years.

While the possibility of an opt-out offering of TOU tariffs has not been at the forefront of retail tariff discussions in GB, we explored the potential impacts of such an offering given its international relevance.

Evidence suggests that customers are much more likely to remain enrolled in TOU tariffs if they are deployed on an opt-out basis. Generally, a successful opt-in offering might attract 20% of customers, whereas 80% or more of customers may remain enrolled in a TOU tariff when deployed on an opt-out basis.[29] Conversely, the price responsiveness of the average

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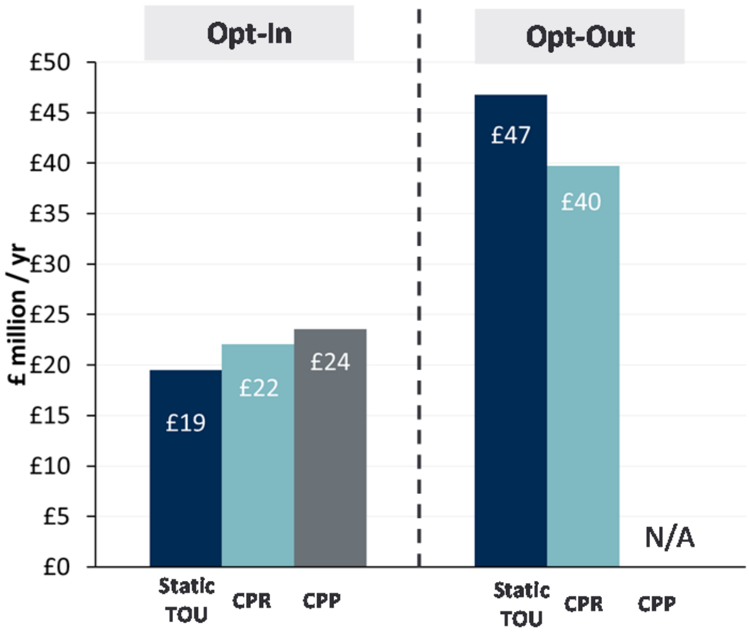
28 Walter Graterri and Simone Maggiore, "Impact of a Mandatory Time-of-Use Tariff on the Residential Customers in Italy," November 14, 2012. http://www.ieadsm.org/Files/Content/14.Espoo_IEA_DSM_Espoo2012_SimoneMaggiore_RSE.pdf

29 See Section V of this report for additional detail. For further discussion, also see Ahmad Faruqui, Ryan Hledik, and Neil Lessem, "Smart by Default," *Public Utilities Fortnightly*, August 2014.

customer in an opt-out offering is lower than in an opt-in offering. One field trial found that peak demand reductions from the average customer in an opt-out offering were 40 to 50% lower than in an equivalent opt-in offering.[30]

Deploying TOU tariffs on an opt-out basis roughly doubled the total system value of the tariff in our analysis. While average per-participant impacts are likely lower with opt-out offerings, this is more than offset by the observed significant increase in enrolment. Figure 4 illustrates the comparison of total annual system value between opt-in and opt-out deployments.[31]

Figure 4: Value of TOU Tariffs, Opt-in versus Opt-out



Regardless of whether TOU tariffs are deployed on an opt-in or opt-out basis, marketing and customer engagement will play a critical role in the success of the offering under either deployment scenario. For an opt-out offering, it will be important to ensure that customers are aware of the tariff change and the options at their disposal to respond to the new tariff, particularly any vulnerable customers who may experience a bill increase.

For opt-in offerings, significant engagement efforts will be needed to achieve meaningful enrolment levels. Case studies from other jurisdictions suggest that significant participation can be achieved even on an opt-in basis. For example, Arizona Public Service has more than half of its domestic customers enrolled in a voluntary TOU, driven in part by a concerted effort by the utility's customer service department to provide customers with information

30 Jennifer M. Potter, Stephen S. George, and Lupe R. Jimenez, "SmartPricing Options Final Evaluation," prepared for the U.S. Department of Energy, September 2014. https://www.smartgrid.gov/files/SMUD-CBS_Final_Evaluation_Submitted_DOE_9_9_2014.pdf.

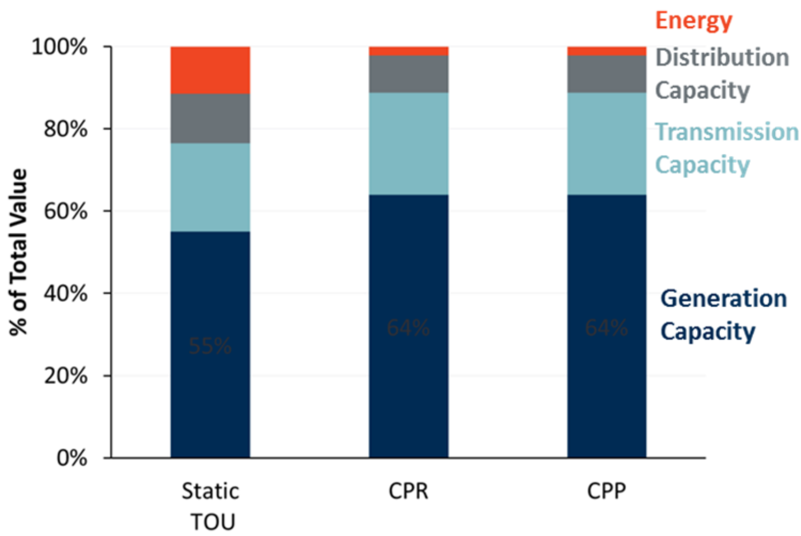
31 CPP tariffs were not considered for opt-out deployment in this study since there is no international evidence of such an offering to domestic customers.

about the tariff that is best suited to their electricity consumption needs. In contrast to the APS example, there are also many international examples of poorly marketed TOU tariffs with very limited enrolment. Innovative customer engagement methods will be critical to the success of future TOU offerings.

Finding #4: Avoided generation capacity investment is the single largest source of value, though TOU tariffs should be designed to maximize total system value

Avoided generation capacity costs account for between 55 and 65% of total value under the Current Trends scenario, even with fairly modest capacity prices of £35/kW-yr. The value of transmission capacity avoidance is modest since transmission represents a small share of total overall power system costs (i.e., 5% of typical domestic bill). The potential for TOU tariffs to lead to the avoidance of distribution capacity costs is significant, though this is the most uncertain of the four sources of value. Figure 5 summarises the share of TOU value by source.

Figure 5: Share of TOU Value by Source



Note: Results shown for Current Trends scenario, opt-in deployment.

To capture these system benefits, TOU tariffs will need to be designed to reduce demand during times when the *total* value to the system is highest, as opposed to maximizing any individual value stream. Under current system conditions, the timing of the system peak (which drives generation and transmission capacity needs) tends to align fairly closely with the domestic class peak (which is a proxy for the driver of avoidable distribution capacity costs). A useful extension of this research would include a more detailed comparison of the timing of the system peak to the timing of those specific localized peaks that are currently driving distribution capacity needs for an individual DNO; the timing of those localized peaks can vary significantly across service territories.

Conversely, tariffs that are designed to increase market share but do not align with system peak demand could actually lead to an increase in system costs. For instance, a perceived "customer friendly" rate with a peak period from 1 pm to 5 pm could actually encourage an increase in consumption as the system is peaking. From a policy standpoint, it will be important to consider the potential implications of this outcome, including the extent to which the increase in cost could be recovered from non-participants and the extent to which these cost increases would be accurately accounted for under current settlement processes.

Finding #5: Critical Peak Rebates have significant potential but are under-researched in GB

CPRs consistently produce value across the market scenarios. Aside from their financial value, CPRs also have a number of non-monetary advantages relative to other TOU tariff designs. First, CPRs offer a risk-free proposition to customers. On a CPR, customers earn a rebate if they reduce peak consumption or otherwise simply continue to be charged the standard price according to their existing tariff. Second, CPRs provide a price signal that has been proven through numerous field trials to produce significant peak demand reductions that are roughly comparable on a per-participant basis to those of a critical peak pricing tariff.[32] Third, evidence from some jurisdictions (such as Maryland and Delaware in the U.S.) suggests that CPRs are the most politically practical option to deploy, particularly on an opt-out basis, due to their no-lose nature for customers.

CPRs also have some disadvantages relative to other TOU tariff designs. In particular, it is challenging to accurately estimate each individual participant's baseline peak period consumption in the absence of the rebate payment. There are various established methods for performing this calculation, though each has some degree of inherent inaccuracy. The tariffs must be carefully designed to avoid over- or under-compensating customers. CPRs also do not correct the cross-subsidy that exists on flat-priced tariffs between customers with flat load profiles and those with peaky load profiles.

In spite of the potential advantages of CPRs, they are under-researched in GB. It would be a useful future research activity to better understand the extent to which customers in GB are likely to enrol in and respond to such a tariff. Market research on customer interest may need to extend beyond conventional surveys. As is discussed in Section V of this report, initial market research has not detected a significant difference in consumer interest in CPRs relative to other possible offerings, including a flat pricing tariff. Given the no-lose proposition that CPRs offer, among many possible explanations it is conceivable that customers simply need more information to be made aware of the potential benefits of such a tariff.

Finding #6: Renewables growth alone is not likely to significantly impact the system value of conventional TOU tariffs

Under the valuation framework adopted for this study, the addition of wind and solar capacity to the GB system does not significantly increase the value of TOU tariffs. Energy prices decrease with the addition of low variable cost generation, thus reducing the already modest energy value associated with shifting load from peak to off-peak periods. Capacity prices are assumed to increase somewhat, to provide the necessary incentive to keep sufficient generation online. The value of TOU tariffs increases in this regard. However, the increase

[32] Some field trials have found no statistically significant difference between CPR and CPP price elasticities, while others have found that customers respond slightly more to the CPP price signal.

in capacity payments is partly offset by the decrease in energy prices, thus only modestly increasing TOU system value relative to the Current Trends scenario. Further, it is possible that requirements for providing capacity in a future high renewables environment may be more difficult for TOU tariffs to satisfy, as system reliability would be less driven by a need to simply meet peak demand and more driven by a need for around-the-clock flexibility.

The value of balancing services[33] seems likely to increase in a future High Renewables scenario. However, the provision of ancillary services by domestic customers is better suited to a demand-side response programme than to a retail pricing scheme.[34] The short notification and frequency of response required by ancillary services means that it is virtually impossible for a domestic customer to respond in the absence of automating technology. The pricing of ancillary services is complex and it therefore may not make sense to convey those prices directly to domestic customers.

In areas with distribution constraints due to high adoption of distributed solar PV, an iTOU tariff may help to relieve some of the congestion and defer the need for capacity upgrades. That possibility is discussed later in this section of the report.

Shifting load to off-peak periods could also help to reduce wind curtailments during times of low net load on the system. Our modeling accounts for the financial value of this curtailment avoidance (reflected by negative energy prices in some hours). There could be an additional environmental benefit that would be useful to analyse through future research.

Finding #7: TOU value will increase significantly if electrification drives a greater need for new capacity

Electrification of domestic heating and transport has the potential to significantly increase the need for new generation and network capacity. Under the assumptions behind the Electrification scenarios in this study, system peak demand would increase by 16% and the residential class peak would increase by 29%.[35]

If accelerated load growth outstrips supply, this would likely drive up capacity auction prices. It is also likely that there would be an increase in the share of locations that are experiencing capacity constraints on both the transmission and distribution systems.

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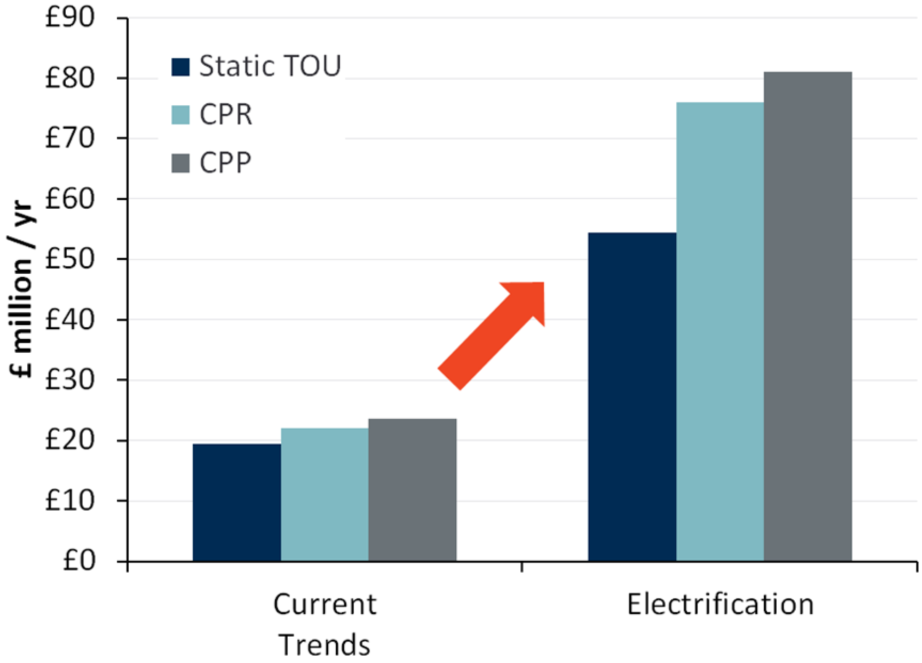
33 Balancing services are ancillary services that support the transmission of electricity from generator to end-user, such as frequency regulation, spinning reserve, non-spinning reserve, and voltage support.

34 For instance, a domestic water heating demand-side response programme has the potential to provide significant ancillary services value. For further discussion, see Ryan Hledik, Judy Chang, and Roger Lueken, "The Hidden Battery: Opportunities in Electric Water Heating," prepared for NRECA, NRDC, and PLMA, January 2016.

35 The impact of electrification on peak demand will be highly dependent on a range of factors, including EV charging patterns and electric heating technologies. See Appendix D for further description of the specific assumptions behind this scenario.

Under this electrification scenario, and assuming only behavioural response to price signals (i.e., no automating technologies), an increased system-wide need for capacity could triple or quadruple the value of TOU tariffs. This finding specifically demonstrates the sensitivity of TOU value to assumed capacity prices. Figure 6 illustrates the impact of rapid load growth on TOU value.

Figure 6: Impact of Accelerated Load Growth on TOU Value



Note: Results only shown for "opt-in" cases.

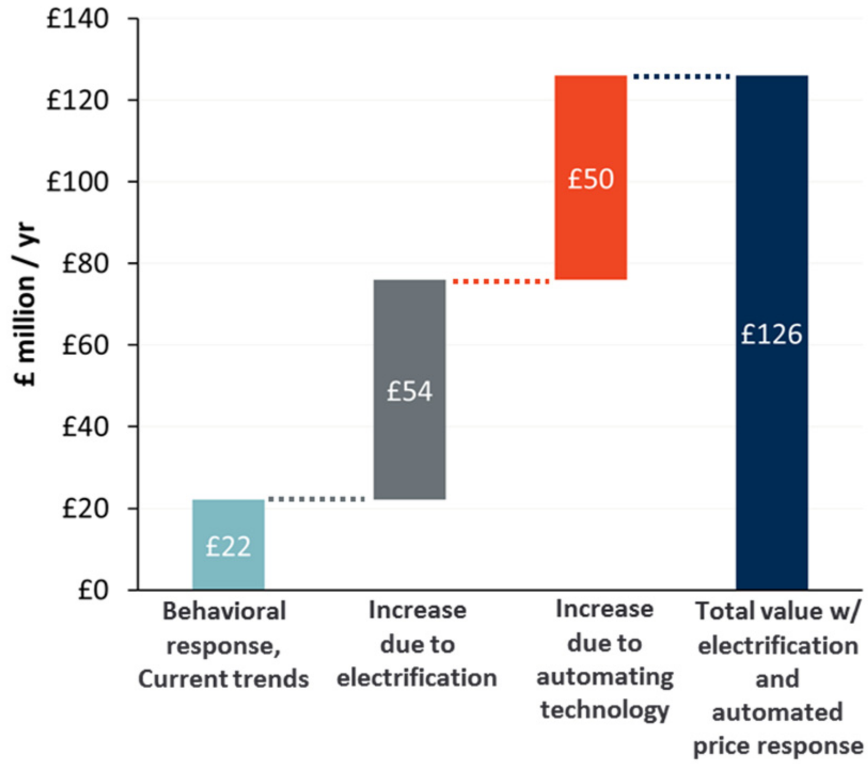
While the Electrification scenario illustrates a plausible case where capacity prices increase in the future, it is possible in a different scenario that capacity value could decrease in the future (e.g., due to lower-than-expected demand). This has been the case in Germany and Spain, for example, where there is significant excess generating capacity during peak times and therefore limited value in conventional peak demand reductions. Expectations around future capacity costs will be a critical consideration when establishing TOU policy.

Finding #8: Automating technology coupled with electrification would further boost value

Field trials have consistently shown that automating technologies (e.g., smart thermostats, smart EV chargers) significantly increase price response. While there is scepticism among some stakeholders in GB around the likelihood that domestic customers will exhibit behavioural price response, many agree that adoption of automating technologies is the key to unlocking the full demand response potential of the domestic sector. The results of our analysis confirm that the possible boost in responsiveness from automating technologies would significantly increase the value of TOU tariffs.

In the Electrification w/Automation scenario, the adoption of enabling technology alone increases the value of an opt-in CPR tariff by £50 million/yr. Roughly proportional increases are observed for TOU and CPP tariffs. The incremental impact of the adoption of automating technology is illustrated in Figure 7. For simplicity, the result for the CPR tariff is shown as an illustrative case.

Figure 7: Incremental Impact of Load Growth and Automating Technology



Note: Results shown for opt-in CPR as illustrative case

It is important to note that the savings of £126 million/year shown above do not account for the cost of the automating technology. On one hand, it is possible that this technology will be adopted by customers regardless of the presence of TOU tariffs. For instance, customers may purchase a smart thermostat for its remote control capabilities and ease of programming, with the ability to respond to price signals being a secondary – or even unrecognised – feature. On the other hand, it could be the case that customers need to be provided a financial incentive to purchase such equipment. For instance, a North American utility offers a higher CPR payment to customers with smart thermostats due to the added reliability associated with a technology-enabled demand reduction. This dynamic will be an important consideration when comparing the societal benefits of technology-enabled price response to its costs.

Finding #9: In the absence of automating technology, sub-hourly prices have limited value

Market research offers a mixed view on customer acceptance of granular (i.e., hourly or sub-hourly) prices. Some studies have found that customers are relatively unreceptive to hourly real-time prices signals. On the other hand, the primary market research described in Section V of this report detected the possibility of some appeal of this type of tariff among consumers.

An hourly tariff offering in Illinois, USA has experienced modest enrolment.[36] Further, participants in the tariff tended to treat the hourly prices as if they were a static TOU tariff. They recognise that afternoon/evening hours are typically the most expensive hours of the day, and exhibit a general shift in consumption from peak to off-peak hours. However, significant price responsiveness is not observed on an hour-to-hour basis.

In some competitive markets such as New Zealand and Texas, suppliers have begun to offer tariffs with hourly prices. The hourly prices are a direct pass-through of wholesale energy market prices. Anecdotally, it appears that some customers have been attracted to the perceived transparency and "honesty" of a tariff which is considered to have no hidden fees. The tariffs are simply presented as a pass through of costs to the customer, with a modest service fee for the supplier. It seems at least possible that this type of messaging might eventually be the gateway to a tariff which, combined with automating technology, results in significant price response among domestic customers.

Informed by the somewhat limited empirical evidence that is available on hourly pricing for domestic customers, in this study we have assumed that customer uptake of the SHR rate will be modest in the absence of automating technologies. That modest uptake, combined with a similarly modest degree of price response among participants, leads to low aggregate system value of only around £3 million/year for an opt-in offering, in the absence of automating technologies (compared to around £20 million/year for static TOU, CPP, or CPR offerings).

Finding #10: Real-time automated price response on a sub-hourly basis can be a game-changer… if it materialises

The benefits of smart home rate (SHR) tariffs could potentially increase dramatically in scenarios where appliances are responding to real-time prices in an automated fashion. Smart home appliances could effectively be programmed to turn on or off in response to hourly price signals, effectively creating a whole-home "demand curve" for electricity.

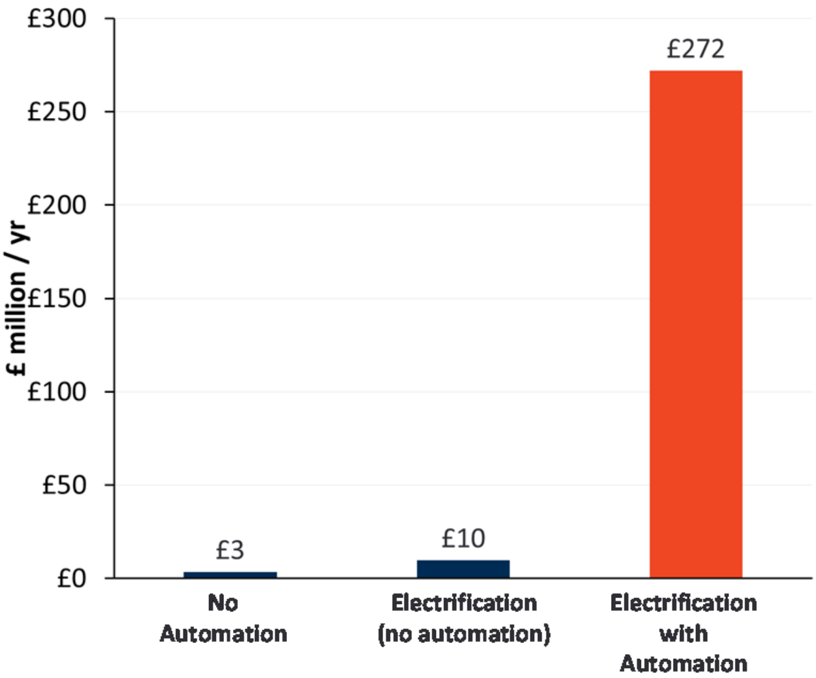
There is considerable uncertainty that this future scenario will materialise. It is not known to what extent smart appliances will be adopted, the degree to which those devices will be programmed to respond to price changes, or whether the appropriate wholesale price signals and market rules will provide an incentive to respond. Thus, this is a scenario with large potential but also very significant uncertainty.

Based on a simple algorithm to model automated real-time price response, even at relatively low levels of participation (i.e., 15% of customers, all of whom are assumed to be equipped with smart home technology), the benefits of automation increase by orders of magnitude for the SHR tariff. Annual benefits could exceed £270 million/year in this scenario. This is the

[36] There are roughly 20,000 customers participating in the programme out of around 5 million households in the state of Illinois. For more information about the tariff, see Anthony Star, Marjorie Isaacson, and Larry Kotewa, "Evaluating Residential Real-Time Pricing: Connecting Customer Response to Energy Market Impacts." http://www.elevateenergy.org/wp/wp-content/uploads/2014/01/Evaluating_Residential_Real_Time_Pricing.pdf

highest value of any scenario analysed in this study. Figure 8 presents the dramatic contrast in the value of a SHR tariff with and without technology.

Figure 8: Potential Value of SHR Tariff Coupled with Smart Home Technology



Finding #11: A longer peak period window would increase TOU value, but there is a trade-off with customer acceptance

Extending the end of the peak period window to 9 pm, rather than the conventional end at 8 pm, could increase the benefits of TOU tariffs to some degree. This is particularly the case in a future scenario with electrification, where the overall system benefits increase by 9% by extending the peak period by one hour. In the Electrification scenario, the timing of the system peak will broaden and the distribution peak will begin to diverge from the system peak, thus requiring a broader peak window (though even in our fairly extreme Electrification scenario, the divergence was not particularly dramatic).

The trade-offs with customer acceptance of a longer peak period would need to be examined through further research. While 5 hours is not an unusually long duration, the period would extend into the late evening. This could potentially hamper customers' ability to delay electricity-intensive activities until the off-peak hours. Figure 9 illustrates the average marginal costs in each hour of the day (averaged over all hours of the year), to provide a sense of the extent to which a 4 pm to 8 pm window captures the highest value hours.

Figure 9: Average Hourly Marginal System Costs, Including Capacity (£/MWh)

Standard 4-hour Peak Window

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Current Trends	£44	£44	£43	£43	£43	£44	£48	£52	£54	£55	£56	£56	£55	£55	£55	£56	£77	£119	£116	£84	£59	£54	£50	£43
High Renewables	£33	£33	£33	£33	£33	£34	£37	£41	£42	£42	£42	£41	£41	£41	£41	£42	£65	£106	£102	£79	£51	£42	£38	£32
Electrification	£52	£51	£49	£48	£48	£49	£51	£55	£57	£59	£59	£58	£58	£57	£57	£59	£83	£134	£176	£117	£78	£59	£56	£53

Hour of Day

Finding #12: The inverted TOU (iTOU) tariff can potentially extend TOU value during the summer season, but in limited applications

An iTOU may be able to defer the need for new distribution capacity in locations where significant excess generation from solar PV is leading to constraints on the network. Increased household consumption during daytime hours in these locations could decrease the amount of energy being exported to the system, and thus lessen the capacity constraints.

WPD's Sunshine Tariff trial tested the iTOU concept.[37] That specific trial found mixed results, particularly regarding challenges around customer enrolment in the tariff. However, the market research described in Section V of this report suggests that there could be consumer interest in such a tariff. Further, the Sunshine Tariff trial did detect significant load shifting among participants, suggesting that it is a useful starting point in further exploring the concept of an iTOU tariff.[38]

The iTOU tariff will largely provide value during summer months, as that is the time when solar-related distribution constraints would occur. In GB, this makes the tariff particularly complementary to other TOU tariffs, which would be designed primarily to reduce winter peak demand. Thus, a summer iTOU could potentially be coupled with a conventional TOU in the winter to provide additive benefits.

We estimated the summer distribution value of an iTOU to be in the range of £3.5 million/year. While that is modest compared to the system value of other TOU offerings in this study, the fact that it is additive to winter-oriented designs suggests that it still worth considering to augment TOU offerings in parts of the grid that may be facing constraints related to distributed PV.

Summary

Across the market scenarios, the highest system value is observed in the cases with rapid load growth due to electrification of heating and transport. This is driven by the potential to avoid

37 The iTOU concept is receiving considerable attention internationally as well. It is being tested for full scale deployment in both California and Hawaii, two jurisdictions with significant adoption of distributed PV.

38 For detailed discussion of the Sunshine Tariff, see the RegenSW website: https://www.regensw.co.uk/sunshine-tariff

higher capacity costs in those scenarios. Adoption of technology to automate the response of those (and other) electric loads to retail prices further increases the system value of TOU tariffs. There is relatively little difference in value between the Current Trends and High Renewables cases. As we have defined the High Renewables scenario, energy prices decrease but capacity prices increase, serving largely as offsetting factors in the TOU value estimation assessment. A summary of the TOU system value estimates for each tariff design and market scenario is presented in Table 6.

Table 6: TOU System Value (£ million/year)

	Current Trends	High Renewables	Electrification	Electrification with Automation
Static TOU (opt-in)	£19	£20	£54	£103
CPR (opt-in)	£22	£25	£76	£126
CPP (opt-in)	£24	£27	£81	£131
SHR (opt-in)	£3	£3	£10	£272
iTOU (opt-in)	N/A	£4	N/A	N/A
Static TOU (opt-out)	£47	£48	£131	£183
CPR (opt-out)	£40	£45	£137	£190

Similarities in the value of different TOU tariffs suggest that non-monetary considerations will be as or more important as financial considerations when developing new TOU tariffs, policies, and programmes. In this light, Sections IV and V of this report specifically assess the consumer appeal of TOU tariff designs and communication strategies.

Putting the Results into Context

Under the Current Trends and High Renewables scenarios, annual savings of opt-in TOU offerings are around £20 to £25 million/year. This equates to around £1 per GB household per year. If those savings were captured entirely by participants, with a nationwide participation rate of around 20%, the savings to participants would be around £5 per household per year. The typical domestic customer's annual electricity bill is between £500 and £600 per year.

It is important to note that these are savings estimates associated only with load shifting. Savings estimates will vary by participant depending on the participant's size and degree of price responsiveness. Additionally, it is the case that the portion of the population with a flatter-than-average load profile would see additional bill savings from these tariffs, by virtue of enrolling in a tariff that better reflects the costs that they impose on the power system.

Further, these estimates do not reflect the non-monetary or difficult-to-quantify benefits of TOU tariffs discussed throughout this report.

At the upper-end of the spectrum, estimates of TOU value are very roughly in the range of £150 to £250 million/year. Achieving savings of this magnitude would likely require higher capacity prices (e.g., driven by electrification), adoption of automating technologies, and/or opt-out deployment of TOU tariffs. These aggregate savings amount roughly to between £5 and £10 in savings per year per GB household. In the specific instance where the benefits are being driven by a relatively small share of customers with automating technologies, savings per participant could be between £30 and £90 per year.[39]

We are aware of two other studies that have looked specifically at the value of domestic TOU tariffs in Great Britain: The Department for Business, Energy, & Industrial Strategy (BEIS) 2016 updated smart metering cost benefit analysis[40] and a 2012 study for the Department of Energy & Climate Change (DECC, predecessor to BEIS) on the system benefits of TOU tariffs[41]. Other studies have considered the potential value of demand response or system flexibility broadly in GB, but did not specifically analyse TOU tariffs.

The 2016 BEIS analysis estimates that load shifting from domestic TOU tariffs could amount to slightly under £1 billion in net present value (NPV) terms for an 18 year period beginning in 2016. These benefits are not provided on an annualized basis. Using scaling factors we developed based on annual values elsewhere in the BEIS report, we estimate that the annual system value of domestic TOU tariffs in the BEIS study may be somewhere around £100 million/year. The BEIS estimate is for opt-in deployment of static TOU.

The 2016 BEIS estimate is within the range of estimates in our study, though the BEIS estimate is above the high end of what we have estimated as feasible for an opt-in offering without automating technology. While several of the assumptions in the BEIS study are similar to those in this study, there are two assumptions that appear to be partially driving the difference in results. The first is that BEIS assumes a participation rate of 30% by the end of the forecast horizon, which is higher than the 20% enrolment rate supported by our analysis. The second is an assumed peak demand reduction among participants of approximately 15%. This is three times the behavioural peak impact we estimated for static TOU participants, and 50% higher than the CPP impact in the Current Conditions scenario. The BEIS impact is in line with assumptions of price response that are aided by automating technology and/or driven by a very significant peak-to-off-peak price ratio in a dynamic tariff. There may also

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39 This is based on a relatively simple algorithm to simulate automated price response. A more detailed assessment of the price responsiveness of a fully-equipped "smart home" would be a valuable extension of this research. Some automated appliances could also potentially provide ancillary services, a benefit which is not captured in this analysis.

40 BEIS, "Smart Meter Roll-out Cost-Benefit Analysis," November 10, 2016. https://www.gov.uk/government/publications/smart-meter-roll-out-gb-cost-benefit-analysis

41 Baringa and Element Energy, "Electricity System Analysis – Future System Benefits from Selected DSR Scenarios," prepared for DECC, August 2012.

be differences in the marginal cost assumptions between the two studies, though we were not able to identify those assumptions in the BEIS reports.

The 2012 DECC study quantifies annual savings ranging from £150 to £400 million per year by 2030.[42] The low end of this range is for a static TOU in a "low demand" scenario and the high end of the range is for a CPP in a "high demand" scenario.

TOU value estimates in the 2012 DECC study begin near the upper-end of the range identified in our study, and extend well above the highest value we have estimated. It appears that one major driver of this difference is an assumption in the DECC study that all scenarios include electrification of heating and demand, and that response from EVs, heat pumps, and other appliances is automated to some degree. As such, the 2012 DECC scenarios would be most comparable to the Electrification w/Automation scenario in this study. Additionally, while marginal cost estimates were not published, the study indicates that the "capital and fixed costs of an OCGT" were the basis for calculating avoided generation capacity costs. That would likely be above the net CONE value used in this study, and well above recent prices observed in the capacity auction (which did not exist at the time the 2012 DECC study was being conducted).

[42] The analysis also includes a scenario with £50 million in annual value, though this scenario largely is designed to illustrate the importance of choosing a peak period window that aligns with the timing of major cost drivers.

IV. Consumer Acceptance of TOU Tariffs: An Evidence Review

We conducted a thorough review of studies on the consumer acceptance of TOU tariffs. This literature review had two purposes. First, it informed the participation and price response impact assumptions in the TOU value analysis discussed earlier in this report. Second, the review provided useful insight on various factors that are likely to influence customer uptake in future TOU offerings, and identified important questions that are unanswered in the current body of literature on TOU tariffs.

Our review was designed to assess the consumer attractiveness of TOU tariffs, the satisfaction of customers who have experience with these tariffs, and the extent to which customers have exhibited price responsiveness when enroled in a new TOU tariff.

Consumer Attractiveness of TOU Tariffs

Approach

Few studies have specifically set out to measure the extent to which consumers would sign up for a TOU tariff voluntarily, and little is known about what might make TOU tariffs more attractive to consumers. We conducted a systematised review to synthesize the available evidence. Using the search criteria outlined in Appendix E, we identified and screened more than 4,000 unique documents (e.g., industry studies, academic articles, government reports) against a set of inclusion criteria. A final list of 27 studies was identified as being sufficient to answer two main research questions:

1. What is domestic consumer demand for TOU tariffs in GB (overall attractiveness)?
2. What factors are associated with a decreased or increased attractiveness of TOU tariffs (factors associated with attractiveness)?

To ensure that sufficient evidence was gathered to conduct a quantitative analysis, our review not only included statistics on sign-up rates to commercially available TOU tariffs but also used responses in quantitative surveys (stated willingness to switch to a TOU tariff) and recruitment rates to TOU tariff trials.

We extracted findings and ran a meta-analysis to estimate the impact of tariff design and other features (e.g. presence and absence of bill protection, automation, type of marketing, etc.) on uptake.[43] The evidence has been extracted from studies conducted in six countries (US, GB, Australia, France, Norway, Netherlands) with most of the evidence coming from the US, followed by GB and Australia. Although we have controlled for country in our analysis (by including it as a variable in the regression model), we recommend that the evidence here be interpreted as being broadly relevant to all countries included. Since most of the GB

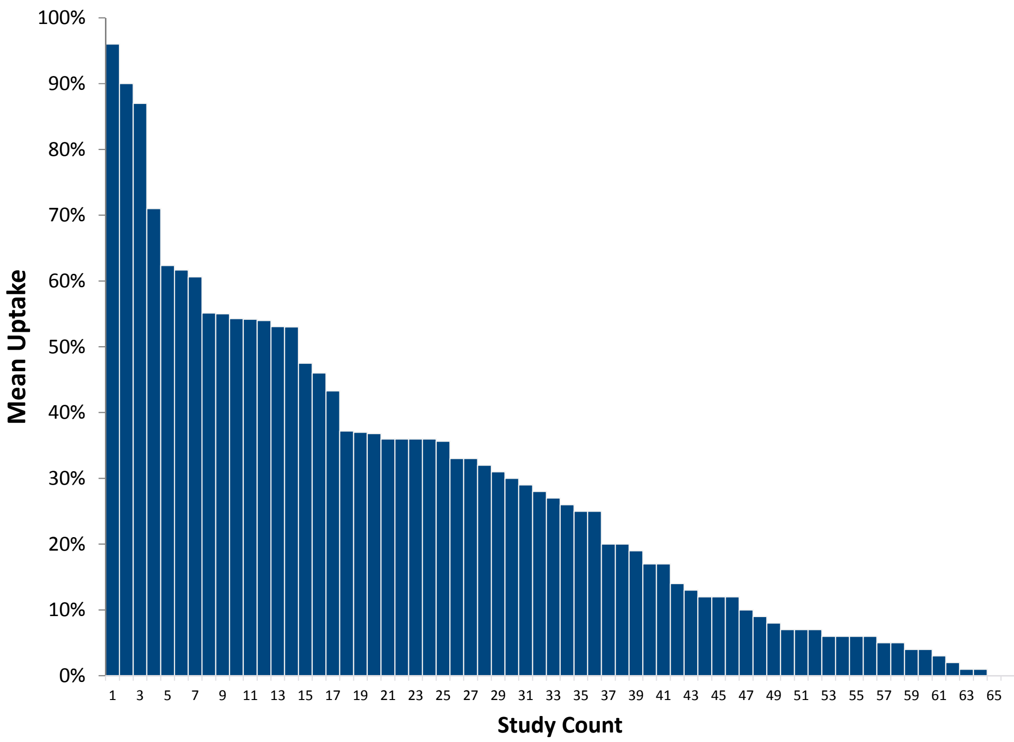
[43] See Appendix E for further discussion.

evidence is survey-based and there is considerable insight to be obtained from analysis of direct participation in a commercially available tariff, the cross-country evidence is likely to provide a better indicator of eventual uptake than relying on GB studies alone.

Overall Attractiveness

Across surveys, tariff trials and commercial deployments, the range of observed uptake of domestic TOU tariffs is very large, ranging from 0 to 96%. The mean enrolment rate is 29% but with considerable variation around this mean. Figure 10 summarises each of the 66 measures of uptake from the 27 studies.

Figure 10: Measures of Uptake to TOU Tariffs from all Reviewed Studies (% of Eligible Population)



Each bar in Figure 10 represents an observed measure of uptake. Some studies obtained multiple measures (for example, in cases where they tested more than one tariff and reported uptake by tariff) so individual studies may appear multiple times. The remainder of this section discusses the factors that are most likely to be driving this variation in uptake observed across measures and across studies.

Factors Associated with Customer Attractiveness

Table 7 summarises the evidence on the factors associated with consumer attractiveness to TOU tariffs, including an indication of strength of findings. High strength means that there is a strong statistical association, which can be interpreted as meaning that this factor is highly likely to be associated with uptake. Moderate means that while there was no association in the meta-analysis (the across study comparison), individual studies that explicitly seek to test the impact of that factor on uptake (using randomization) do find an association. Inconclusive means that there was no statistical association found. This cannot be interpreted as evidence that the factor has no impact on uptake but just that there is not enough evidence to say either way.

Table 7: Factors Associated with Customer Attractiveness to TOU Tariffs

Factor	Key takeaways	Strength of findings
Recruitment method (opt-in versus opt-out)	Biggest driver of differences across studies. 83% average enrolment with opt-out versus 26% with opt-in. Customers who are enrolled on TOU tariffs by default under opt-out policies reduce their peak time electricity consumption by substantially less than those who actively opt-in (US Department of Energy, 2015), however overall peak reductions under an opt-out policy will be higher than under opt-in by virtue of the fact opt-out enrolment achieves much higher enrolment rates (Cappers *et al.*, 2016).	High
Financial incentive (e.g. gift card)	Statistically significant impact in comparison across studies, with 35% enrolling when offered incentive versus 20% enrolling when not offered	High
Static vs. dynamic	Static (35% average uptake) is more popular than dynamic, particularly hourly RTP (18%).	High
Automation	Comparison across studies finds no statistically significant difference in uptake associated with automating technologies. However, individual studies that have tested this experimentally (e.g. by assigning customers to the same tariff but randomly varying whether it is accompanied by automation) find that automation increases uptake, possibly to a greater extent for dynamic tariffs than static.	Moderate
Bill protection	Comparison across studies finds higher uptake with bill protection (35%) than without (27%) though the difference is not statistically significant. However, one survey study from Australia which tested the impact of bill protection experimentally (assigned participants to the same tariff but randomly varied whether it was accompanied with bill protection) found that bill protection had a modest positive impact on uptake(Stenner *et al.*, 2015).	Moderate
Dynamic tariff options	Limited data makes it difficult to compare across individual dynamic tariff designs like CPP, CPR, etc.	Inconclusive
Messaging (e.g. "sign up to save money")	There is limited research on this issue since most studies emphasise the potential financial savings, making it hard to find a control for comparison. The only alternative type of messaging tested was telling customers about the environmental benefits of TOU tariffs however the evidence on this is conflicting: two international survey studies(Buryk *et al.*, 2015; Schwartz *et al.*, 2015) find that it increases willingness to switch while another survey study on GB consumers finds that it has no effect(Nicolson, Huebner and Shipworth, 2017).	Inconclusive
Type of customer (e.g. low income, region)	This was not included in the analysis because the reviewed studies did not break down uptake by participant or customer type. Two survey studies which tested this explicitly found no correlation between various socio-economic and demographic factors and willingness to switch to a TOU tariff (Fell, 2016; Nicolson, Huebner and Shipworth, 2017). However, there is no evidence based on actual enrolment rates to commercially available tariffs.	Inconclusive

Summary

The literature review suggests that attractiveness of TOU tariffs varies substantially across studies. Uptake of time-varying tariffs offered on an opt-in basis can reasonably be expected to fall anywhere between 1% and 43%. If the tariffs are rolled out on an opt-out basis, enrolment can be expected to exceed 50% and approach 100%. The UK Government is working on the basis of 30% of domestic consumers being enrolled on a TOU tariff by 2030 as part of its smart meter cost benefit analysis.[44] This falls toward the higher end of the opt-in estimate. The upper bound of consumer opt-in uptake was obtained from surveys, in which consumers stated the likelihood that would switch to a tariff if it was available today. The lower end of the range comes from commercially available tariff participation.

Our analysis suggests that, aside from opt-out enrolment, other ways of increasing uptake to TOU tariffs include small upfront financial payments (e.g. gift card), with some evidence that bill protection and combining a TOU with automation could increase uptake. However, since bill protection has not been widely tested, more research is required as to whether it is likely to affect GB consumer uptake.

More research is also required to investigate whether automation is likely to increase the attractiveness of TOU tariffs, particularly because automation could both increase the number of customers who could save money on a TOU tariff and reduce the hassle burden on consumers of responding to price changes. Finally, opt-in enrolment of any type (e.g. combined with bill protection etc.) is unlikely to yield uptake rates as high as could be achieved with opt-out enrolment.

Consumer Satisfaction with TOU Tariffs

Approach

A "satisfaction review" was conducted to assess the perceptions of customers who had some experience with a TOU tariff. The satisfaction review was based on documents identified in the attractiveness review (discussed above) and additional documents provided by The Brattle Group.[45] In total, 19 documents were reviewed, covering 16 field trials. As all documents except for one were reports from US trials, no differentiation according to country was feasible. In most studies that had used multiple TOU designs, satisfaction ratings were not reported based on tariff type, making it difficult to draw conclusions about relative difference in satisfaction with various tariff specifications. Satisfaction was measured in a number of ways, including (1) an expression by participants of overall satisfaction, (2) an indication that participants would recommend the tariff to a friend, and (3) an indication that participants would enrol again in the future.

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44 BEIS, "Smart meter roll-out cost benefit analysis," 2015. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/567167/OFFSEN_2016_smart_meters_cost-benefit-update_Part_I_FINAL_VERSION.PDF

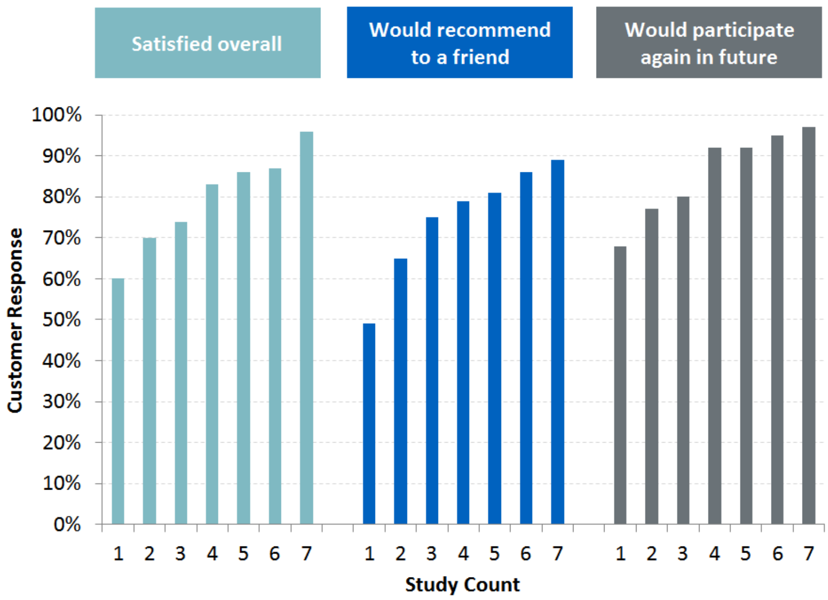
45 See list in References and Additional Resources at the end of this report.

Satisfaction

Between 60 and 96% of participants indicated that they were satisfied overall with their respective TOU programme. A tariff design combining static TOU with critical peak pricing (CPP) had both the lowest and the highest rating (as observed in different treatments), indicating that factors beyond the tariff design played a role in influencing satisfaction. For instance, a measure including smart control systems in the study had the highest satisfaction ratings among all programmes we reviewed. The average proportion of customers who were satisfied across the programmes was 79%. Similarly, on average, 86% of participants said they would participate again in a similar programme. One study had both an opt-in and an opt-out group with over 90% considering staying on the tariff. Whilst this result was not reported separately for opt-in and opt-out customers, one can infer that, at minimum, 72% of those in the opt-out group would participate again. Two studies actually offered customers a second year of participation, which was accepted by 74% and 90% of customers. Additionally, across all studies reviewed, the percentage of customers who would recommend the programme to others averaged 75%.

Figure 11 summarises the results of the satisfaction review. We generally conclude that experience of being on a TOU tariff was positively evaluated.

Figure 11: Results of Satisfaction Review (% of TOU Tariff Participants)



It is important to note that the response rate to satisfaction surveys was often low (or, more frequently, not reported). With one exception, those who dropped out of the study were not surveyed. Hence, the results reflect the opinion of those who stayed enrolled in the study and were willing to participate in a survey about their satisfaction levels with a TOU tariff.

Drop-out rates across the studies ranged from 10 to 43%, with an average of 23%. It often was not clear if customers dropped out for reasons connected with the study itself or because they were unable to participate any longer (e.g. because they moved away). One study explicitly measured satisfaction amongst drop-outs and found that only 20% of those who dropped out were satisfied. Not saving money was the most important reason for dissatisfaction and drop-outs, while unpredictability of peak events was associated with dissatisfaction in one study. Similarly, saving money was observed to be the most important motivator to participate in the study and satisfaction.

Summary

Generally, customers had a positive experience with TOU tariffs. About four out of five customers were satisfied, and similar numbers would participate again or recommend the programme to others. However, not everyone chose to respond to satisfaction surveys and drop-out satisfaction would most likely have been lower overall. Still, this is an encouraging finding and suggests that initial skepticism regarding TOU tariffs may eventually be overcome as customers gain experience with the tariffs. Transition methods such as temporary bill protection and enhanced consumer engagement and outreach efforts could help to facilitate this experience.

Customer Responsiveness to TOU Tariffs

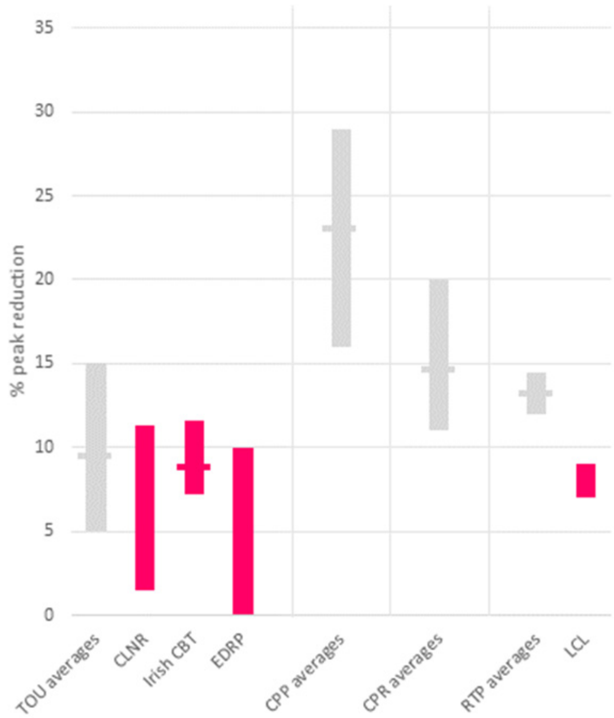
Approach

A number of wide-ranging reviews have already been conducted with the aim of assessing the extent to which consumers on TOU tariffs vary their electricity consumption in response to the tariff. We conducted a 'review of reviews' with the aim of presenting an overall picture of response to different TOU types and the factors that are associated with this. Using a search strategy outlined in Appendix E, we identified a pool of 23 sources (post-screening), with more detailed information extraction from 10 reviews on peak reduction and bill savings, the role of technology and automation, and possible distributional impacts. The same information was also extracted from four major recent trials conducted in the UK/Ireland which included testing the effects of TOU tariffs – the Customer Led Network Revolution, Low Carbon London, the Irish Customer Behaviour Trials, and the Energy Demand Reduction Project.

Peak Demand Reduction

TOU tariffs commonly aim to reduce peak electricity demand. Figure 12 summarises findings from six reviews according to this metric, broken down by tariff type. For each review the average peak reduction was calculated by tariff type; the range of these averages, and the mean of these averages, is shown on the chart in grey.

Figure 12: Range of Average Peak Reductions in Field Trials



The review averages (in grey) show a large degree of variability in responsiveness even within classes of tariff design. CPP tariffs have tended to elicit the strongest peak reductions (on event days), followed by critical peak rebate (CPR), and finally static TOU and hourly or sub-hourly real-time pricing (RTP, for which there is relatively little data). One study found a slight decrease in peak reduction in longer static TOU trials, while the opposite was the case for CPP/CPR trials.[46] The same study also broke down pilots by sample size; there was substantial variability, but no indication that larger trials saw smaller peak reductions. U.S Department of Energy trials showed that opt-in customers tended to be more responsive than opt-out customers (11% peak reduction after two years, vs 6%).[47] Peak reductions in the UK/Ireland trials were at the mid to lower end of the ranges represented in the reviews. It is noteworthy that the LCL trial also showed an average 11 to 14% increase in consumption during low price periods, suggesting potential for trough-filling (such as during times of low net load).

Large Loads and Automated Response

The reviews are consistent in showing that the magnitude of response tends to be larger when customers have large loads such as air conditioning, electric heating and other major

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46 Stromback, J., Dromacque, C. and Yassin, M., 'The potential of smart meter enabled programmes to increase energy and system efficiency: a mass pilot comparison', VaasaETT Global Energy Think Tank, 2011.

47 U.S. Department of Energy, Final Report on Customer Acceptance, Retention, and Response to Time-Based Rates from the Consumer Behavior Studies, 2016. Available at: https://www.smartgrid.gov/files/CBS_Final_Program_Impact_Report_20161107.pdf

appliances. Modelling by The Brattle Group suggests that while customers with major appliances in hot climates may be able to reduce peak demand by 15 to 40%, depending on TOU price ratio, the reduction for customers in cool climates with no major appliances is did not exceed 10% at any price ratio.[48] This latter figure is broadly in line with the results of recent UK/Irish trials included above, representing a cooler climate with limited penetration of large electrical loads.

The presence of technology which could automate response to TOU pricing consistently increased peak reduction. The U.S. DOE trials focused on the use of programmable communicating thermostats (notably, all for air conditioning), which increased response to static TOU, CPP and CPR tariff designs. Automation also had modest reliability benefits. None of the recent UK/Irish trials tested automation of appliances in response to price signals. CPP and CPR tariffs have most often been tested thus far for their ability to reduce summer peak demand, so most of the effects shown in the results reflect automaton of air-conditioning systems. Although GB expects growth in major electric appliances (i.e. heat pumps and electric vehicles), there is currently little evidence on automating response in GB. However, evidence that is available elsewhere suggests that automation has an important role to play. For example, a study by SDG&E found EV owners used timers to set their EVs to charge at off-peak times.[49]

Bill Savings

Few of the studies reviewed reported on financial savings, and the extent of savings is clearly dependent on specific aspects of tariff design. Trial results on this and other metrics can be skewed as bill protection is often offered, meaning customers face no actual penalty if they do not alter their behaviour. Reported savings for the UK/Irish trials were as follows:

- Low Carbon London (LCL): Over 75% saved compared to flat rate, mean saving £21, 4.3% (info on average loss unavailable), maximum loss £40
- Customer Led Network Revolution (CLNR): 40% of participants would have lost money (without bill protection), median loss £18.40 (info on average saving was unavailable), maximum loss £190.78
- Irish Customer Behaviour Trial (CBT): Range of measures used, but on average participants saved (average €0.67 to €25.47 depending on measure)

Distributional Impacts

There is mixed evidence on the existence of associations between various socio-economic variables and response to TOU pricing. Previous Brattle review and modelling based on data

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48 Faruqui, A. and Sergici, S., 'Arcturus: International Evidence on Dynamic Pricing', *The Electricity Journal*, 26(7), pp. 55–65, 2013. doi: 10.1016/j.tej.2013.07.007.

49 Cook, J., Churchwell, C. and George, S., Final Evaluation for San Diego Gas & Electric's Plug-in Electric Vehicle TOU Pricing and Technology Study. Nexant, 2014. Available at: https://www.sdge.com/sites/default/files/documents/1681437983/SDGE%20EV%20%20Pricing%20%26%20Tech%20Study.pdf

from U.S. trials has suggested peak reduction tends to be slightly lower for low-income than average customers, but that the majority of such customers will benefit financially even without load shifting as their demand tends to be flatter.[50] The review of pilots by VaasaETT found that 'social factors such as age, income, education, household size, load profile and environmental factors such as house type, house size, house age etc. ... do not have an impact on pilot results'.[51] However, they note that such factors are rarely captured by studies.

The UK/Irish trials also show somewhat mixed results. The CLNR trial found no significant difference between customer sociodemographic categories either in peak reduction or likelihood of saving/losing money overall. Similarly, Low Carbon London found no significant differences in response between sociodemographic groups. In the Irish Customer Behaviour Trials, higher socio-economic groups achieved greater overall electricity reductions – they also tended to consume more electricity originally. There was less of a pattern for peak reduction, with higher reduction associated with more education and having children in the home.

Summary

The reviews included show high variability of peak reductions within and between tariff designs, but CPP tends to provoke highest reductions, followed by CPR and static TOU (RTP is similar, but with less evidence). UK/Irish trials are at the mid to lower end of the range (usually up to 10% peak reduction) – consistent with low penetration of major appliances such as air conditioning and lack of automated response (which has been shown to significantly increase response, although predominantly in the case of air conditioning). Field trial participants tended of save money on TOU tariffs compared to flat rate tariffs, but savings (and the proportion who save) are variable and large losses are possible. There is no strong evidence for consistent associations with socio-demographic factors.

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50 Faruqui, A., Sergici, S. and Palmer, J., The Impact of Dynamic Pricing on Low Income Customers. IEE Whitepaper, 2010. Available at: http://www.edisonfoundation.net/IEE/Documents/IEE_LowIncomeDynamicPricing_0910.pdf

51 Stromback, J., Dromacque, C. and Yassin, M., 'The potential of smart meter enabled programmes to increase energy and system efficiency: a mass pilot comparison', VaasaETT Global Energy Think Tank, 2011.

V. TOU Marketing Considerations: Primary Market Research

Introduction

The systematised review we undertook for this report (see Section IV) identified relatively little research which set out explicitly to measure potential uptake to TOU tariffs, and no research on certain tariff designs and marketing considerations. We therefore conducted a large survey experiment to begin to address these research needs. Administered online to a nationally representative sample of nearly 3,000 energy bill-payers in Great Britain, the experiment measured customers' stated uptake to a range of TOU tariffs and related offerings with different experimental groups being shown different tariff designs or other information in a randomized control trial design. This section of the report describes the aims and findings of each experiment.[52]

Tariff Design

In the tariff design experiment, participants were randomly assigned to one of five groups, and were shown one of five TOU tariffs and an attractive flat-rate tariff that was the same across all groups (with single rate of 12p/unit of electricity).[53] Participants were then asked if they would switch to the TOU tariff, the flat-rate tariff, or stick with their current tariff. The five TOU designs were:

1. A **static TOU** with off-peak rate of 6p/unit (weekends, daytime, night) and on-peak rate of 18 p/unit (weekday evenings)
2. An **inverted TOU (iTOU)** with a standard rate of 15p/unit applying in non-summer months and during specific times in summer and a day rate of 5p/unit applied during summer months in mid-day hours.
3. **Critical Peak Pricing (CPP),** where a price of 60p/unit was charged during up to 18 events, with a base rate of 10p/unit.
4. **Critical Peak Rebate (CPR),** where bill credit was given during up to 18 peak events if consumers reduced their peak period consumption, with a base rate of 12p/unit.
5. **Real-time pricing (RTP)** with last year's annual average being given as 10p/unit.

All tariffs were advertised with the same standing charge of 22p and as being fixed for a year, with switching possible at any time without paying a fee. Given that the main outcome of interest was switching to a TOU tariff, we combined the answer categories of switching to the flat rate tariff and staying on one's current tariff into one, and contrasted it with switching to a TOU tariff.

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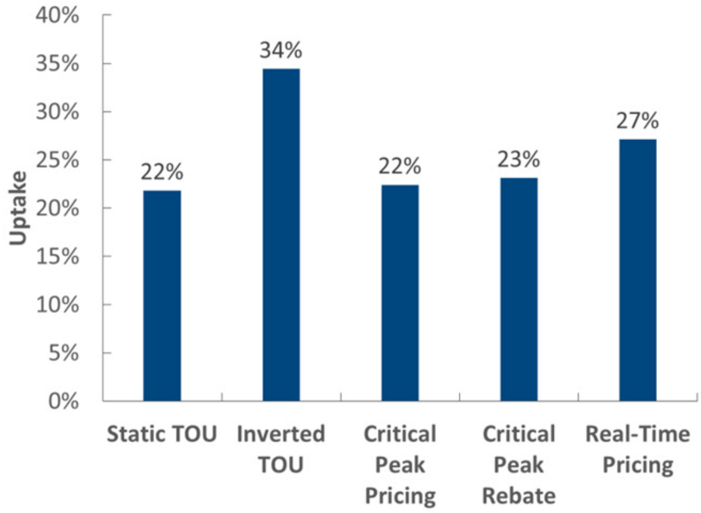
52 Further detail on this study is provided in Appendix F.

53 Showing both tariffs was seen as being closer to reality as in any real-world switching, consumers would see TOU tariffs and static tariffs when e.g. using a comparison webpage.

Overall, about one quarter (26%) of respondents indicated they would switch to the TOU tariff, with the same proportion (26%) switching to the flat-rate tariff; the remaining half (48%) indicated they would rather stay on their current tariff. Figure 13 shows the percentage of respondents switching to the various TOU Tariffs.

Figure 13:%age of Respondents who would Switch to a TOU Tariff



The inverted TOU was the most popular tariff, with a statistically significantly greater proportion switching to it than to any other tariff.[54] The second most popular tariff was real-time pricing; however, the difference in percentage switching was only significantly different to the static TOU. The share of those switching to a static TOU, critical peak pricing, and critical peak rebate did not differ significantly from each other.

These results are somewhat surprising in light of previous research. The relatively low uptake of the static TOU and the high uptake of real-time pricing are particularly noteworthy. Regarding the latter, anecdotal evidence[55] suggests that real-time pricing could be perceived as fair and/or transparent, if consumers feel they are paying the actual price of electricity without any hidden fees to the supplier. The lower attractiveness of static TOU in comparison to both previous estimates and to the inverted TOU is potentially explained by respondents putting greater emphasis in their decision on unit prices – which were lower in the inverted TOU – and neglecting the temporal aspect of when the prices would apply.

In a second step we analysed which factors were related to switching to a TOU tariff. Those living in socially rented accommodation were significantly less likely to sign up to a TOU tariff than owner-occupiers (78% vs 73% not signing up). Also, those older than 65 years were significantly less likely to sign up to a TOU tariff than those aged 18-34 (78% vs 69%

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54 Statistical significance is set at $p < 0.05$.

55 For example media reports on Flick Electric Co. in New Zealand, which offers a real-time pricing tariff (see Reed, R. [2015], 'Cheap is never nasty with NZ's fairest power deal', Kiwi Families, https://www.kiwifamilies.co.nz/2015/10/cheap-is-never-nasty-with-nzs-fairest-power-deal/

not signing up).[56] Also, those with an income above £120,000 were significantly more likely to sign-up to a TOU tariff than those with a median income (category £20,000-30,000). Both the perceived ease of use of a tariff and in particular the perceived ability to save money on the tariff were highly significant impact factors.

No other analysed factors were significantly related to switching rates (i.e., gender, employment status, type of heating system, occupancy pattern, children under 15, being on prepayment meter, household size, being on a TOU, having appliances with timers).

Marketing

In this experiment, participants were asked if they would sign up to a three-period static TOU tariff.[57] Instead of randomly assigning participants to different tariff designs, participants were randomly shown different types of marketing messages promoting the same tariff to see what effect, if any, this might have on the average person's willingness to switch to the TOU tariff or even the willingness of particular consumer sub-group to switch. One group of participants were shown a flat-rate tariff to control for general willingness to switch. Overall, there were six experimental groups altogether:

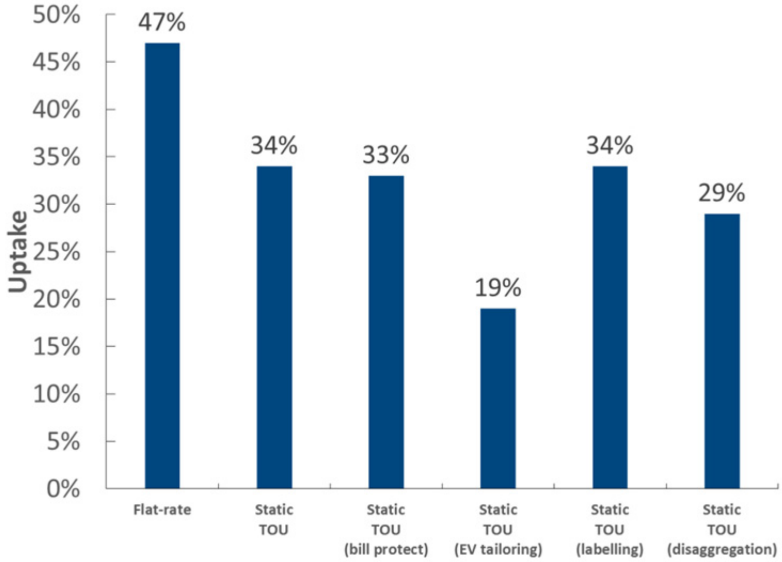
1. **Flat rate tariff** (no marketing message)
2. **Static TOU** (no marketing message)
3. **Static TOU + bill protection** where participants are informed that they will get reimbursed during the first six months should their bill be higher than under a flat rate tariff
4. **Static TOU + tailoring** where the tariff is described as being particularly suitable for electric vehicles owners
5. **Static TOU + labelling** where the tariff is presented to be approved as a 'good tariff' by the British energy regulator
6. **Static TOU + disaggregation**, where participants are told they will see electricity consumption broken up by appliance

Participants were asked whether they would switch to the tariff or whether they would like to stick with their current tariff. The average willingness to switch across all conditions is high compared to observed switching rates in GB; 32% of participants said that they would switch across all experimental conditions with an average switching rate to the TOU tariff of 30%. However, willingness to switch varies depending on the group to which participants were assigned.

56 However, the effect of tenure and age were relatively weak and no longer significant at $p < 0.05$ once controlling for multiple comparisons. The percentages provided are not adjusted for other variables.

57 A three-period static TOU tariff would have a high priced peak period during late afternoon / early evening, a low-price off-peak period during nighttime hours, and a mid-priced mid-peak period during all other hours.

Figure 14: Intention to Switch to Tariff Across Marketing Conditions



Regression analysis[58] shows that compared to the static TOU group with no marketing intervention, uptake of the flat-rate tariff is significantly higher and, as expected, uptake of the tariff tailored to electric vehicle owners is significantly lower – both with large effect sizes. There were no statistically significant differences in uptake for the other groups. When compared to the flat-rate tariff, uptake to the TOU tariff is statistically significantly lower regardless of what marketing method is used.

Finding that a TOU tariff with bill protection is less appealing than a flat-rate tariff and no more appealing than a TOU tariff *without* any bill protection at all was quite surprising. A similar survey run in Australia found that bill protection increased willingness to switch to a TOU tariff by 10%, making it as appealing to switch to as a standard flat-rate tariff.[59] However, our analysis did show that for loss-averse consumers (people more concerned about avoiding financial losses than making financial savings), combining the TOU tariff with bill protection means that this group of consumers are no longer less willing to switch to a TOU tariff than a flat-rate tariff.

The finding that the EV-tailored message reduced the average bill payers' willingness to switch is consistent with our predictions given that the average person does not own an EV and just 5% of the participants in our sample indicated that they owned or leased an electric

58 A type of analysis which estimates the level of association between variables.

59 One possible explanation for this difference is that the Australian survey did not give customers an option to stick with their current tariff; rather, they were asked to indicate how willing they would be to switch to the time of use tariff on a scale ranging from 1-100. Although a score of 1 could be interpreted by customers as not switching, it is perhaps not as salient an option as in this survey, where customers were making a binary choice over whether to switch to the tariff or stick with their current one. In reality, this is the choice customers will be faced with, and, as is evident, inertia is highly prevalent in the GB energy market, with the majority of consumers not switching tariff or supplier despite large savings potential.

vehicle. Nevertheless, and as expected, our results do suggest that EV owners are significantly more likely to switch to a TOU tariff when they are told it is well suited to them. Used wisely, this tailoring approach could also be used to deter customers who may be financially better off sticking with a flat rate tariff, from switching to a time of use tariff.

Including a quality assurance label was expected to increase TOU tariff uptake. That it did not may be reflective of the fact consumers are not familiar with the UK energy regulator (see findings in next section regarding trust). It is possible that approval by another external body could increase willingness to switch.

Similarly, telling customers the tariff would come with an app showing them how much electricity is being used by each of their household appliances (disaggregation) had no impact on willingness to switch. That is also surprising, considering anecdotal evidence indicating that customers have expressed a desire for this type of information.[60] A possible reason for this is that customers have limited use for the energy information due to constraints on time and capacity to process the information.

Critical Peak Rebates

In this study, we have identified CPRs as a potentially attractive tariff design option for domestic GB customers. Given the relevance of that tariff design, we used this experiment to explore the impact of various schemes to compensate customers for reducing electricity demand at specified times throughout the year. We tested two options:

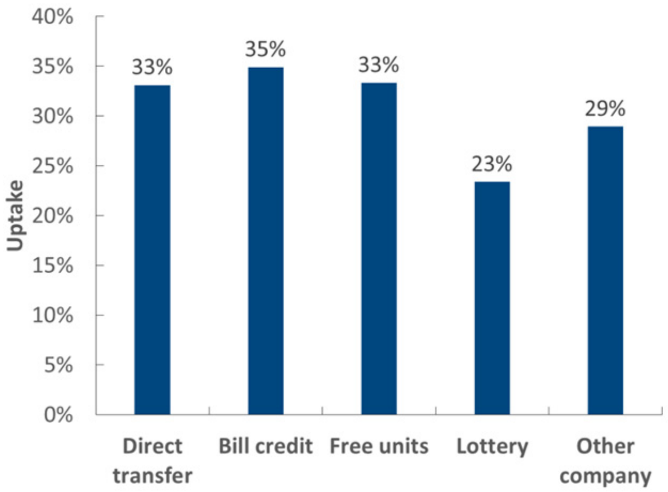
- **The effect of the type of rebate on uptake.** The control option was a payment of £20 directly into the participant's bank account. Comparators were a £20 electricity bill credit, 100 free units of electricity and a lottery to win one of five £1000 cash prizes. We were interested to know if consumers would be less willing to sign up to lower value offerings (especially the free units, equivalent to around £12-14 per consumer, and lottery which would be worth an average of £5 per consumer if 1000 customers participate[61]).
- **The effect of the identity of the organisation offering the rebate.** The control (and other) options were framed as offered by the participant's current supplier. The comparator was a direct payment from a fictional company "Purple Power, an energy management company". The objective was to test the potential for non-suppliers unknown to consumers to offer this kind of product.

Figure 15 shows the proportion of participants in each group who said they would sign up to the offering.

60 There are a number of commercially available products that aim to enable consumers to see a breakdown of their household electricity use by appliance – see for example Bidgely, PlotWatt and Smappee.

61 These financial equivalents were intentionally not made explicit to participants.

Figure 15: Percentage of Customers Signing up to CPR



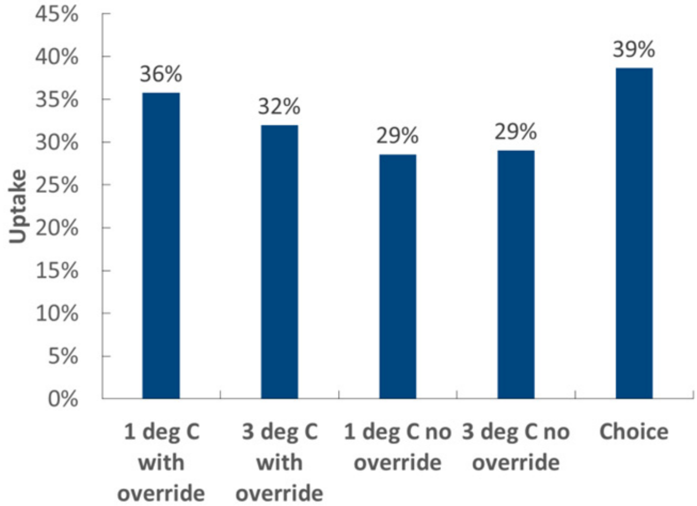
Mean uptake across the groups was 31% (range 23 to 35%). Statistical testing revealed no significant differences in uptake across the experimental groups, with the exception of the lottery, which was significantly less attractive. This option is likely to have constituted the lowest average value per consumer, and participants may have recognized this. It was also the only option where a reward was not guaranteed. However, the equivalence in uptake between the free units and direct payment (and bill credit) options suggests that the lower value of free units was not recognized. Under this option consumers would be a third worse off than under the direct payment or bill credit options for providing the same service, while the saving to suppliers would be even greater since the marginal cost to them in supplying a unit is less than the retail price. Significant differences were also apparent between age groups, with more than twice as many 18-34 year-olds (55%) willing to sign up to the basic offering (with bank transfer) than those aged 55 and over (25%).

The finding that there was not a significant impact on uptake when CPR is offered by an unknown company suggests the market for this kind of offering is open to a wider variety of non-supplier entrants and actors (including distribution network operators), which may be good for consumer choice and competition.

Direct Load Control

Other sections of this report have touched on the potential for automation to support flexibility of electricity demand. This experiment set out to test the acceptability of a scheme where suppliers offer consumers a free smart thermostat in return for permission to turn their heating up and down to help shape demand. We explored the effect on uptake of changing the temperature range over which this could operate (either 1 or 3 ^{o}C up and down), the provision (or not) of override ability and the effect of offering a choice of thermostats versus a single model. Figure 16 shows the uptake results for each experimental group.

Figure 16: Percentage of customers signing up to the Thermostat Offer



Mean uptake of the thermostat offer was 33% (range 29 to 39%). The difference in uptake between offerings allowing 1 or 3 °C changes up or down was not significant. However, customers were significantly more likely to sign up when they had the possibility to override supplier control (bars 1 and 2) compared to when they were explicitly told they did not (bars 3 and 4). This suggests that consumers either are not concerned about the potential to experience up to 6 °C swings in temperature so long as they can override it, and/or that that giving temperature information in this way was not meaningful to many customers. It is notable that 29% of customers still said they would sign up to the offering with maximum temperature range and no override – a situation with potentially concerning consequences, especially for vulnerable individuals.

Providing consumers with a choice of thermostats did not significantly affect uptake compared to the control group (low [1 °C up or down] temperature change, with override), perhaps suggesting that thermostat design is not the driving consideration in this decision. There were, again, significant differences in uptake by age group, with almost two-thirds (65%) of 18-34 year-olds signing up to the basic offering (low temperature range, with override) compared to just 26% of those aged 55 and over.

TOU Tariffs and Trust

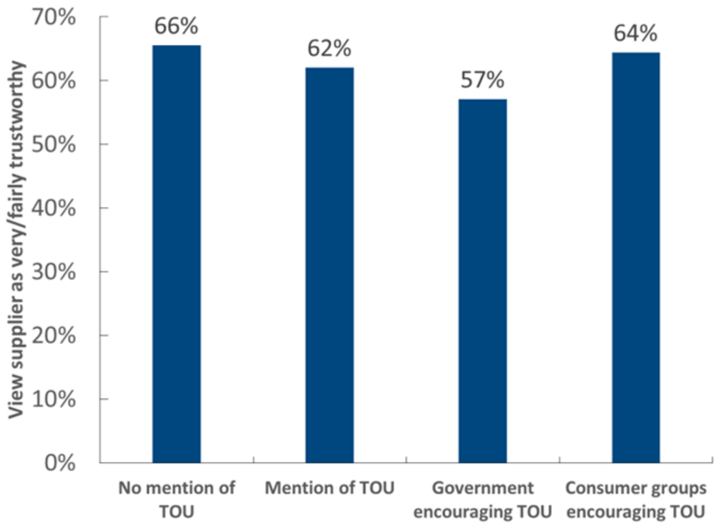
Previous work has shown that customers who say they trust their energy supplier are more likely than those who do not to switch to a TOU tariff offered by that supplier[62]. However, in the experiment we explored the opposite question – whether the act of offering TOU tariff might have an effect on consumer trust in suppliers. This interest was prompted by informal discussions with suppliers suggesting concern that consumers perceive such tariffs as just

[62] Fell, M.J., Shipworth D., Huebner G.M., Elwell C.A, Knowing Me, Knowing You: The role of trust, locus of control and privacy concern in acceptance of domestic electricity demand-side response. ECEEE 2015 Summer Study Proceedings, Presqu'île de Giens, France: 2015, p. 2153–63.

another attempt by suppliers to make profit. Such a perception amongst suppliers could prevent TOU tariffs coming onto the market.

We measured customers' stated trust in their supplier in four different experimental groups. The first group simply included the questions on trust. The second group saw these questions preceded by a statement that many suppliers, including theirs, are looking offer more TOU tariffs. The third group saw a similar statement, but in this case it said that the government was encouraging suppliers to introduce such tariffs. The final saw the same statement but with 'consumer organizations' instead of the government. In this way, we aimed to test both the effect of offering TOU tariffs on trust in suppliers, and also whether this could be affected depending on where the driver for this was seen to come from. Figure 17 summarises the results.

Figure 17: Customers Stating they View their Supplier as Very/Fairly Trustworthy



Mentioning time of use tariffs had a statistically significant negative impact on stated trust in supplier, although the effect was very small. This negative effect increased when it was suggested that this was driven by government. However, when it was suggested that it was encouraged by consumer groups, mentioning TOU tariffs was statistically no different from not mentioning TOU tariffs at all. To some extent this finding validates possible concerns amongst suppliers that introducing TOU tariffs could have negative trust impacts. It also suggests that government may not be the best organization to mitigate this impact, and that trusted independent bodies could have a more important role to play.

VI. Conclusions and Recommendations

The findings of this study lead to a number of recommendations for policymakers, network operators, suppliers, and other industry stakeholders that are exploring the possibility of a transition to TOU tariffs.

Focus on customer engagement and communication, as they will be critical considerations in any tariff transition.

The estimates of TOU value established in this study essentially scale linearly with enrolment. At low levels of TOU enrolment, value will be very limited. But if a significant number of domestic customers enrol in well-designed TOU tariffs in the future, the benefits could be on the order of tens or hundreds of millions of pounds per year. It will therefore be critical to explore innovative options for engaging with customers about the potential benefits of the new tariff offerings. This is supported by the conclusion of the "satisfaction assessment" described in Section IV, which suggests that customers may demonstrate initial risk aversion when considering enrolling in a TOU tariff, but are typically highly satisfied once they have experience with the tariff and understand its impacts and the opportunities it presents.

The findings of the primary market research described in Section V further suggest that additional considerations may be necessary for vulnerable households. Across all designs, average TOU uptake (at 26%) is broadly consistent with previous findings[63] and government aspirations[64]. However, the lower uptake amongst the older population suggests these consumers may in need of greater outreach and engagement efforts in order to benefit from any savings potential associated with TOUs.

Tailored messaging was effective at boosting demand for a static TOU amongst EV owners (a group that is potentially more likely to save money on TOU tariffs). If suppliers could design TOU tariffs suited to the lifestyles or consumption patterns of particular consumer groups – and market these tariffs accordingly – this may provide a potential avenue for increasing uptake to TOU tariffs while helping consumers to switch to tariffs that will save them money (see Section IV which showed that some customers who signed up to TOU tariffs in trials experienced bill increases).

Finally, the findings of our primary market research hint that there should be some concern that offering TOU tariffs could have negative implications for trust in the electricity supply industry, although this effect is small. They also suggest that trusted non-governmental

63 Fell, M.J., Nicolson, M., Huebner, G.M., Shipworth, D., "Is it time? Consumers and time of use tariffs", report to Smart Energy GB, 2015. https://www.researchgate.net/publication/273446769_Is_it_time_Consumers_and_time_of_use_tariffs

64 BEIS, "Smart meter roll-out cost benefit analysis," 2015. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/567167/OFFSEN_2016_smart_meters_cost-benefit-update_Part_I_FINAL_VERSION.PDF

organizations could be best placed to mitigate such concern. A strategic approach will therefore be needed to minimize the risk that TOUs are not introduced by suppliers through concern about negative trust implications.

Take a holistic view of the value of TOU tariffs that extends beyond simple monetary value.

There is surprisingly limited variation in value across the core TOU tariff designs (i.e., TOU, CPP, and CPR). This is partly because, from an operational standpoint, the strengths and weaknesses of the design of each tariff tend to have offsetting influence on the relative value of each tariff option. The similarity in value estimates is also due to a lack of evidence from the available research to suggest very significant differences in customer uptake of the different tariff options.[65]

The similarity in system value estimates across the TOU options means that non-monetary considerations could be as or more important than monetary considerations in future TOU deployment decisions. If TOU deployments are part of future policy considerations, non-monetary considerations will include simplicity in tariff design and perceived "ease of use" of the tariff by consumers, fairness, the potential impacts on low income customers, and the extent to which the tariff designs align with the UK government's energy policy objectives.[66]

Give critical peak rebate (CPR) tariffs serious consideration and test them through an opt-out field trial.

CPR tariffs have received relatively little attention as a tariff option in GB thus far. Field trials in GB and Ireland have largely focused tariffs with higher peak period prices and lower off-peak period prices (both static and dynamic). The customer-friendly design and proven impact on peak demand of CPR tariffs makes them a potentially attractive candidate for cost-effectively tapping into the demand response potential of the domestic sector.

CPR tariffs could be particularly interesting to explore through a field trial that is deployed on an opt-out basis. There is some scepticism in GB around the validity of the findings prior TOU field trials, in part due to concern about self-selection bias among voluntary participants. A field trial with opt-out participation would help to assess the validity of these concerns.[67] CPR tariffs are perhaps easier to test on an opt-out basis than other tariffs due to the no-lose proposition that they offer to customers (i.e., they are simply "layered" on the customer's existing tariff, with no financial downside to the customer).

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65 Future primary market research that extends beyond surveys and includes focus groups and other methods may help to identify more distinct differences in consumer preferences for the tariff options.

66 For further discussion of fairness in tariff design, see Jon Bird, "Smarter, Fairer? A discussion paper on cost reflectivity and socialisation of costs in domestic electricity prices," prepared for Sustainability First, March 14, 2016.

67 For instance, opt-in and opt-out offerings could be tested side-by-side in a controlled experiment to assess the relative impacts of each.

It is arguably surprising that uptake of the CPR offering was not higher in the market research conducted in our study, given the no-lose proposition of the tariff. This suggests that non-financial considerations – such as not wanting to have to pay attention to alerts – may be influencing customers' perception of the tariff. In a future CPR offering, it will be critical to better understand any concerns and identify the type of information that needs to be provided to consumers to make the benefits of such an offering clear.

Ensure charging and settlement processes facilitate the provision of economically efficient TOU design.

If there is an expectation that suppliers will offer TOU tariffs in the future, they will need to have a financial incentive to do so. Without half-hourly settlement, and to the extent that network charges do not accurately reflect the time-varying nature of the cost of delivering power, suppliers currently do not incur costs in a manner that rewards them or their domestic customers for shifting load from high-cost to low-cost hours. In fact, without this incentive, it is conceivable that suppliers could develop tariff designs that may facilitate an increase in market share but would encourage electricity consumption behaviour that would unintentionally also increase system costs.

Of course, the costs of improving the settlement and charging processes should be compared to the benefits of doing so. This activity is currently underway in part through Ofgem's ongoing Mandatory Half Hourly Settlement business case analysis.

TOU design should focus primarily on avoiding capacity costs in the near- to medium-term.

In our analysis, across a range of scenarios, avoided generation capacity cost drives the bulk of TOU value. Exploring opportunities to avoid the capital costs associated with new generation, transmission, and possibly distribution capacity is likely to continue to be more productive than chasing energy value, particularly if the addition of renewable and nuclear capacity leads to reductions in wholesale energy market prices in the future.

The situation could change if, in the future, the GB market has little marginal generation capacity value due to significant excess generation supply (e.g., similar to the situation in Germany and Spain). In this case, particularly if the supply mix is dominated by renewables, it seems likely that the widespread adoption of smart home technologies would be needed to unlock the value of real-time energy price arbitrage and/or the provision of ancillary services (the latter of which would likely need to be pursued through demand-side response programmes rather than pricing programmes due to the complexity of conveying real-time ancillary services prices to consumers).

It is also important to consider the implications of TOU tariff design in the context of the system value that the tariffs can provide. In this study, we have quantified the value of TOU tariffs that are well designed from a system cost standpoint. That is, we have examined cost-based tariffs that are designed specifically to encourage customers to consume electricity in a more economically efficient manner. At the same time, we have identified a significant amount of general customer interest in TOU tariffs (26% indicated that they would switch to a TOU tariff). It is possible that, in the future, suppliers will choose to offer TOU tariff designs which maximize customer uptake but do not accurately reflect system costs.[68] In this situation, it is possible that TOU participants will change their electricity consumption behaviour in response to the TOU price signal in a way that actually contributes to an increase in system costs. It will be important from a policy standpoint to consider the extent to which this may lead to costs being over-recovered from non-participants in order to make up for the shortfall.

Voluntary smart home rate (SHR) tariffs may help to solve the "chicken and egg" problem that is perceived to limit the adoption of automating technologies.

There is a perception among some industry stakeholders that automating technologies will not achieve significant market traction until there are granular retail price signals to which the technologies can respond. A cost-based, voluntary SHR tariff could provide this opportunity. The voluntary nature of such an offering would provide an opportunity for financial savings to those customers who have the technology without exposing those customers who do not invest in the technology to the financial risk associated with variable prices. A well-designed tariff that is cost-based would ensure that non-participants would not bear the burden of under-recovered costs in the SHR tariff.

Explore options available for making automating technologies available to low income customers.

This study has demonstrated that there is significant value in TOU tariffs to be unlocked by automating technologies. According to our study, widespread adoption of automating technologies could easily double the value of TOU tariffs, and would potentially provide other demand-side response benefits as well.

Further, consumer interest in direct load control in our market research study (see Section V) was significant (at one-third of customers), particularly considering that the only associated reward was the upfront provision of a smart thermostat. There are indications that a substantial proportion of customers could be willing to sign up to such an offer while yielding large amounts of control to third parties (i.e. up to 6 °C temperature range with no possibility of override).[69] This suggests fairly broad interest in automating technology among GB customers.

Given the up-front cost of both automating technology and the new electric end-uses that they are designed to control (e.g., electric vehicles), it is possible that these opportunities could be limited to customers with higher incomes. However, maximising the net societal value of automating technologies – and ensuring that there will not be negative distributional impacts associated with their adoption – will likely require facilitating widespread uptake of the technology. As such, it will be important to examine options that are available to extend

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68 This is more likely in a situation where suppliers are not exposed to and settled in a matter that fully reflects the time-varying nature of power costs.

69 Regulators or consumer advocates should ensure that vulnerable consumers are protected against possible harm or discomfort that may result from such potentially severe conditions.

these opportunities to all types of customers and not just those with higher incomes. On-bill financing, rebates, and low-income energy efficiency assistance programmes are policy options that have been explored in various contexts in other jurisdictions and could be useful to consider in the context of smart home technologies for customers in GB as well.

Further exploration of the benefits of an inverted TOU (iTOU) tariff in areas with high distributed solar PV adoption could be a valuable future research activity.

The strong showing of the inverted TOU tariff – the first time uptake for such a tariff has been measured amongst the average British energy bill payer – could be positive for distribution networks struggling to deal with high levels of solar generation. However, given that preliminary experience with the Sunshine Tariff identified difficulty in enroling customers, more research is needed to explain and confirm the popularity demonstrated in our study.

There is a need for new and innovative research on consumer preferences for TOU tariffs and their potential system impacts.

Throughout this report, we have identified a number of areas that would benefit from further research. Regarding system value, there is a particular need to better understand the potential impacts that TOU tariffs could have on the distribution system. Avoided distribution capacity costs are a very system-specific calculation. It would also be valuable to conduct bill impact analysis using individual customer load shapes. This could provide insight regarding how bills for various customer segments are likely to change under the new tariff offerings, and the magnitude of bill savings that might be achieved by participants with various energy management technologies.

Further research would also be valuable in regarding customer preferences for TOU tariffs. For instance, further analysis of customers' relative preferences for different TOU tariff designs (static TOU, CPP, CPR, etc) is needed. While the research conducted in this study detected limited differences in uptake across the tariff designs, alternative research methodologies may enhance our understanding of these findings.

As the supply mix changes and customers adopt new electricity intensive technologies and distributed generation, it is possible that the timing of the peak period will change for system planning purposes. New research on customer preferences for different peak period pricing windows would be useful in this regard.

Finally, this study found that TOU uptake is surprisingly resistant to measures aimed at increasing enrolment, such as adding bill protection or quality assurance labelling. More work is needed to understand the reasons for these findings and explore alternative ways of reassuring and protecting consumers.

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