PREPARING DISTRIBUTION UTILITIES FOR THE FUTURE - UNLOCKING DEMAND-SIDE MANAGEMENT POTENTIAL

A Novel Analytical Framework

GREENING THE GRID (GTG)
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Authors

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List of Acronyms and Abbreviations

AC	air conditioner
BRPL	BSES Rajdhani Power Ltd.
BTM	behind-the-meter
C&I	commercial and industrial
DSM	demand-side management
DR	demand response
EFLCH	Equivalent Full-Load Cooling Hours
EFFORT	Effectiveness of Rate Structures for Enabling Demand Response
NREL	National Renewable Energy Laboratory
PEM	price elasticity matrix
PV	photovoltaic
R	rupee
TOD	time-of-day
TOU	time-of-use

Abstract

The balance of supply and demand in the power systems has traditionally been served solely through generation and network capacity planning and operations. However, with increased requirements for flexibility due to the uptake in variable renewable generation sources such as wind and solar, there is a need to increase demand-side flexibility. In addition, there are increased communications and flexibility capabilities emerging on the demand-side from the adoption of advanced metering infrastructures with smart meter deployment and intelligent loads such as smart thermostats and schedulable white goods (e.g., dishwashers and washing machines). Unlocking demand-side flexibility can bring system benefits, from peak load reduction bringing about generation capacity and network upgrade deferral to reducing demand and bringing about more efficient utilization of generation and network capacity.

Unlocking demand-side flexibility is an evolving process for utilities, and solutions must be tailored to each specific consumer class. Demand-side management (DSM) is a broad set of tools that can include demand response (DR) (both dispatchable and non-dispatchable), energy efficiency and distributed energy resources, and consumer-sited resources. NREL, in collaboration with BRPL and GTG-RISE, examined the potential of DSM in BRPL's service territory, developing detailed information on consumer classes and willingness to participate in DSM. The study developed modeling frameworks for load analysis and the analysis tools to assess the potential of time-of-use (TOU) tariffs in motivating consumers to reduce their peak period energy consumption. The study shows that BRPL consumers, specifically their domestic consumers, are willing to participate in DSM programs and that TOU pricing can help BRPL reduce their peak demand and help unlock demand-side flexibility.

Executive Summary

Context and Problem Description

The power system requires supply and demand to be balanced at all times; otherwise, system voltage and frequency challenges can occur. Until few years ago, it was common to treat demand as an inflexible resource and to adjust supply to match demand at any given time. In recent years, unlocking demand-side flexibility has been a topic of interest, with strong potential, all over the world. Enabling demand-side flexibility can bring about utility and consumer cost benefits such as providing effective peak load reduction and avoiding the use of expensive peaking generation. Three primary stakeholders can be identified for DSM to be an effective mechanism—consumers who enable DSM, utilities that encourage the consumers, and regulatory authorities who provide directions for utilities. This research work is designed to enrich the knowledge base for these three stakeholders as the study addresses some of germinal questions about DSM and its implementation.

As energy consumption in the Indian grid is expected to grow steadily, triggered by electrification, DSM is recognized as an effective mechanism to promote energy efficiency. For instance, the recently published Draft National Electricity Policy 2021 issued by Ministry of Power emphasizes the importance of energy conservation and DSM. Converting these policy initiatives to regulatory directives, nodal stakeholders such as State Electricity Regulatory Commissions can contribute to making DSM a reality. Along similar lines, Rajasthan Electricity Regulatory Commission recently issued directives to utilities to implement the policy provision on energy storage purchase obligation (in MW) for up to 5% of the overall renewable purchase obligation target. With this Rajasthan Electricity Regulatory Commission order, utilities can specify storage requirements (minimum rated capacity to be 50% of project capacity) with solar/wind capacity bidding on a pilot basis. Similar actions for DSM can prescribe energy efficiency targets for distribution companies and help them attain those targets by implementing utility-led DSM programs.

Before regulatory directives are put forward from policy initiatives, sufficient evidence is needed to determine the value add from new technologies. This work is designed to provide this required evidence that can help regulatory authorities sanction applications of DSM and foster growth of distributed energy resources. In this work, we focus on the first step in unlocking flexible demand for all the primary stakeholders involved in DSM programs. NREL, in collaboration with BRPL and Greening the Grid RISE, studied the potential of DSM in Delhi, India, for this study. The research team addressed the DSM design problem and presented their findings in the form of two major research components: i) tool development for evaluating DSM as a resource in utilities' planning processes, and ii) a survey component to understand possible consumer participation in designing an effective DSM program.

The first component is a tool/analysis framework developed by NREL for evaluating optimal TOU tariffs called EFFORT. This open-source tool uses a scalable analysis framework that utilities and distribution companies can use for their TOU rate planning. The potential of time-varying rate structures is investigated under this framework by conducting load analysis. EFFORT utilizes insights from the survey on BRPL consumers to output the optimal ratio of peak to off-peak price points.

For the second component, BRPL conducted surveys among a select set of consumers. This survey was critical in understanding the importance of consumer classes under their service territory and how they can contribute to managing the system peak. One of the important aspects of this survey was unveiling how consumers are adopting new technologies such as solar, energy storage, and electric vehicles (EVs); DSM programs can make the best of these technologies. While rooftop solar can play a cardinal role in changing the grid landscape with grid-edge generation, EVs, on the other hand, denote a new class of consumer category with unique characteristics, able to reshape traditional demand profiles. There is a need for a suitable time-of-day (TOD)/TOU regime for EVs to integrate renewable energy further for EV charging and optimize the distribution network usage.

This report focuses on the first step in unlocking flexible demand for utilities and consumers in Delhi. NREL, in collaboration with BRPL and the Greening the Grid RISE team, studied the potential of DSM in Delhi. The work described in this report aims at developing a scalable framework that the utilities and distribution companies can utilize to evaluate DSM as a resource in their planning processes. The potential of time-varying rate structures was investigated by conducting load analysis, surveying BRPL consumers, and performing optimization and sensitivity analysis.

Methodology

Data analysis, consumer surveys and analysis, and optimization techniques were used to evaluate the potential of DSM for BRPL and their consumers. The methodology used to assess the DSM potential involved four steps as listed below:

- Assessing the overall consumer class breakdown in BRPL's service territory
- Establishing the energy consumption end-uses for each class
- Evaluating consumer class willingness and ability to participate in designing a DSM program
- Quantifying the overall potential benefit to BRPL and their consumers

The methodology ensured that our steps to identify the potential for DSM in BRPL were correct. The purpose of this research study was achieved performing the actionable tasks listed below:

- **Load analysis:** BRPL's system and consumer level load data were analyzed to investigate the characteristics of peak load and the key consumer classes (e.g., domestic, commercial, industrial) that contribute to overall system energy consumption and peak demand.
- **Survey construction and surveying consumers:** A survey was constructed and circulated to domestic, commercial, and industrial consumers to gather socioeconomic data and to assess their energy consumption patterns, motivation, and willingness to participate in DSM programs and their attitudes toward emerging demand-side technologies and distributed energy resources. Four hundred and thirteen residential and 318 commercial and industrial (C&I) consumers were surveyed from June to October 2020.
- **Survey analysis:** The survey results were analyzed to understand consumption patterns and assess the key motivations and consumer groups willing to participate in DSM and what mechanisms they would adopt to respond to DSM programs.
- **TOU modeling optimization and potential:** A TOU modeling and optimization analysis tool was created to aid in modeling TOU to obtain the maximum peak demand reduction and cost savings potential. A sensitivity analysis was run to obtain a sweep of results for different levels of consumer price responsiveness.

Notable Outcomes

There has been an increased evolution of the role of the demand side in power systems over the past decades in terms of increased load responsiveness, increased energy efficiency, and adoption of behind-the-meter (BTM) technologies such as rooftop solar and battery technologies. DSM has been shown to deliver cost and efficiency benefits both to the consumer and to utilities operating and managing the grid. Successful implementation of DSM involves assessing the load sector breakdown and potential for efficiency and response from consumers in a utility's service area and tying the load potential to DSM schemes that will produce a successful response.

The results presented in this report establish the positive outcomes from tariff-based DSM programs as they can bring cost benefits to both consumers and the utility, BRPL in this case. The following bulleted list provides a brief snapshot into notable outcomes from this study.

- **Quantifying need for and value from peak load reduction**: Peak load results in cost capacity and energy cost inefficiencies that are passed on to BRPL and their consumers. One percent of network and generation capacity (approximately 30 MW) is only required 0.01% (less than 1 hour) of the year, and 2% of capacity (approximately 60 MW) is only required 0.05% of the year. Reducing peak demand could bring capacity savings, and BRPL estimates annual savings of Rs 2 crore (rupees) per MW peak load reduction. Peak demand also has a positive correlation with higher electricity prices; for every MW increase in load, the energy price per MWh on average increases by 1 rupee, so leveling the load could reduce the cost of providing energy to BRPL consumers.

- **Targeting domestic consumers for reducing peak demand is key**: Domestic consumers account for approximately 87% of the overall consumer base and 67% of annual energy consumption. C&I consumers account for 13% of consumers and 31% of annual energy consumption. Average domestic consumption during the top 10% of loads hour is 58% of its peak, whereas for industrial l consumers it is 38% and for commercial consumers, 26%. This shows that domestic consumers are the key driver behind BRPL peak demand. TOU pricing schemes are currently in place for BRPL non-domestic consumers. However, non-domestic consumers are not the main driver of peak demand, and the survey shows they are also less willing to participate in DR than domestic consumers.

- **Domestic consumers are willing to participate in DR**: Domestic consumers are willing to participate in DSM measures, with more than 95% of consumers interested in reducing energy consumption for both environmental reasons and to achieve bill savings, and over 95% of respondents interested in further transitioning to energy efficient lighting. More than 75% of consumers were willing to stop doing laundry during evening hours and increase AC temperature during summer evenings.

- **C&I consumers are more willing to participate in energy efficiency than DR**: C&I consumers are more willing to participate in energy efficiency than in DSM measures that involve changing consumption patterns. More than 80% of consumers are willing to reduce energy consumption to protect the environment and believe they should be more active in using energy efficient appliances, and more than 77% of consumers are interested in energy efficiency to reduce their electricity bill, whereas only 58% of consumers were willing to modify cooling use during on-peak hours and only 22% of consumers were willing to change the operation of some business activities.

- **BRPL's journey towards enabling DSM**: BRPL load has two distinct seasonal shapes with dual peaking in summer, with peak load of 2,972 MW in July of 2018, and single peak in winter, in January (1,824 MW in 2019). The minimum load for 2019 of 532 MW, occurred in February. This study found that a two-season TOU price structure had the opportunity to reduce summer and winter peak load. In summer (April to October) a two-peak tariff was found to have potential, as load was found to peak between the hours of 15:00 and 17:00 and 22:00 and 01:00, and a single on-peak tariff in winter

(November to March) between the hours of 09:00 and 12:00 was found to have potential. This study estimates that BRPL has the potential to reduce summer peak demand by 2% (58 MW) and winter peak demand by 3.8% (70 MW). This could bring reduced capacity and energy costs to BRPL and their consumers. BRPL should further investigate rolling out a TOU tariff for its consumers and examine introducing smart meters for domestic consumers, providing information on smart appliances (e.g., smart thermostats and schedulable white goods) and energy efficiency measures to consumers.

- **Reusable Framework for Assessing Demand-Side Potential (EFFORT)**: EFFORT is an analysis framework developed in Python for modeling and designing TOU tariffs using optimization. It uses historical time series system-level load data, cost and capacity data of dispatchable generators, and consumer price responsiveness to compute optimal on-peak and off-peak price ratios. The utility can customize the level of consumer price responsiveness based on surveyed information and pricing trails to better reflect the response levels of their consumers. In addition to this, independent modules are also included to generate realistic on-peak hours by analyzing utility load profile data. Utilities can also compute seasonal TOU by grouping year-long load profiles into multiple seasons to specifically target seasonal changes in peak load consumption patterns. Scenario analysis can be leveraged in the absence of data required for computing realistic consumer price responsiveness.

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1 Introduction

BRPL is a distribution utility that serves part of the city of Delhi in North Central India. The utility serves over 2.4 million consumers as of March 2017 in a highly urban territory, with a consumer density of 3,100 consumers per square kilometer. BRPL is a distribution load-serving utility. Both consumers and the utility benefit from flexibility on the demand-side to help alleviate peak demand and underutilized generation and network capacity, to use demand response to help integrate renewable energy, and to help promote energy efficiency to reduce energy consumption.

The work in this report details research performed by NREL in collaboration with GTG-RISE team and BRPL to support and investigate the potential of DSM for consumer- and grid- benefits in Delhi. This research was supported by the U.S. Agency for International Development. The overall aim of this research was to assess the potential responsiveness of BRPL consumers and establish the potential benefits of DSM (About BRPL).

BRPL is a public-private company and is a joint venture between the Government of Delhi and Reliance Infrastructure Limited. It is one of three electricity distribution companies in Delhi; see Figure 1 (BRPL, FAQ). The utility principally serves residential and commercial consumers and has a high consumer density. The utility has experienced high growth in the number of consumers served, increasing its number of distribution transformers by 63% between 2003 and 2017.

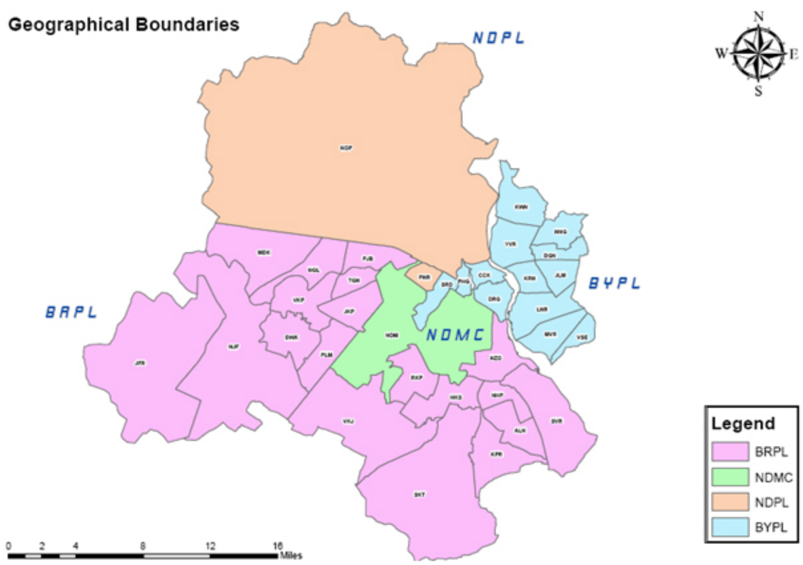


Figure 1. BRPL's service territory map in Delhi and neighboring utilities

As a distribution load-serving utility, BRPL can achieve energy reduction and flexibility by motivating DSM strategies. The principal form of achieving this is through retail price plans. To date, BRPL has some forms of variable pricing schemes, detailed in the next section, for their C&I consumers. However, the majority of the utility's energy consumption comes from their residential sector. The next section documents the different forms of DSM and focuses on those that might be of greatest import for BRPL.

1.1 DSM Review

The U.S. Energy Information Administration states about DSM, "Demand-side management (DSM) programs consist of the planning, implementing, and monitoring activities of electric utilities which are designed to encourage consumers to modify their level and pattern of electricity usage (USEIA).

DSM comes in many forms, such as DR and energy efficiency, and it can be expanded to include demand-side, or BTM, resources such as distributed generation; see Figure 2. The three broad categories of DSM are as follows:

- **Demand response:** DR can be broadly defined as trying to motivate a change in the level and pattern of consumer energy consumption. DRs can be broken down into those that are dispatchable and those that generate a response but are non-dispatchable.

  - **Dispatchable:** Dispatchable DRs are those forms of DR which a utility has some form of control over, either through direct dispatch comments, wholesale market dispatch, or controllable DR for capacity services, ancillary services, and/or energy voluntary services. These forms of DR require communication and generally a level of sophistication for calculating energy bid prices, ensuring reliability of response and outcome. Typically, larger C&I consumers are best suited to these forms of DR.

  - **Non-dispatchable:** Non-dispatchable DRs are those forms of DR for which a utility can create a signal to motivate a response, but over which typically the utility does not have any direct control regarding reliability or level of response. Retail price plans that motivate energy shifting and energy efficiency fall into this category and can be used for a wide set of consumers (e.g., residential and C&I consumers) without the need for any sophisticated controls or communications. Smart metering infrastructures are typically needed to provide these forms of DR.

- **Energy efficiency:** Energy efficiency can be achieved through a variety of mechanisms, including behavioral changes, appliance upgrades, and dwelling thermal insulation. The incentives for energy efficiency are principally economic (i.e., reducing consumer utility bills) and conscientiousness (e.g., concern for environmental impacts of energy use). Regulations on appliances meeting efficiency targets and the regulatory phase-out of inefficient appliances (e.g., bans on incandescent light bulbs) are a major way of achieving energy efficiency. Energy efficiency can also be achieved by availability of information on saving energy and switching to energy efficient appliances and price plans (e.g., incremental block tariffs) that incrementally increase the price per unit of energy as energy consumption increases.

- **Distributed generation and storage:** BTM or demand-side distribution generation can be classified as a form of DSM and can have many of the characteristics of non-dispatchable DR and energy efficiency. The same conscientiousness around environmental impacts of energy use that may motivate energy efficiency can motivate the adoption of rooftop solar photovoltaic (PV), and both serve to decrease the energy consumed from the grid. Likewise, distributed storage can achieve energy shifting that has characteristics similar to price responsiveness of consumers moving consumption away from peak periods.

The research performed and documented in this report focuses on non-dispatchable DR techniques such as using retail price plans to motivate energy efficiency and peak demand reduction and/or energy shifting.

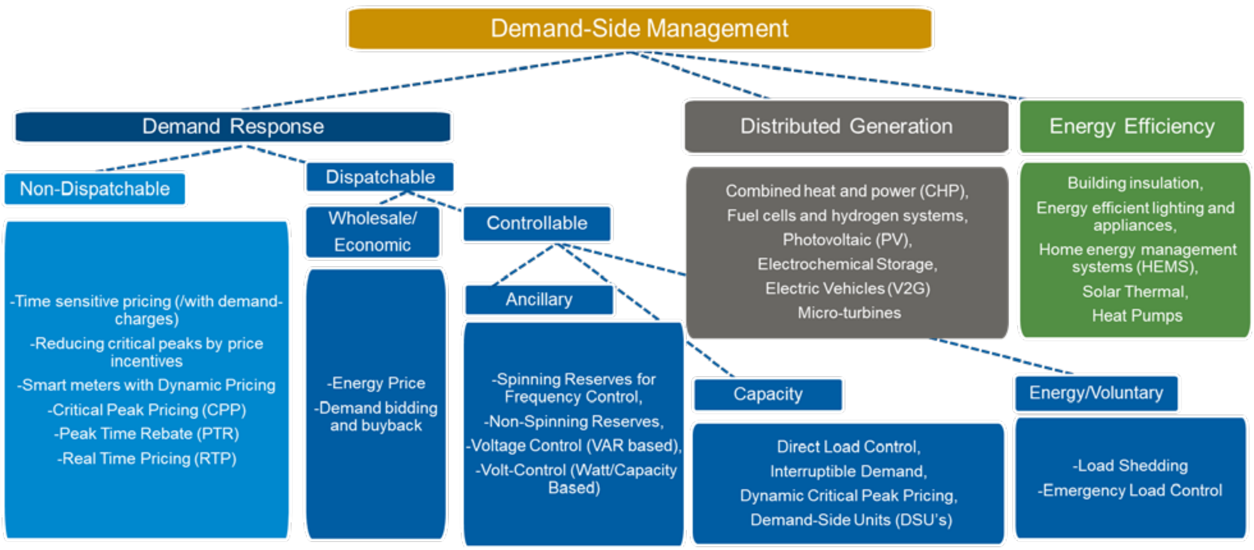


Figure 2. Classification of DSM strategies

1.1.1 Price Plans for Achieving Demand Response

Pricing for electricity can be used to motivate changes in energy usage patterns and overall reduction in energy consumption. Utility price plans have been evolving over decades, motivating energy efficiency, flexible demand, and peak flat-rate tariffs (e.g., a single price per kWh) do not motivate lower energy consumption usage beyond a consumer simply purchasing less of electricity as a commodity. Flat-rate tariffs, where electricity costs are uniform across all hours, also do not motivate any change in consumption patterns. Both rewarding consumers who have lower energy consumption and motivating a change in energy consumption patterns can be achieved with incremental block tariffs and time-based, or TOU, price plans:

- **Incremental block tariffs**: These tariffs, also known as block tariffs, stepped rate, or slab tariffs, incrementally increase the unit price of electricity as consumers' electricity consumption increases. This gives low energy consumption consumers an overall lower levelized cost of electricity (i.e., overall cost divided by total energy consumption) and motivates high consumption consumers to reduce their energy consumption, promoting energy conservation and efficiency.

- **TOU:** Motivating a change in energy consumption patterns and a shift away from peak period usage to help flatten the load curve can be achieved by time-based or TOU pricing. Utilities can design tariffs to shift energy consumption away from peak periods and thereby promote both an overall reduction in demand and shifting of other energy usage. TOU tariffs can be multiperiod, such as those used for EVs, where utilities motivate both a reduction in on-peak energy consumption and off-peak or shoulder tariff, and a super off-peak price to shift EV charging to late night periods.

Utility price plans have also evolved to motivate and provide price signals for the adoption and use of solar PV systems as a form of distributed generation. The evolution of utility price plans typically moves from no financial reimbursement for generation export, to net energy metering, to some form of feed-in tariffs, to demand charges and zero export; these are documented below:

- **Net energy metering:** Net energy metering is the most financially rewarding rate structure for solar PV adoption. Net energy metering offers exports the same price as imports, allowing consumers to offset their energy bill with any excess solar exported to the grid, which also eliminates the need for energy storage. Although this price plan strongly motivates solar adoption, it can cause issues for utilities where fixed costs that are still incurred from consumers (i.e., market operation charges, generation, and network capacity charges) are lumped into the unit price of electricity are no longer fully recovered.

- **Feed-in tariffs:** Feed-in tariffs, also known as export tariffs or export credits, are unit prices for export that are typically lower than import tariffs. These prices are designed to not pay consumers for fixed costs for solar export and are generally oriented around offering consumers a price that tries to fairly reflect the value of exported solar. These rate structures do not motivate solar adoption as strongly as net energy metering, and there are arguments that consumers with solar should get paid for some fixed costs as solar installations can avert network upgrades and provides a form of generation capacity in addition to energy exports.

- **Demand charges and zero export periods:** Demand charges price consumers based on their highest kW consumption (usually the highest consumption over a discrete time period during a predefined range of time). These rate structures provide an alternative route for utilities to get reimbursed for fixed capacity costs incurred as a result of consumption; it is dependent on a consumer's highest capacity usage rather than their energy consumption (Hledik 2014). These can be introduced as a means of fixed cost recovery in scenarios of high PV penetration where recovering these costs through other rate structures can be more challenging. Utilities are also introducing retail rates that emphasize export, with some utilities moving to timed zero export periods (Hoke et al 2018).

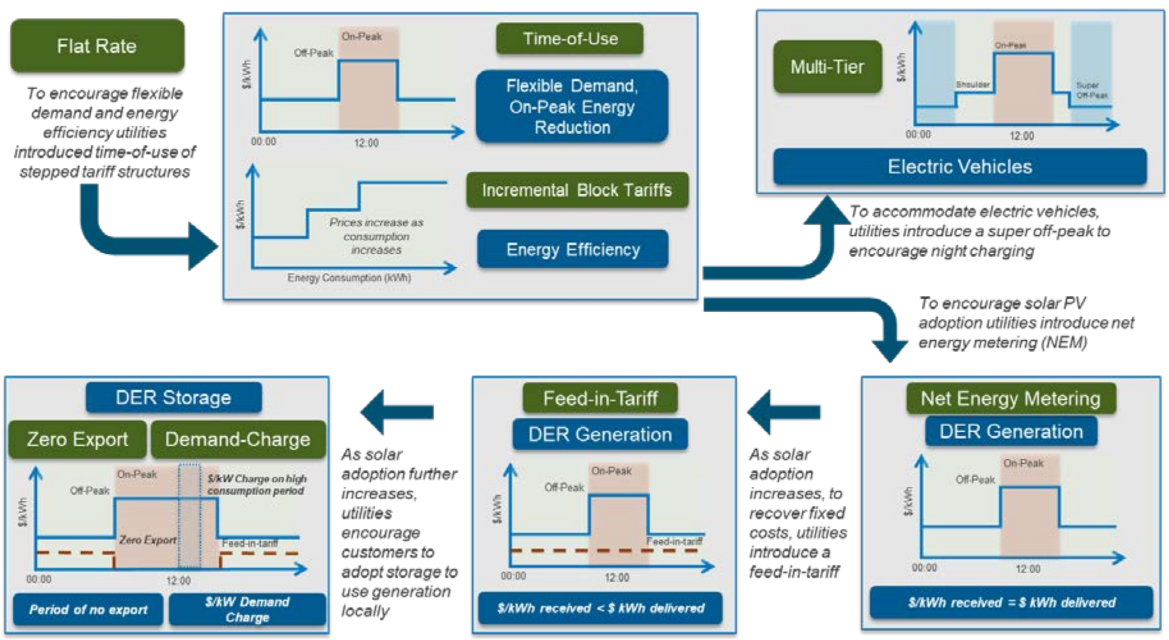


Figure 3. Evolution of price plans to motivate flexible demand, smart charging, adoption of solar PV, and use of energy storage for self-consumption and energy shifting

Another element of rate structure design is how each cost component is recovered. Utility costs can generally be broken down into fixed costs (e.g., transmission and distribution network and generation capacity), variable costs (operation and maintenance, energy and fuel costs, market operator charges) and taxes and obligations (renewable energy surcharges, taxes and other direct costs). These utility costs can be recovered through four principal price components: kWh prices (i.e., energy), kW prices (i.e., demand), service and amperage connection charges, and monthly fixed charges; see Figure 4. Lumping fixed charges into energy prices (i.e., kWh prices) runs the risk of these prices not being recovered, however, higher kWh prices better motivate energy efficiency and energy shifting.

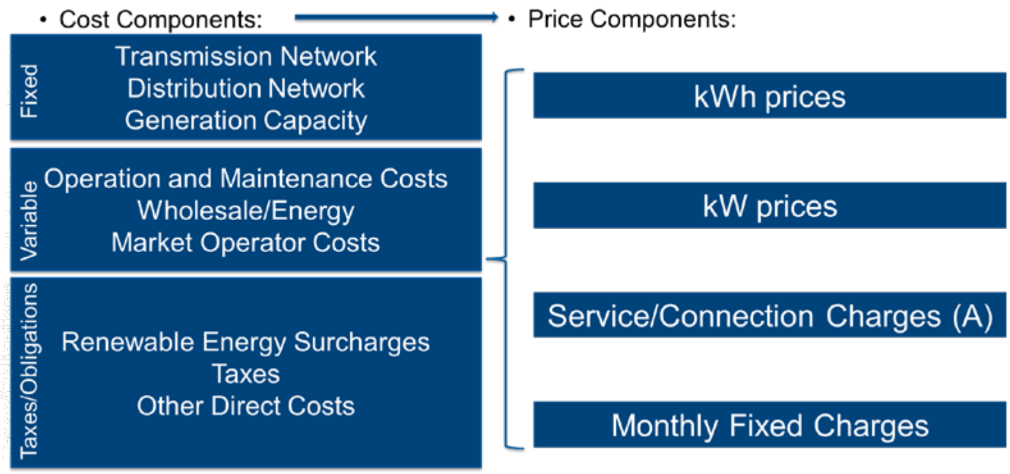


Figure 4. Utility cost components and methods of recovery through different retail price components

In the next section we assess the demand-side potential for BRPL of non-dispatchable DR in the form of TOU tariffs. We also detail the tariff structures that BRPL currently has on offer to their consumers.

1.2 Assessing the DSM Potential for BRPL

Introducing DSM measures in BRPL's service territory will help reduce peak demand, providing network and capacity upgrade cost deferral, and could also motivate increased energy efficiency. DSM can bring cost savings to both the consumer and the utility through overall efficiency gains in supply and demand. BRPL can motivate DSM through their tariff structures, moving to TOU and more advanced retail structures that can motivate changes on the demand side.

As of February 2021, BRPL has incremental block tariffs for their consumers and has a time-of-day (TOD) tariff structure available to their C&I consumers (BRPL,FAQ). C&I consumers are also billed on their sanctioned load (kW or kVA), and a surcharge is added to this bill if their maximum demand exceeds the sanctioned load. The details of the TOD tariff available to C&I consumers is given in Table 1 (BRPL,Facts you should know) (Comission (CPUC), California Public Utilities).

Table 1. BRPL TOD Tariff for Non-Domestic and Industrial consumers

Month	Peak Hours	Surcharge on Energy Charges	Off-Peak Hours	Rebate on Energy Charges
May–September	14:00–17:00 22:00–01:00	20%	04:00–10:00	20%

While TOD tariffs are available to BRPL's C&I consumers, only incremental block tariffs are available to their residential consumers. Residential consumers account for 67% of BRPL overall energy consumption. In addition, C&I consumers can be inflexible; this is because the value of their end-use may be greater than any provided opportunity cost of shifting or reducing demand during peak hours. To evaluate whether introducing a TOU (this is the same as a time-of-day in structure, but this report uses "TOU") tariff structure an evaluation framework was established, see Figure 5. This involved assessing the consumer class breakdown in BRPL's service territory, establishing the end-uses for each class, assessing consumer class willingness and ability to participate, and finally, designing a DSM program and assessing the overall potential benefit to BRPL and their consumers.

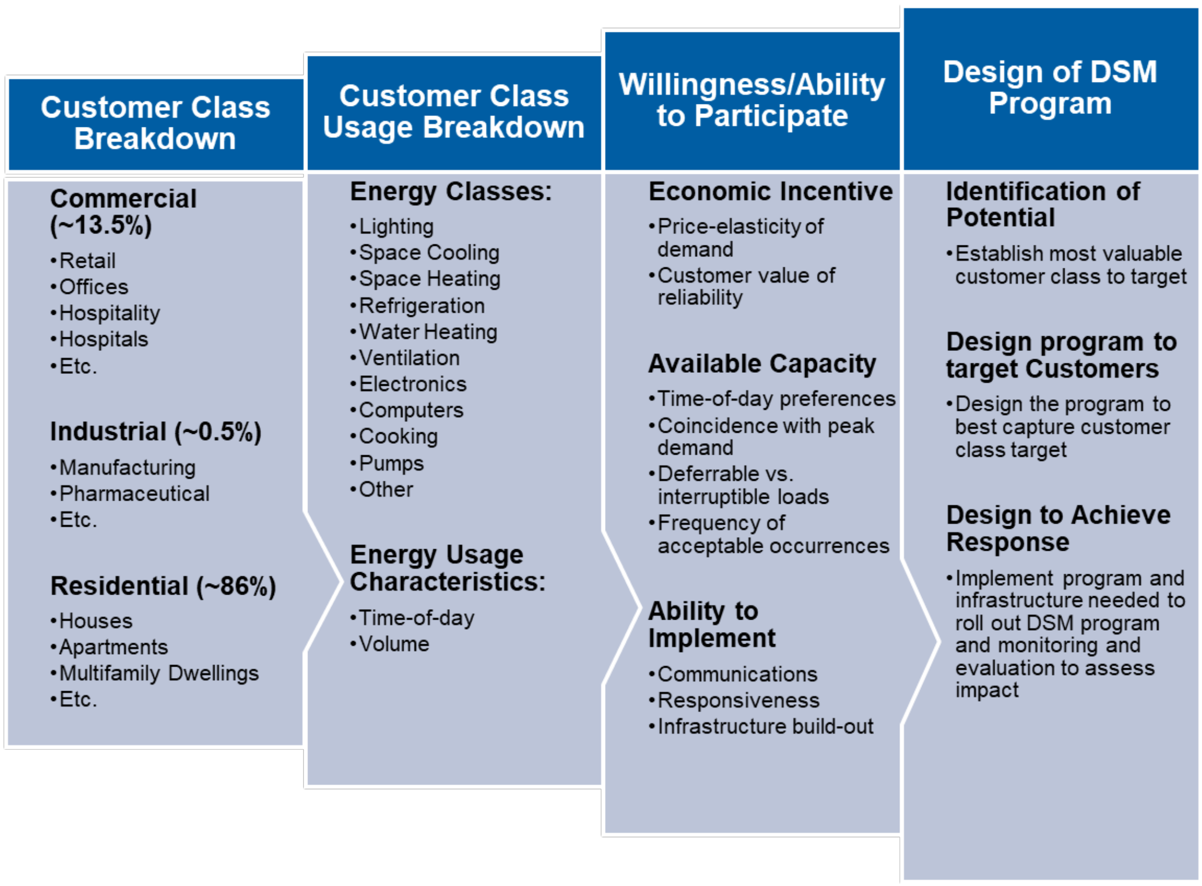


Figure 5. Classification of DSM strategies

This assessment involved three main stages:

- **Consumer class breakdown and load analysis:** This stage involved analyzing BRPL data on their different consumer classes, including percentage breakdowns, energy, and peak demand contribution. This also involved looking at seasonal peak load analysis; this is documented in the next Chapter.

- **Surveying consumers, usage, and motivation:** In this stage, we surveyed 413 domestic consumers and 318 C&I consumers, gathering information on their energy usage patterns, motivation to achieve demand response, and end-uses that had the greatest DR potential.

- **Identification of potential through modeling and optimization:** Identifying the TOU potential involves examining how to choose TOU seasons, on-peak hours, and on- to off-peak price ratios. This section builds a modeling and optimization framework to examine the TOU structure and identify the potential peak demand reduction with a sensitivity analysis on consumer responsiveness.

2 Demand-Side Load Profile Analysis

An initial step in DSM assessment is to understand the seasonal and diurnal patterns in consumer demand and to identify which load classes drive overall consumption. Understanding consumer energy consumption patterns is crucial in designing an effective DSM strategy, to both target peak hours and impact consumers. NREL received annual 30-minute load data from BRPL for the year 2018–2019 and distribution transformer data that served specific consumer classes; see Table 2 for a description of data received. This data was later used to help design a TOU tariff for BRPL. More on the TOU design is discussed in Section 3. This section will provide in-depth analysis of BRPL's load profile using historical data.

Table 2. Data Received from BRPL That Was Used for Load Analysis

Data	Data Description
System data	• 30-minute resolution load data from April 2018 to March 2019 • Monthly generation cost (Rs/MWh) data along with contracted capacity for 22 generators
Distribution transformer data	• 30-minute resolution energy consumption data for 24 distribution transformers
Consumer class energy consumption and number of consumers data	• Monthly energy consumption data for 413 domestic consumers, 318 C&I consumers

2.1 Seasonal Energy Consumption Pattern

The BRPL system-level load profile exhibits seasonal energy consumption patterns related to heating and cooling use across months. The system annual peak demand occurs in summer months, specifically July for 2018. The load profile is dual peaking in summer with system peaks in late afternoon (around 4 p.m.) and at night (around midnight); see Figure 6. In winter months, the system peak is during the morning (around 10 a.m.–11 a.m.), as shown in Figure 6. The energy consumption is significantly higher in summer months when compared to winter months.

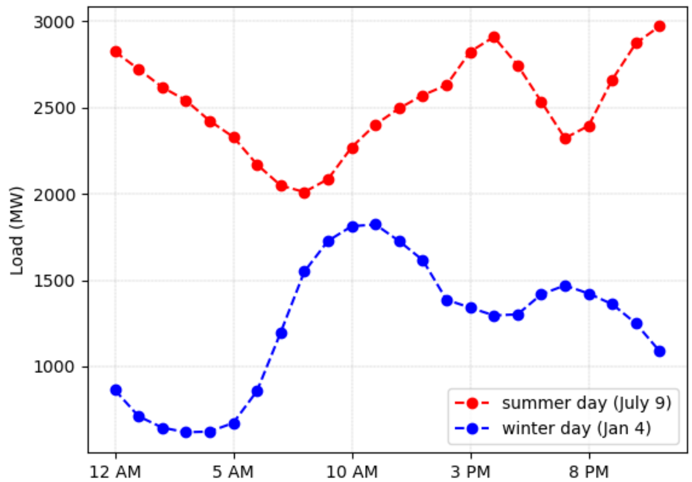


Figure 6. Seasonal energy consumption of BRPL system-level load profile

2.2 Load Sector Analysis

Consumption patterns vary by consumer class (e.g., domestic, industrial, commercial, etc.). Analyzing individual consumer classes allow an assessment of consumer class contribution to overall system peak demand. Consumer classes are broadly broken into three categories for this analysis: domestic, non-domestic and industrial. BRPL consumer classes by number of consumers and annual energy consumption are shown in Figure 7.

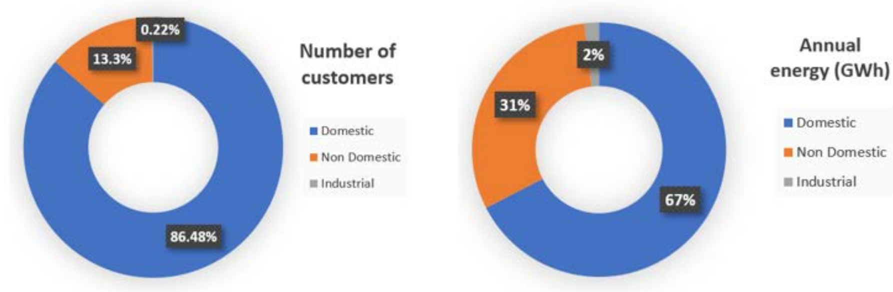


Figure 7. Number of consumers and annual energy consumption (for 2018) for three consumer classes in percentage

Although domestic consumers account for close to 87% of total number of consumers, their contribution to annual energy consumption is lower, at 67%. Similarly, C&I consumers account for a greater proportion of energy consumption than the number of consumer breakdown, contributing to 31% and 2% of total annual energy consumption respectively in BRPL territory in 2018. This is intuitive, as C&I consumers have much greater energy end-use by consumer by virtue of the scale of energy requirements. Figure 8, Figure 9, and Figure 10 show the breakdowns of domestic, non-domestic, and industrial consumers further by number of consumers and annual energy consumption and utility-sanctioned load (i.e., connected load). Approximately 73% of BRPL domestic consumers have a connected load less than 2 kW and contributed to 50% of total domestic energy consumption in 2018.

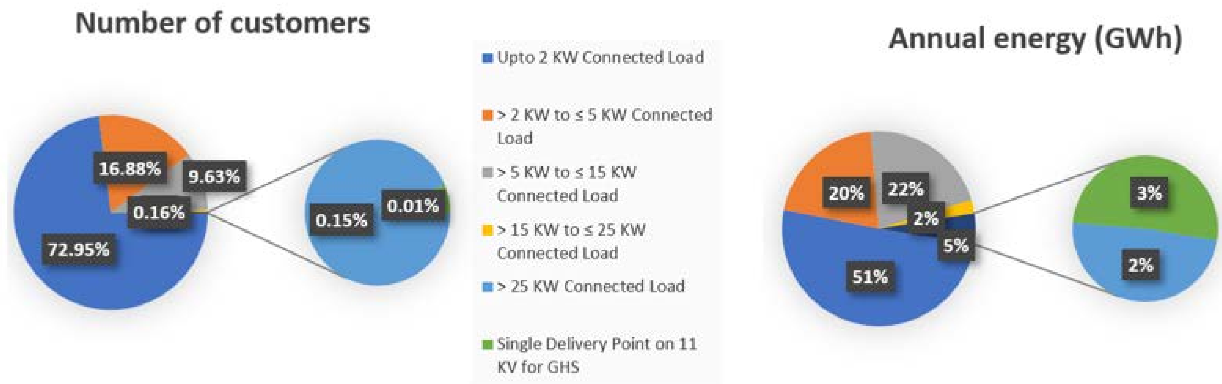


Figure 8. Breakdown of domestic consumers: number of consumers on the left and total energy consumption on the right

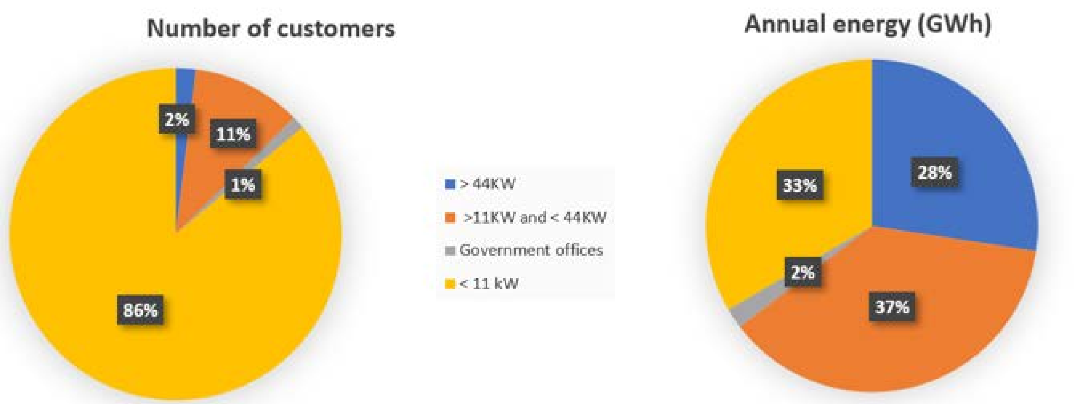


Figure 9. Breakdown of non-domestic consumers: number of consumers on the left and total energy consumption on the right

Figure 10. Breakdown of industrial consumers: number of consumers on the left and total energy consumption on the right

The energy consumption pattern of domestic consumers drives the overall system-level demand; this can be seen by comparing Figure 11 with Figure 17, where it can be observed that the daily average load profile pattern for all months for domestic demand and system-level demand are correlated. This is intuitive, as domestic consumers account for 67% of total annual energy consumption. Smaller domestic loads (sanctioned to be less than 2 kW) contribute to 50% of domestic energy consumption and therefore play a vital role in changing the shape of system-level load profile.

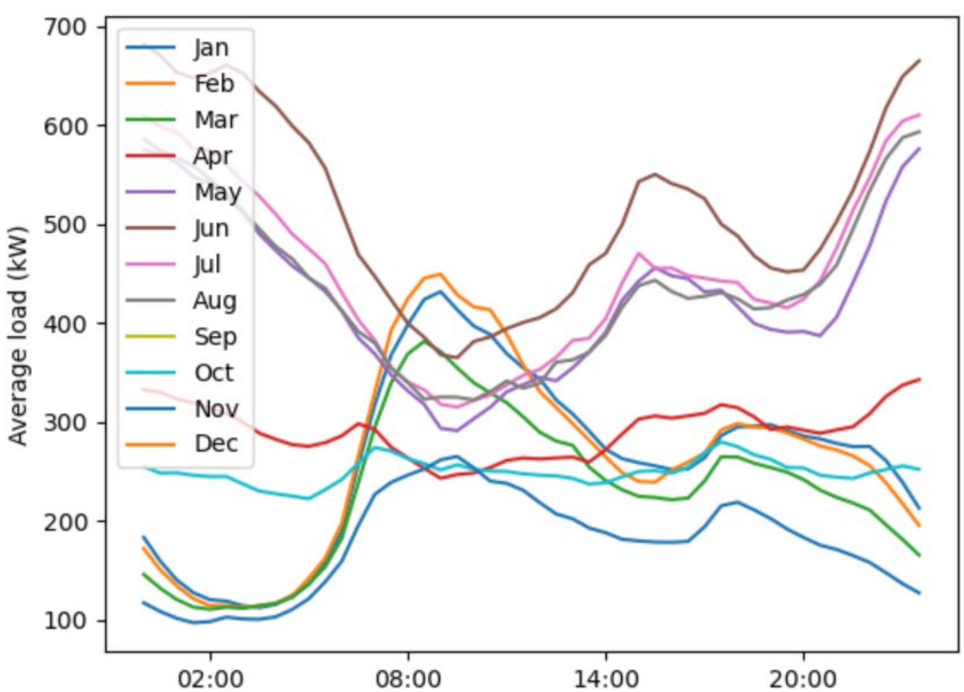


Figure 11. Domestic consumers' daily average profile for all months (data from distribution transformer serving apartments)

On average 56% of domestic peak load (in per unit or pu) occurrences, 26% of industrial peak load, and 6% of commercial peak load coincide with summer peak hour (i.e., 11 p.m.), as shown in Figure 12. The average per unit load for domestic consumers closely follow the system load pattern at all hours. Industrial consumers are driving summer afternoon peak; average consumption by industrial consumers during summer afternoon peak is close to 75%.

On average, 24% of domestic peak load, 14% of commercial peak load, and 45% of industrial peak load coincide with winter peak hour (i.e., 11 a.m.), as shown in Figure 13.

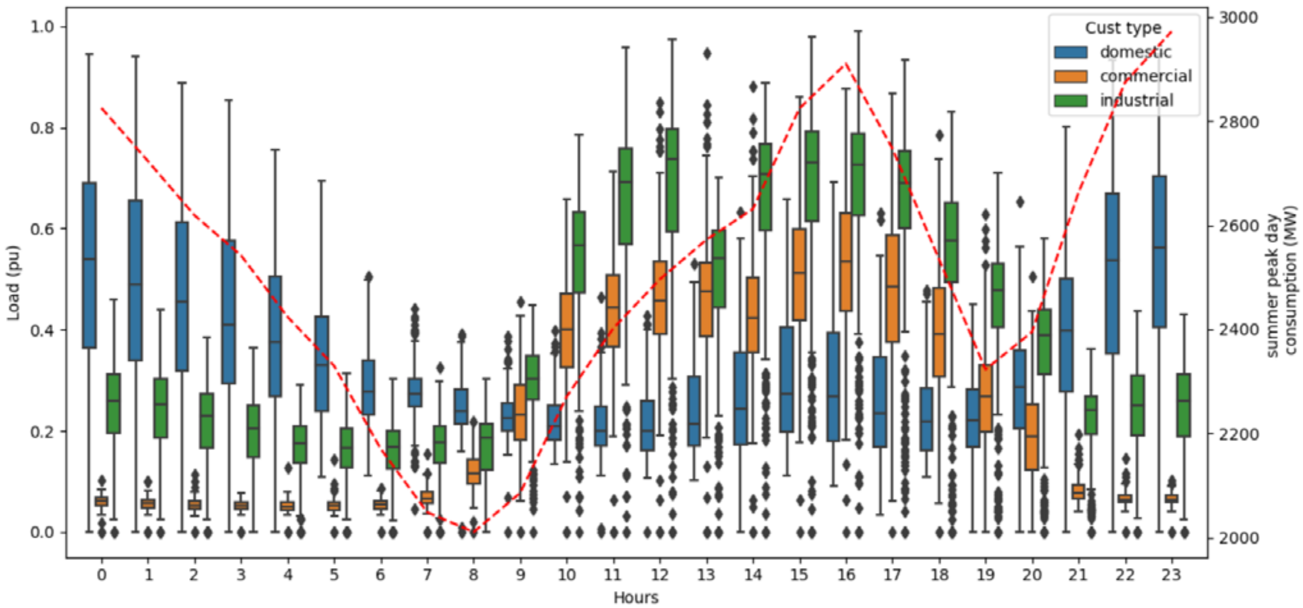


Figure 12. Box plot of summer load by consumer category for three consumer groups

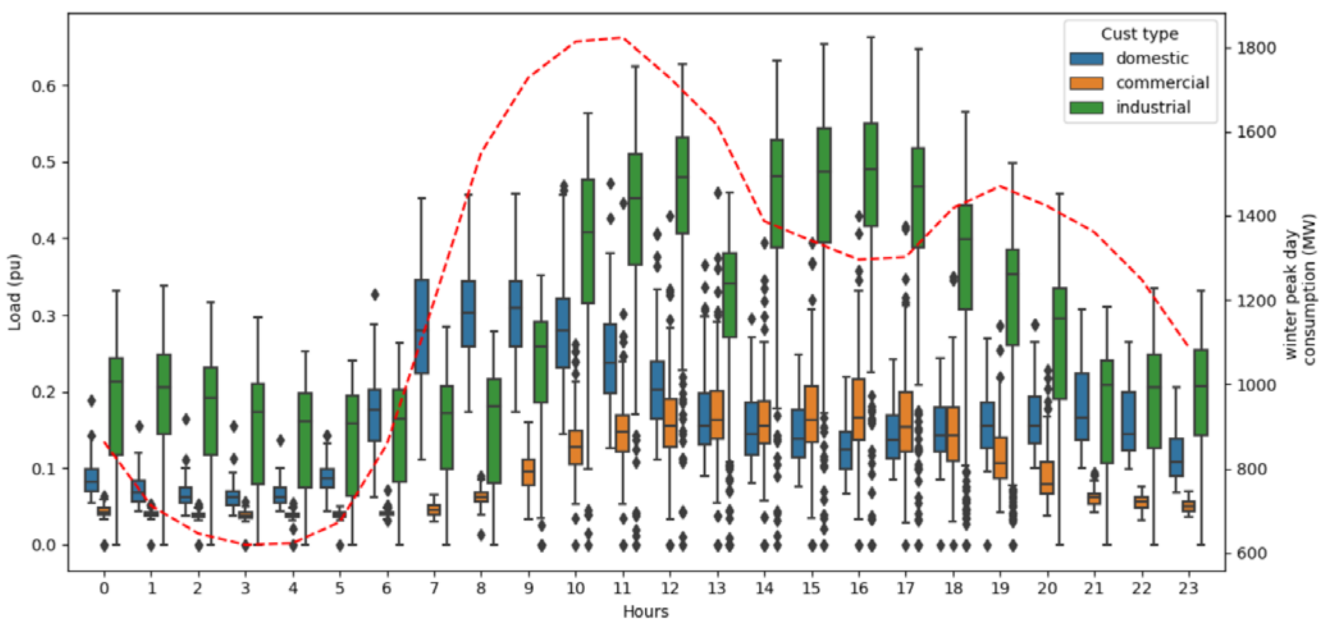


Figure 13. Box plot of winter load by consumer category for three consumer groups

The average load profile of market complex (a non-domestic consumer) is shown in Figure 14, and the average load profile of an industrial consumer is shown in Figure 15. Most of the loads are concentrated around office time, and loads reduce sharply at other times. The peak for such consumers does not align with system peak load.

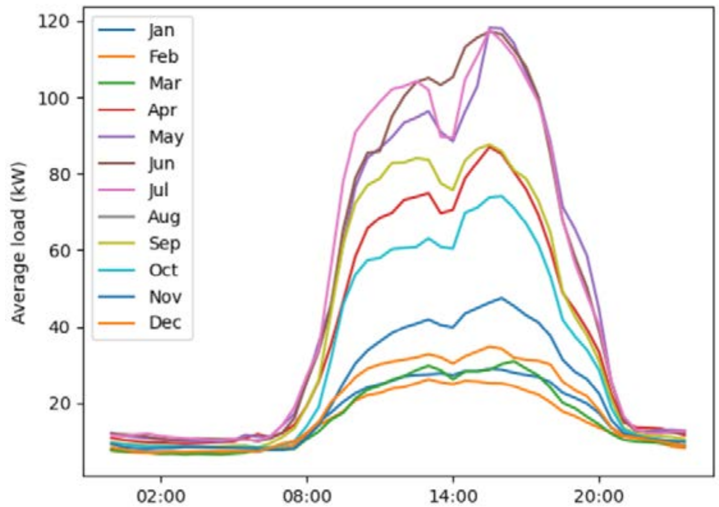


Figure 14. Non-domestic consumer daily average profile for all months (data from distribution transformer serving market complex)

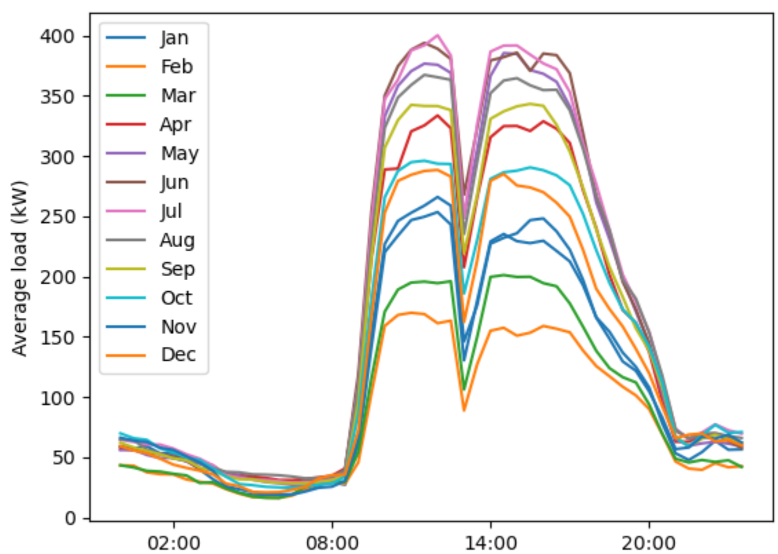


Figure 15. Industrial consumer daily average profile for all months

2.3 Peak Load Analysis

Figure 16 shows the time series load profile for BRPL utility. The peak load and minimum load for 2018 were 2,972 kW and 444 kW respectively.

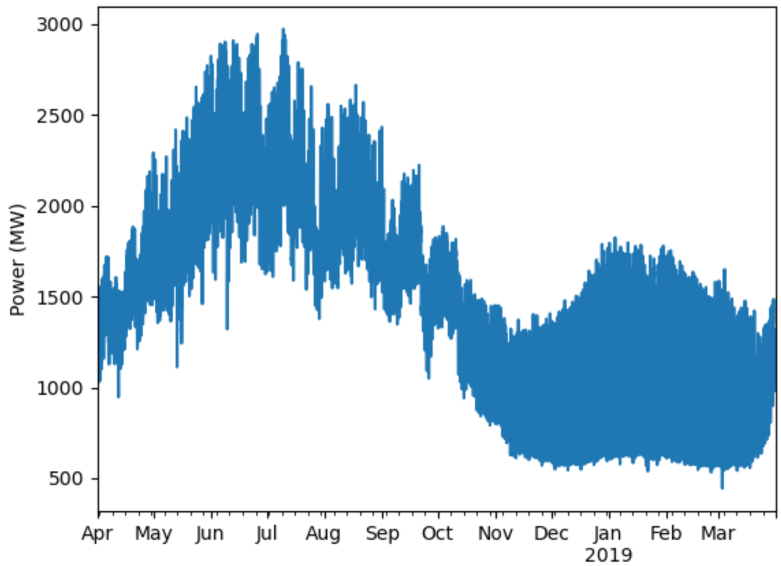


Figure 16. Time series BRPL system-level load profile for year 2018-19

Figure 17 shows average daily profile for all months. The peak load, minimum load, and time at which they occur are listed in Table 3. Most of the months have two peak times and two off-peak times in a day except for January, June, and July. Summer months tend to have late evening and late afternoon peak and off-peak during early morning and evening. Winter months are almost opposite; for them peak occurs during morning and evening.

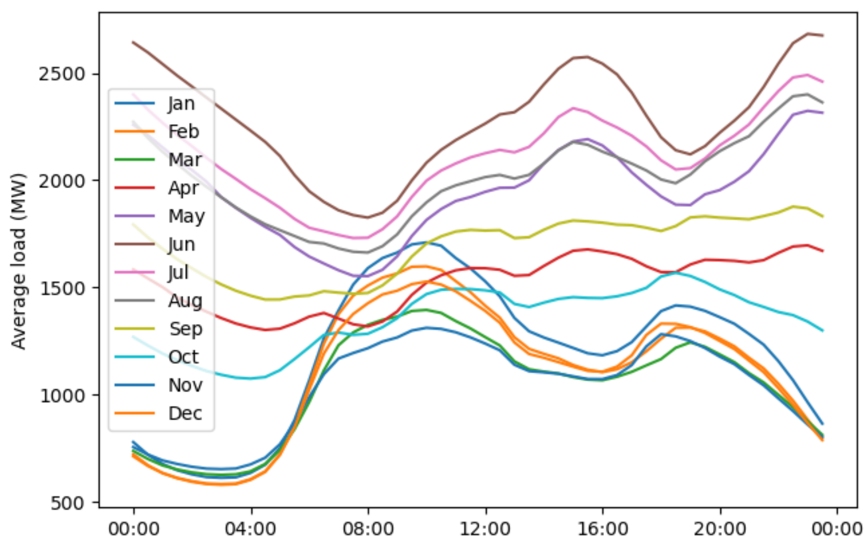


Figure 17. Average daily load profile for all months of 2018

From April to October peak load occurs at late evening (22:30, 00:00), whereas from November to March peak occurs in the morning and evening. Minimum load occurs between 2:20 to 4:00 at night for most of the months, which is within reasonable expectation.

Table 3. Monthly Statistics of System-Level Load Profile

Month	Peak load	Peak Time	Minimum Load	Low load time
January	1824	4th, 10:00:00	538 kW	22nd, 2:30:00
February	1779	3rd, 10:30:00	532 kW	25th, 2:30:00
March	1649	4th, 9:30:00	444 kW	3rd, 4:00:00
April	2291 kW	30th, 23:00:00	946 kW	12th, 4:30:00
May	2823 kW	31st, 23:00:00	1112 kW`	13th 17:30:00
June	2944 kW	25th, 23:00:00	1320 kW	9th, 17:30:00
July	2972 kW	9th, 22:30:00	1377 kW	29th, 7:00:00
August	2663 kW	17th, 22:30:00	1430 kW	28th, 8:00:00
September	2320 kW	1st, 00:00:00	1049 kW	26th, 4:00:00
October	1886 kW	3rd, 22:30:00	791 kW	29th, 3:30:00
November	1450 kW	2nd, 18:00:00	570 kW	26th, 2:30:00
December	1787 kW	28th, 10:00:00	544 kW	10th, 3:00:00

To get more in-depth understanding of peak load hours and off-peak load hours, we can analyze the top 10% load hours and bottom 10% load hours in a load duration curve.

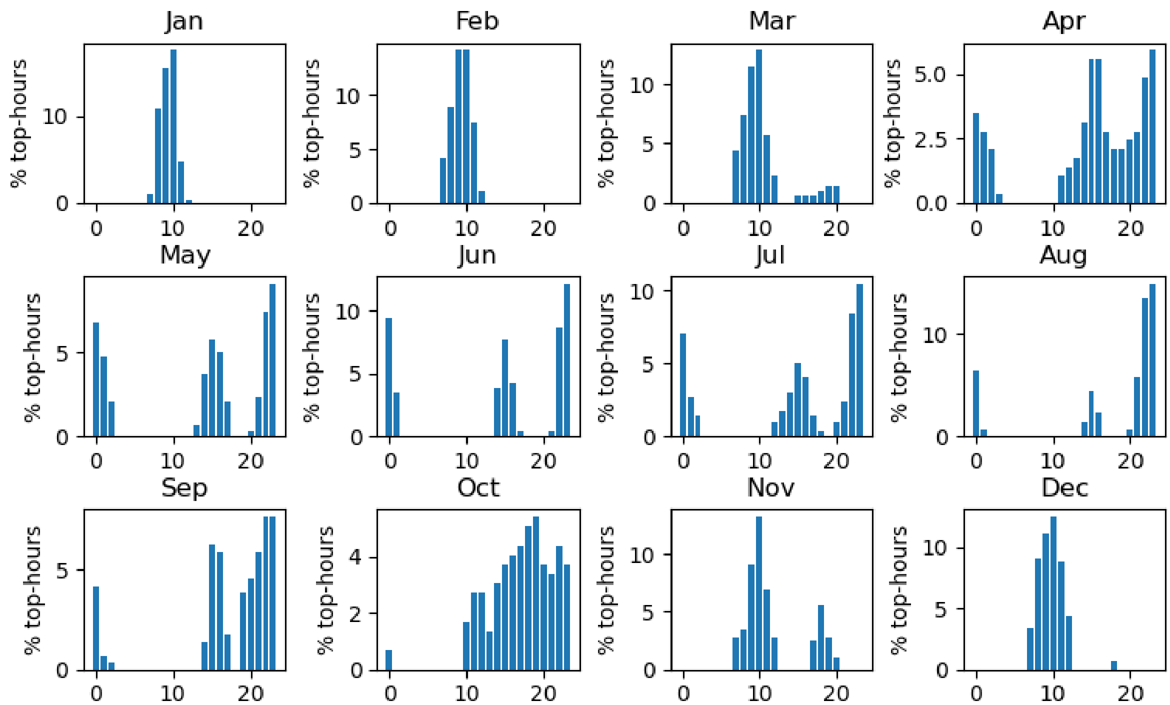


Figure 18. Percentage of top 10% load hours from monthly load duration curve

A load duration curve is a sorted time series profile in a descending order. Figure 18 shows a bar plot of the percentage of top 10% load hours that belong to each hour separately for each month. An hour with a higher percentage indicates that most of the top 10% load hours belong to that hour. Figure 19 shows a bar plot of the percentage of the bottom 10% load hours that belong to each hour separately for each month. An hour with a higher percentage indicates that most of top 10% load hours belong to that hour.

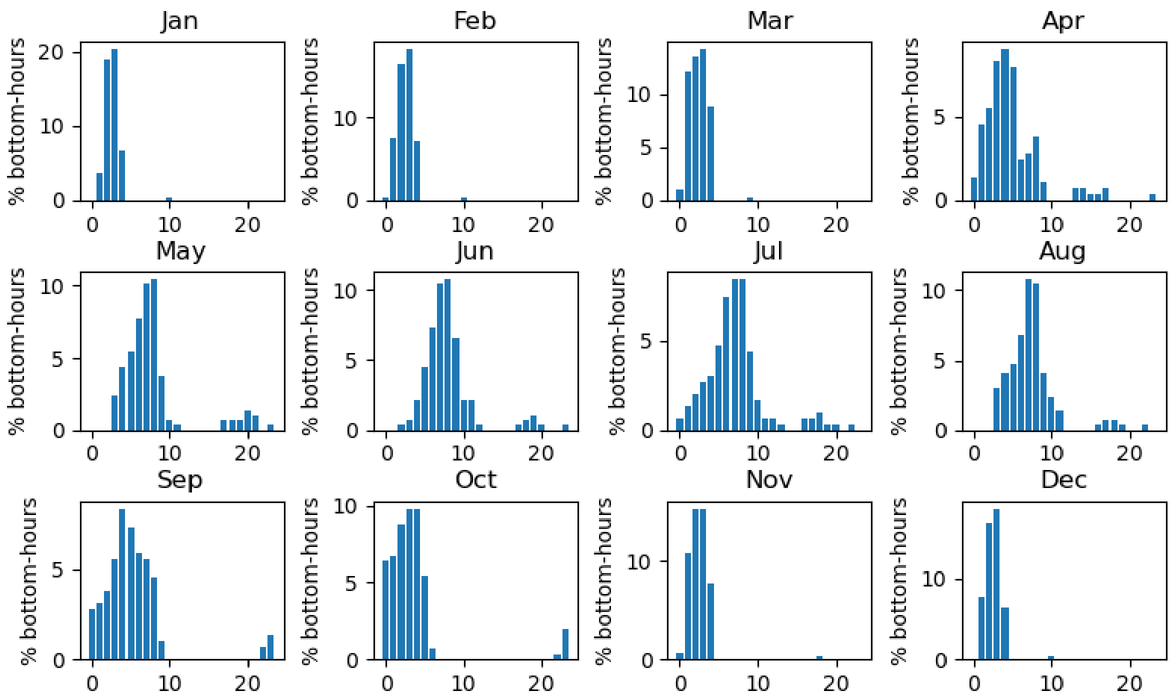


Figure 19. Percentage of bottom 10% load hours from monthly load duration curve

This information is very useful for designing TOU tariffs. For example, from April to October, 15:00 to 17:00 and 22:00 to 1:00 can be considered peak hours, and 2:00 to 7:00 can be considered off-peak hours. Similarly, from November to March, 9:00 to 12:00 can be considered peak hours, and 1:00 to 4:00 can be considered off-peak.

The load duration curve for the BRPL system is shown in Figure 20. The system peak in 2018 was close to 3GW at the system level for BRPL. However, when we look closely at the time series profile, we see the relation between duration of occurrence and peak load is highly nonlinear in nature. Looking at the annual load duration curve for the BRPL system gives perspective. Load duration curve is simply time series energy consumption data arranged in a descending order from largest to smallest load. What we found is that 10% of system peak (i.e., about 300 MW) occurs only for five days in the whole year, which is close to just 1.5% of total time, meaning, 300 MW generation is required for only five days in a whole year, a clear example of ineffective infrastructure utilization. If we could target times of day in which the system is expected to peak to reduce the demand, we could reduce ineffectiveness in infrastructure utilization.

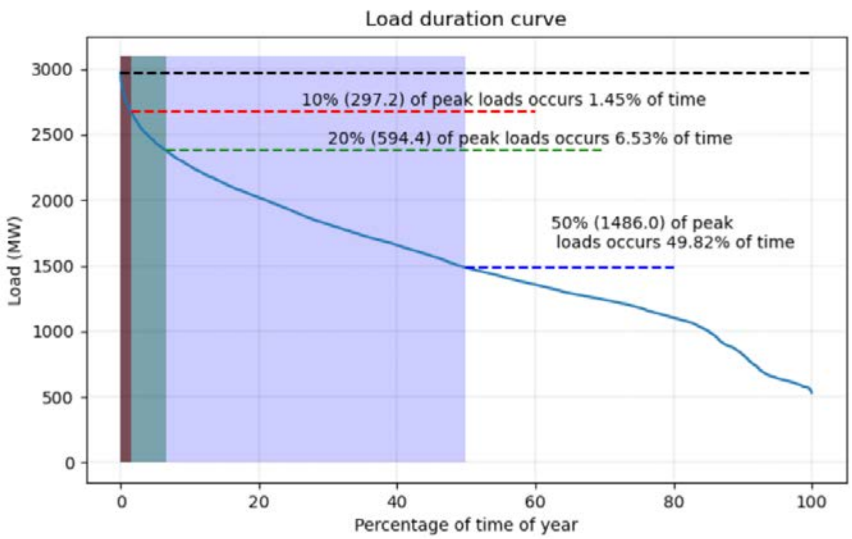


Figure 20. Load duration curve for BRPL system

2.4 Relation Between Load and Price

The ineffective utilization of generating resources makes peak load expensive. To verify this, we looked at average price per MWh for different blocks of load; you can see a positive trend in average price with increase in demand as shown in Figure 21. Reduction in peak loads can also allow utilities or distribution companies to defer system upgrades. BRPL estimates annual savings of close to 2 crore per MW reduction in peak. In this project, we looked at whether and to what degree we can achieve peak reduction with the help of a new tariff scheme, specifically TOU tariffs.

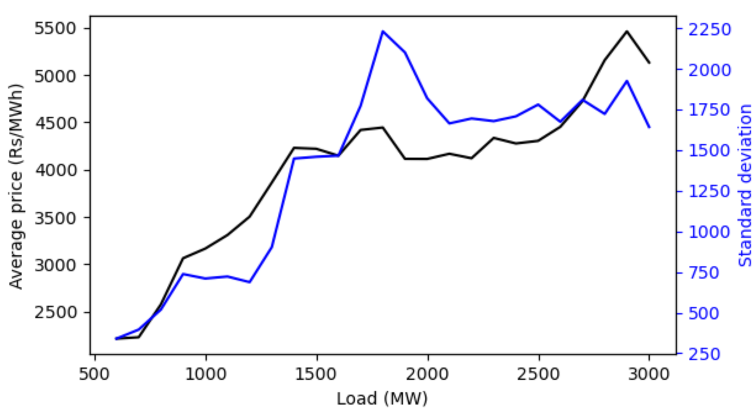


Figure 21. Relation between load and price

3 BRPL Demand-Side Survey Analysis

To foster deeper understanding of consumer intent and energy usage behavior, two sets of surveys were conducted from June–October 2020 for select BRPL consumers. These surveys were categorized into two broad groups: one group consisting of domestic consumers and the other group consisting of C&I consumers. A more complete selection of all results is in Appendix B. The survey was administered by BRPL staff. The consumers were randomly selected, and the questions were provided via online forms. BRPL followed up with the consumers to complete the survey, helping whenever consumers faced difficulties.

The questionnaire was developed by NREL and the GTG-RISE team. Survey questions were structured to capture basic profile-related information, equipment ownership, equipment usage patterns, energy efficiency-related awareness, and willingness to participate in DSM programs. The next sections outline the findings from these surveys.

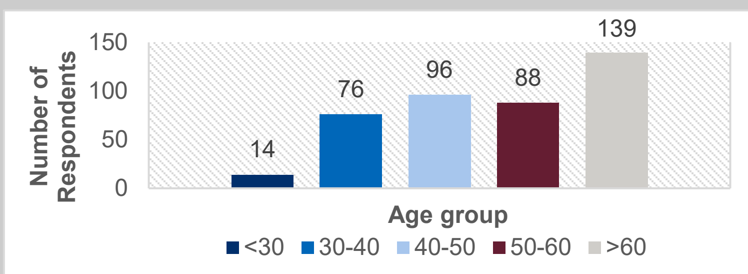
3.1 Domestic Survey Analysis

In this survey, responses from 413 consumers were recorded from June–July 2020. Domestic consumers account for approximately 87% of the overall consumer base and 67% of annual energy consumption. These consumers contribute the most to overall peak consumption, and the peak for this consumer class strongly coincides with the system peak; see Figure 12.

3.1.1 Profile of Respondents

Table 4 gives the profile and key demographics of the domestic survey respondents. Respondents who were over 50 years old (200 out of 413), were employed or retired (180 and 122 out of 413, respectively), owned their own houses (370 out of 413), and had up to three household members (270 out of 413) were well represented.

Table 4. Profile of Domestic Survey Respondents

Parameter	**Findings**
Age of Respondents	More than 200 respondents were aged 50 or above; the most represented group was those above 60, and the least represented was those under 30.  **Figure 22. Age distribution of respondents**
Employment Status	More than 180 were employed and about 122 respondents were retired.
Ownership	About 370 residents were living in their own house.
Type of House	About 325 respondents were living in an apartment, while 43 were living in a bungalow.
Household Size	About 270 households had up to three members.

3.1.2 Equipment Ownership

Basic household equipment such as lights and fans are present in almost every household. Ninety-nine percent of households responded that they have at least one fan in their house. With regards to fans, 89.3% of households reported having more than three. Additionally, 86% of households have washing machines, and 86.7% of respondents reported owning at least one air conditioning (AC) unit. Figure 23 shows the percentage of ownership of major equipment types by the respondents.

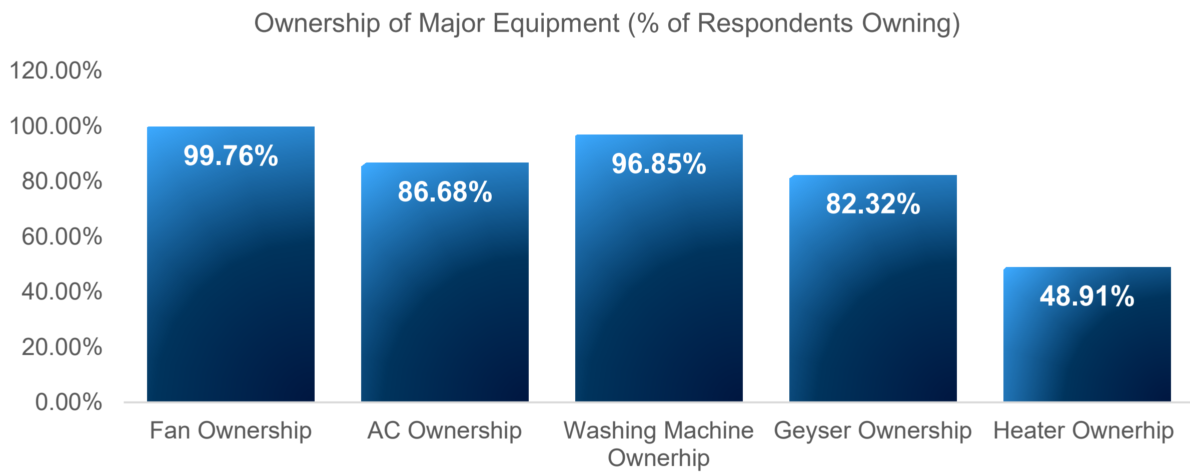


Figure 23. Ownership of major equipment

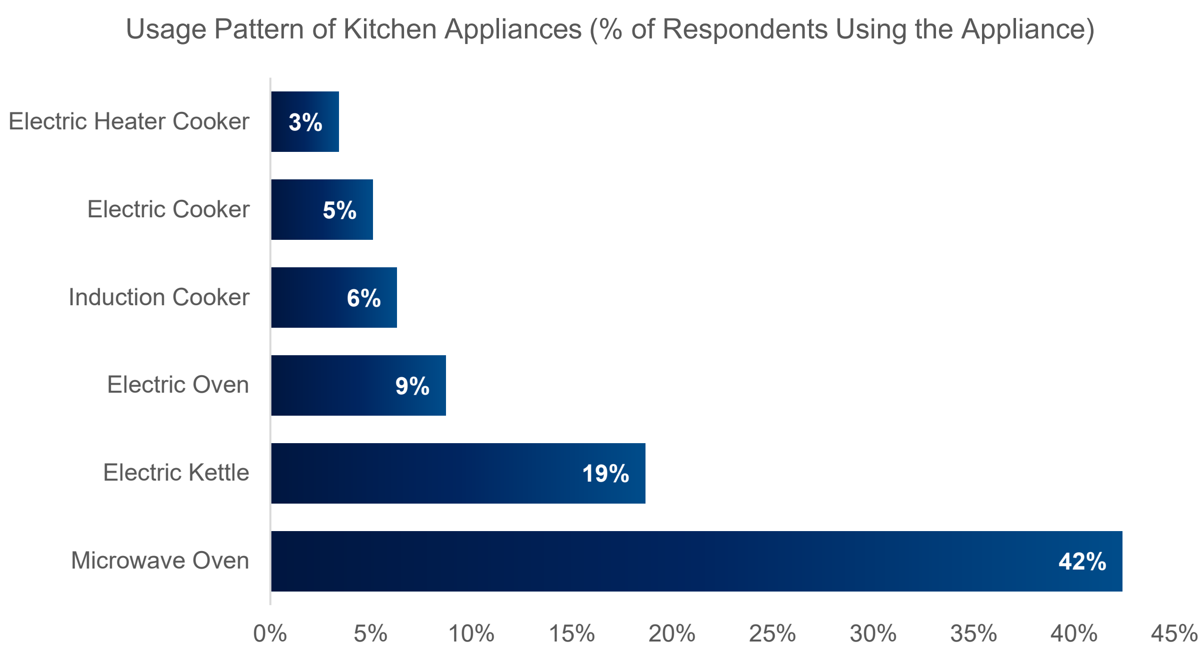


Figure 24. Usage of kitchen appliances

In terms of kitchen appliances, 67% of the respondents own a microwave oven. Forty-two percent of respondents have reported frequent use (either daily or used a few times in a week) of microwave ovens, making it the most used equipment in the kitchen, followed by the electric kettle at 19%. Equipment such as electric cookers and electric cookers are used by less than 5% of the sample.

3.1.3 Usage of Cooling and Heating Load

For this study, we have considered ACs, geysers, and room heaters as cooling and heating loads. Geysers are small tank capacity electric hot water heaters that are typically used to heat hot water on demand; they are more commonly known as instant hot water heaters or small storage tank water heaters. We found that only 13% (55 out of 413 respondents) did not have an AC in their residence, but a total of 31.5% (130 out of 413 respondents) reported that they have at least three ACs in their residence. BRPL provided data with the consumer-connected load (kW) and monthly energy consumption (kWh) of the respondents, which was used to help understand the consumption patterns and seasonality of energy use—principally driven by heating and cooling loads.

Examining the ownership distribution of ACs across various consumer classes, we can see that consumers with higher connected loads own more ACs. Twenty percent (83 out of 413 respondents) have at least 5 kW of connected load and at least three ACs in their residences. Table 5 shows how the ownership of ACs varies across connected load ranges.

Table 5. Distribution of ACs Across Various Categories

Number of ACs Owned	Connected Load of Consumers			
	0–2 kW	2–5 kW	More than 5 kW	Total
0	45	9	1	55
1	66	41	7	114
2	34	51	29	114
3 or more	11	36	83	130
Total	**156**	**137**	**120**	**413**

We found that 83% (340 out of 413) of respondents owned a geyser. Out of these, more than 58% (240 out of 413) of respondents used the geyser for more than 15 minutes per day, and about 6% (24 out of 413) of respondents kept their geyser on for more than 60 minutes per day.

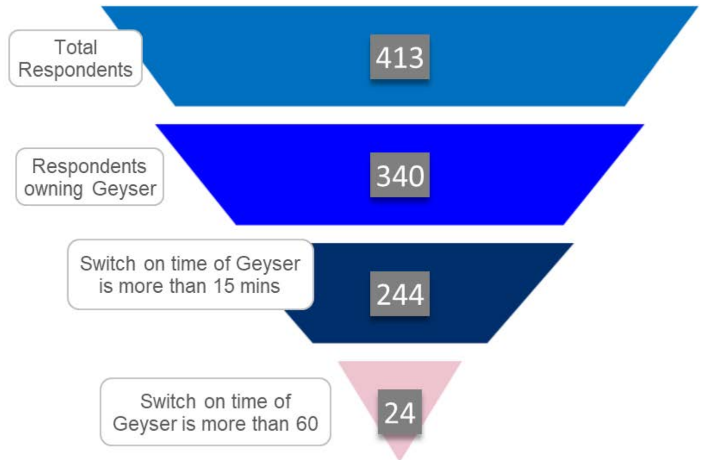


Figure 25. Geyser usage pattern among the respondents

3.1.4 Analysis of Monthly Energy Consumption

The average monthly consumption of the sample set is 368 kWh. In summer months, the average consumption of the respondents may increase by as much as three times the average consumption, primarily driven by cooling demand. Analysis of the collective consumption of the consumers in each connected load category shows that the highest average monthly consumption is up to 2,400 kWh per month for those with 12 kW of connected load in the summer months.

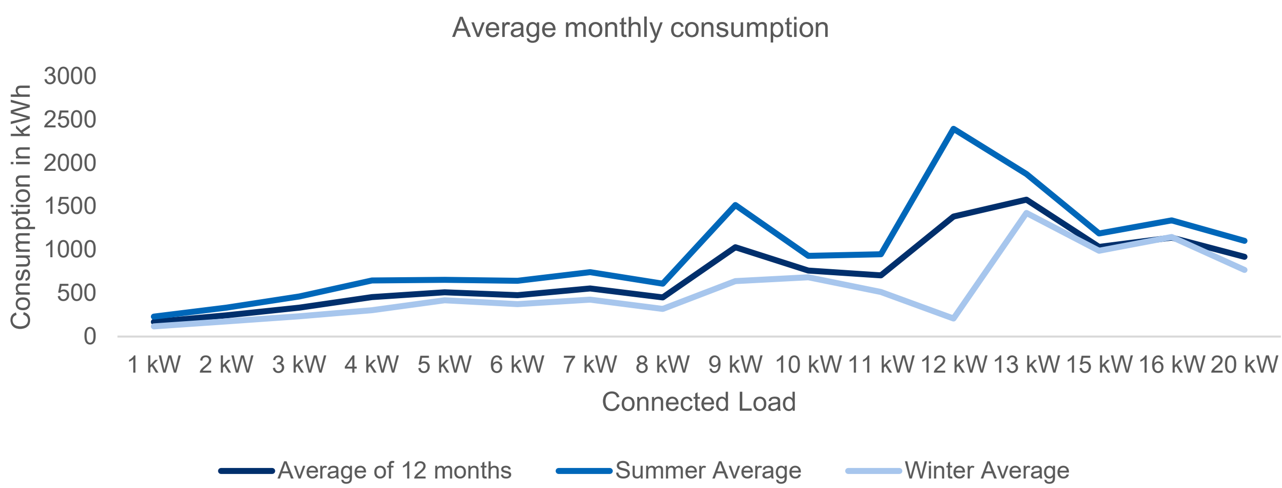


Figure 26. Average monthly consumption of sample

The average monthly consumption by consumers in the 5 kW and below connected load category is up to 570 kWh per month. The following observations are made from the monthly energy consumption data:

a) Maximum monthly consumption can be as high as twice the average monthly consumption in some consumer categories, with maximum consumption occurring during summer months.

b) The consumers with connected load between 1 and 2 kW show similar consumption trends across seasons, possibly due to low penetration/usage of heating and cooling load.

c) Consumers in the 3–5 kW category and higher have seasonal consumption patterns across the year, with maximum energy consumed during the summer months.

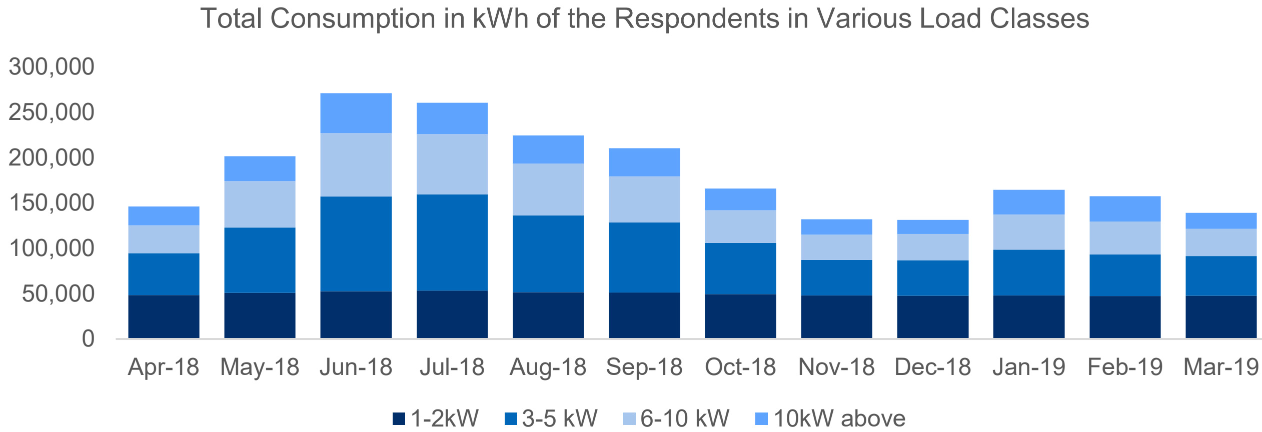


Figure 27. Total energy consumption across the year for surveyed consumers

3.1.5 Consumption Pattern of Consumers

The monthly energy consumption for each consumer was provided by BRPL, and we analyzed the data to understand the individual consumer and collective consumer behavior. We also analyzed seasonal energy consumption patterns, revealing the following:

- Consumers with connected loads up to 7 kW had their peak energy consumption during the summer months driven by cooling loads (such as fans and AC consumption). This can be observed from Figure 28.
- Consumers with a higher connected load were more likely to have dual-peaking seasonal load (with consumption peaks in both summer and winter). The slight increase in average winter energy consumption can be observed in Figure 28 and is due to these consumers.

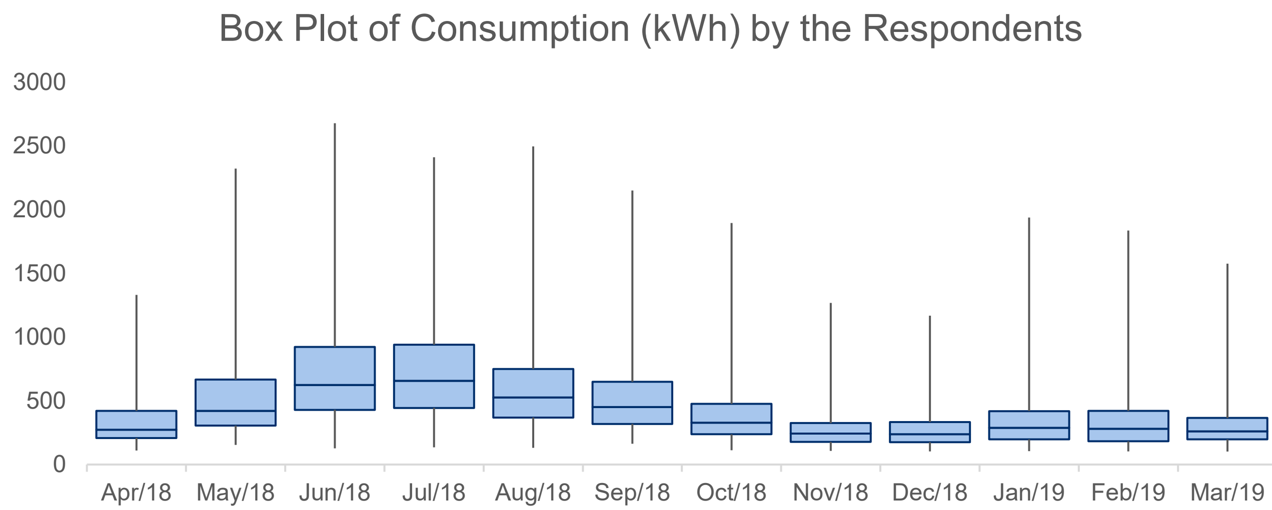


Figure 28. Box plot of domestic consumers' energy consumption per month (kWh)

This figure shows a box plot of consumption data. The upper lines represent the first quartile, and the middle line represents the median of the sample. The bottom line represents the third quartile of the sample. Whiskers are indicative of the maximum and minimum values of the sample.

3.1.6 Estimating the Consumption of AC

From the preceding analysis, it is clear that summer load is a major source of overall electricity consumption. The most seasonal summer-driven load that consumers own is their AC and fan usage. It is estimated that the consumption from these cooling loads drives summer seasonal energy consumption patterns, as can be seen by the spike in consumption during summer months; see Figure 28. To estimate the AC and cooling load, we used a three-step approach to determine the total AC consumption used and its duration of usage. This approach is described in the following steps.

Step 1: Estimating the ACs in the Sample

In this step, the total AC consumption was calculated as a product of ACs per house and number of houses. An assumption of 3.5 as the average of the number of ACs per respondent, where the total ACs owned is "more than 3," was made for this analysis. Using this figure, survey data results show that the total number of ACs in the sample is approximately 797.

Table 6. Total ACs in the Sample

Number of ACs Owned per Respondent	**Total Respondents**	**Total ACs**
1	**114**	**114**
2	**114**	**228**
3.5	130	455
Total	**358**	**797**

Step 2: Types of ACs in the Sample Set

The next step is to segregate the sample of ACs into various configurations based on operating load (1 ton, 1.5 ton), performance (3-star, 5-star), and type of AC (window AC, split AC). Using data from the Bureau of Energy Efficiency, the total number of ACs was split into these categories. With this, the effective load of each AC was calculated as 1.171 kW. Table 7 shows the steps used to arrive at this value.

Table 7. Calculating Load (in kW) of ACs

Metrics	**System Load of ACs in the Sample**[1]			
	Window AC: 3-Star	**Window AC: 5-Star**	**Split AC: 3-Star**	**Split AC: 5-Star**
Average Annual Energy Consumption by 1 Ton (kWh)[2]	**934**	**810**	**717**	**575**
Average Annual Energy Consumption by 1.5 Ton (kWh)[3]	1,275	1,072	1,104	847
Average Operating Power Loading by 1.5 Ton AC, kW	1.06	0.89	0.92	0.71
Average Operating Power Loading by an AC, kW	**0.78**	**0.68**	**0.60**	**0.48**
Window and Split AC Distribution in Sample[4]	15%		85%	
Penetration of ACs as per Star Rating	**70%**	**30%**	**70%**	**30%**
Load by 1-Ton ACs in Sample	89	32	436	143
Load by 1.5-Ton ACs in Sample	**65**	**24**	**284**	**97**
Equivalent Loading of ACs in Sample on Power System (kW)				**1,171**

[1] Share of 3-star and 5-star labelled ACs is considered as 70% and 30%. (Per the meeting minutes of the 11th Technical Committee meeting for room ACs was held on March 19, 2019, at Conference Hall, West Block-2, BEE, the share of 3-star is 65% and of 5-star is 18%; the remaining share belongs to other categories. However, the calculation of a 3-star share is considered as 70% and 5-star share as 30%.) (M. o. Bureau of Energy Efficiency 2019)

[2] Based on annual consumption datasheet available in online retailers in Amazon/Flipkart

[3] Operating hours are derived from Bureau of Energy Efficiency Analysis on Air Conditioner ratings (I. Bureau of Energy Efficiency 2019)

[4] Penetration of window and split ACs is considered as 15% and 30% respectively (Source: Motilal Oswal (Report 2017)).

Step 3: Calculating the Monthly Average Consumption of AC

In this step, the average number of operating hours is calculated for each month based on the inputs provided by the respondents, including months in which ACs are usually in operation and the duration of use. Table 8 summarizes the number of ACs in operation during summers. Most of the ACs are on during May–July, and usage gradually tapers off in September as units stop being used in winter months.

Table 8. Percentage of ACs in Operation

Months	% Of Users Keeping Their ACs in Operation
March	6%
April	34%
May	78%
June	96%
July	80%
August	66%
September	33%

To find the monthly consumption of ACs, an average annual number of operating hours of 1,600 is considered. (This assumption is from Policy Brief, January 2020, TREI & MacArthur Foundation.) These 1,600 hours are then allocated to each month based on the share of consumers using the ACs. Accordingly, we get the Equivalent Full-Load Cooling Hours (EFLCH) of the ACs, as shown in Table 9. Using this value, the total energy consumed by an AC in a month can be estimated. The amount of energy consumed by an AC in a month can vary between 100 and 218 kWh per AC.

Table 9. Estimating Monthly Energy Consumption (kWh) by the ACs for the Summer Months

Month	Monthly Average EFLCH of ACs (hours)	Monthly Average EFLCH of ACs of Samples Connected Load Between 2 kW and 7 kW (hours)	Share of EFLCH of Selected Consumer Class	Energy (kWh) Consumed per Domestic Consumer (2–7 kW) by the AC
May 2018	91	86	95%	100.62
June 2018	169	158	94%	184.86
July 2018	193	187	97%	218.79
Aug. 2018	165	155	94%	181.35

3.1.7 Understanding the Willingness of Domestic Consumers to Participate in DSM Programs

One of the primary objectives of the study was to understand the willingness of domestic consumers to respond and participate in DSM programs. The results show there is a willingness to change consumption patterns and participate in DSM programs; see Figure 29.

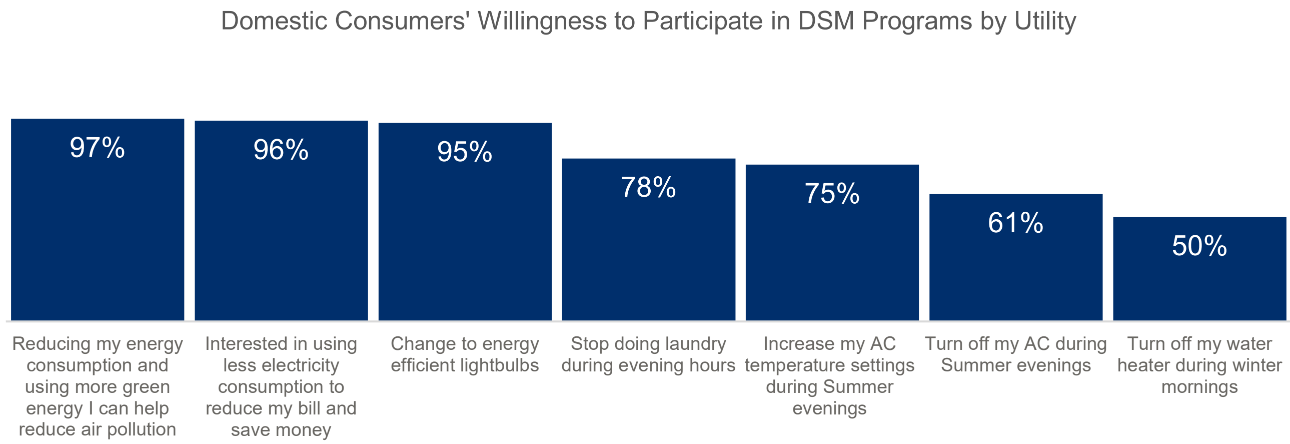


Figure 29. Willingness of consumers to participate in DSM programs

Most consumers are willing to change some element of their appliance usage behavior, in principle, to reduce their energy bills (97%). Consumers are willing to change the way they use electric equipment in their homes. Many consumers are willing to switch to energy efficient bulbs (96%); similarly, they also are willing to stop doing laundry during evening hours (78%). However, this willingness to participate in DSM decreases to 61% when it comes to turning off the AC during summer evenings and turning off the geyser during winter mornings (50%), both of which are major sources of overall energy consumption. These findings indicate that the majority of consumers are willing to participate in some form of DSM.

Another question asked of participants was their willingness to change their energy consumption patterns under a scenario in which there was a 40% reduction in energy charges (rupee/kWh) during off-peak hours. This question was asked to understand how responsive to changes in price consumers may be under a TOU rollout, and the responses are shown in Figure 30.

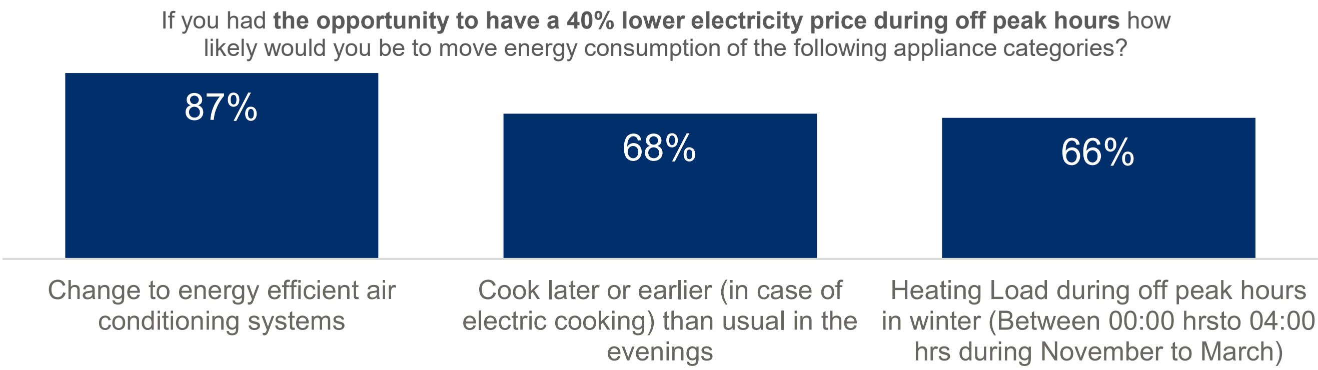


Figure 30. Willingness to change equipment operation during off-peak hours

The results show that consumers are willing to participate in programs that incentivize off-peak energy consumption. Most consumers are willing to switch to energy efficient cooling systems (87%) and to shift cooking times for electric cooking (68%), and about 66% of consumers are willing to shift their room-heating loads to off-peak hours to consume more electricity at lower electricity rates.

Because ACs contribute to a large percentage of overall consumption, a specific question was asked regarding price response for this load category. Consumers responded to a question about the payment amount they would accept from the utility so that they would change their hours of AC usage. The results are shown in Figure 31.

A little over a quarter of consumers would accept a monthly payment of 250–400 rupees as financial motivation to switch off or reduce their AC usage during summer peak hours. Thirty-two percent of the respondents did not indicate that any proposed payment amount (which ranged from 0–400 rupees) was sufficient to induce a change in their usage pattern. Overall, the majority (68%) of consumers are willing to participate in DSM programs, provided they are compensated well for the change in usage pattern.

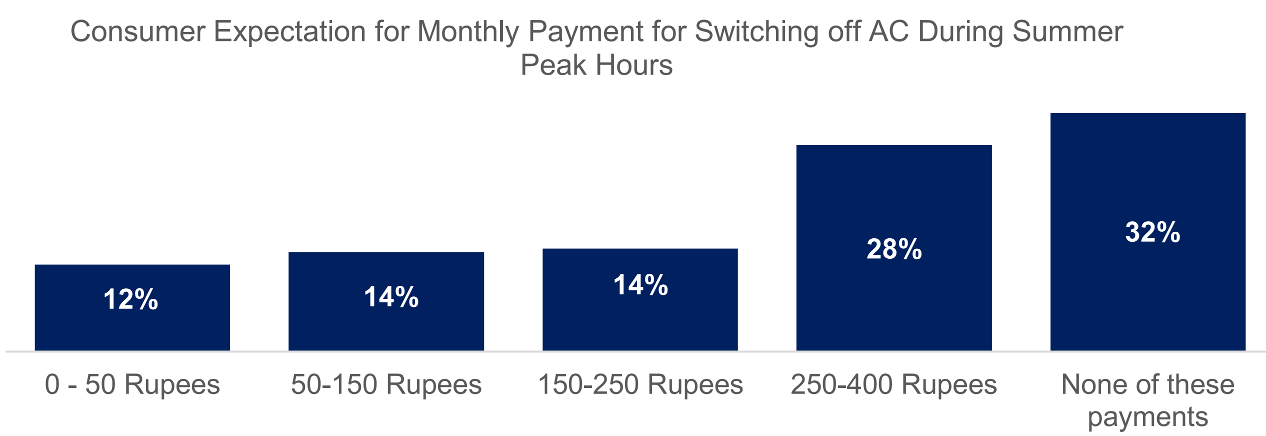


Figure 31. Expected compensation for change in usage pattern

3.1.8 Affinity for New Technologies

The last set of survey questions investigated consumer sentiment for emerging technologies such as solar PV and EVs. Over 60% of consumers have indicated some level of wanting to adopt solar rooftop in the next 10 years. While only four consumers had an EV at home and charged their vehicle on their premises, up to 25% of the consumers replied that they were willing to become an early adopter of EVs.

3.2 C&I Consumer Survey Analysis

The survey for C&I consumers was carried out from August–October 2020 after the survey of domestic consumers. The business activities of these consumers were mainly either manufacturing of goods or providing services. The profile of the respondents is shown in Table 10. The surveyed group was mainly small C&I businesses, with up to 70% of businesses having fewer than 20 employees and 87% of respondents' businesses occupying less than 5,000 square feet.

Table 10. Profile of the Respondents in C&I Survey

<table>
<tr><th>Parameters</th><th>Details</th></tr>
<tr><td>Number of Participants</td><td>318</td></tr>
<tr><td>Major Category</td><td>Small Industrial Power Consumers</td></tr>
<tr><td>Connected Load</td><td>43% had connected load up to 10 kW</td></tr>
<tr><td>Consumer Profiles</td><td>
Most of the respondents were operating from a location about 1,000–5,000 square feet in size, as seen in Figure 32.

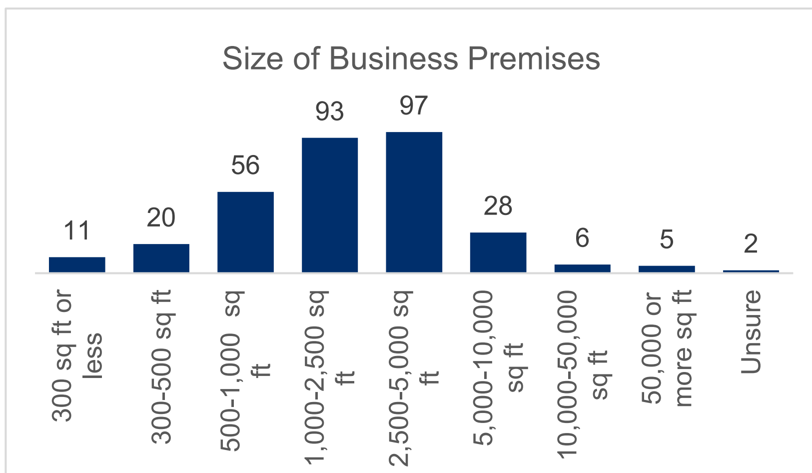


Figure 32. Square feet distribution of survey consumers' premises
</td></tr>
<tr><td>Employees</td><td>70% of the respondents had up to 20 employees.</td></tr>
<tr><td>Ownership</td><td>40% of the respondents were owners of their business.</td></tr>
<tr><td>Operational Hours</td><td>More than 50% of the respondents have a day shift (9 a.m. to 9 p.m. or 9 a.m. to 5 p.m.).</td></tr>
</table>

3.2.1 Consumption Profile

The average monthly consumption of the respondents ranged from 10,000–17,000 kVAh, and the metered data for these consumers was in apparent power (VA), which also considers reactive power (VAR consumption) rather than active power (W). Seasonal variation had some effect on the consumption pattern of the C&I consumers (Figure 33). April–November 2018 recorded an average of 13,000 kVAh or higher, peaking in October, and the consumption fell to less than 12,500 kVAh for the remaining months of the year (December–March).

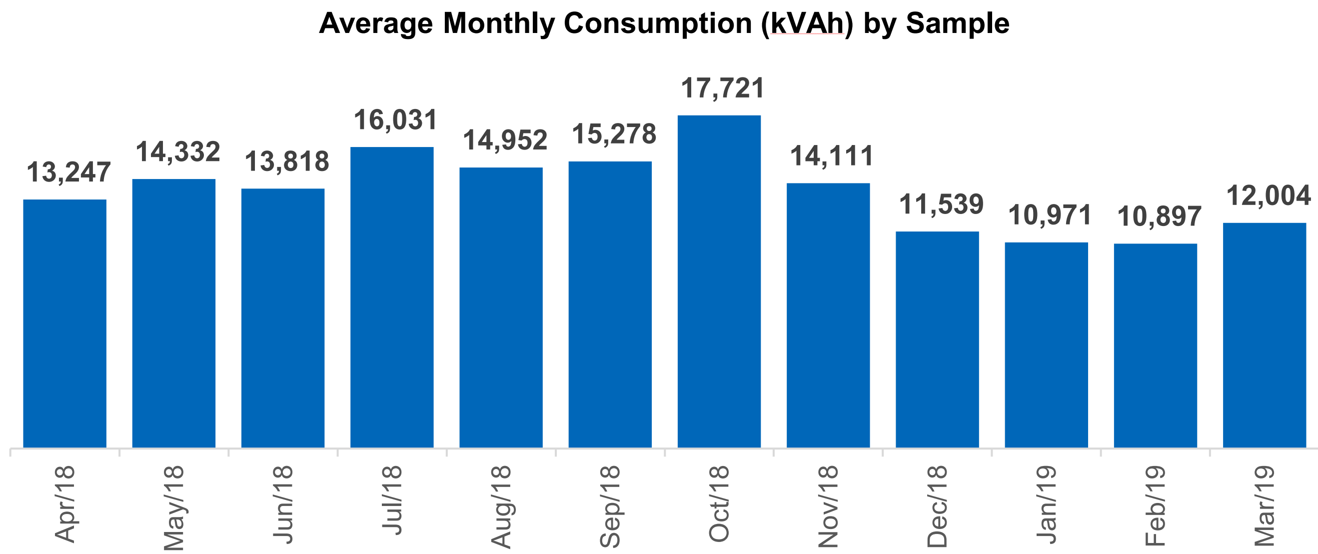


Figure 33. Average monthly consumption by C&I consumers

Consumption Patterns by Connected Load

Irrespective of the connected load, the consumption during the period of May to August is higher than the remaining months, which indicates that cooling load, as with domestic consumers, is a major driver of energy consumption for C&I consumers. Overall electricity consumption is driven by the consumers in the higher load category. Box plots of various load classes of the sample are shown in Figure 33.

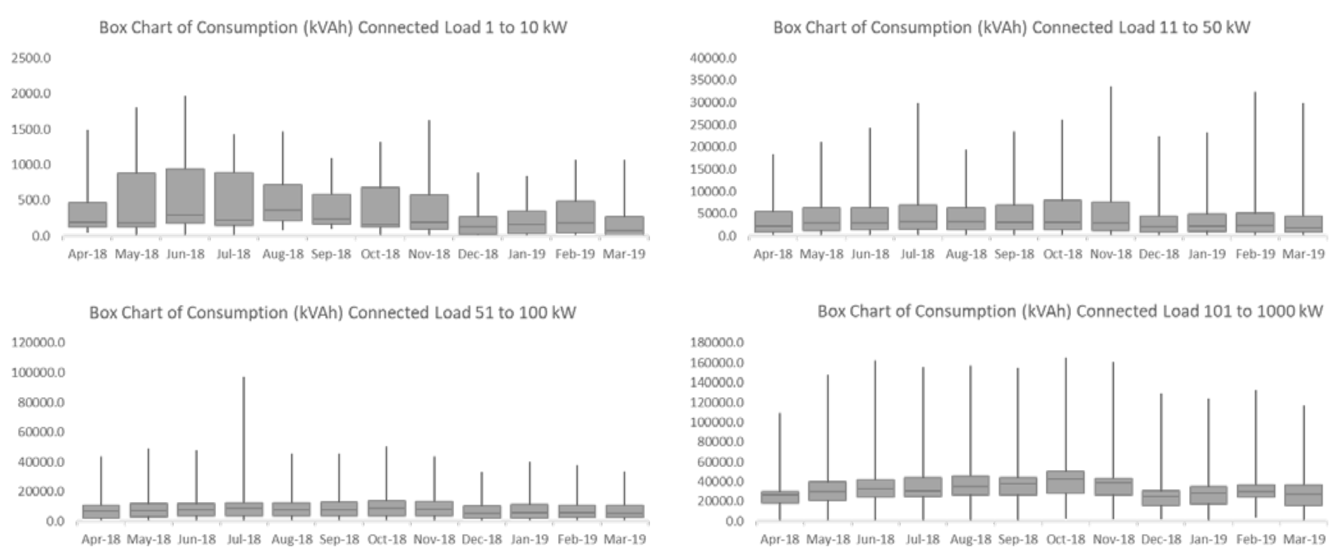


Figure 34. Average monthly consumption (kVAh) of C&I consumers

The following observations can be made:

1. Consumers in the 1–10 kW load category have a strong seasonal consumption pattern, and May–July have the largest consumption levels.

2. Both connected load categories of 11–50 kW and 101–1,000 kW show the average peak consumption in October, as opposed to June and July, which is typical for domestic consumers.

3. In the case of higher load classes 51–100 kW, the seasonal pattern is not as strong, with consumers exhibiting a relatively flat consumption profile.

3.2.2 Equipment Ownership and Usage

About 30% of the respondents had air coolers installed on their premises, whereas almost all respondents had a fan. Most respondents switched on and off the cooling equipment to control temperature as required, rather than adjusting thermostats, which can be seen in Figure 35.

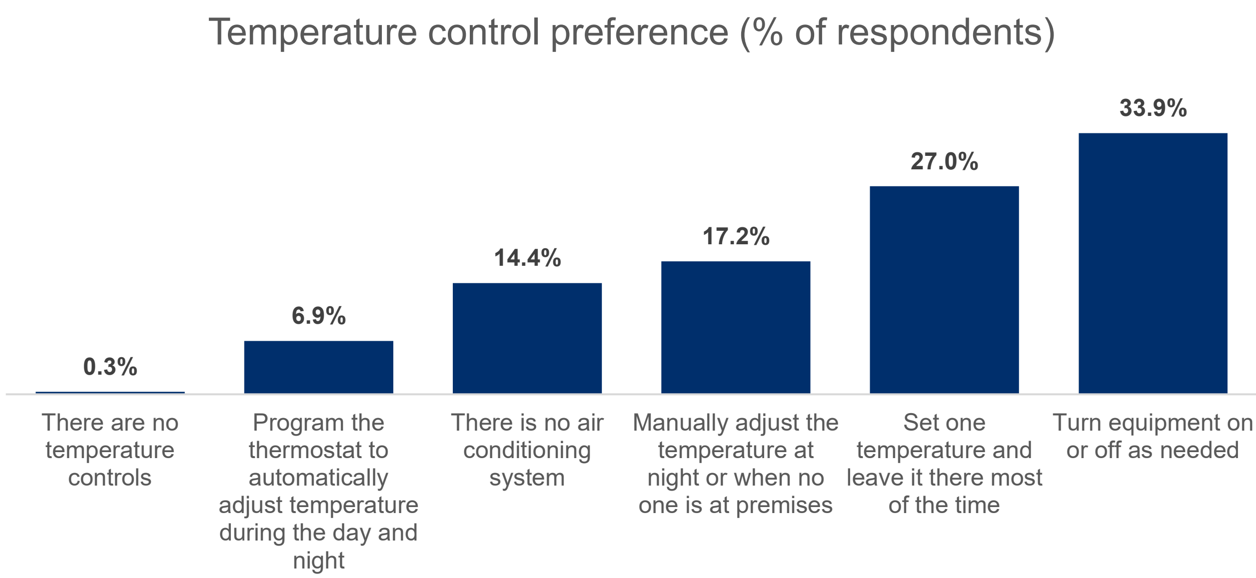


Figure 35. Temperature control preferences of respondents

Some other insights into C&I equipment ownership are:

- Most respondents (68%) reported that they started using their portable cooling/AC equipment in April, whereas less than 5% of respondents reported using cooling all year.
- More than 50% of respondents replied that the preferred range of temperature on the cooling device is 20–24°C. Fewer than 80 respondents used heating solutions on their premises.
- 92% of respondents said that they do not use any heating equipment on their premises.
- Heaters, if owned, are used mostly in November and December.
- Most C&I consumers (69%) had a diesel generator as a form of backup power.
- Only 4% consumers had a solar rooftop plant installed.

3.2.3 Understanding the Willingness of C&I Consumers to Participate in DSM Programs

The survey posed a set of questions intending to capture the sentiment of C&I consumers with respect to energy efficiency and DSM measures and to gauge their awareness on the environmental aspects of energy consumption.

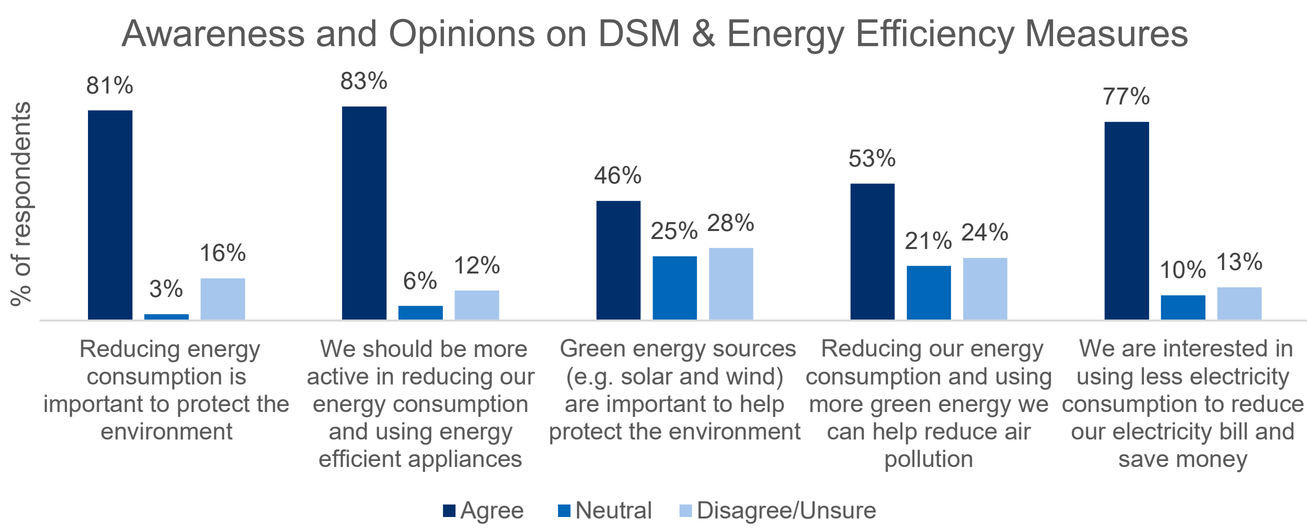


Figure 36. C&I awareness and sentiment toward DSM and energy efficiency

Most C&I consumers surveyed were willing to reduce energy consumption for environmental protection (81%). More than 82% of C&I consumers were willing to be more active in reducing their energy consumption. Similarly, 77% of respondents said that they were interested in using less electricity to reduce their energy bills. However, fewer respondents replied (46%) that green energy sources (e.g., wind and solar) are important to help protect the environment. These opinions do not translate to effective actions, as can be seen Figure 37.

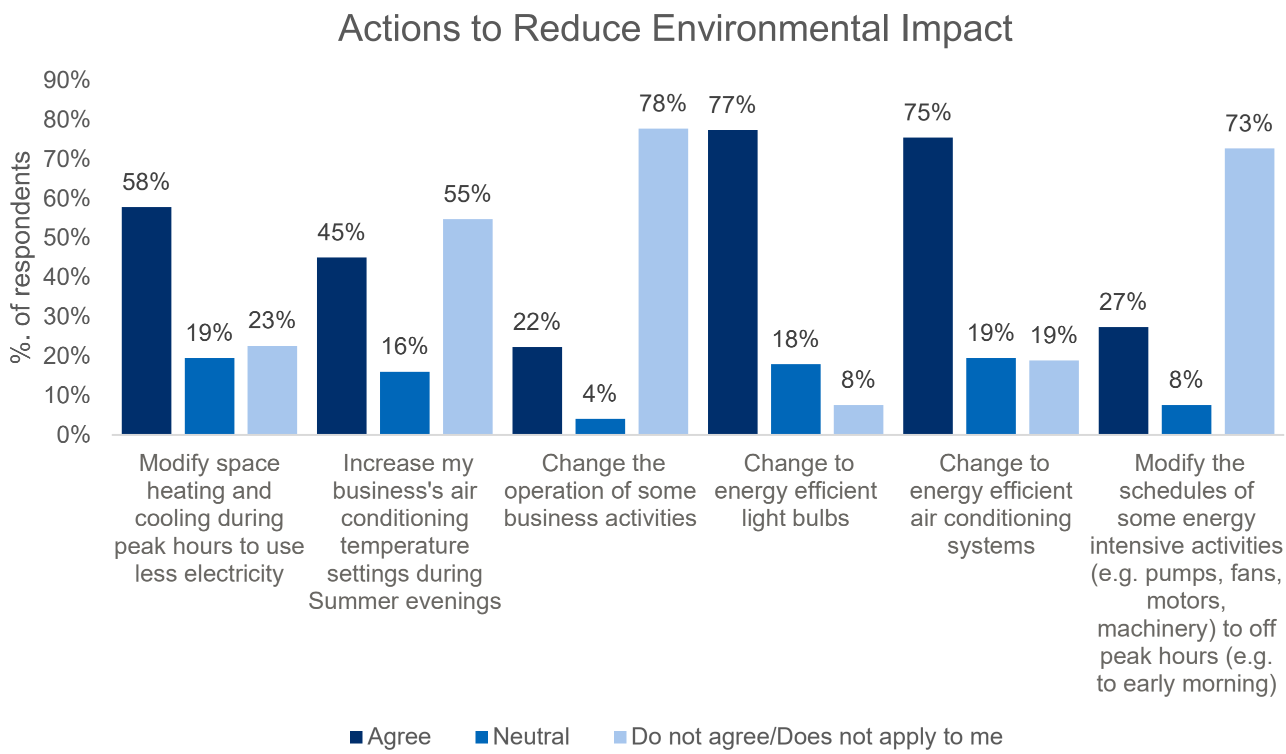


Figure 37. Actions to reduce environmental impact and reduce energy consumption

C&I consumers were not inclined to realign their business working hours to reduce their energy bills. This may be due to the other restrictive factors, including difficulties in facilitating such measures as part of overall business operations. This is seen from the answers to the question: *"If you had the opportunity to have a 40% lower electricity price during* ***off-peak*** *hours how likely would your business be to move energy consumption of the following appliance categories?"* Most respondents indicated that they were not likely to change the operating hours of heating load or cooling load, as shown in Figure 38; however, there is a strong inclination toward greater energy efficiency within this group, again indicating that, while reducing energy consumption is important for this load class, they may find it difficult to change consumption patterns (i.e., assisting in reducing peak demand) without impacting business operations.

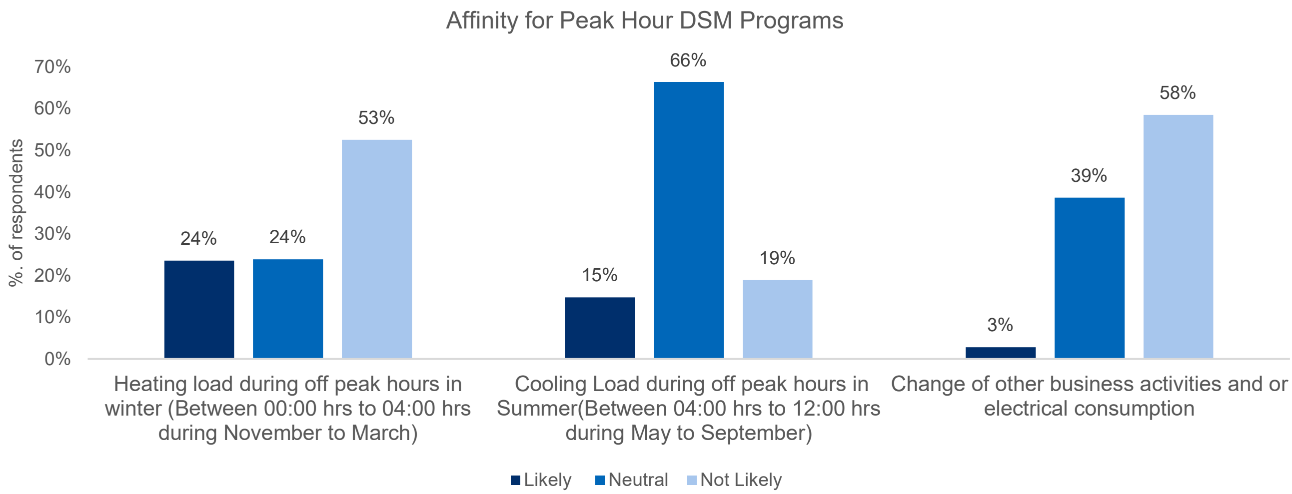


Figure 38. Likelihood of participation in off-peak hour DSM

A low inclination toward energy shifting was observed in the response to the question: "*If the electricity price during peak hours (in between 14:00 and 17:00 and in between 22:00 and 01:00) was 40% more expensive than other hours how likely would you be interested to reduce or move your electricity consumption of the following appliance categories during these peak hours?"* The respondents did not answer affirmatively for changing the operating hours of their heating and cooling loads (Figure 39).

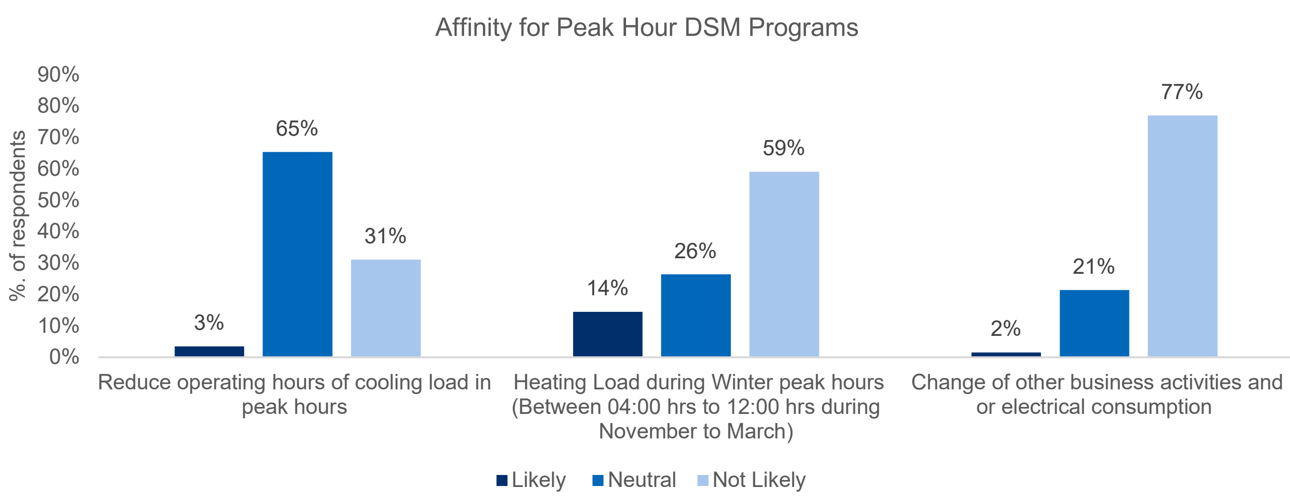


Figure 39. Likelihood of participation in peak-hour DSM

The responses to the previously mentioned questions indicate that C&I consumers are inclined to reduce energy bills through energy efficiency, but generally are not willing to change or are constrained by their business operations. There is a low prevalence of energy management systems on these C&I premises, with 88% of respondents replying that they did not own an energy management system. Rollout of energy management systems for C&I consumers may be a way of unlocking C&I flexibility in energy consumption patterns.

3.3 Notable Mentions From the Consumer Survey

The domestic and C&I consumers responded differently to the offer of participating in utility-sponsored DSM programs. This may be due to fact that the C&I consumers are operational during day shifts, and there are added costs for shifting their business operations to different time slots. While designing a DSM program, the following key points can be considered, as observed in the survey results:

- **Domestic Consumer Findings:**
  - Domestic consumers show high seasonal variation in consumption, mainly driven by cooling loads (ACs) during summer. In summer, the average monthly energy consumption per respondent was about 650 kWh, whereas in winters, this value is about 330 kWh per respondent. Domestic consumers with higher connected loads (>7 kW) can show two peaks of consumption (summer and winter peaks).
  - AC cooling is a prevalent driver of load consumption, with 86.7% of households having ACs. This load drives seasonal consumption, accounting for an estimated half of summer domestic energy consumption.
  - More than 95% of consumers are interested in reducing energy consumption for both environmental reasons and to achieve bill savings. In addition, over 95% of respondents were interested in transitioning to energy efficient lighting.
  - More than 75% of consumers were willing to stop doing laundry during evening hours and increase AC temperature during summer evenings.
  - Sixty-one percent of consumers would turn off their AC during summer evenings, and 50% would turn off the water heater during the morning period.
  - For a 40% reduction in price during peak hours, over 60% of respondents would cook earlier or later and would using heating in the winter during off-peak hours.
  - Sixty-eight percent of consumers expect a monthly payment or savings of less than 400 rupees for switching off AC equipment during the peak period, with 40% of consumers accepting a payment of 250 rupees or less.
  - Sixty percent of consumers indicated some willingness to adopt rooftop solar over the next 10 years, and 25% were willing to become early EV adopters.
- **C&I Consumer Findings:**
  - C&I consumers have higher summer consumption than in winter months (average of June–August consumption was 30% higher than December–February); for the consumers analyzed in this report, their overall peak energy consumption was in October.
  - Thirty percent of respondents have cooling loads on their premises, and 92% have no heating loads on their premises. 69% have backup diesel generators on their premise.
  - More than 80% of consumers are willing to reduce energy consumption to protect the environment and believe they should be more active in using energy efficient appliances, and more than 77% of consumers are interested in energy efficiency to reduce their electricity bill. Over 75% of consumers were interested in changing to more efficient AC systems and energy efficient lighting.
  - Only 58% of consumers are willing to modify cooling use during on-peak hours, and only 22% of consumers are willing to change the operation of some business activities.

4 TOU Pricing Modeling and Analysis: Potential for Consumers And The Utility

TOU pricing structures change the rupee/kWh retail rate according to the time of day and season (utilities also have retail rates depending on type of day, i.e., weekday, weekend/holiday, or critical peak day). High retail rates are applied during peak hours, and low rates are applied during off-peak hours (Comission (CPUC), California Public Utilities). An example of two-tier TOU tariff is shown in Figure 40. There may also be multiple on-peak hours periods (i.e., for a dual peaking system).

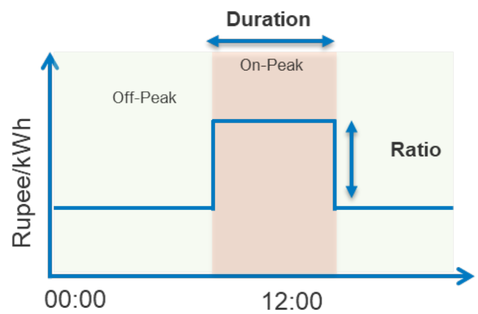


Figure 40. Illustration for two-tier TOU tariff

To effectively design a TOU tariff, it is important to understand how consumers respond to price changes. Like other commercial commodities, electricity demand is inversely proportional to the price. However, electricity demand in one time period may be substituted for demand in another period (i.e., energy shifting) based on price and consumer preference; this is known as cross-elasticity. Electricity demand is also discrete, with consumers having to make on/off decisions based on end-use characteristics and on the duration of demand of certain consumer loads (e.g., washing and drying cycles of laundry white goods). High prices tend to motivate consumers to both lower demand and/or shift demand to other times in a day. There is also a diversity in response as a function of the consumer classes, as not all consumers behave in the same way. Highly responsive consumers tend to change their demand by a greater amount for a given price change. The ratio of percentage demand change over percentage change in price is also referred to as price elasticity of demand. The relation between price and electricity demand for highly responsive consumers has a steeper slope, as shown in Figure 41.

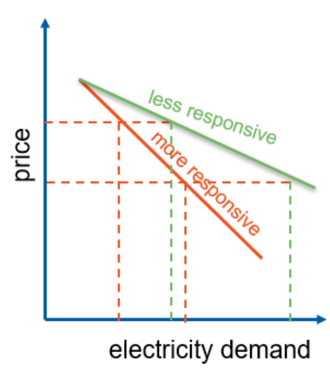


Figure 41. Relation between price and electricity demand

TOU tariffs are designed to incentivize consumers to use more energy during off-peak hours by making the price of electricity cheaper at off-peak hours and expensive during peak hours. This also encourages consumers to shift their electricity demand.

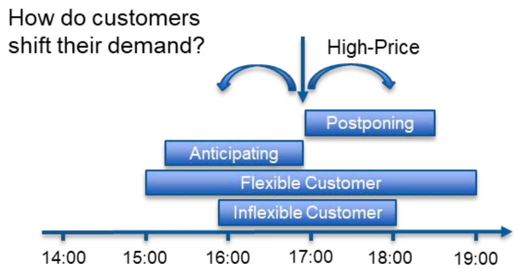


Figure 42. Different types of loads and energy shifting; anticipating and postponing; flexible and inflexible consumers

Consumers response to price changes typically involves two aspects; how much demand consumers will shift and how much demand consumers may forgo/increase (McKenna and Keane 2015). Anticipating consumers will bring forward their demand on time-axis to avoid future high prices. Postponing consumers will delay their demand to avoid high price periods, and some might both postpone and anticipate demand to in response to high price periods. Also, more flexible consumers change their demand over a longer period for a given price change, as shown in Figure 42.

4.1 Technical Terminology

Before we discuss the details of a developed framework, it is important to understand the following terminology.

- **Price elasticity of demand or level of responsiveness:** Ratio of percentage change in electricity demand to percentage change in price. Low, medium, and high elasticity corresponds to 0.2, 0.4, and 0.6 elasticity values (Fan and Hyndman 2011). High levels of responsiveness, or price elasticity, leads to greater demand change. The green curve in Figure 43 is the load response for medium responsive consumers, and the orange line is the load response for low responsive consumers. Notice that demand is reduced during on-peak hours and demand shifted to off-peak hours. The shaded region represents on-peak time for TOU. More about on-peak hours is explained later in this chapter.

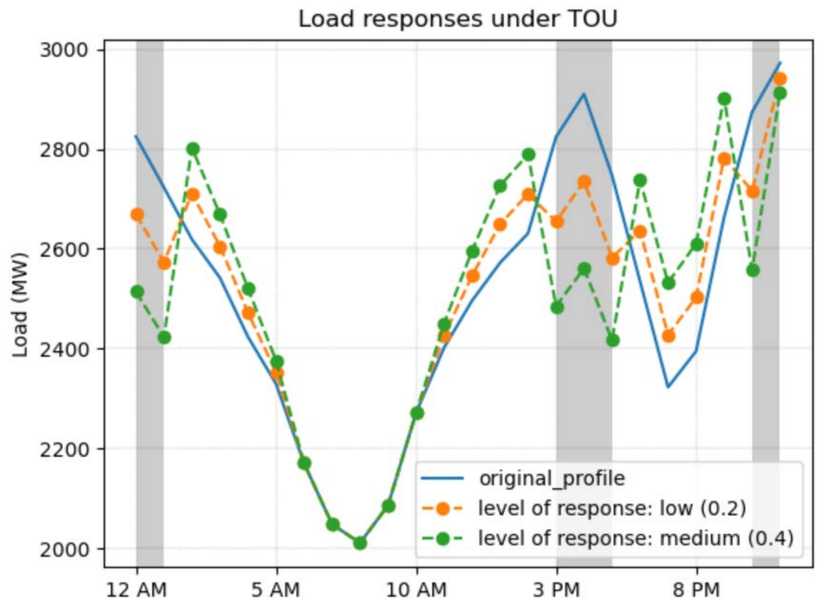


Figure 43. TOU load response for different elasticity magnitudes

- **Response window:** The time over which consumers anticipate or postpone demand is defined as the response window for consumers. "Short", "medium", and "long" windows correspond to 3, 5 and 8 hours, respectively. Figure 44 shows that more flexible consumers (consumers with high response window) will result in more shift in peak demand.

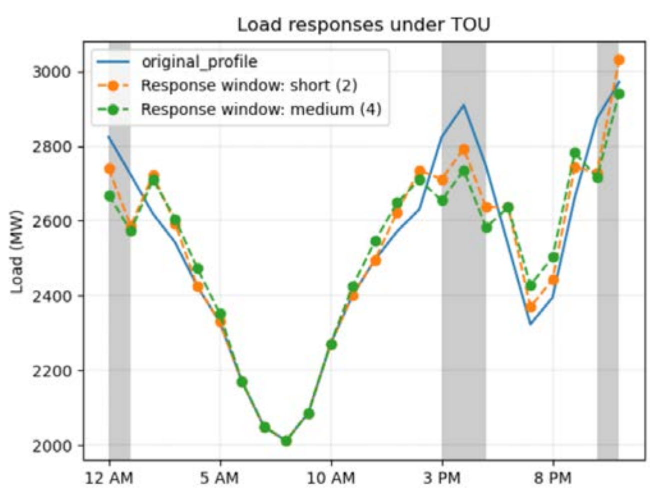


Figure 44. TOU load response for different response window

- Demand shift characteristics across the response window:
    - **Uniform:** The level of responsiveness, or cross-elasticity, is the same across all hours in the response window.

- **Gradient:** The level of responsiveness, or cross-elasticity, changes linearly, decreasing further away from the period in consideration across the response window, i.e., the further out in time for either anticipating or postponing consumers, the lower the likelihood of response.

- **Nonresponsive hours:** Hours in which demand remains unaffected, irrespective of price change.
- **Linear elasticity model:** The level of price responsiveness (i.e., price elasticity) is constant with respect to different initial demand and retail prices.
- **Lossless model:** Total energy consumption remains the same before and after implementing a TOU tariff, so all change in consumption is due to energy shifting.

4.2 Design of TOU Tariff—Analysis and Optimization

The design of TOU tariffs should present optimal solutions for the seasons, on- and off-peak hours, and on- and off-peak prices to best reduce peak demand and reduce overall utility and consumer costs. For example, in a two-tier TOU, it would mean finding hours as well as prices for the on-peak and off-peak periods. A combination of analysis and optimization are used to find the optimal design of the TOU. This is done in two steps:

- **Analysis:** The TOU seasons and on- and off-peak times are determined through peak load analysis of BRPL's system load profiles. The percentage of peak hours to be targeted determines the duration and times of the on-peak period, and these are then used in the second step.
- **Optimization:** Once the seasons and on-peak hours have been determined, an optimization model with an aggregate price responsiveness and basic generator dispatch model is used to determine the on- and off-peak prices.

The proposed optimization framework requires a price elasticity matrix to be provided as input. This contains information on the self-elasticity in each hour and cross-elasticity across hours and is a TxT matrix where T is the number of time-steps. Price elasticity is defined as the ratio of percentage change in demand to the percentage change in price as given by Equation (1).

$$E = \frac{\Delta l / l_o}{\Delta p / p_o} \quad \textbf{(1)}$$

Here $E, \Delta l, \Delta p, L_0, P_0$ represent elasticity, change in load, change in price, base load or equilibrium load, and base price or equilibrium price, respectively. It is important to note that the price elasticity of electricity demand changes throughout the day. Change in electricity demand at hour i because of change in electricity price at the same hour is called self-elasticity and will be designated by symbol $E_{i,i}$ in this report. A price change at hour i also affects electricity consumption of a consumer at other hours. Change in electricity demand at hour j because of change in electricity price at hour i is called cross-elasticity and will be designated by symbol $E_{j,i}$ in this report.

Now for 24 hours in a day, price elasticity of electricity demand can be represented by a 24×24 matrix as shown in Equation (2). The diagonal elements in this matrix represent self-elasticities and the off-diagonal elements represent cross-elasticities.

$$PEM = \begin{pmatrix} E_{1,1} & \cdots & E_{1,24} \\ \vdots & \ddots & \vdots \\ E_{24,1} & \cdots & E_{24,24} \end{pmatrix} \quad \textbf{(2)}$$

The total change in load at hour i can then be computed using Equation (3).

$$\Delta L_i = \sum_{j=1}^{24} E_{i,j} \times \frac{P_j - P_0}{P_0} \times L_i \tag{3}$$

4.2.1 Price Elasticity Matrix

A price elasticity matrix (PEM) is a matrix of price elasticity values. Diagonal elements in this matrix represent self-elasticity, which relates to change in demand because of price changes in the same hour.

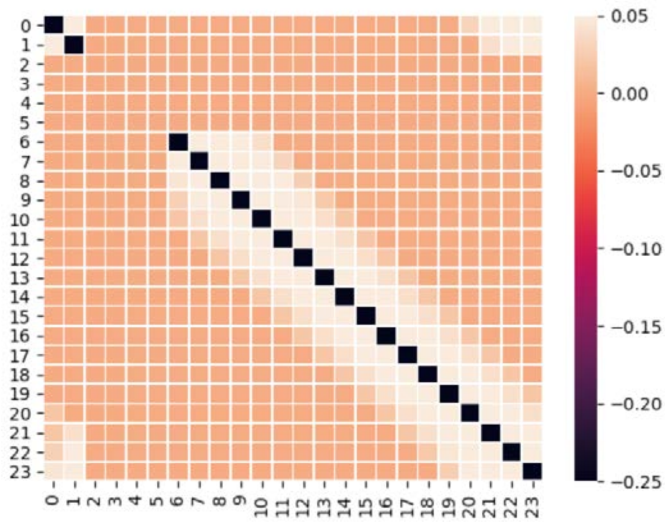


Figure 45. Illustration for price elasticity matrix

Self-elasticity takes negative values, indicating an inverse relation between price and change in demand. An off-diagonal element represents cross-elasticities which relate to change in demand at other hours because of price change in given hour. Table 13 shows a heatmap of the price elasticity matrix of a day, where 0–23 represents 24 hours of a day with 0 being midnight and 23 being 11 p.m. Notice the self-elasticity values for hours 2, 3, 4, and 5 are zero, indicating they are non-responsive hours. The cross-elasticity magnitudes follow a linear gradient distribution in each column.

4.2.2 Optimization Model

The optimization is formulated with the elasticity model of BRPL's consumers as an aggregate model using a PEM. The objective function of TOU tariff optimization is to minimize the cost of electricity generation and of capacity upgrade cost. The electricity cost is attributed to non-renewable energy purchases, as renewable energy is must-run, so we examine the net load that conventional generation must meet. BRPL provided incremental generation costs (rupee/MWh) of 22 dispatchable generators that are used to meet non-renewable energy demand. The monthly average cost of energy purchase for each generating plant is used to compute cost. The network avoidance cost per MW as estimated by BRPL (Rs 2 crore/MW) is used to compute capacity upgrade costs. Equation (4) summarizes the objective function used.

$$Minimize \sum_{g=1}^{22} \sum_{t=0}^{T} G_{g,t} \times \boldsymbol{\lambda_{g,t}} + Z \times \boldsymbol{\lambda_{NX}} \tag{4}$$

Here $g, t, G_{g,t}, \lambda_{g,t}, \lambda_{NX}, Z, T$ represent generator index, time index, output of generator g(in MW) at time t, energy purchase price of generator g at time t (Rs/MWh), network avoidance cost (Rs/MW), new peak load (in MW), and total time duration for optimization, respectively. The following constraints are included in the optimization formulation. Note $G_{g,t}$ and Z are optimization variables.

- The new load at time t is affected by the price elasticity matrix, on-peak price, and off-peak price. If p_{on} and p_{off} are on-peak and off-peak prices that we intend to find after solving optimization, new load at time t can be computed as:

$$\Delta L_t = \sum_{k=t-12}^{t+11} \boldsymbol{E}_{(\boldsymbol{t\%24}),(\boldsymbol{k\%24})} \frac{p_{off} \times \boldsymbol{B_{k,off}} + p_{on} \times \boldsymbol{B_{k,on}}}{\boldsymbol{P_0}} \times L_t \tag{5}$$

  Here $p_{off} \times \boldsymbol{B_{k,off}} + p_{on} \times \boldsymbol{B_{k,on}}$represents price at time k. $B_{k,off}, B_{k,on}$ are binary quantities representing whether time k belongs to on-peak or off-peak time. If time k belongs to on-peak time then $B_{k,on} = 1$ and $B_{k,off} = 0$. As we have prior knowledge of on-peak and off-peak time, B_{on} and B_{off} are predefined parameters for all time periods. Also, there are three expressions for computing change in load at time t. More details regarding computation of change in load because of the price elasticity matrix are described in Appendix A.

- The new peak load Z must be greater than or equal to all other loads.

$$Z > \boldsymbol{L_t} + \Delta L_t \ \forall t \tag{6}$$

- The on-peak price must be greater than or equal to the off-peak price.

$$p_{on} > p_{off} \tag{7}$$

- The sum of all generator output must always be equal to the new load.

$$\sum_{g=1}^{22} G_{g,t} = \boldsymbol{L_t} + \Delta L_t \quad \forall t \tag{8}$$

- Generator output must not exceed contracted capacity.

$$G_{g,t} \leq \boldsymbol{G_g^c} \quad \forall t, \forall g \tag{9}$$

  Here $\boldsymbol{G_g^c}$represents contracted capacity for generator g.

- The total of consumers' payments is assumed to be equal to energy purchase and capacity upgrade cost.

$$\sum_{t=0}^{T} (\boldsymbol{L_t} + \Delta L_t) \times (p_{on} \times \boldsymbol{B_{t,on}} + p_{off} \times \boldsymbol{B_{t,off}}) = \sum_{g=1}^{22} \sum_{t=0}^{T} G_{g,t} \times \boldsymbol{\lambda_{g,t}} + Z \times \boldsymbol{\lambda_{NX}} \tag{10}$$

4.2.3 Seasons and On-Peak Hour Design

BRPL system load data is used to analyze peak hours and seasonality. The load profiles are divided into summer and winter seasons by looking at consumption pattern and peak hours. Summer months have peak load at night and in late afternoon periods, whereas winter months have peak load during morning. Specifically, months from April to October fall in summer, and months from November to March fall in winter. The optimization problem is solved for each season separately.

To design a TOU tariff, we first need to pick on-peak times from the load profile. These on-peak hours are then fed to optimization to find optimal on-peak and off-peak prices. The process for on-peak hour selection is depicted in Figure 46. Time series load profile for a day is shown in red, and corresponding load duration curve is shown in green. For 20% of load hours of the day, on-peak hours are shown by a shaded region (19:00–22:00). Now depending on the percentage of load hours to be targeted we pick on-peak hours. This is done separately for summer and winter seasons because the peak falls in different hours.

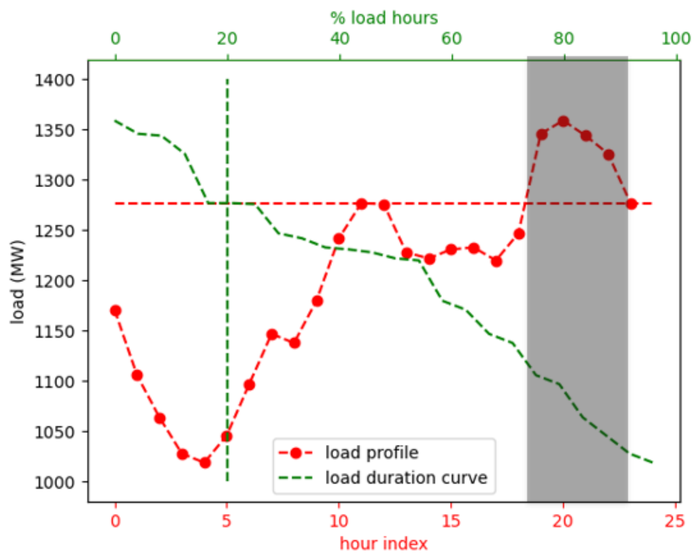


Figure 46. Time series load profile and how to choose on-peak hours

A target of the top 1% of load hours was used to choose on-peak hours for both summer and winter. This yields two on-peak periods for summer months (15:00–17:00 and 22:00–00:00) and one on-peak period for winter months (09:00–12:00). These on-peak hours are used as input to find the on-peak and off-peak prices for both seasons.

4.3 Optimization Results

The optimization was run separately for summer and winter season and was run across multiple elasticity and price responsiveness windows in order to get a sweep of sensitivities. The results show potential annual peak reduction in the order of 2% (annual peak occurs in summer) for high price elasticity (self-elasticity magnitude of -0.6) and medium consumer response window (5-hour window). The annual load duration curve for the top 5% of load hours with and without TOU is shown in Figure 47.

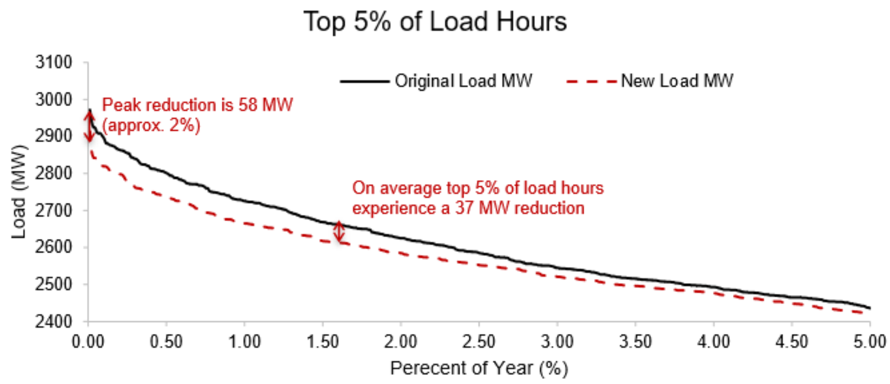


Figure 47. Annual load duration curve before and after TOU (only 5% of load hours shown)

The annual peak occurred on July 9, 2018, at 11 p.m., before TOU and occurred at the same time even after TOU but with a reduced magnitude. The hourly load profile before and after TOU for the peak day of the year is shown in Figure 48. Notice that load has been shifted from on-peak hours to adjacent off-peak hours because of TOU. Similarly, Figure 49 shows hourly load profile before and after TOU for the peak day of winter.

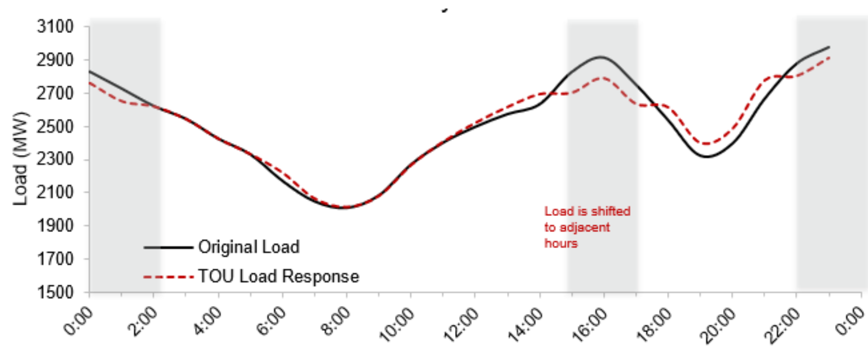


Figure 48. Hourly load profile for peak day (July 9, 2018) before and after TOU

The peak for winter occurred on January 4 at 11 a.m. before TOU. The peak time remained unchanged after TOU, but its magnitude was reduced from 1823 MW to 1753 MW.

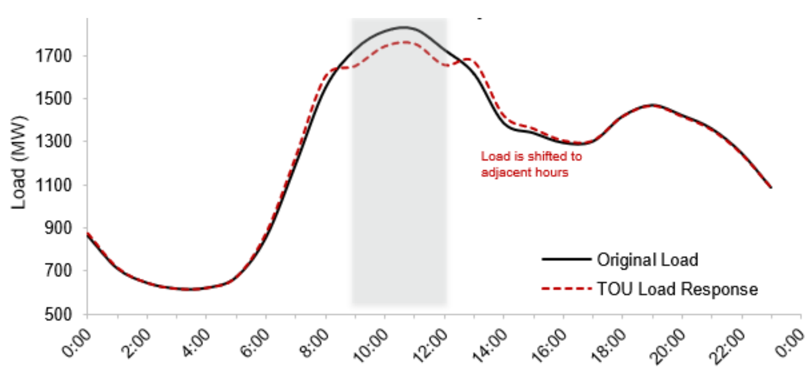


Figure 49. Hourly load profile for peak day for winter (January 4, 2019) before and after TOU

The optimization results for summer and winter seasons are summarized in Table 11.

Table 11: Summary of Optimization Results for Summer and Winter Seasons

Metric	Summer (Apr.–Oct.)	Winter (Nov. –Mar.)
Peak Reduction	2%	3.8%
On-peak to off-peak price ratio excluding fixed costs	1.28	1.36
Savings	1.24%	2.5%
On-peak hours	15:00–17:00 and22:00–01:00	9:00–12:00

The percentage saving is higher is winter than in summer because of higher peak reduction magnitude. The results shown in Table 11 are for high price elasticity and a medium response window. A sensitivity analysis across different consumer responsiveness levels was conducted. Table 12 shows on-peak to off-peak price ratios for different levels of price elasticity and the response window for both summer and winter seasons.

Table 12. On-Peak to Off-Peak Price Ratio for Different Price Elasticities and Consumer Response Window in Both Summer and Winter Seasons

Price elasticity/ Response Window	**Summer**			**Winter**		
	High (0.6)	**Medium (0.4)**	**Low (0.2)**	**High (0.6)**	**Medium (0.4)**	**Low (0.2)**
High (7 hours)	1.27	1.43	2.01	1.34	1.55	2.28
Medium (5 hours)	1.28	1.46	2.09	1.36	1.58	2.33
Low (3 hours)	1.32	1.51	2.22	1.5	1.78	2.85

The change in on-peak to off-peak price ratio is less for a large response window. This means that to achieve a similar TOU impact (such as savings and peak reduction), consumers with a high response window require a smaller change in price between on-peak and off-peak times, while for consumers with a low response window, the on-peak to off-peak price needs to be higher. Table 13 shows percentage peak reduction for different levels of price elasticity and response window for both summer and winter.

Table 13. Percentage Peak Reduction for Various Levels of Price Elasticities and Response Window in Both Summer and Winter Seasons

	Summer			**Winter**		
Price elasticity I **Response Window**	*High (0.6)*	*Medium (0.4)*	*Low (0.2)*	*High (0.6)*	*Medium (0.4)*	*Low (0.2)*
High (7 hours)	2.2%	2.24%	2.27%	3.94%	3.93%	3.92%
Medium (5 hours)	1.96%	1.98%	2.01%	3.84%	3.8%	3.76%
Low (3 hours)	0.782%	0.78%	0.76%	3.19%	3.15%	3.12%

4.4 TOU Challenges and Opportunities to Deployment

There are several challenges and opportunities to deployment of TOU. These should be investigated in order to enable and enhance TOU deployment:

- **Use of information:** Utility pamphlets and literature have been shown to increase consumer response levels. Utilities should educate consumers on the structure of TOU, such as seasonality, billing, and on- and off-peak hours. Information should also educate consumers on the means to respond to TOU tariffs such as changing energy consumption patterns and using energy efficient and smart appliances (Regulation 2011).

- **Consumer ability to respond:** Utilities should help ensure that consumers have the ability to respond. This could be achieved by partnering with manufacturers of smart appliances and helping educate consumers that smart appliances are available and how to best utilize them. The use of devices such as smart thermostats and controllable loads will enhance the ability of consumers to respond to price signals.

- **Need for digital meters:** Digital meters will be needed to calculate energy consumption across on- and off-peak hours. These meters could bring other utility benefits such as making the billing process more efficient, giving more insight into load profiles and end-use, and greater visibility to the grid-edge.

4.5 TOU Rate for Different Categories of Consumers

The analysis in this section of the report has demonstrated the potential opportunities for introducing TOU tariffs for domestic consumers. Currently in BRPL's service territory a slab rate (also known as an incremental block rate/stepped tariff) is available for domestic consumers. TOU tariffs are also available to C&I consumers; see section 1.2 and Table 1. The analysis in this section shows a tariff with two on-peak periods for the summer season (April–October) and one on-peak period for winter (09:00–12:00) will help target the top 5% of peak load hours, giving an average of a 37 MW reduction across these hours; see Table 14. Currently BRPL operates an on-peak period for non-domestic and industrial consumers year-round. Moving towards seasonal on-peak times will allow specific targeting of peak demand hours as seasonal consumption patterns change. BRPL's peak demand occurs in summer months, and winter has much lower demand. Given this, BRPL could avoid using any on-peak hours during winter months, however, the relative magnitude of peak demand to other hours is still high (see Figure 17), and winter on-peak period prices and hours may help reduce peak demand and avoid the use of expensive peaking generation. BRPL has the potential to reduce summer peak demand by 2% (58 MW) and winter peak demand by 3.8% (70 MW).

The need to install digital meters, ensuring consumers have the information and technology to respond to on-peak prices, will be both a challenge and an opportunity. Smaller scale tariff trials (on the order of hundreds of consumers) have been shown to provide useful information on the price responsiveness of consumers, allowing the utility to trial multiple on- to off-peak price ratios. BRPL could also consider tariff structures to help deal with challenges from EV charging, increased penetration of rooftop solar, and BTM battery energy storage; see 1.1.1.

5 Conclusions

This report presented the results from a detailed evaluation of the potential for DSM for BRPL and their consumers. The results included analysis of BRPL's system and consumer load data, surveying of domestic and C&I consumers, and modeling and optimization analysis that demonstrated the potential of TOU price plans. This work was a collaboration between the Greening the Grid RISE team, BRPL, and NREL. The study shows that BRPL could benefit from rolling out TOU tariffs to their domestic consumers which could deliver a reduction in system peak demand.

As part of this effort BRPL delivered extensive system and distribution transformer load data to NREL which was used to analyze aggregate, domestic, and non-domestic consumer load profiles. NREL created multilinear regression models that BRPL could use for forecasting system load and established relationships between environmental variables (such as day of the week and temperature) and system load. BRPL could expand the tool and use it for short-term and long-term load forecasting. NREL used the tool to examine the key variables that drive BRPL system load and perform peak load analysis.

Domestic consumers in BRPL's service territory account for approximately 87% of the overall consumer base and 67% of annual energy consumption, whereas C&I consumers account for 13% of consumers and 31% of annual energy consumption. These two consumer groups were targeted with detailed survey questions detailing their socioeconomic and energy consumption characteristics and their willingness to participate in DSM programs. A total of 413 domestic consumers answered over 90 questions over the period from June to July 2020. For C&I consumers 318 consumers answered over 60 questions from July to October 2020. The results gave detailed insight into energy consumption patterns, willingness to participate in DSM, and attitudes towards sustainability and emerging demand-side technologies and distributed energy resources such as EVs and solar PV.

Domestic consumers showed a strong willingness to participate in DSM, with over 95% willing to reduce energy consumption and use more green energy, interested in achieving bill savings by reducing consumption, and willing to change to energy efficient light bulbs. Over 75% were willing to stop doing laundry during evening peak hours and increase AC temperature settings to reduce peak consumption. Only 60% were willing to turn off AC devices during peak hours, and half were willing to turn off water heaters during winter mornings. Overall, these statistics show a strong willingness of domestic consumers to participate in DSM measures. C&I consumers were more unwilling to participate in DSM schemes; for example, 77% of respondents said they were not likely to change business activities or energy consumption patterns, likely because end-use is necessary for business operations.

As part of this project NREL developed the EFFORT tool for assessing and optimizing TOU rate structures. The tool examined a range of consumer responses and helped find the most effective hours and price ratios to get the best response from consumers given their price responsiveness. The developed tool can be used by BRPL to run sensitivity analysis for different consumer types and examine the best TOU structure to maximize peak reduction. The analysis showed that BRPL has the potential to reduce summer peak demand by 2% (58 MW) and winter peak demand by 3.8% (70 MW).

6 Notable Outcomes of This Study

This study led to numerous interesting findings. This chapter summarizes the modeling, simulations, and analyses of selected outcomes. Some findings are specific to the evaluation of battery energy storage systems and EVs, and some outcomes are generic policy suggestions. The following sections summarize six outcomes. References to chapters and subsections are included for more detail.

6.1 BRPL Has Dual Peaking Summer Demand

The largest load sector in BRPL's service territory is driven by domestic consumers and peaks during the summer. Domestic consumers account for approximately 87% of BRPL's overall consumers and 67% of annual energy consumption. BRPL's summer demand is dual peaking (afternoon 15:00–17:00 and late evening 22:00–01:00) and is principally driven by heating, ventilation, and air conditioning (HVAC) consumption. This summer peak load results in inefficiencies for BRPL and their consumers, with 1% of the peak load network and generation capacity (approximately 30 MW) only required less than 0.01% (less than 1 hour) of the year. Reducing peak demand could bring energy and capacity savings, and BRPL estimates annual energy savings of Rs 2 crore per MW peak load reduction. Targeting domestic consumer usage of HVAC energy consumption will help BRPL alleviate and shift peak demand.

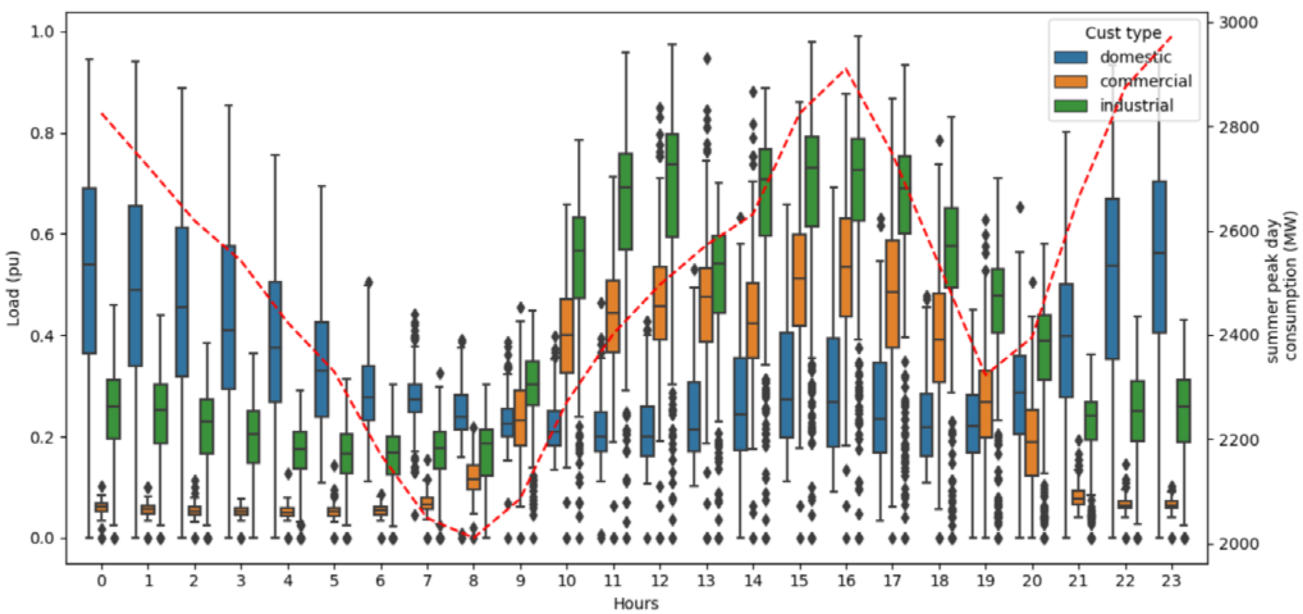


Figure 50. Box plot of summer load by consumer category for three consumer groups

6.2 Domestic Consumers Are Willing to Participate in DR

The survey results show that domestic consumers are willing to participate in DR measures, with greater than 75% of consumers willing to stop doing laundry during evening hours and increase their AC temperature during summer evenings. In addition, under a DSM program, 61% of consumers indicated their willingness to turn off their AC during summer evenings and 50% would turn off water heaters during the morning period. Consumers are also driven towards achieving energy efficiency, with more than 95% of consumers interested in reducing energy consumption for environmental reasons and to achieve bill savings. In addition, over 95% of respondents were interested in transitioning to energy efficient lighting. Regarding motivating consumers financially to achieve demand response, the survey shows that for a 40% reduction in price during peak hours, 60% of consumers responded that they would cook earlier or later and would use heating in the winter during off-peak hours. For minimum monthly payment or savings of less than 400 rupees, 68% of consumers indicated they would be willing to switch off AC equipment during the peak period, with 40% of consumers willing to accept a minimum monthly payment of 250 rupees or less. AC cooling is a prevalent driver of load consumption, with 86.7% of households having ACs present and this load driving seasonal consumption and overall peak demand.

6.3 C&I Consumers Are More Willing to Participate in Energy Efficiency Than in Demand Response

The survey results show that C&I consumers were more willing to participate in energy efficiency than in demand response. C&I consumers have higher summer consumption than winter (average of June to August consumption was 30% higher than December to February); among the consumers analyzed in this report overall peak energy consumption was in October. With regard to load consumption, 30% of respondents have cooling loads on their premises, and 92% have no heating loads on their premises. With respect to onsite generation, 69% have backup diesel generators on their premises, which could indicate that these consumers may be able to participate in some emergency load shedding program. More than 80% of consumers are willing to reduce energy consumption to protect the environment and believe they should be more active in using energy efficient appliances, and more than 77% of consumers are interested in energy efficiency to reduce their electricity bill. Over 75% of consumers were interested in changing to more efficient AC systems and energy efficient lighting. However, only 58% of consumers were willing to modify cooling use during on-peak hours, and only 22% of consumers were willing to change the operation of some business activities.

6.4 TOU Has the Potential to Reduce Peak Demand

TOU has the potential to reduce BRPL peak demand. There are two distinct load consumption pattern seasons for summer and winter. Creating a tariff with two on-peak periods for the summer season (April–October) and one on-peak period for winter (09:00–12:00) will help target the top 5% of peak load hours (as seen in Figure 51 and Table 48 in Appendix C), giving an average of a 37 MW reduction across these hours; see Table 14. BRPL has the potential to reduce summer peak demand by 2% (58 MW) and winter peak demand by 3.8% (70 MW). BRPL currently has a TOU tariff structure for their non-domestic consumers. However, domestic consumers drive peak demand, and more specifically demand from domestic HVAC consumption. Targeted campaigns on domestic HVAC consumption and the rollout of smart appliances, e.g., smart thermostats, may help specifically target the driver of BRPL peak demand.

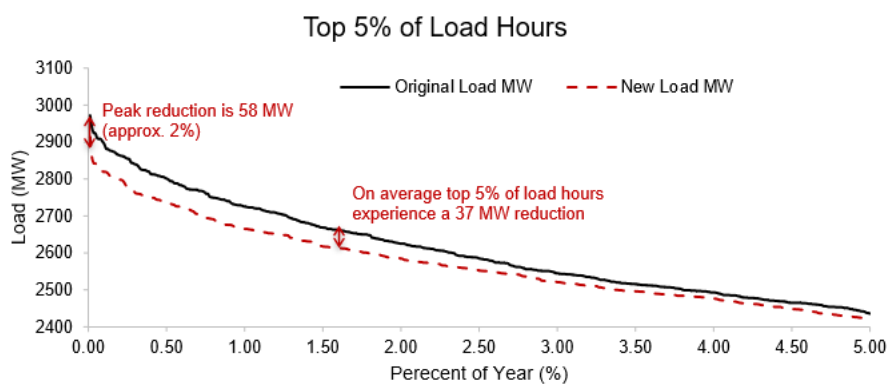


Figure 51. Annual load duration curve before and after TOU (only 5% of load hours shown)

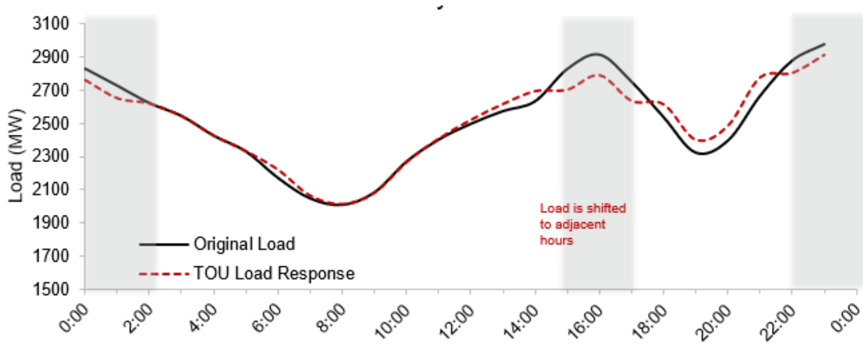


Figure 52. Hourly load profile for peak day (July 9, 2018) before and after TOU

Table 14. Summary of TOU Results and Analysis for Summer and Winter Seasons

Metric	**Summer (Apr. –Oct.)**	**Winter (Nov. –Mar.)**
Peak Reduction	2%	3.8%
Savings (in comparison to flat rate tariff)	1.24%	2.5%
On-peak hours	15:00–17:00 and 22:00–01:00	9:00–12:00

6.5 Utilities Should Further Investigate Steps to TOU Rollout

BRPL and similar utilities in India, should examine further steps to roll out TOU. Domestic consumers will need smart metering to produce volumetric interval data to create TOU bills; BRPL does not currently have this or an advanced metering infrastructure. There are ancillary benefits of advanced metering infrastructure rollout, including more transparent billing, providing greater visibility of consumption patterns, better outage detection, support of renewable energy adoption by enabling metering consumer exports, and facilitating timed-metering and billing of consumption. This study has shown that domestic consumers drive peak demand but are also more willing to participate in DR programs than non-domestic consumers. Providing consumers with information on smart appliances (e.g., smart thermostats) and the means to achieve energy efficiency will help unlock this potential, particularly given that independent of price some consumers responded that they were very aware of the impacts of carbon intensive energy consumption, with over 90% of surveyed domestic consumers interested in reducing energy consumption to reduce environmental impacts.

6.6 DSM Beyond TOU

Beyond TOU there are multiple opportunities for BRPL to consider. Rolling out TOU will equip consumers with smart meters; these will enable BRPL to meter consumer exports, which is essential for the rollout of BTM solar adoption. Developing net metered rate structures or feed-in tariffs for consumer exports will give an economic incentive for consumer to adopt solar, and survey results have shown that 60% of domestic consumers are interested in adopting rooftop solar. Beyond solar, BRPL could start looking at how to best motivate battery energy storage for their consumers, looking at energy shifting, self-consumption, and peak shaving storage use cases and retail rate structures that can motivate those actions. Targeted peak programs, such as critical peak period, could be of use if BRPL establishes good communication channels to their consumers. Retail rate structures such as critical peak pricing, which issue targeted peak prices on specific forecasted days, can be even more effective than TOU at reducing consumer peak demand as they have the benefit of low frequency events with high prices which consumers have been demonstrated to be more responsive towards (Herter 2007). In terms of other demand-side technologies, multi-rate tariff structures could be of benefit to motivate EV charging to off-peak periods and can help manage the extra loading that increased EV adoption and charging brings on the grid. In our survey results, while only four consumers currently had an EV, over 25% of respondents were willing to become an early adopter of EVs. Finding methods to educate consumers on both how to respond to DSM programs and what appliances can help them do so is a critical element in the success of these programs. Motivating consumers to adopt smart appliances such as smart thermostats, schedulable white goods, and energy efficiency appliances enable consumers to achieve energy and demand reductions.

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Appendix A. Optimization Initialization

The new load at time t is affected by price elasticity matrix, on-peak price and off-peak price. If p_{on} and p_{off} are on-peak and off-peak price that we intend to find after solving optimization, new load at time t can be computed as,

$$\Delta L_t = \begin{cases} \sum_{k=0}^{t+23} E_{(t\%24),(k\%24)} \times \frac{p_{off} \times B_{k,off} + p_{on} \times B_{k,on}}{P_0} \times L_t \ \forall k < 12 \\ \sum_{k=t-12}^{t+11} E_{(t\%24),(k\%24)} \times \frac{p_{off} \times B_{k,off} + p_{on} \times B_{k,on}}{P_0} \times L_t \ \forall\ 12 < k < T - 11 \\ \sum_{k=t-(23-T+t)}^{T} E_{(t\%24),(k\%24)} \times \frac{p_{off} \times B_{k,off} + p_{on} \times B_{k,on}}{P_0} \times L_t \ \forall\ k > T - 11 \end{cases}$$

Here $p_{off} \times \boldsymbol{B_{k,off}} + p_{on} \times \boldsymbol{B_{k,on}}$represents price at time k. $B_{k,off}, B_{k,on}$ are binary quantities representing whether time k belongs to on-peak or off-peak time. If time k belongs to on-peak time then $B_{k,on} = 1$ and $B_{k,off} = 0$. As we have prior knowledge of on-peak and off-peak time, B_{on} and B_{off} are predefined parameters for all time periods. There are three expressions for computing change in load at time t. We are assuming load profile is available in hour resolution so 24 hours makes a day, and no consumers will take more than 24 hours (12 hours forward and 12 hours backward) to change their demand because of price change at time t. Since for the first 12 hours, going 12 hours backward involves negative hours, we considered the initial 24 hours as given in the first expression and similarly for the last 11 hours going forward. 11 hours involves hours greater than T, so we considered last 24 hours. To use 24 x 24 price elasticity matrix for any number of hours T, indexes for price elasticity are computed using mod of 24.

Appendix B. Key Survey Results

These are the key results from both the domestic and C&I surveys. Numbers in each table represent the number of responses to each question; respondents could select one from a set of possible answers. Not all respondents answered all questions. A total of 413 domestic and 318 C&I consumers answered all or part of the survey.

Table 15. C&I Consumers' End-Use Frequency for Different Categories

End-Use Category	Do not own	Low energy Use	Moderate energy use	High energy use
Electric Space Cooling	15	123	111	39
Electric Space Heating	229	25	19	2
Ventilation	93	89	28	0
Refrigeration	193	30	3	0
Office Equipment (Computers/Printing)	6	134	10	2
Electric Cooking	246	6	0	1
Electric Washing Equipment	257	17	6	0
Electric Pumps	215	23	16	1
Electric Motors	78	41	55	7
Electric Water Heating	279	2	8	0
Electric Machine-Drives	57	28	48	120
Process and Boiler Heating	257	4	9	24
Electrochemical Processes	293	1	0	1

Table 16. C&I Consumers' Attitudes and Responses to Changes in Energy Consumption and Behavior

Question/Statement on energy consumption and behavior	This statement does not apply to my business	Not at all likely	Slightly likely	Moderately likely	Very likely
How likely do you think you are to get rooftop solar photovoltaic system in the next 5 years?	0	105	115	62	5
Modify space heating and cooling during peak hours to use less electricity	15	50	159	61	14
Increase my businesses air conditioning temperature settings during summer evenings	18	142	77	51	10
Change the operation of some business activities	13	218	48	12	8
Change to energy efficient lightbulbs	3	18	48	55	127
Change to energy efficient air conditioning systems	18	34	46	61	122
Modify the schedules of some energy intensive activities (e.g., pumps, fans, motors, machinery) to off-peak hours (e.g., to early morning)	16	199	45	23	16
Heating load during off-peak hours in winter (between 00:00 and 04:00 during November to March)	0	156	33	35	62
Cooling Load during off-peak hours in summer (between 04:00 and 12:00 during May to September)	0	55	121	76	45
Change of other business activities and or electrical consumption	0	173	77	40	9
Cooling load	0	91	138	59	11
Heating load during winter peak hours (between 04:00 and 12:00 during November to March)	0	174	44	35	32
Change of other business activities and or electrical consumption	0	228	55	11	5

Table 17. C&I Consumers' Response to Different Energy Efficiency and Environmental Energy Use Statements

Energy efficiency and environmental statements	Strongly Disagree	Disagree	Indifferent	Agree	Strongly Agree
Reducing energy consumption is important to protect the environment	0	9	8	231	16
We should be more active in reducing our energy consumption and using energy efficient appliances	0	14	18	240	10
Green energy sources (e.g., solar and wind) are important to help protect the environment	3	42	77	132	9
Reducing our energy consumption and using more green energy we can help reduce air pollution	6	38	66	152	9
We are interested in using less electricity consumption to reduce our electricity bill and save money	2	16	31	218	12

Table 18. C&I Consumers' Response to Air Conditioning Demand Response Proposal

Response	If the utility pays you to control the temperature set of your air conditioning unit for two hours during evening peak hours (between 14:00 and 17:00 and between 22:00 and 01:00 in the summer season (May–September), what is the lowest monthly payment you would be willing to accept in rupees?
Unsure	191
0–100 Rupees	2
100–300 Rupees	1
300–500 Rupees	5
500–800 Rupees	17
None of these payments	83

Table 19. C&I Consumers' Interest in Rooftop Solar Systems

Response	How interested are you in getting a rooftop solar photovoltaic system on your roof in the next 10 years?
Extremely interested	2
Very interested	7
Moderately interested	60
Not at all interested	99
Slightly interested	121

Table 20. C&I Consumers' Number of Ceiling and Portable Fans Owned

Response	How many fans (i.e., ceiling fans and/or portable fans) are there in your establishment, approximately (choose one)?
None	10
1–5	158
6–5	129
16–30	17
31 or more	4

Table 21. C&I Consumers' Number of Air Coolers at Establishment

Response	How many air coolers are there in your establishment, approximately (choose one)?
0	222
1–3	85
4–10	9
11 or more	2

Table 22. C&I Consumers' Months of the Year in Which Air Coolers Are Used

Response	In general, how many months of the year, coolers are used (choose one)?
5 months or more	24
4 months	56
3 months	15
Not used	1

Table 23. C&I Consumers' Types of AC Used on Premises

Types of air condition systems	Which type of air conditioning system is used at your business premise? (You can choose multiple options)
Do not have air conditioning system	46
Individual window/wall or portable units	212
Both central and individual units	44
Individual window/wall or portable units, Both central and individual units	3
Central air conditioning system	12
Central air conditioning system, Both central and individual units	1

Table 24. C&I Consumers' Ability to Control AC System

Types of air conditioning control	Do you have the ability to control your air conditioning system (i.e., change the temperature)? If so, what best describes how this is used?
Program the thermostat to automatically adjust temperature during the day and night	22
Set one temperature and leave it there most of the time	86
Turn equipment on or off as needed	108
Manually adjust the temperature at night or when no one is at premises	55
There is no air conditioning system	46
There are no temperature controls	1

Table 25. C&I Consumers' Temperature Setting Used During Summer Months

Cooling temperature setting	If you use cooling, what temperature setting do you use during summer months?
24–26°C	6
22–24°C	53
20–22°C	116
18–20°C	87
Not used	44
Less than 18°C	12

Table 26. C&I Consumers' Temperature Settings Used for Heating in Winter Months

Heating temperature setting	If you use heating, what temperature setting do you use during winter months?
Not used	243
Less than 14°C	1
Greater than 22°C	18
20–22°C	11
18–20°C	35
16–18°C	10

Table 27. C&I Consumers, What Months Air Cooling Usage Starts and Ends

Month	If any air cooling (i.e., portable air cooler/air conditioning) is used at your business premises, what month of the year do you typically start using cooling mode (choose one)?	If any air cooling (i.e., portable air cooler/air conditioning) is used at your business premise, what month of the year do you typically stop using cooling mode (choose one)?
February	1	0
March	57	0
April	217	0
May	18	0
July	0	2
August	0	12
September	0	32
October	0	205
November	0	39
Not used	19	21
Cooling is used all year	6	7

Table 28. C&I Consumers' Presence of Plug-In Heaters

Response	How many air heaters (i.e., portable plug heating appliances) are there in your establishment, approximately (choose one)?
None	293
1–5	22
6–10	3

Table 29. C&I Consumers' Start and End Month for Use of Air Heating If Used

Month	If any air heating is used at your business premises, what month of the year do you typically start using heating mode (choose one)?	If any air heating is used at your business premises, what month of the year do you typically stop using heating mode (choose one)?
November	9	0
December	15	0
January	0	9
February	0	15
Heating is used all the year	1	1

Table 30. C&I Consumers' Percentage of Owned Light Bulbs That Are Energy Efficient

% Of light bulbs that are energy efficiency	Approximately what percentage of the light bulbs at your business are energy efficient (e.g., LED tube lights, and LED bulbs)?
Unsure	1
None	22
0–5%	74
5–10%	109
10–25%	68
25–50%	20
50–75%	17
75–100%	7

Table 31. Domestic Consumers' Use of Key Appliances

Which of the following cooking appliances do you use from most to least?	Do not know	Do not own	Little to no use (A few times per year)	Rarely use (A few times per month)	Infrequently use (A few times per week)	Frequently use (Almost every day)
Electric Heater Cooker	12	11	14	11	17	13
Induction Cooker	334	319	326	124	267	238
Electric Cooker	28	31	32	52	42	48
Microwave Oven	25	26	20	51	51	37
Electric Oven	4	9	9	73	25	29
Electric Kettle	10	17	12	102	11	48

Table 32. Domestic Consumers: How Many Light Bulbs Are on Premises

Which of the following appliances do you have at your residence and how many of each?	Do not know/ Unsure	1–4	5–8	9–12	13–16	17–20	21–24	25–32	33–44	45–56	57–80	80 or more
Approximately how many light bulbs are installed in your residence? Include light bulbs and tube lights in ceiling fixtures, fans, and table and floor lamps as well as those used less often such as in hallways, closets, garages, and cupboards. For fixtures wit	7	30	101	88	57	42	26	16	20	8	6	5
Out of all light bulbs installed approximately how many are incandescent or halogen light bulbs?	10	55	14	4	3	3	1	1	0	1	0	0
Out of all light bulbs installed approximately how many are CFL light bulbs?	10	135	48	28	13	10	1	0	3	0	0	0
Out of all light bulbs installed approximately how many are LED light bulbs?	10	141	116	43	22	16	9	0	7	6	1	0
Out of those light bulbs approximately how many are tube lights?	5	213	95	18	11	1	1	0	1	0	1	0

Table 33. Domestic Consumers' Likelihood of Responding to Different Demand Response Measures

		Not at all likely	Slightly likely	Moderately likely	Very likely	Extremely likely
Changing your electricity patterns can help the environment and reduce costs. If the electricity utility was willing to pay you to change your electricity consumption patterns how likely would you be willing to make the following changes?	Increase my AC temperature settings during summer evenings to consume less energy	31	18	43	127	186
	Turn off my AC during summer evenings	47	37	71	95	156
	Turn off my water heater during winter mornings	75	44	78	81	124
	Stop doing laundry during evening hours	22	21	36	85	238
	Change to energy efficient light bulbs	9	4	6	66	328
	Change to energy efficient air conditioning systems	14	9	32	86	272
If you had the opportunity to have a 40% lower electricity price during off-peak hours how likely would you be to move energy consumption of the following appliance categories?	Cook later or earlier (in case of electric cooking) than usual in the evenings	67	30	37	82	197
	Heating load during off-peak hours in winter (between 00:00 and 04:00 during November and March)	48	31	61	93	180
	Cooling load during off peak hours in summer (between 04:00 and 12:00 during May to September)	38	24	79	118	154
	Electric cooking (after 10:00 during November to March and 00:00 to 12:00 and 18:00 to 21:00 from May to September)	95	21	58	82	157
If the electricity price during peak hours (in between 14:00 and 17:00 and in between 22:00 and 01:00) was 40% more expensive than other hours how likely you would be interested to reduce or move your electricity consumption of the following appliance categories during these peak hours?	Cooling load	49	38	85	109	132
	Electric cooking	90	23	46	81	173
	Heating load during winter peak hours (Between 04:00 and 12:00 during November to March)	67	30	77	89	150
	Lighting	49	28	80	109	147
	Use Personal Computing/TV	77	43	83	101	109
Propensity towards electric vehicle and solar rooftop adoption	How likely are you to buy an electric vehicle as your next car?	160	76	75	52	46
	How likely do you think you are to get rooftop solar photovoltaic system in the next 5 years?	170	56	60	60	54
	How likely do you think you are to get rooftop solar photovoltaic system in the next 10 years?	109	65	61	72	93

Table 34. Domestic Consumers' Use of Cooling and Heating Loads Across Months

Response:	What month of the year do you typically start using air heaters for home heating (choose one)?	What month of the year do you typically stop using air heaters for home heating (choose one)?	If any air cooling (i.e., portable air cooler/air conditioning) is used at your residence, what month of the year do you typically start using home cooling (choose one)?	If any air cooling (i.e., portable air cooler/air conditioning) is used at your residence, what month of the year do you typically stop using home cooling (choose one)?
Not used	27	28	0	0
January	0	56	1	0
February	0	97	0	0
March	0	18	22	0
April	0	3	101	0
May	0	0	157	0
June	0	0	64	0
July	0	0	3	59
August	0	0	5	56
September	0	0	0	119
October	2	0	0	92
November	21	0	0	23
December	152	0	0	4
Cooling is used all year	0	0	5	5

Table 35. Domestic Consumers: Type of AC Used

Response	Type of AC
Individual window/split AC	353
Central air conditioning	1
Unsure but do have an air conditioning system	4

Table 36. Domestic Consumers' Control of AC Systems

Response	Do you have the ability to control your air conditioning system (i.e., change the temperature)? If so, what best describes how this is used?
Turn equipment on or off as needed	168
Set one temperature and leave it there most of the time	95
Program the thermostat to automatically adjust temperature during the day and night	47
Manually adjust the temperature at night or when no one is at home	46
There are no temperature controls	2

Table 37. Domestic Consumers' Set-Points Use for AC Systems

Response	If you use cooling, what temperature setting do you use during summer months?
Not used	4
Less than 18°C	1
18–20°C	10
20–22°C	22
22–24°C	70
24–26°C	184
Greater than 26°C	67

Table 38. Domestic Consumers' Temperature Settings Used for Heating in Winter Months

Response:	If you use heating, what temperature setting do you use during winter months?
Do not use in winter	258
Less than 14 °C	7
14–16 °C	4
16–18°C	8
18–20°C	15
20–22°C	29
Greater than 22°C	37

Table 39. Domestic Consumers' Duration of Use for Electric Geysers When Turned on

Response	How much time geyser(s) will be in service when it is turned ON
Less than 15 min	98
15–30 min	153
30–45 min	47
45–60 min	20
More than 60 min	24

Table 40. Domestic Consumers' Time of Use for Electric Geysers

Response	What is the preferred time of usage of geyser?
Early Morning (before 6:00)	36
Morning hours (6:00–10:00)	270
Afternoon (10:00–18:00)	26
Evening (18:00–22:00)	7
Night (22:00–00:00)	3

Table 41. Domestic Consumers' Size of Battery Systems Owned in kWh

Response	Size of Battery Systems in kWh
None	235
1–2 kWh	119
3–6 kWh	31
7–10 kWh	11
10 kWh or more	17

Table 42. Domestic Consumers' Occupancy Patterns Before and During the COVID-19 Pandemic

	Occupancy Patterns Before Pandemic				Occupancy Patterns During Pandemic			
Response	Adult 1	Adult 2	Adult 3	Adult 4	Adult 1	Adult 2	Adult 3	Adult 4
Not applicable	0	51	183	266	0	48	176	253
00:00–07:00	51	32	24	13	36	24	17	14
00:00–07:00, 07:00–14:00	3	0	1	0	2	1	1	1
00:00–07:00, 07:00–14:00, 17:00–21:00, 21:00–00:00	7	6	2	1	4	2	0	1
00:00–07:00, 17:00–21:00, 21:00–00:00	29	22	24	15	12	6	10	7
00:00–07:00, 21:00–00:00	40	17	22	14	11	2	3	5
17:00–21:00	10	11	10	7	6	8	4	2
17:00–21:00, 21:00–00:00	1	2	1	0	1	2	1	1
21:00–00:00	7	15	9	7	15	11	5	2
00:00–07:00, 07:00–14:00, 17:00–21:00, 21:00–00:00	7	6	2	1	4	2	0	1
All the day	193	195	92	54	273	282	169	112

Table 43. Domestic Consumers' Ownership of Rooftop Solar

Response	Do you have a rooftop solar photovoltaic system on your roof (i.e., rooftop electricity generation from sun power), if so how is owned?
Do not have this on your roof	400
Self-owned	11
Third party owned	2

Table 44. Domestic Consumers' Capacity of Rooftop Solar

Response	If you own a rooftop solar photovoltaic system (i.e., rooftop electricity generation from sun power), if so, approximately what capacity is this system?
0–1 kW	5
2–4 kW	1
4–6 kW	1
6–15 kW	0
Greater than 15 kW	1
Unsure of capacity	5

Table 45. Domestic Consumers' Ownership of EVs

Response	Do any of the occupants of this residence own an electric vehicle?
None	409
1	4

Table 46. Domestic Consumers' Method of Charging EV

Response	If one or more of the occupants of this residence own an electric vehicle, how is it primarily charged?
Home charging	4

Table 47. Domestic Consumers' Response to Demand Response Potential Payments for Reducing AC Load

Response	If the utility was to pay you to turn off your air conditioning unit for two hours during evenings (8 p.m.–01 a.m.) in the summer season (May–September), what is the lowest monthly payment that you would be willing to make for this monthly decrease in power consumption?
0–50 rupees	49
50–150 rupees	56
150–250 rupees	58
250–400 rupees	116
None of these payments	134

Appendix C. Annual Load Duration Data

Table 48. Annual load duration data as seen in Figure 51 (for top 5%)

Percent Duration of Year (%)	Original Load MW	New Load MW
0.0114	2972	2913.61
0.0228	2939	2858.47
0.0342	2925	2842.83
0.0457	2923	2841.85
0.0571	2910	2837.15
0.0685	2909	2825.38
0.0799	2908	2825.20
0.0913	2901	2820.48
0.1027	2894	2819.50
0.1142	2882	2818.93
0.1256	2881	2815.47
0.1370	2877	2808.72
0.1484	2876	2806.67
0.1598	2874	2804.02
0.1712	2872	2803.58
0.1826	2867	2801.79
0.1941	2865	2798.91
0.2055	2863	2797.88
0.2169	2862	2796.90
0.2283	2861	2791.12
0.2397	2857	2783.23
0.2511	2855	2782.48
0.2626	2854	2777.23
0.2740	2844	2775.40
0.2854	2843	2773.77
0.2968	2840	2763.67
0.3082	2839	2760.74
0.3196	2835	2759.77
0.3311	2828	2759.64
0.3425	2825	2756.83
0.3539	2824	2756.76
0.3653	2824	2755.78
0.3767	2821	2753.82
0.3881	2820	2752.83
0.3995	2813	2750.87
0.4110	2813	2749.02
0.4224	2812	2749.02
0.4338	2811	2744.47
0.4452	2809	2744.00
0.4566	2808	2743.03
0.4680	2806	2740.84
0.4795	2806	2739.32
0.4909	2803	2739.24
0.5023	2801	2739.11
0.5137	2798	2738.29
0.5251	2794	2733.23
0.5365	2794	2731.59
0.5479	2789	2730.45
0.5594	2788	2726.54
0.5708	2788	2726.01
0.5822	2784	2725.56
0.5936	2783	2722.02
0.6050	2781	2720.00
0.6164	2779	2719.70
0.6279	2774	2718.52
0.6393	2773	2716.56
0.6507	2772	2716.56
0.6621	2771	2713.89
0.6735	2771	2712.00
0.6849	2771	2707.07
0.6963	2771	2705.00
0.7078	2768	2704.79
0.7192	2768	2702.87

0.7306	2767	2697.34
0.7420	2765	2696.95
0.7534	2760	2694.27
0.7648	2760	2694.01
0.7763	2752	2693.00
0.7877	2751	2691.92
0.7991	2749	2691.50
0.8105	2749	2688.12
0.8219	2748	2686.63
0.8333	2747	2682.56
0.8447	2745	2681.58
0.8562	2744	2679.63
0.8676	2744	2678.33
0.8790	2742	2676.37
0.8904	2740	2676.00
0.9018	2740	2675.92
0.9132	2735	2675.92
0.9247	2732	2673.28
0.9361	2731	2670.26
0.9475	2730	2669.50
0.9589	2729	2669.00
0.9703	2729	2667.16
0.9817	2728	2666.93
0.9932	2726	2665.47
1.0046	2725	2665.00
1.0160	2724	2665.00
1.0274	2723	2663.62
1.0388	2723	2663.02
1.0502	2723	2662.29
1.0616	2721	2660.67
1.0731	2720	2658.75
1.0845	2720	2658.40
1.0959	2720	2658.13
1.1073	2717	2657.79
1.1187	2715	2657.00
1.1301	2714	2655.46
1.1416	2712	2654.92
1.1530	2712	2653.53
1.1644	2710	2653.13
1.1758	2710	2652.84
1.1872	2710	2652.68
1.1986	2709	2651.00
1.2100	2707	2650.61
1.2215	2706	2648.92
1.2329	2705	2648.36
1.2443	2703	2648.36
1.2557	2703	2648.32
1.2671	2701	2647.69
1.2785	2697	2647.24
1.2900	2695	2641.52
1.3014	2693	2641.01
1.3128	2691	2639.57
1.3242	2691	2638.97
1.3356	2688	2637.96
1.3470	2687	2635.69
1.3584	2684	2635.32
1.3699	2683	2633.00
1.3813	2683	2633.00
1.3927	2681	2632.00
1.4041	2681	2631.27
1.4155	2679	2631.15
1.4269	2678	2630.18
1.4384	2676	2623.61
1.4498	2675	2623.49
1.4612	2672	2621.00
1.4726	2672	2620.02
1.4840	2669	2619.00
1.4954	2669	2618.00
1.5068	2668	2617.00
1.5183	2668	2616.55

1.5297	2665	2616.37
1.5411	2665	2615.72
1.5525	2665	2615.59
1.5639	2663	2615.59
1.5753	2663	2615.41
1.5868	2663	2614.52
1.5982	2662	2613.37
1.6096	2661	2612.79
1.6210	2660	2612.46
1.6324	2660	2612.00
1.6438	2658	2611.95
1.6553	2657	2610.68
1.6667	2657	2609.00
1.6781	2655	2607.16
1.6895	2654	2606.21
1.7009	2653	2605.24
1.7123	2653	2604.38
1.7237	2651	2604.29
1.7352	2651	2604.08
1.7466	2650	2602.84
1.7580	2650	2601.08
1.7694	2650	2600.97
1.7808	2650	2600.88
1.7922	2648	2599.50
1.8037	2648	2598.92
1.8151	2641	2598.16
1.8265	2641	2597.59
1.8379	2639	2596.94
1.8493	2638	2595.98
1.8607	2638	2595.68
1.8721	2636	2593.28
1.8836	2636	2592.00
1.8950	2633	2591.19
1.9064	2633	2589.29
1.9178	2632	2588.00
1.9292	2631	2588.00
1.9406	2631	2587.15
1.9521	2629	2587.00
1.9635	2628	2586.82
1.9749	2627	2586.67
1.9863	2626	2586.66
1.9977	2625	2584.69
2.0091	2625	2584.21
2.0205	2625	2581.06
2.0320	2623	2580.93
2.0434	2621	2579.41
2.0548	2621	2578.72
2.0662	2619	2577.76
2.0776	2618	2576.69
2.0890	2618	2576.50
2.1005	2617	2576.04
2.1119	2617	2575.58
2.1233	2617	2575.33
2.1347	2615	2574.91
2.1461	2613	2573.76
2.1575	2613	2573.76
2.1689	2612	2573.39
2.1804	2612	2573.39
2.1918	2611	2572.83
2.2032	2611	2570.74
2.2146	2609	2570.74
2.2260	2607	2570.17
2.2374	2607	2570.08
2.2489	2606	2569.69
2.2603	2606	2566.57
2.2717	2606	2566.27
2.2831	2604	2566.05
2.2945	2603	2564.01
2.3059	2601	2563.63
2.3174	2601	2563.37

2.3288	2600	2563.03
2.3402	2599	2562.95
2.3516	2595	2561.67
2.3630	2593	2561.43
2.3744	2592	2560.49
2.3858	2592	2560.00
2.3973	2592	2559.27
2.4087	2591	2559.09
2.4201	2589	2558.45
2.4315	2589	2558.07
2.4429	2589	2555.73
2.4543	2588	2555.73
2.4658	2588	2555.22
2.4772	2588	2554.70
2.4886	2587	2553.56
2.5000	2585	2552.59
2.5114	2584	2551.61
2.5228	2583	2551.32
2.5342	2582	2551.00
2.5457	2582	2551.00
2.5571	2581	2551.00
2.5685	2579	2548.51
2.5799	2579	2548.45
2.5913	2577	2548.00
2.6027	2574	2547.43
2.6142	2574	2547.43
2.6256	2574	2546.72
2.6370	2573	2545.57
2.6484	2573	2544.75
2.6598	2573	2544.62
2.6712	2572	2543.79
2.6826	2572	2543.52
2.6941	2568	2543.12
2.7055	2566	2543.00
2.7169	2565	2542.26
2.7283	2563	2542.00
2.7397	2562	2541.86
2.7511	2562	2541.59
2.7626	2562	2540.34
2.7740	2560	2537.70
2.7854	2559	2536.69
2.7968	2556	2536.34
2.8082	2556	2536.34
2.8196	2556	2536.34
2.8311	2556	2534.22
2.8425	2555	2533.04
2.8539	2554	2532.47
2.8653	2554	2531.11
2.8767	2552	2530.11
2.8881	2552	2529.02
2.8995	2551	2525.00
2.9110	2551	2524.79
2.9224	2551	2524.07
2.9338	2551	2523.81
2.9452	2551	2523.51
2.9566	2550	2522.45
2.9680	2549	2522.11
2.9795	2548	2522.00
2.9909	2545	2521.72
3.0023	2545	2520.74
3.0137	2544	2520.65
3.0251	2543	2520.10
3.0365	2543	2519.00
3.0479	2543	2518.15
3.0594	2542	2518.13
3.0708	2542	2517.62
3.0822	2542	2517.00
3.0936	2541	2516.68
3.1050	2540	2516.00
3.1164	2540	2516.00

3.1279	2539	2515.45
3.1393	2539	2514.00
3.1507	2539	2513.38
3.1621	2538	2513.36
3.1735	2537	2512.41
3.1849	2535	2512.41
3.1963	2535	2510.57
3.2078	2535	2510.55
3.2192	2533	2510.50
3.2306	2533	2510.35
3.2420	2532	2510.35
3.2534	2531	2510.00
3.2648	2529	2507.00
3.2763	2527	2507.00
3.2877	2527	2506.00
3.2991	2527	2504.81
3.3105	2526	2504.70
3.3219	2525	2504.00
3.3333	2524	2503.00
3.3447	2522	2501.46
3.3562	2522	2500.88
3.3676	2522	2500.05
3.3790	2520	2500.05
3.3904	2520	2499.61
3.4018	2519	2499.00
3.4132	2518	2498.78
3.4247	2518	2497.98
3.4361	2518	2497.86
3.4475	2517	2497.86
3.4589	2517	2496.94
3.4703	2516	2496.81
3.4817	2516	2496.69
3.4932	2516	2496.33
3.5046	2515	2496.00
3.5160	2515	2495.91
3.5274	2514	2495.31
3.5388	2513	2495.25
3.5502	2513	2495.00
3.5616	2513	2493.89
3.5731	2512	2493.04
3.5845	2512	2492.82
3.5959	2512	2491.08
3.6073	2511	2490.43
3.6187	2511	2490.10
3.6301	2511	2489.86
3.6416	2510	2489.44
3.6530	2509	2489.12
3.6644	2508	2488.43
3.6758	2508	2488.19
3.6872	2508	2488.05
3.6986	2507	2487.31
3.7100	2507	2486.63
3.7215	2507	2486.38
3.7329	2506	2486.16
3.7443	2506	2486.11
3.7557	2504	2486.00
3.7671	2504	2484.34
3.7785	2503	2484.18
3.7900	2503	2484.18
3.8014	2500	2484.18
3.8128	2499	2483.98
3.8242	2499	2483.70
3.8356	2499	2483.23
3.8470	2499	2483.23
3.8584	2498	2483.03
3.8699	2498	2482.26
3.8813	2498	2481.47
3.8927	2497	2481.24
3.9041	2497	2481.05
3.9155	2497	2480.87

3.9269	2496	2480.05
3.9384	2496	2480.01
3.9498	2496	2478.94
3.9612	2495	2477.36
3.9726	2494	2477.35
3.9840	2493	2477.02
3.9954	2493	2477.00
4.0068	2493	2476.20
4.0183	2492	2475.40
4.0297	2491	2474.10
4.0411	2489	2472.45
4.0525	2488	2472.00
4.0639	2486	2471.50
4.0753	2486	2470.49
4.0868	2486	2470.13
4.0982	2486	2469.35
4.1096	2485	2468.84
4.1210	2485	2468.53
4.1324	2485	2468.42
4.1438	2485	2467.88
4.1553	2483	2466.12
4.1667	2483	2465.00
4.1781	2480	2464.27
4.1895	2480	2464.00
4.2009	2479	2464.00
4.2123	2479	2463.59
4.2237	2478	2462.91
4.2352	2478	2462.65
4.2466	2478	2462.65
4.2580	2478	2461.77
4.2694	2477	2461.67
4.2808	2477	2461.17
4.2922	2476	2460.73
4.3037	2475	2459.15
4.3151	2474	2458.73
4.3265	2473	2458.69
4.3379	2473	2458.64
4.3493	2472	2457.06
4.3607	2471	2454.86
4.3721	2471	2454.64
4.3836	2471	2454.46
4.3950	2470	2454.00
4.4064	2470	2454.00
4.4178	2469	2453.88
4.4292	2469	2453.76
4.4406	2469	2451.81
4.4521	2468	2451.00
4.4635	2468	2451.00
4.4749	2466	2450.95
4.4863	2465	2449.98
4.4977	2465	2448.00
4.5091	2465	2447.94
4.5205	2465	2447.90
4.5320	2465	2447.50
4.5434	2465	2447.29
4.5548	2465	2446.37
4.5662	2464	2446.20
4.5776	2464	2446.00
4.5890	2464	2445.79
4.6005	2463	2444.25
4.6119	2462	2443.03
4.6233	2462	2442.69
4.6347	2461	2441.18
4.6461	2461	2440.63
4.6575	2460	2440.10
4.6689	2460	2437.23
4.6804	2459	2437.00
4.6918	2459	2436.21
4.7032	2456	2436.20
4.7146	2456	2436.18

4.7260	2455	2435.68
4.7374	2454	2434.12
4.7489	2454	2434.00
4.7603	2454	2433.85
4.7717	2454	2433.00
4.7831	2453	2432.57
4.7945	2453	2431.23
4.8059	2453	2430.99
4.8174	2453	2430.30
4.8288	2452	2430.10
4.8402	2451	2430.02
4.8516	2451	2428.75
4.8630	2450	2428.48
4.8744	2448	2427.86
4.8858	2448	2427.84
4.8973	2446	2426.52
4.9087	2446	2426.27
4.9201	2444	2426.27
4.9315	2444	2424.94
4.9429	2442	2424.75
4.9543	2442	2424.73
4.9658	2441	2424.42
4.9772	2438	2424.00
4.9886	2437	2424.00
5.0000	2436	2423.00
5.0114	2436	2423.00
5.0228	2436	2422.89
5.0342	2435	2422.61
5.0457	2434	2422.44
5.0571	2434	2422.03
5.0685	2434	2422.00
5.0799	2433	2422.00
5.0913	2433	2422.00
5.1027	2433	2421.00
5.1142	2432	2420.00
5.1256	2431	2420.00
5.1370	2431	2419.91
5.1484	2430	2419.68
5.1598	2430	2419.61
5.1712	2428	2419.52
5.1826	2427	2419.51
5.1941	2426	2418.61
5.2055	2426	2418.61
5.2169	2425	2416.98
5.2283	2424	2416.57
5.2397	2424	2416.39
5.2511	2424	2415.53
5.2626	2424	2414.79
5.2740	2424	2414.79
5.2854	2424	2414.73
5.2968	2424	2414.61
5.3082	2423	2414.49
5.3196	2423	2414.07
5.3311	2422	2413.00
5.3425	2422	2413.00
5.3539	2422	2412.92
5.3653	2422	2412.84
5.3767	2422	2412.25
5.3881	2422	2412.00
5.3995	2422	2411.67
5.4110	2422	2411.64
5.4224	2422	2411.00
5.4338	2422	2410.83
5.4452	2421	2410.00
5.4566	2421	2408.93
5.4680	2420	2408.63
5.4795	2420	2408.25
5.4909	2420	2408.00
5.5023	2420	2407.75
5.5137	2420	2407.54

5.5251	2420	2407.22
5.5365	2420	2406.63
5.5479	2419	2406.54
5.5594	2418	2406.51
5.5708	2418	2406.51
5.5822	2417	2405.96
5.5936	2416	2405.95
5.6050	2415	2405.79
5.6164	2413	2405.02
5.6279	2413	2405.00
5.6393	2413	2404.92
5.6507	2412	2404.92
5.6621	2412	2403.83
5.6735	2411	2402.41
5.6849	2411	2402.05
5.6963	2410	2402.00
5.7078	2410	2401.73
5.7192	2410	2400.74
5.7306	2410	2400.00
5.7420	2408	2400.00
5.7534	2408	2399.31
5.7648	2408	2399.00
5.7763	2408	2399.00
5.7877	2407	2398.93
5.7991	2406	2398.66
5.8105	2406	2398.51
5.8219	2405	2398.32
5.8333	2405	2397.20
5.8447	2404	2396.86
5.8562	2404	2396.55
5.8676	2403	2395.99
5.8790	2402	2395.87
5.8904	2402	2395.87
5.9018	2402	2395.53
5.9132	2401	2394.52
5.9247	2401	2393.27
5.9361	2401	2393.27
5.9475	2400	2392.40
5.9589	2400	2392.40
5.9703	2399	2392.40
5.9817	2399	2392.08
5.9932	2399	2391.81

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