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ENERGY INNOVATION
FOR A SUSTAINABLE ECONOMY

11th-13th February 2020 The Park, Hyderabad, India

PAPER PROCEEDINGS

Organisers

Alliance for an Energy Efficient Economy

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Ministry of Power, Government of India

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Foreword

India's energy consumption, driven by economic growth, a large and growing population, and rapid urbanization, is expected to grow faster than that of any other major economy in the world. Concurrently, India is also transitioning to a sustainable energy future amidst international commitments like the Paris Agreement (2015), the Kigali Amendment to the Montreal Protocol (2016) and Sustainable Development Goals 2030. Energy efficiency can emerge as a low-cost mediator between the drive towards economic maximization and environmental sustainability.

To realize this pressing need in the wake of a global climate emergency, it is important to create policy frameworks supported by evidence-based and data-driven research and development - this is where Alliance for an Energy Efficient Economy (AEEE) steps in. AEEE has emerged as a credible platform to foster a culture of energy efficiency in India by engaging the triple-sector leadership approach. AEEE works across different levels of stakeholders in the public sector, the private sector, and civil society. We stay committed to our mission with Energise 2020: *Energy Innovation for a Sustainable Economy*.

Energise is India's signature biennial conclave that convenes torchbearers of energy efficiency and sustainability from a diverse group of stakeholders including, the government, industry, civil society, and academia. It is the second of two editions of such conferences – INSPIRE 2017 was the first edition. Participants will gather at this pre-eminent meeting to discuss the technological basis for, and the practical implementation of actions to reduce the energy use and climate impacts associated with a wide range of sectors like buildings, manufacturing, agriculture, and transport. Energise, will further enable the sharing of ideas and engaging in dialogue with global leading thinkers, leaders and luminaries in the field. This will be executed through moderated panel discussions, keynote speeches, industry exhibitions, and paper presentations through three days. This electronic document includes all the technical papers presented during this conference. The papers cover the depth and breadth of the energy efficiency landscape – space cooling, electric mobility, energy performance measurement, and data analytics to name a few.

Bringing out credible research in the public domain can have a tremendous influence on effective policymaking and scaling business innovation. Therefore, the conveners have been careful to use a double-blind peer review process to curate the papers presented in the conference, as was done previously at INSPIRE in 2017. Such a state-of-the-art review process for selecting research papers in conferences in the Indian milieu has raised the bar for producing research on pressing policy and market questions. The conveners hope that the energy efficiency community finds this compilation of papers enriching and useful in their technical projects, and policy and business decisions.

Over 150 abstracts were received in mid-2019, from which 52 papers have been published in this electronic document to advance the discourse on energy efficiency in India and close knowledge gaps. The technical papers in this proceeding have been organized under three sections – Buildings and Communities, Energy Efficiency for Business Competitiveness and Urban Infrastructure and Utilities representing the three thematic tracks under which the whole set of technical papers were requested and evaluated. The peer-review effort was led by 38 technical committee members including four senior advisors and nine panel leaders comprising leading national and international experts from academia, policy think-tanks, and foundations, consulting, and the industry, representing the three thematic areas, to lend a balanced perspective to the whole process. Despite our best efforts, there might be some inconsistencies in the formatting of this document, considering the papers have been sourced from multiple authors – however, the technical information is accurate (to the best of the conveners' knowledge) and best attributed to the authors.

The conveners are delighted to present this electronic proceeding, which captures the research produced for Energise 2020.

Satish Kumar, Ph.D. and LEED Fellow
Energise Convener
President & Executive Director, AEEE

EMPIRICAL ASSESSMENT OF THE APPLIANCE-LEVEL LOAD SHAPE AND DEMAND RESPONSE POTENTIAL IN INDIA

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ABSTRACT

Over the next 15 years, electricity demand from the key residential and commercial appliances is projected to be nearly 300 GW or ~65% of India's total peak demand. The objective of this study is to characterize appliance level demand and temporal variation, and identify the overall DR potential in India. We use Bangalore Electricity Supply Company territory (peak load of 3,505 MW in 2016) as a case study, using actual one-minute resolution load data for 2,979 distribution feeders and a detailed load survey. Our results show that agricultural pumping and space cooling (residential, commercial, and industrial) are the main contributors to the peak demand – with shares of 23-27% and 14-23%, respectively. Both sectors have about 1,000 MW of DR potential – agricultural pumps offering load shifting service while space cooling offering shimmy service that is capable of dynamically adjusting to react to short-run ramps and grid disturbances. Residential electric water heaters contribute nearly 18% of the winter morning peak demand and can also offer about 500 MW in shimmy service. Overall, we find that shifting and shimmy services offer 1,199 MW and 1,511 MW total DR potential, respectively.

Keywords—electricity, electricity demand, load forecasting, load modeling, demand response

INTRODUCTION

Over the next 15 years, electricity demand from the key residential and commercial appliances is projected to be nearly 300 GW or ~65% of India's total peak demand (Abhyankar et al., 2013; CEA, 2016). This is equivalent to the output of nearly 600 large power plants.

The objective of this study is to characterize end-use level demand and temporal (seasonal/hourly) variation, and identify the overall demand response (DR) potential in India. Up to now, only a few studies look at the temporal variations in end-use load and their DR potential in India. These studies are mostly based on load surveys and lack empirical load data. For example, Garg et al. (2010) characterize the demand in the city of Gujarat, based on load surveys. Similarly, Energy Efficiency Services Limited (EESL) presents system demand charts based on a number of representative feeders and load surveys conducted for Bangalore Electricity Supply Company (BESCOM) (PWC, 2015). Chunekar et al. (2016) analyzed the load shapes of typical household appliances in India. None of these studies examines system-level load issues, provides detailed bottom-up analysis, or estimates appliance DR potential.

We analyze the BESCOM territory, which serves the city of Bangalore and the surrounding area, as a case study.

BESCOM TERRITORY

BESCOM is an electricity distribution company serving eight districts of the state of Karnataka, which covered 8.8 million customers in 2016. It has four operating zones: Bangalore Metropolitan Area Zones - North and South (which we combine into one zone abbreviated BGM), Bangalore Rural Area Zone (BGR), and the other rural areas, Chitradurga Zone (TMK). Bangalore and surrounding area have a tropical climate with distinct wet and dry seasons. The coolest month is January (typically range from 16°C to 27°C), and the hottest month is April (typically range from 23°C to 34°C) (Weatherspark, 2019). The monsoon season, which runs from June through September, brings frequent rainfall that moderates the summer heat. November, December and January are considered winter months, while April and May are considered summer months. February, March, and October are the transition months, when the temperatures has an increasing/decreasing trend entering the summer and winter.

About 53% of BESCOM customers are urban and 47% are rural. Among those, 67% are residential, 9% are low-tension (LT) commercial, e.g., small offices, grocery stores, and shops, and 9% are agricultural (**Table 1**). Most agricultural customers are rural, most commercial customers urban, and industrial customers—including industries such as steel, copper, aluminum, food processing, plastic molding, and packaging—were evenly distributed between urban and rural areas.

Table 1: BESCOM Customers by Sector (2016)

	NUMBER ('000)	SHARE (%)
Total	8,798	
Residential	5,926	67.4%
LT commercial	782	8.9%
HT commercial	5	0.1%
HT industrial	7	0.1%
LT industrial	160	1.8%
Agricultural	824	9.4%
Others*	1,094	12.4%

* Others include municipal water pumping and supply, street lighting, and advertising boards. Note: LT = low tension that has less than 1 kV voltage, HT = high tension that has more than 1 kV voltage. Customers like individual houses, small offices, shops, and small manufacturing units are on LT lines, while HT is applicable to large industries and large commercial units such as information technology offices, malls, hospitals, and universities.

Figure 1 shows each sector's share in total BESCOM electricity sales in 2016. Agriculture consumed the most (27%), although it only receives electricity from 22:00 to 06:00 the next day to prevent power outages when system demand is higher. The next-largest consumers were residential (19%) and HT industrial (18%). The entire commercial sector, including LT and HT, accounted for about 25%, while LT industrial and others constituted smaller shares.

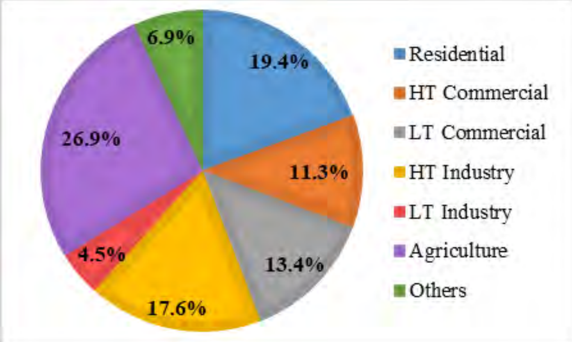

Figure 1: BESCOM Electricity Sales by Sector (2016)

DATA AND METHODS

Three primary data sets used in this analysis are as follows.

1. One-minute temporal resolution actual load data for the entire year of 2016 for every 11kV distribution feeder in the BESCOM territory (2,979 feeders in total). This data has operating zone details and was supplied by BESCOM.
2. Feeder-level consumer characteristics such as number of consumers in each sector category and zone broken down by electricity tariff slabs, average revenue in each month, and so on. This data was supplied by BESCOM.
3. A load survey performed by PWC / EESL in BESCOM's service territory to identify the penetration rates of certain key appliances and temporal profiles for various end-uses in the residential, commercial, agricultural, and industrial sectors (PWC, 2015). This data was supplied by BESCOM and EESL.

The analysis structure is shown in **Figure 2**. In step 1, we used programming languages Python and R to organize and clean the load data to create 15-minute averages for each of the 2,979 feeders. This feeder level load data is used in Lawrence Berkeley National Laboratory (LBNL)'s S-LOAD model that utilizes the feeder level consumer characteristics (described in #2 above) and the load survey data (described in #3 above) to decompose the total feeder load into various end-uses / appliances. In order to be computationally more efficient, S-LOAD decomposes the feeder load by sampling the most important feeders in terms of overall energy consumption. In Step 2, we used the consumer characteristics and load survey data from ~300 feeders (288 feeders to be exact in this study) covering over 30% of total annual energy consumption in BESCOM; 36 feeders were dedicated to residential areas / apartment complexes, 58 feeders were dedicated to industrial establishments (sum of

HT and LT), 31 dedicated to large commercial consumers like malls or large office buildings, 97 dedicated to agricultural consumers, 19 dedicated to other consumers, while 47 were mixed feeders for residential and small commercial or industrial consumers. S-LOAD can distinguish seasonal variations in daily/hourly load profiles to account for differences in human and economic activity. In Step 3, we use the month January to represent winter and April to represent summer. This is also consistent with the data presentation in PWC (2015). The appliance level load on each feeder is then used to assess the overall DR potential (Step 4).

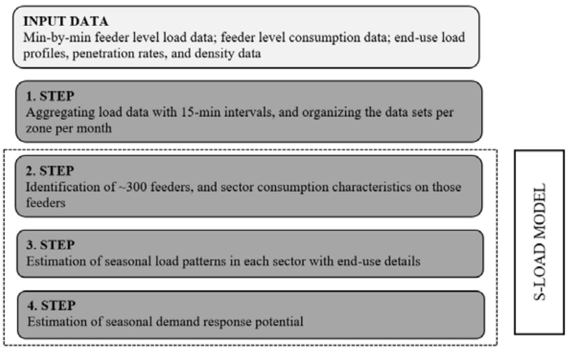

Figure 2: Summary of the Methodology

The model uses the annual 15-minute system load with operating zone detail to calculate the average daily load curves for each month with a 24-hour period. Next, the model creates the sector-level load profiles per momth based on the top 288 feeders. The remaining load calculated as the difference between the average daily load of a month and the sum of all sectors' loads in that month is labeled "Other". Each sector load is then decomposed to analyze the end-use details. In this analysis, S-LOAD uses load patterns (i.e., for a 24-hour period), appliance penetration, and appliance density (i.e., number of appliances per household or commercial unit) data from PWC (2015) for most appliances. For sectors that have no appliance (or end-use) penetration and/or hourly load pattern information, load characteristics from other cities are used, such as Garg et al. (2010). End-use decomposition of load curves is calculated as follows:

*End-use load (MW) = Average end-use load during the day (MW) * Load profiles* (1)

*Average end-use load during the day (MW) = Maximum possible end-use load during the day (MW) * Seasonal coincidence factor* (2)

*Maximum possible end-use load during the day (MW) = Total stock of end-use (million units) * Power consumption of end-use (W)* (3)

*Total stock of end-use (million units) = Total number of customers in sector i * end-use penetration * average density* (4)

In the final step, S-LOAD's DR potential module calculates the maximum DR potential of certain end-uses in each sector.

The sectors and end-uses included in this study are based on the BESCOM customer profiles and the end-uses provided in PWC (2015) survey.

Table 2 summarizes the unit power consumption levels, appliance penetration, and density levels used for the residential and LT commercial sectors in this study. Please see Karali et al. (2019) for the residential and LT commercial load profiles used in the analysis.

Table 2: Residential and LT Commercial Appliance Characteristics

		UEC	PENETRATION-DENSITY
Residential	Fan	70	94%-2.1
	Tube lights	60	75%-2.4
	Incandescent bulb	60	41%-2.2
	CFL	20	61%-2.9
	Electric water heaters	2,000	19%-1.1
	Refrigerator	55	48%-1.0
	Air conditioner	1,415	2%-2.0
	Television	80	80%-1.0
	Standby power	3	100%-1.0
LT Commercial	Fan	90	66%-1.8
	Tube lights	60	95%-3.6
	Incandescent bulb	60	20%-2.9
	CFL	20	42%-4.4
	Electric water heaters	2,000	2%-1.0
	Refrigerator	65	26%-1.1
	Air conditioner	1,415	3%-5.0

Note: UEC is unit energy consumption in Watts. Source: PWC (2015) and Abhyankar et al. (2017).

For the industrial sector, based on stakeholder consultations, we assume the end-use shares presented in PWC (2015)—5% pumps, 41% motors, 38% air conditioning, 10% thermal fluids, 6% others—of total daily industrial load are constant during the day across the LT and HT industrial sectors. On the other hand, the 100 industry customers surveyed by PWC (2015) include five information technology (IT) operations and two hotels that were on the industry-dedicated feeder. Thus, the real shares of industrial load from electrical equipment, particularly air conditioners, could be different.

In addition, because no directly relevant end-use information for HT commercial sector under BESCOM territory is provided by PWC (2015) or any other source, we base estimates for this sector on an analysis of commercial end-use loads from the state of Gujarat (Garg et al., 2010) after adjusting for the seasonal weather differences between Gujarat and Karnataka. Please see Karali et al. (2019) for the end-use shares that we used for HT commercial sector. Finally, because about 90% of Bangalore's agricultural load comes from irrigation, we treat the agricultural sector's load as one large end-use. For all sectors, we did modify the load shapes and shares based on inputs from BESCOM experts. In addition, because we analyze the region's entire stock of end-uses—hundreds of thousands of units of each—we do not consider load intermittency to be an issue.

DISCUSSION AND RESULT ANALYSIS

Figure 3 displays 15-minute load data aggregated at each of the three zones within BESCOM – BGM, BGR, and TMK. BESCOM's peak load in 2016 was about 3,505 MW, occurring on March 7 at 10:15 in the morning. The rural BGR and TMK zones peaked on March 2, while the urban BGM zone peaked on November 16. BESCOM's 2016 load factor is 0.7.

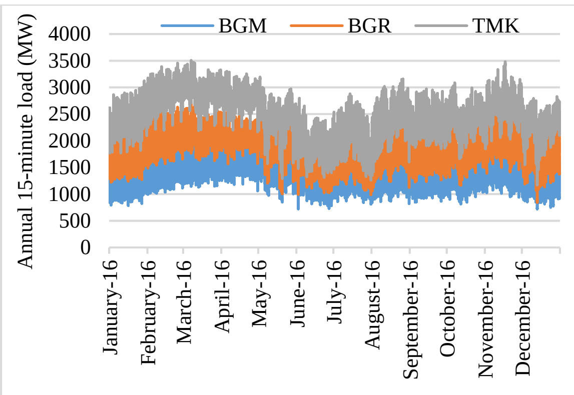

Figure 3: BESCOM 15-minute load in 2016 with operating zone detail

Figure 4 shows the BESCOM-wide 15-minute load curves, averaged for each month of 2016. Electricity demand is higher in February, March, and April. Summer peaks occur late in the morning (e.g., 08:00–10:00) and late in the evening (e.g., around 20:00-22:00). Electricity demand declines quickly in May. With the start of the monsoon season, June and July have the lowest electricity demand during most of hours of the day.

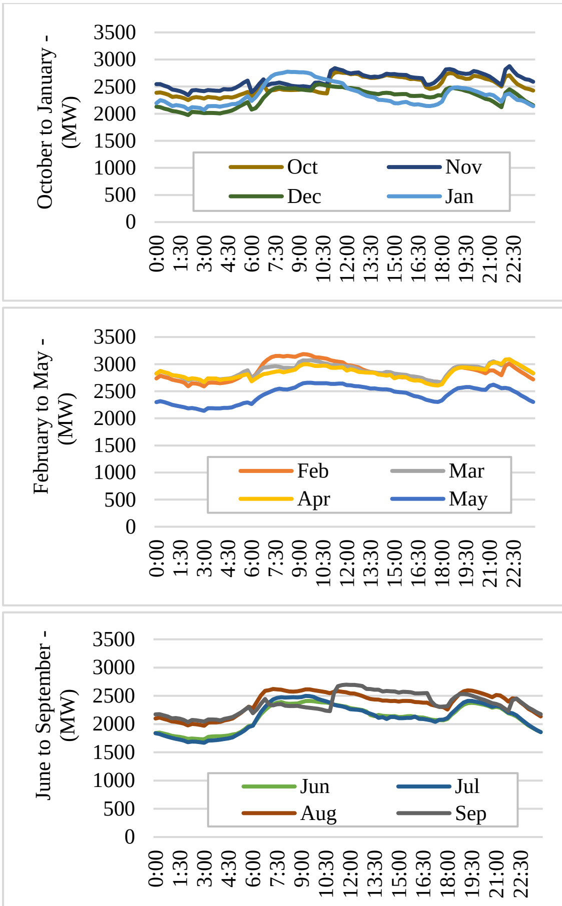

Figure 4: BESCOM-wide 15-minute average load curves for each month in 2016

BESCOM's average peak demand is estimated as 2,775 MW in winter and 3,090 MW in summer 2016 (**Figure 5**). Agricultural and residential demands decrease during the day, while LT commercial demand rises. Demands from the industrial sector (both LT and HT) and HT commercial sector are relatively constant, with some declines between 20:00 and 09:00 the next day. The two peaks in winter—with the morning peak higher than the evening peak—align with the residential load pattern.

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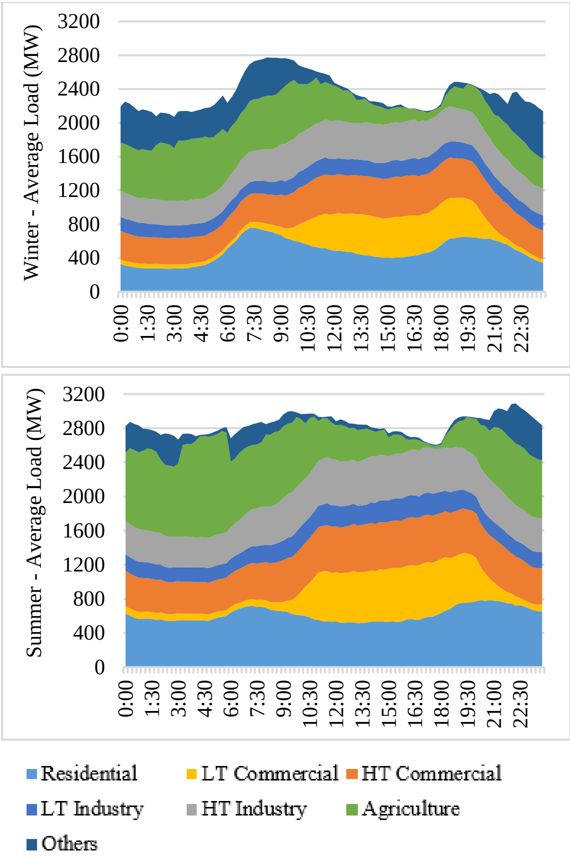

Figure 5: Average load curves with sector details

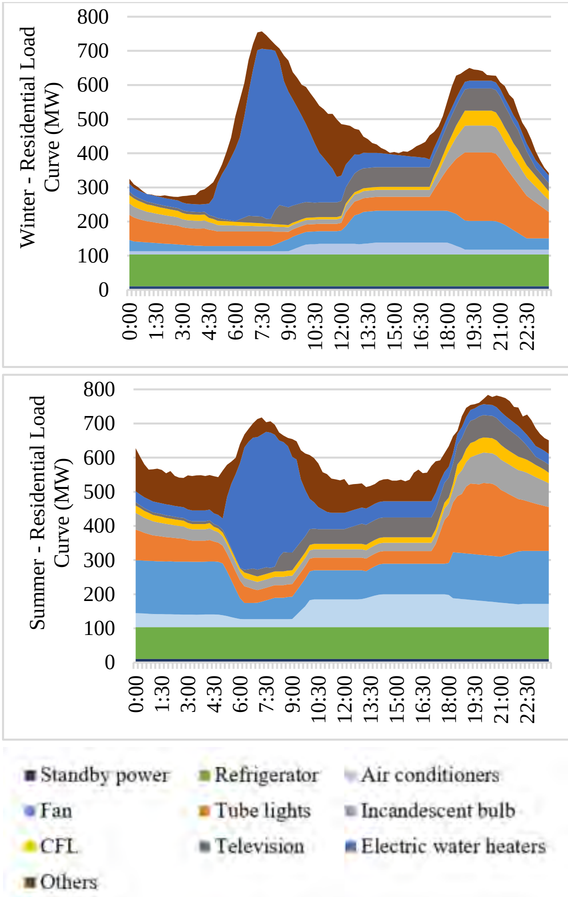

Figure 6: Average residential loads with end-use details

Residential Sector

As shown in **Figure 6**, BESCOM's average residential peak demand is estimated as 757 MW in winter and 784 MW in summer. The peak occurs in the morning in winter and in the evening in summer. Electric water heating accounts for almost 65% of the morning peak in winter and 56% in summer, even though the penetration of this appliance is assumed 19% with 1.1 density. Increasing demand for cooling is the reason for drop in hot water demand in summer mornings. In contrast, the evening peaks are mainly driven by lighting across the seasons (winter–55% and summer–40%). Cooling demand (both fans and air conditioners) accounts for 15% of the evening peak in winter and 27% in summer.

HT Commercial sector

BESCOM's demand from the HT commercial sector peaks around 10:30 and remains relatively constant until around 19:30, with minor variations in summer and winter (**Figures 7**). Average peak demand for this sector is estimated as 478 MW in winter and 561 MW in summer. The peak occurs during the evening in winter and late afternoon in summer.

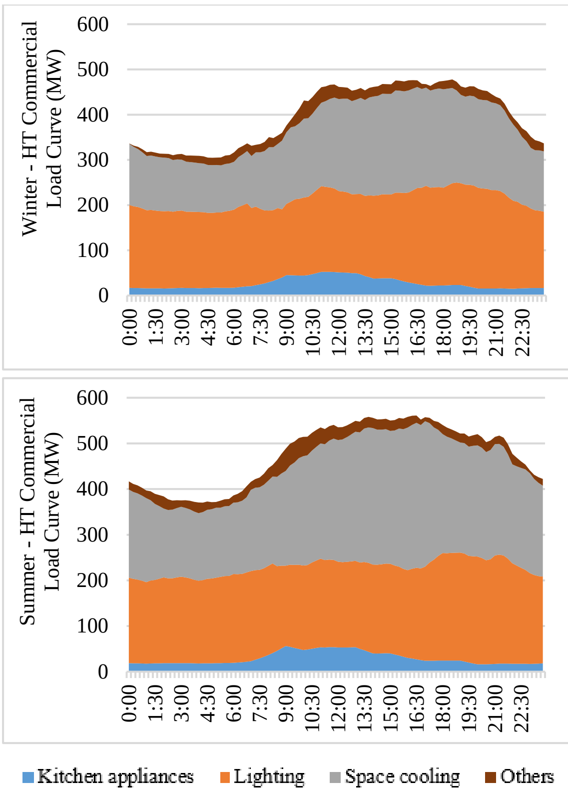

Figure 7: Average HT commercial loads with end-use details

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LT Commercial sector

BESCOM's LT commercial demand starts peaking around 13:00 and stays relatively constant until around 18:00, with some variations, in summer and winter (**Figure 8**). Average peak demand is estimated as 493 MW in winter and 644 MW in summer. Primary contributors to the peak include lighting (36% in winter, 29% in summer) and space cooling (fans plus air conditioners: 36% in winter, 50% in summer).

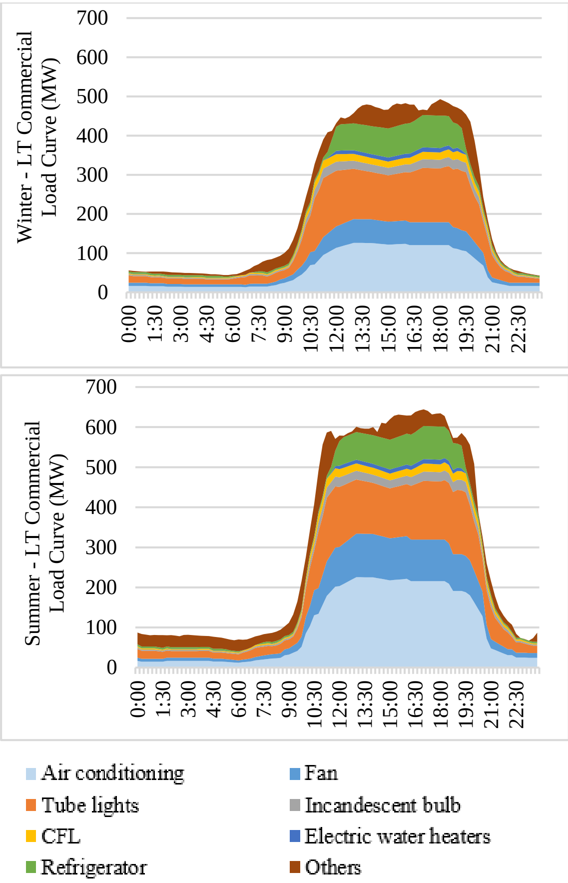

Figure 8: Average LT commercial loads with end-use details

Industrial sector

HT and LT industrial loads are based on the electrical equipment shares listed in Data and Methods section. We apply these shares equally across the day and seasons (**Figure 9**). In addition, as mentioned, industrial customers surveyed by PWC (2015) to calculate those shares include five information technology operations and two hotels that were on the industry-dedicated feeder. Thus, in reality, air conditioning share on hourly load curve could be much smaller.

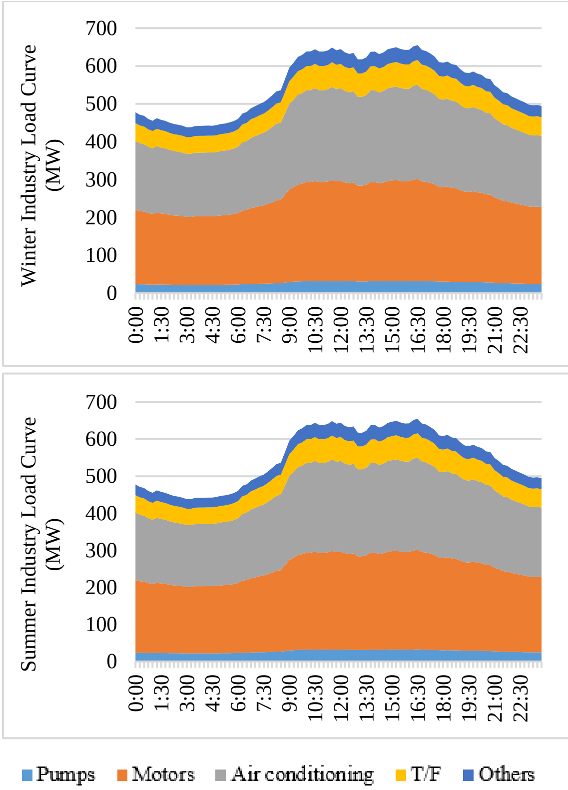

Figure 9: Average industrial loads with end-use details

Agricultural sector

Figure 10 shows the agricultural load curves in winter and summer. Based on temperature and precipitation, the patterns change significantly between seasons and even among months within a season. However, the power cut off to this sector from 6:00 to 22:00 creates large variations between maximum and average demand, particularly in the summer months: 727 MW compared to 445 MW in winter and 1,199 MW compared to 625 MW in summer.

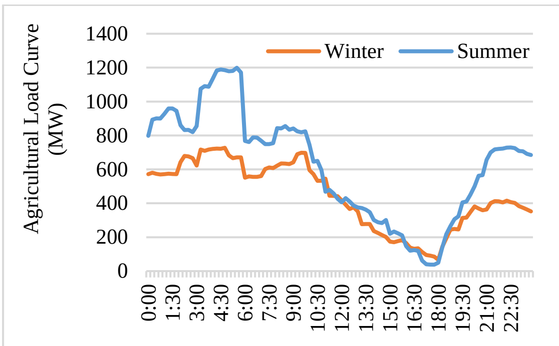

Figure 10: Average agricultural loads

END-USE DR POTENTIAL

Figures 11 shows average hourly winter and summer load curves decomposed into 34 end-uses – covering all major consuming sectors and clearly illustrating the key peak drivers. For example, the agricultural sector

(23%) and residential electric water heaters (18%) are the primary contributors to the winter morning peak, at around 08:00; total cooling demand from all sectors (14%) are other sizable contributors. In summer, the agricultural sector's share of the peak increases to 27%, while the share from residential electric water heaters drops to 6%; the peak time of 09:30 explains the lower share of water heater demand. Total cooling demand rises to a 23% share.

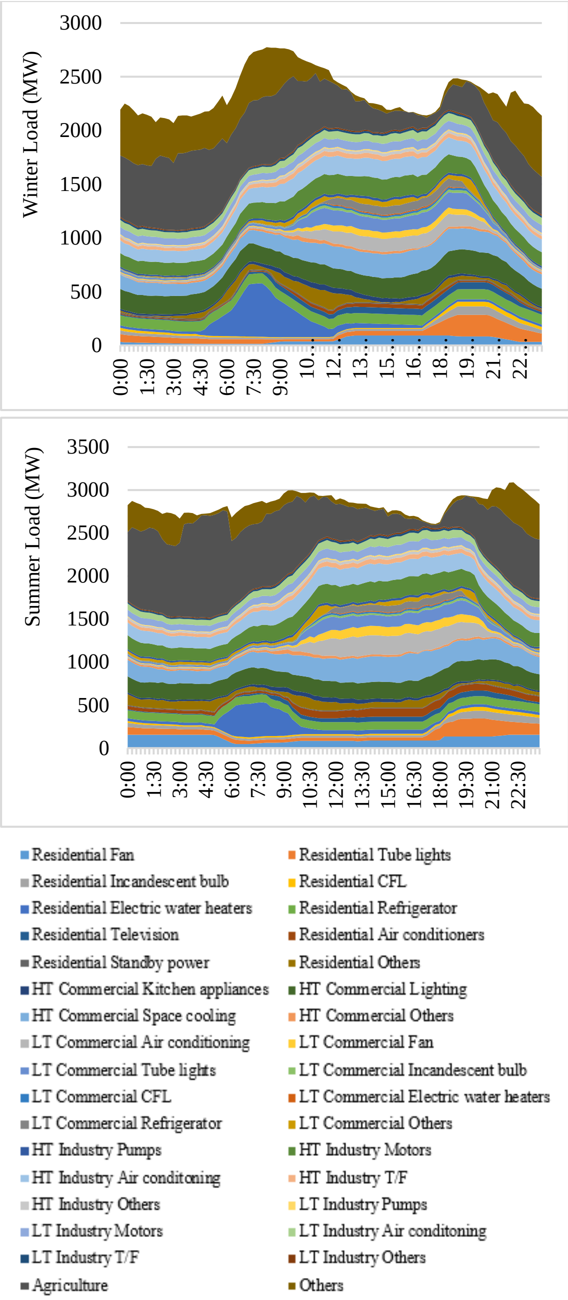

Figure 11: End-use shares on average winter and summer loads

Table 3 displays the total technical DR potentials of the key end-uses. Based on the work of Alstone et al. (2016), we have considered the following three DR services: (a) "Shift" represents DR that enables the movement of energy consumption from times of high demand to times of surplus of renewable generation or low energy market prices; (b) "Shed" describes loads that can be curtailed to provide peak capacity and support the system in emergency or contingency events—at the statewide level, in local areas of high load, and on the distribution system—with some advance notice; and (c) "Shimmy" involves using loads to dynamically adjust demand on the system to alleviate short-run ramps and grid disturbances at timescales ranging from seconds up to an hour, such as through ancillary services or frequency regulation.

Contributions from each end-use in **Table 3** are based on our stakeholder interactions in India and existing DR programs in other countries including the U.S. For example, air conditioners could offer shed service such as voluntary demand reduction or shimmy service by changing the output/set-point for a short duration such as Direct Load Control DR programs in California. Agricultural pumping cannot offer shimmy service but they can offer shift service, as already practiced by several utilities in India. Industrial consumption cannot be shifted to other hours of the day and therefore can only offer the shed service. For each end-use, **Table 3** also shows the technical DR potential in the BESCOM territory, which is the total load for that end-use.

Overall, we find that agricultural (via load shifting) and space cooling (via shimmy service) end-uses each offer ~1,000 MW of DR potential. Residential electric water heaters can also offer ~500 MW in shimmy service. The results show that shifting and shimmy services offer 1,199 MW and 1,511 MW total DR potential, respectively.

Note that **Table 3** only shows the total DR potential; further analysis is required for assessing the economic and market potentials for these services and end-uses.

Table 3: Maximum end-use DR potential in each sector

SECTOR	END-USE	MAX DR POTENTIAL (MW)	DR SERVICE
Residential	Air conditioners	96	Shed, shimmy
	Refrigerators	93	Shed
	Water heaters	497	Shed, shimmy
HT Commercial	Kitchen appliances	56	Shed, shimmy

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	Space cooling	319	Shed, shimmy
LT Commercial	Air conditioners	226	Shed, shimmy
	Refrigerators	83	Shed
	Electric water heaters	11	Shed, shimmy
HT Industry	Pumps	27	Shed
	Motors	224	Shed
	Air conditioners	207	Shed, shimmy
LT Industry	Pumps	13	Shed
	Motors	107	Shed
	Air conditioners	99	Shed, shimmy
Agriculture	Agricultural pumps	1,199	Shift

CONCLUSION

This study analyzes the sectoral and end-use details of BESCOM load curves in 2016 as a way to estimate the potential for DR to reduce peak loads. The largest drivers of the winter peak, around 08:00, are the agricultural sector (23%) and residential electric water heaters (18%). The summer peak is around 09:30, and the agricultural sector's share increases to 27%, while the share from residential electric water heaters drops to 6%, mostly because hot water demand declines later in the morning while cooling demand increases across all sectors. Cooling demand from all sectors contributes 23% to the peak in summer, compared with 14% in winter. Overall, we find that agricultural and space cooling end uses each offer ~1,000 MW of DR potential – agricultural pumps offering load shifting service while space cooling offering shimmy service. Residential electric water heaters can also offer ~500 MW in shimmy service. The results show that shifting and shimmy services offer 1,199 MW and 1,511 MW total DR potential, respectively.

Our results entail several caveats and limitations. Assumptions around variables—penetration of end-uses in particular—are subject to uncertainty. All of our end-use inputs are based on survey data, but the survey samples might not accurately represent the entire population. To address this concern, we held multiple workshops to address data issues with the BESCOM team, and the final results and trends were validated by BESCOM experts. As an example, if we changed the penetration of residential electric water heaters to 15% and 25%, the DR potential of this end-use would be ~390 and 650 MW. In addition, because Karnataka (including the BESCOM territory) experienced power cuts in 2016, feeder-level actual load data may exclude significant pent-up demand, especially from the residential and LT commercial sectors. As a result, total load and DR potential estimated in this study may be underestimated.

Our future work may include refining our analysis by using end-use level temporal consumption data, assessing the cost-effectiveness of different DR services, assessing the strategies for dispatching the DR for load management by the utility, and leveraging this analysis to assess the future peak load impacts of certain key end-uses such as air conditioners.

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