Variations in residential electricity demand across income categories in urban Bangalore: Results from a primary survey

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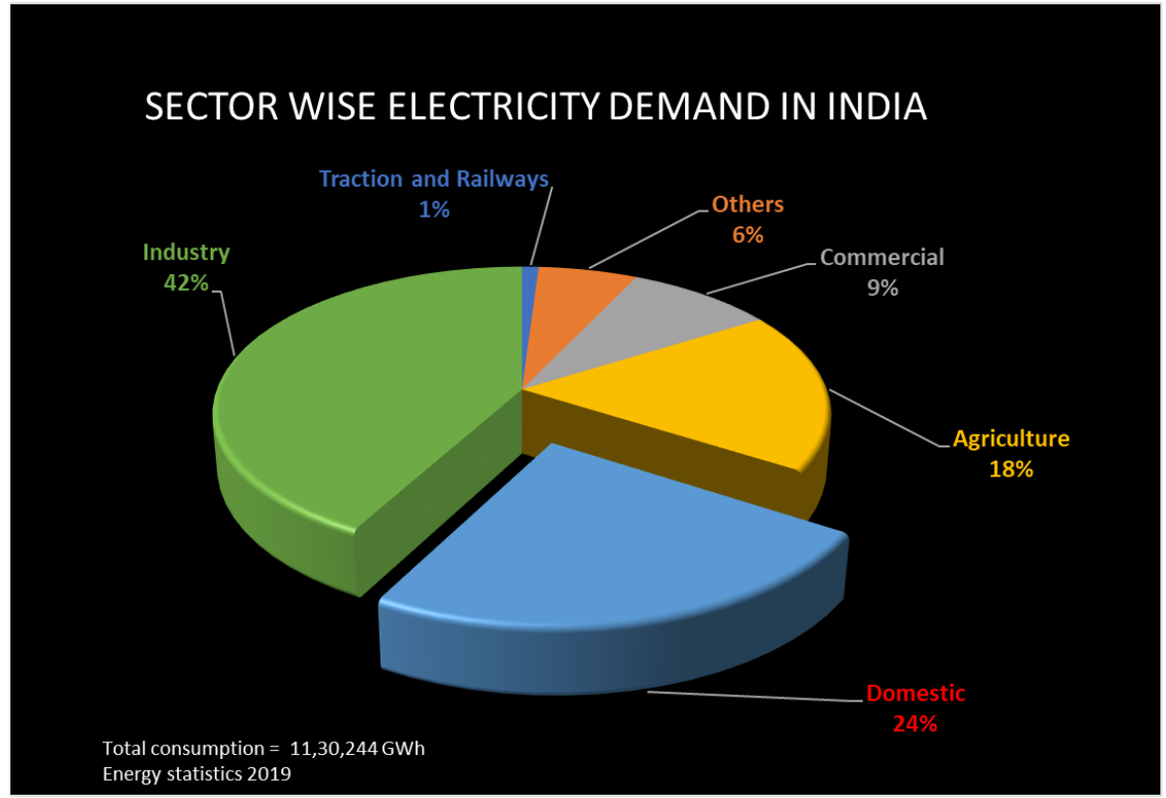
Presentation Outline

- **Quick overview**
  - Understanding REC and Collecting REC data
- **Residential electricity use data**
  - Current limitations
  - A survey of Bengaluru
- **Residential electricity survey of Bengaluru**
  - Questionnaire design
  - Identifying representative sample to survey
  - Key statistics and results
  - Load curve model and load curves
- **Policy interventions based on survey results**
  - Solar PV policy in Karnataka
- **Summary**
- Appendix

Quick overview: Residential Electricity Consumption(REC)

- **REC:** Total **electricity used by households** to meet various end use needs
- About 50% increase from 1971, **growing at 9% annually** between **2000-2016**, constitutes **24% of total demand**
- **Increase will continue:** universal access, improvement in quality of supply, increasing incomes and affordability, higher penetration of lifestyle appliances
- Understanding changing trends in consumption key for realistic estimation of future demand



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Quick overview: **Understanding REC and Collecting REC data**

Importance of understanding REC

- Integrated planning
  - **Targeted DSM** programs, **refined dispatch planning** for efficient **peak management**, better inputs for energy models
- Improved adoption of new technologies and efficiency programs
  - Better **planning** with **RE integration**
  - **Awareness** for purchase of efficient appliances, **stricter efficiency standards** (star rating)

Few methods of collecting usage data

- **Smart meters** for household level and **energy consumption meters** for individual appliances
- **Surveys**

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Residential Electricity use Data: Current limitations

- **Smart meter** programs still **nascent, privacy** concerns, no open access to pilot program data
- Currently **no comprehensive REC surveys** that covers the entire country
- **Open access surveys** NSSO, CENSUS, IHDS **do not cover all aspects**
  - **Covers** appliances ownerships, electricity access information
  - **No** temporal data, age of appliances, usage patterns, etc.
  - **Integrating** these **surveys** will **not produce** significantly **different results** to better estimate REC
- Surveys by BEE and other agencies with ESCOMS, **data is not open access**
- Data on appliance ownership and usage patterns provides better insights into REC

Prayas REC in india, 2016, Murthy,Sumithra and reddy, 2001

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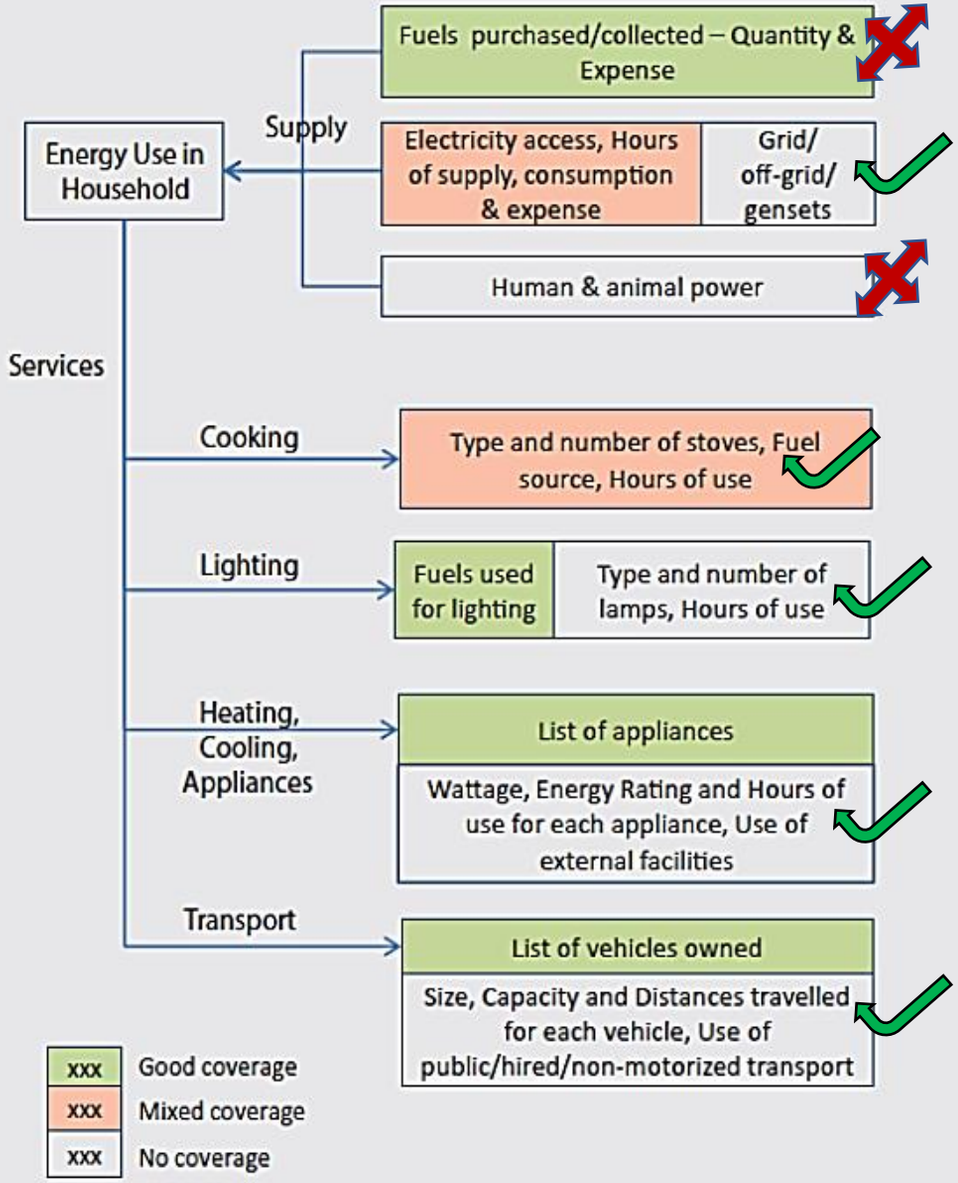
Residential Electricity use Data: **A survey of Bengaluru**



- Given **limitations on data**, we **conducted a survey** in **urban Bengaluru** to understand how households consume electricity
- The **goal** of the survey was to
  - Capture **ownership data** of various appliances including capacities/sizes, wattages, star rating, etc.
  - Collect **time** of use and **seasonality of use**
  - Produce **daily load curves** for urban Bengaluru
- To design an effective questionnaire we covered some indicators listed in Dukkupadi et al. (2014)
- Green check marks show indicators covered in our questionnaire and red for the ones not covered

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Residential Electricity Survey of Bengaluru: Questionnaire design

Basic household information

- Area
- Type
- Ownership
- Gender of head

Area
- Location of the household

Type
- Apartment
- Independent

Ownership
- Own
- Rent
- Lease

Demographics and income profiles

- **Total residents** (T,M, F, C)
- **Built area**
- **Number of rooms**
- **Earning members** (T,M, F)
- **Income Bracket** (5 brackets)

Income brackets
- < 2L
- 2L to 4L
- 4L to 7L
- 7L to 10L
- > 10L

Members
- T : Total residents
- M: Total Male
- F: Total Female
- C: Total Children

Basic electricity information

- **Bill amount** (3 periods)
- **Hours of power cut**
- **Bill paid to**
- **Type of backup used**

Bill amount periods
- Summer
- Winter
- Survey Month

Appliances Owned

Living spaces
- Lighting
- Space cooling and heating
- Entertainment and Productivity

Kitchen and utility
- Lighting
- Appliances

Bathroom
- Lighting
- Water heating appliances

Lighting types
- Incandescent, Tube Light, CFL, LED

Space comfort :
- Fan, Cooler, AC, heater

Ent & prod
- CRT, LCD, LED, Other
- Laptop, Desktop

Kitchen and utility
- Refrigerator, Microwave, Induction, gas stove, washing machine, motor

Water heating
- Geyser, immersion, solar, gas, stove, firewood, other

Vehicle ownership and usage

Traditional
- 2 wheeler
- 4 wheeler

Electric
- 2 wheeler
- 4 wheeler

Usage
- Fuel type
- Weekly frequency
- Distance
- Preferred Public transport

Preferred public transport
- Bus
- Cab
- Auto

Propensity to buy

Appliances
- AC
- Cooler

Electric vehicles
- 2 wheeler
- 4 wheeler

Propensity to buy

Appliances
- Next one year

Vehicles
- Next five years

Usage

Times of the day
- **Peaks**
  - 6am-10am
  - 6pm – 11pm
- **Non-Peak**
  - 10am-6pm
  - 11pm-6am

Seasons
- Summer
- Winter

Duration of use
- Hours/minutes used

Appliance Descriptors

- **Numbers owned**
- **Size/capacity**
- **Wattage**
- **Star rating**
- **Age**

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Residential Electricity Survey of Bengaluru: Identifying representative sample

Survey population size

- Population of Bangalore **8.5 million** (census 2011)
- Confidence level of **95%**
- Survey population **385**
- Totally **surveyed 403** households

Identifying areas to survey

- Had to design **survey** to be **representative**
- Identify **Bangalore's** household distribution
- Identify **wards** with similar distribution
- **No open access survey** that covers all households and has income information
- **Used Census 2011**, chose 5 out of 26 categories covered
- HH type, No. of rooms, No. of residents, source of lighting, assets owned
- Constructed **Asset, room, resident** and **congestion indices**

Constituency identification

- **Grouped wards** at **assembly constituency** level to identify intra ward variance
- Identified **10 wards with 10% variation** compared to Avg. Weighted Bangalore asset value
- Further **shortlisted 5** that had
  - Avg. Wt. asset, room and resident values close to Bangalore
  - **Max**(**intra constituency** avg. wt. **asset** value range)

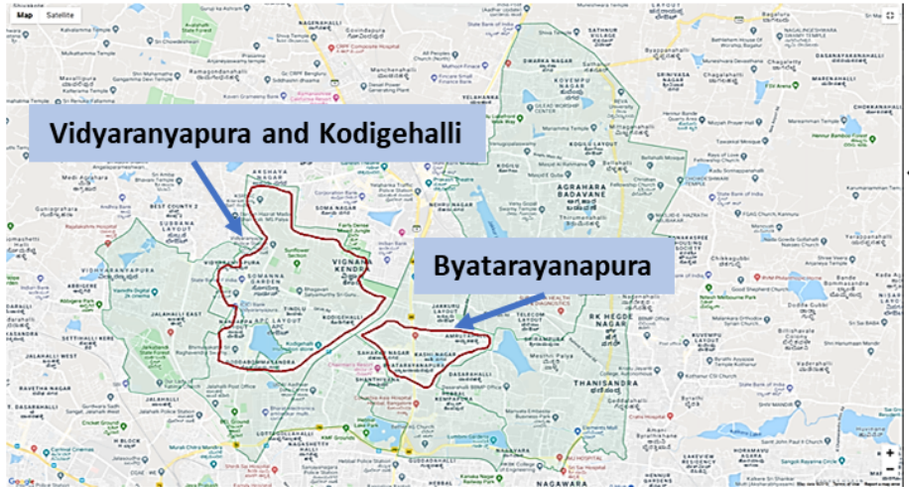
Final wards identification

- Similar methodology carried out on shortlisted constituencies
- One constituency shortlisted
- Distributions of shortlisted constituency's ward indices compared to Bangalore
- **Three out of seven wards** chosen finally to **Survey**

Household type identification

- **BBMP – SWM** (Bangalore municipal body) has data of **wards split into blocks**
- **Shortlisted** wards had a total of **65 blocks**
- Each **block** has between **800-1000 households**
- Further classified into Regular, Apartments, Slums
- Regular households further classified into high, mixed incomes and slums

Category	Slums	Apts	High income	Mixed income	Low income
Bengaluru	7.13	6.41	16.19	35.65	34.62
Vidyaranyapura	1.54	8.75	22.86	38.53	28.35
Byatarayanapura	4.86	5.79	22.00	43.98	23.38
Kodigehalli	2.32	6.02	21.38	43.88	26.40



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Residential Electricity Survey of Bengaluru: **Key statistics, need for quintile split**

Dwelling types	
Type	**Percentage**
Independent households	90.32
Low income households	10.17
Apartments	9.68

Ownership of Households	
Status	**Percentage**
Households owned	67
Households Rented	30.77
Households Leased	2.23

Electricity bills	
Period	**Average Value**
Survey Month	1084.83
Summer	1258.83
Winter	1085.08

- On the left are statistics of coverage from the survey
- Ownership **statistics** in **aggregate** will **not give** us **distributions** of **ownership** of appliances
- Appliance **ownership** follows a **preference ladder** linked to **income** levels
- **Variation** in **demand** therefore can be observed as **income varies** and can be looked at as a function of three composite variables

$$E_H = f(\mathrm{A}, \mathrm{C}, \mathrm{D})$$

- Makes sense to divide data into **income** (or income representative) **quintiles**
- We **asked** for which **income bracket** a household fell into (5 brackets)
- **47%** of the households **did not respond** to which bracket they fell into
- Used **Principal component analysis** to divide the data into 5 quintiles

Murthy, Sumithra and Reddy, 2001, Pachauri 2004, World Bank 2008, Ruijven 2008, Garg 2016, N.Rao 2017

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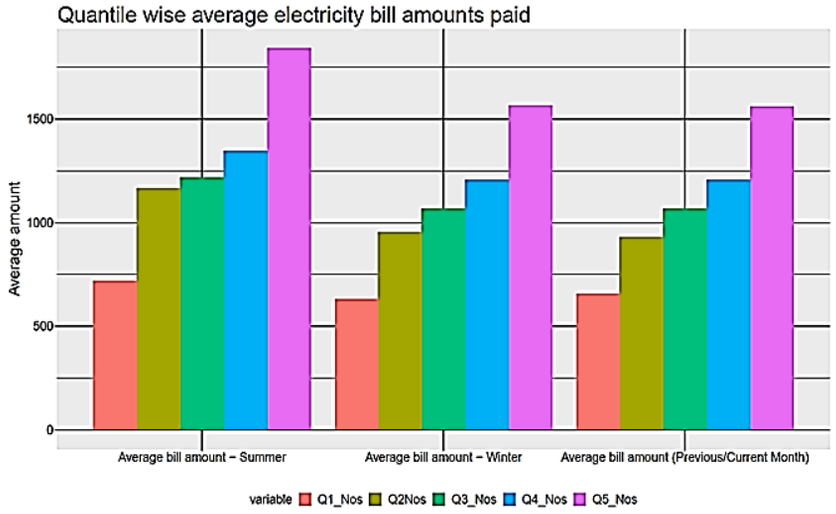
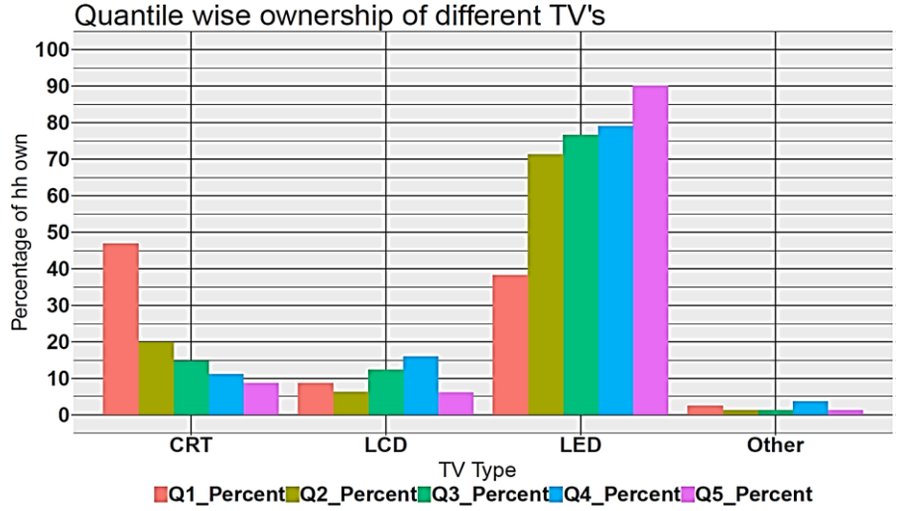
Residential Electricity Survey of Bengaluru: **Quintile statistics**



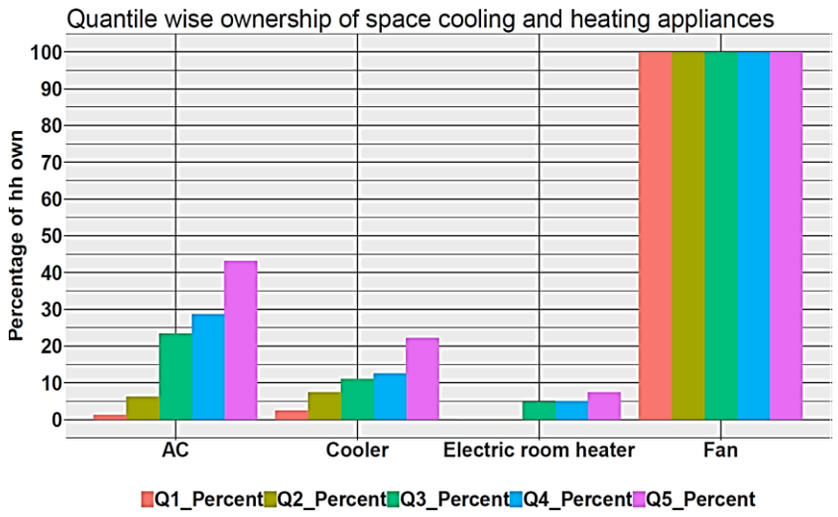
Bill amounts seasonally



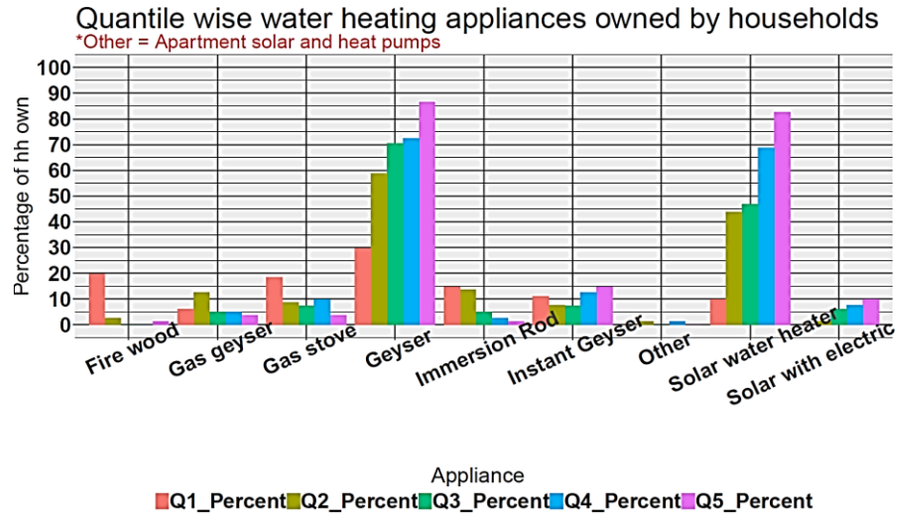
Entertainment appliances

- Quintile wise statistics for
  - Electricity bill amounts
  - Entertainment appliances
  - Space cooling and heating
  - Water heating appliances

- **Influence of income** on **ownership** and **usage** (bill) of these appliance categories can be seen clearly



Space cooling/heating appliances



Water heating

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Residential Electricity Survey of Bengaluru: **Load curves**

- **Load curves** gives us an understanding of the **pattern of energy consumption** in households
- We built a **model** to generate **load curves** based on **4 time slots** (resolution of data collected)
- We **modified** this **model** to generate **load curves** at an **hourly** resolution
  - Assumptions data/work by NEEM (EDS) national survey, Prayas, IIM-A
  - Temperature and daylight profiles for Bangalore
- Estimated energy consumed by a household using

$$\mathbf{E = \sum_{j,t,s,k}\{\sum(A_{i,k}|T_{t,s} = 1) * P(H_{T,Ai}) * W_{avg\ Ai}\}}$$

Where,

A_i = i^{th} appliance

J = j^{th} household (1:403)

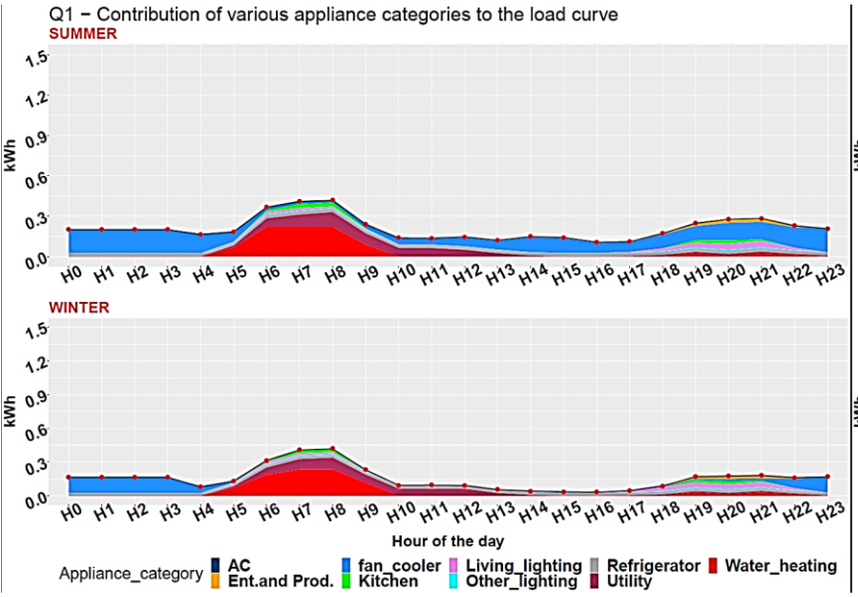
T_t = one of 4 time slots for which usage data was collected (6am-10am, 10am-6pm, 6pm-11pm, 11pm-6am)

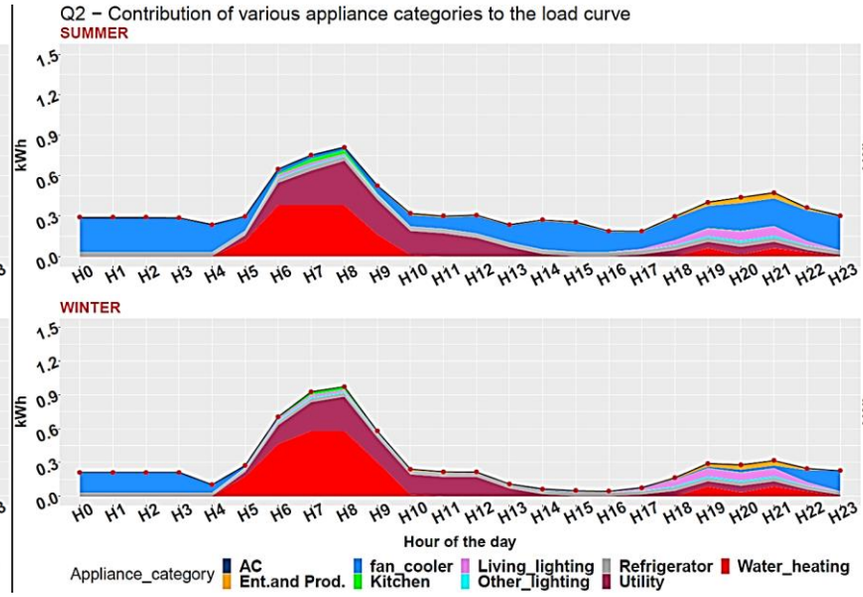
S = season (Summer or winter)

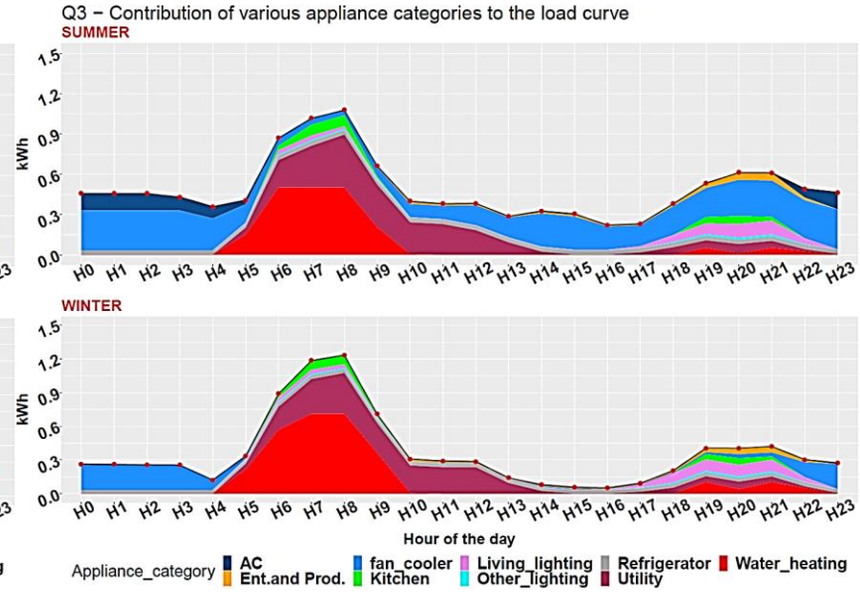
$P(H_{T,Ai})$ = Probability of appliance i being used at hour T

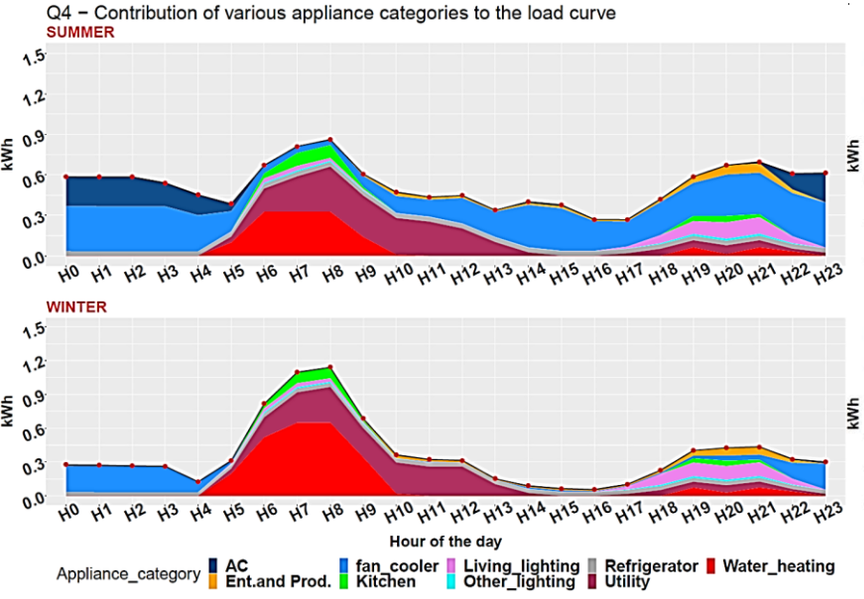
$W_{avg\ Ai}$ = Average wattage of the i^{th} appliance

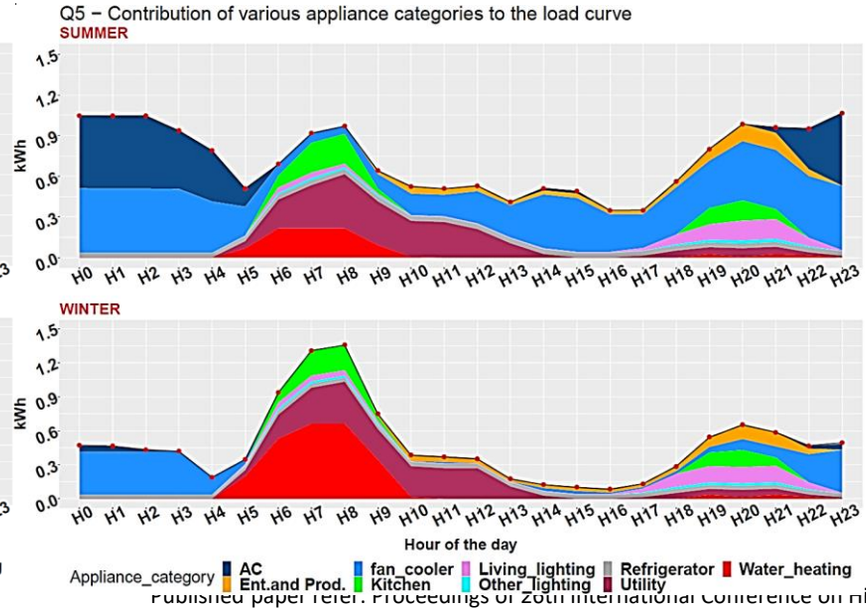
Residential Electricity Survey of Bengaluru: **Load curves**











- **Load curves** are at **hourly** resolution and indicate the **contributions** made by different **appliance categories** in **each** income representative **quintile**

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Policy interventions based on survey analysis: Push for solar rooftop

Karnataka's rooftop policy

- Target of **2.4GW** by march **2021**
- **145MW** as of March **2018**, <10% of target

Approximate costs of solar rooftop and feed in tariff (FIT)

- **Subsidized** system ₹48,000/kW (~$700/kW), **unsubsidized** ₹65,000 to ₹75,000 (~$1100/kW) for units below 5kW
- **FIT** ₹3.08 (subsidized), ₹4.15 (unsubsidized)

Target households

- Two primary **criteria – affordability** and **roof top space**
- Affordable by **top two** may be **three quintiles**
- Approximately 120-150 sqft for installation of 1kW
- **Top two** or **three quintiles** only have the **rooftop space**
- Cost of solar water heaters close to solar PV per kW
- Good proxy to narrow down target audience

	Q1	Q2	Q3	Q4	Q5
Avg built up area (sqft)	667.41	938.75	1154.5	1262.2	1740.4

Average built up area quintile wise

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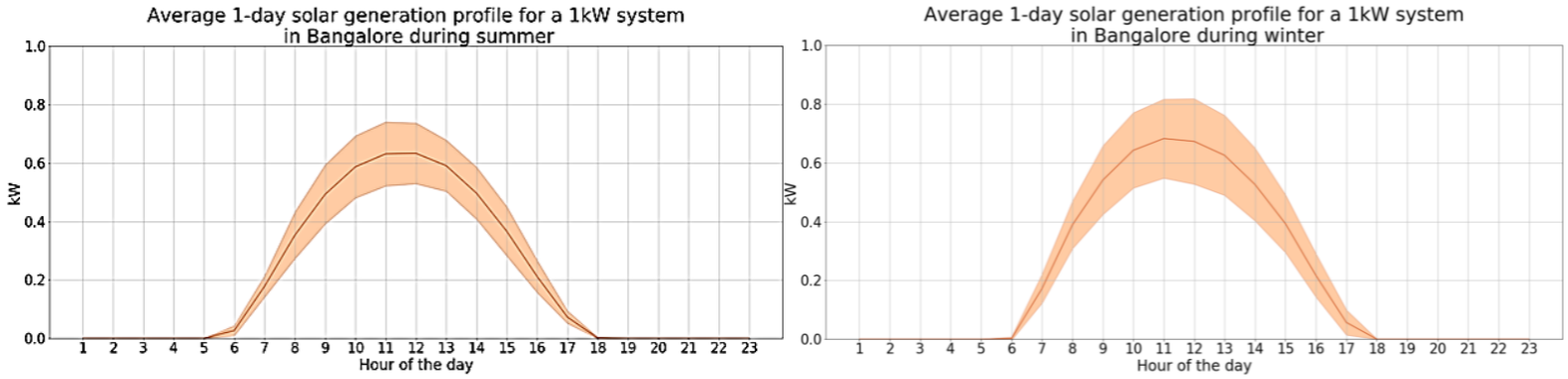
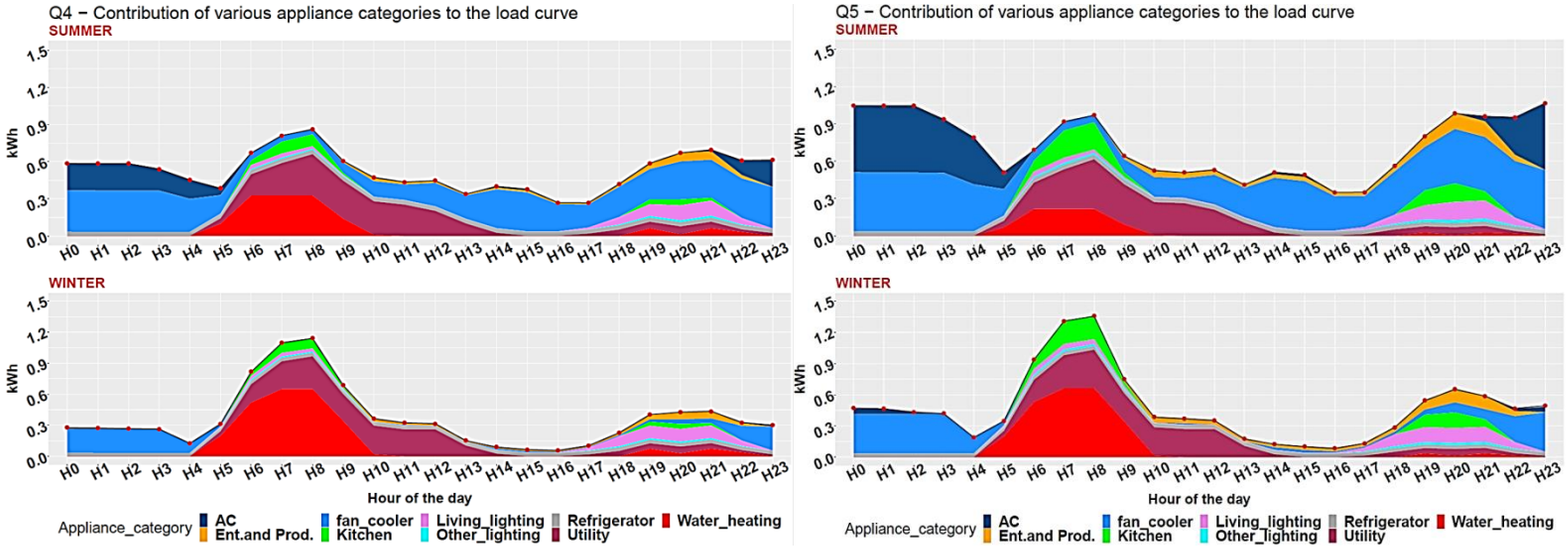
Policy interventions based on survey analysis : **Solar profiles for Bengaluru**

Figures:

Typical generation from **1 kW** solar PV in Bengaluru, **Summer and winter**

Summer and **winter load curves** for households in **Q4** and **Q5**





- **Mismatch** between solar peak **generation** and average household **demand**
- **Summer** will see **higher consumption** of generated solar electricity than winter
- Safe to assume **large part** of roof top **generation** will be **fed back** to the grid
- **Well structured FIT** a good **incentive** to install roof top solar
- Currently a **flat rate** of ₹3.08 or ₹4.15 offered

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Policy interventions based on survey analysis : **Suggestions for policy amendments**

Units	Tariff charged for different slabs (INR)	FIT Subsidized (INR)	FIT Unsubsidized (INR)
0-30	3.75	3.08	4.15
31-100	5.2	3.08	4.15
101-200	6.75	3.08	4.15
Above 200	7.8	3.08	4.15

- **End users tariffed** by ESCOM in a **slab wise** tariff
- Units fed not deducted from bill in case of Net metering
- **Flat rates** for **FIT** and **Net metering tariff** given

Comparison of ROI calculations with 100% and 50% fed back

1: Net metering with units fed deducted from bill, effectively slab wise FIT

2: Flat FIT

ROI based on net metering					
S1: 100% fed to grid					
Size	Average Units Per Month	Subsidized Price (INR)	ROI Subsidized (Years)	Unsubsidized Price (INR)	ROI Unsubsidized (Years)
1 kW	150	48000	4.91	70000	7.17
1.5 kW	200	72000	5.21	105000	7.60
2 kW	250	96000	6.64	140000	9.69
S2: 50% - 50% consumed - feed in					
Size	Average Units Per Month	Subsidized Price (INR)	ROI Subsidized (Years)	Unsubsidized Price (INR)	ROI Unsubsidized (Years)
1 kW	150	48000	11.54	70000	16.84
1.5 kW	200	72000	12.59	105000	18.36
2 kW	250	96000	12.40	140000	18.08

Net metering

1

ROI based on Fixed feed in tariff (FIT)					
S1: Fixed tariff					
Size	Average Units Per Month	Subsidized Price (INR)	ROI Subsidized (Years)	Unsubsidized Price (INR)	ROI Unsubsidized (Years)
1 kW	150	48000	8.66	70000	9.37
1.5 kW	200	72000	9.74	105000	10.54
2 kW	250	96000	10.39	140000	11.24
S2: 50%-50% consumption - feed in					
Size	Average Units Per Month	Subsidized Price (INR)	ROI Subsidized (Years)	Unsubsidized Price (INR)	ROI Unsubsidized (Years)
1 kW	150	48000	17.32	70000	18.74
1.5 kW	200	72000	19.48	105000	21.08
2 kW	250	96000	20.78	140000	22.49

Fixed FIT

2

- "**Net metering**" or effective variable price structure offer **better ROIs**
- Could **incentivize users** to consider installation
- Coupled with **improved depreciation** rates
- Currently 70% spread over 13 years and 30% spread over remaining 12 years of warranty
- **Current policy** structure is **more suited** to **commercial** consumers who pay **higher prices**
- At **~₹8/unit**, **ROI** for **commercial** is **4 years** for **2 kW** system, **not considering depreciation**

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Summary

- Currently **no comprehensive survey** that **collects data** to get a better understanding of **REC**
- Important to understand REC for better dispatch and integration planning
- **REC accounts** for **24%** of the **total** national electricity **demand**
- In order to address this gap, **we designed** and **conducted** a **representative urban survey** of **Bengaluru**
- From the results we saw the **relationships** between **appliance ownership** profiles and **electricity consumed**
- Key contributors included space cooling and water heating
- We saw the **differences in types of appliances** of **each category** owned **across income** representative **quintiles** and their **impacts on** the **demand patterns**
- We **generated load curves** indicating **contributions** of **each appliance category** across different income quintiles, seasonally
- Based on the understanding from the load curves generated we **analysed** the **solar roof top policy** in **Karnataka**
- We **identified** the **shortcomings** in terms of **tariff structure** currently in place and **suggested amendments** that could incentivise users to adopt solar rooftop PV
- Overall making a case for more data driven analysis and policy formulation

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