Behavioural Dimensions in the Indian Power Sector

Electricity to play a pivotal role in India's energy decarbonization

- The three key elements underpinning India's energy sector decarbonization include:
  - Decarbonization of electricity
  - Electrification of end-uses
  - Improvement in energy efficiency

- The role of electricity in this transition is undeniable
  - Goal no. 4 of India's NDC targets to achieve 40% cumulative installed capacity from non-fossil sources
  - World Economic Forum states that electrification can supercharge the energy transition
  - IRENA anticipates that electrification of energy services will be pervasive while BP estimates that share of electricity as a form of energy will rise up to 50%
  - Bloomberg projects that electrification can cut emissions from transport, buildings and industries in Europe by 60% by 2050

- Improving our understanding of demand and supply of electricity is paramount
  - Need to understand the aspects of electricity demand (e.g. load curves)
  - Deepen our understanding of electricity supply constraints (e.g. intermittence of renewables)
  - Strengthen our ability to forecast future electricity demand
  - Improve our ability to integrate electricity demand with supply constraints

An overview of the study

- Under the Norwegian Framework Agreement (NFA), TERI undertook this study between 2016 and 2019 with the following objectives:
  - To deepen the understanding of electricity demand at a more granular level (both spatially and temporally)
  - To integrate demand side behavior with supply side intermittence in an energy system model

- The key research questions raised in this study include:
  - How is the electricity demand expected to increase as the economy develops?
  - Which end-uses are likely to exhibit changes in terms of levels and patterns of consumption?
  - What is the regional variation in terms of electricity consumption, and how is it likely to evolve?
  - How can renewables be integrated in the electricity grid while ensuring that electricity demand is fulfilled?

Structure of the study

- The study was divided into two work packages (WP):
  - WP1 focused on estimation and forecasting of electricity service demands for various sectors across five grid regions within India
    - Methodology: Survey; Secondary data
    - Geographic coverage: 2 states each from the five grid regions of India
      - North-Punjab, Uttar Pradesh
      - East- Bihar, Jharkhand
      - West-Madhya Pradesh, Maharashtra
      - South- Karnataka, Kerala
      - North-East- Manipur, Mizoram
  - WP2 focused on integration of electricity demand and supply to better represent demand load curves and supply intermittency
    - Methodology: TIMES energy system model
    - Geographic coverage: National level model with five regions

End-Use Electricity Demand Estimation

Residential Sector

Rationale for end-use electricity demand estimation

- Electricity consumption data aggregated at the sector level can provide limited insights:
  - Different end-uses exhibit different trends of electricity consumption (e.g. efficiency improvement trajectory)
  - Different income groups and different regions show different pattern of consumption
  - Introduction of new technologies (e.g. electric cooking) can change the load curve significantly

- Analysis at a more disaggregated level can strengthen the analysis substantially:
  - Strengthening electricity demand forecast at a more granular level
  - Estimation of base-load and peak-load requirements
  - Identification of need for demand side management (DSM)
  - Leveraging behavioral aspects of consumers to facilitate peak-shaving, etc.
  - Capturing the effect of households moving into higher income groups

- Such an analysis is challenging due to numerous data gaps
  - Appliance penetration data available for 2006 and 2011 from NSSO survey data
    - But this data lacks technological granularity and usage pattern
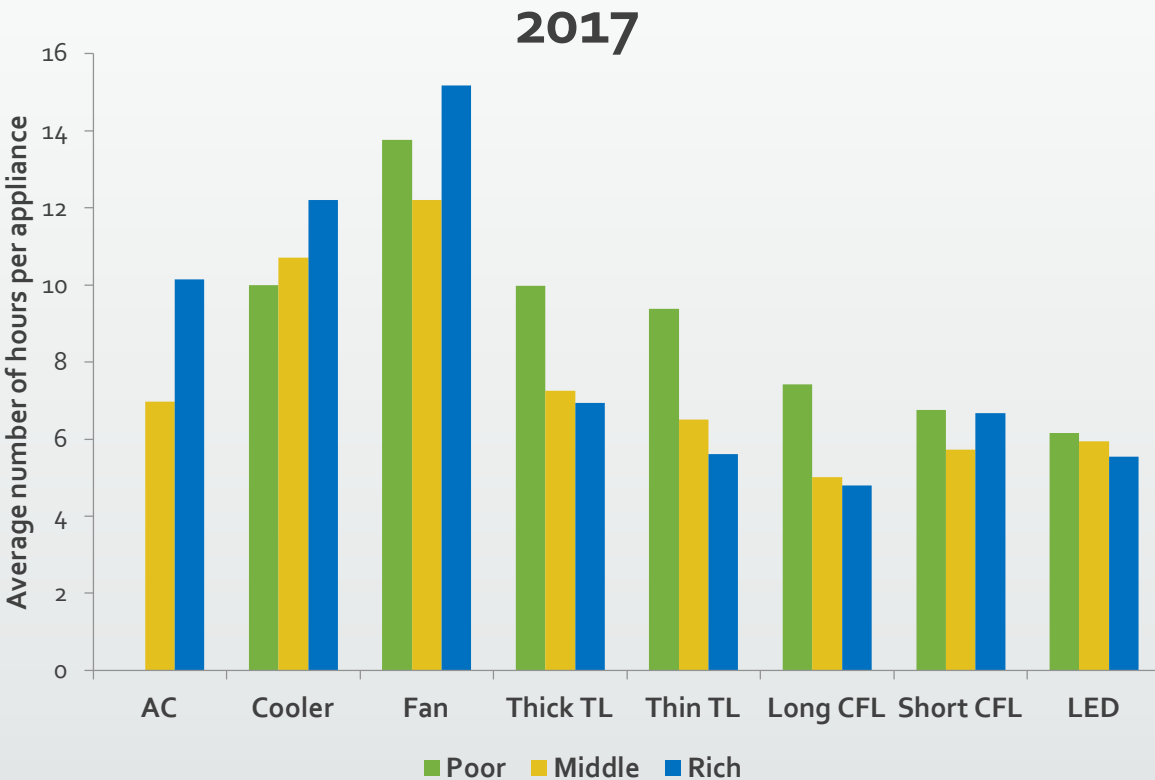 - This challenge was overcome by conducting a survey in 2017-18

Approach for end-use electricity demand estimation

- Choice of end-uses and technologies:
  - Lighting- Incandescent Light Bulb (ILB), Tube Light (TL, thick & thin), CFL (long & short), LED
  - Space Conditioning- Fans, Coolers, ACs
  - Water Heating-Geysers, Immersion rods
  - Cooking- Electric hotplate
  - Others- (includes refrigeration, washing, etc.)

- Level of disaggregation:
  - Income Class- Poor, Middle, Rich
  - Regions- North, East, West, South, North-East

Methodology for end-use electricity demand estimation

- Primary research
  - Purposive stratified sampling
  - 10 states (2 from each region) were surveyed
  - 4000 households within various income groups were surveyed

- Key variables of interest
  - Average usage (number of hours) for each appliances
  - Share of appliances in total electricity consumption
  - Number of appliances per households

- Forecast of appliance penetration and technological variation
  - Forecasted using a growth factor (based on stakeholder consultation)
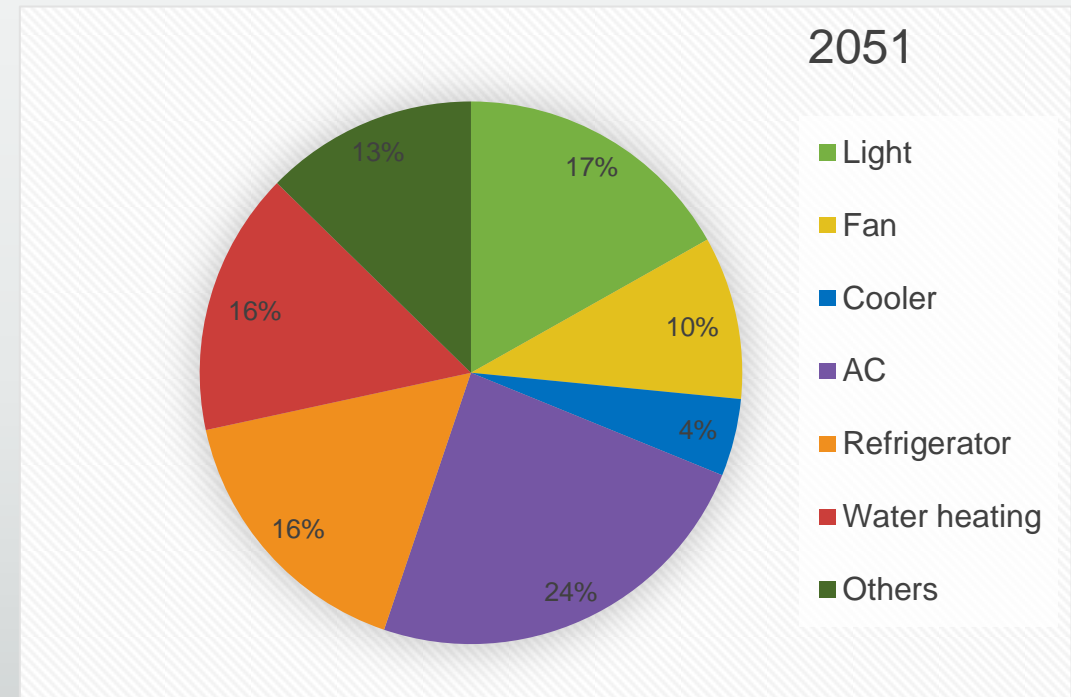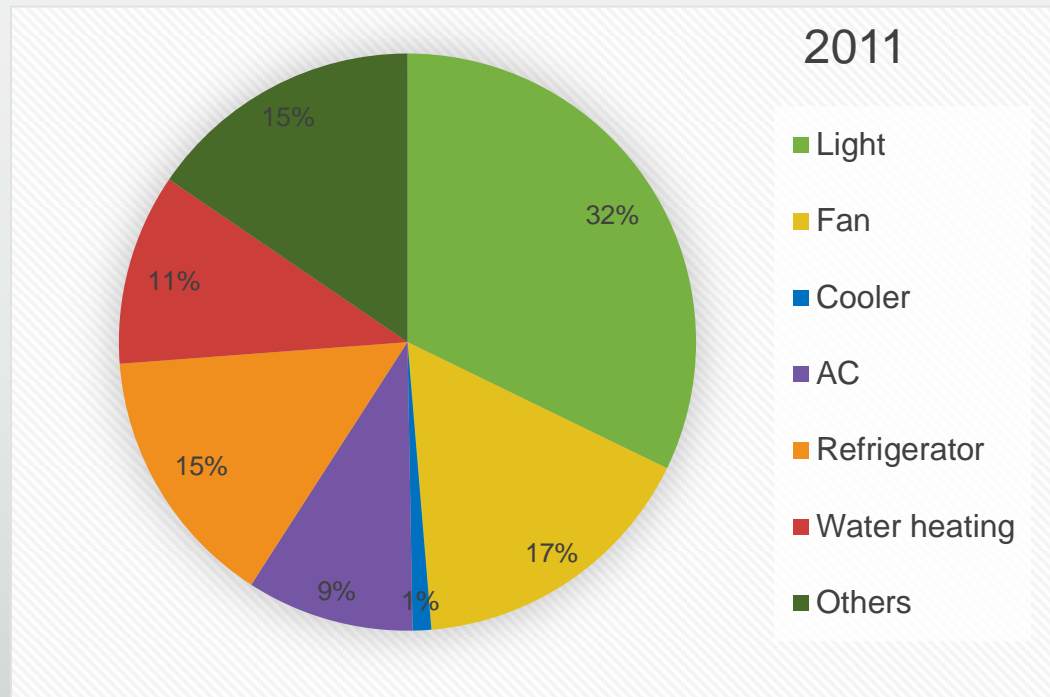 - Penetration of appliance, number of appliances, technological variation, usage pattern (fixed)

Usage Pattern: Variation by income class

2017

Y-axis: Average number of hours per appliance (0 to 16)

Categories: AC, Cooler, Fan, Thick TL, Thin TL, Long CFL, Short CFL, LED
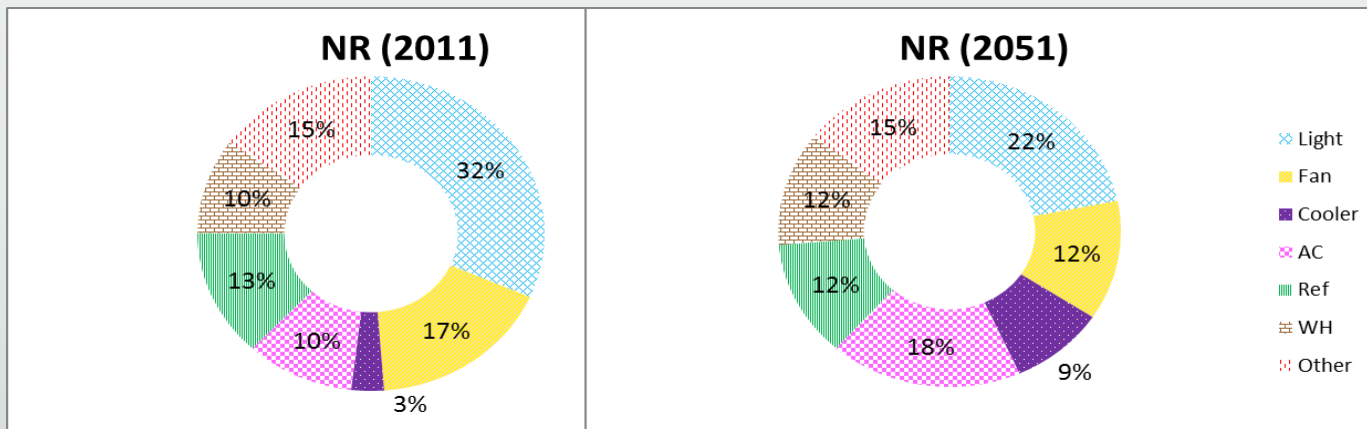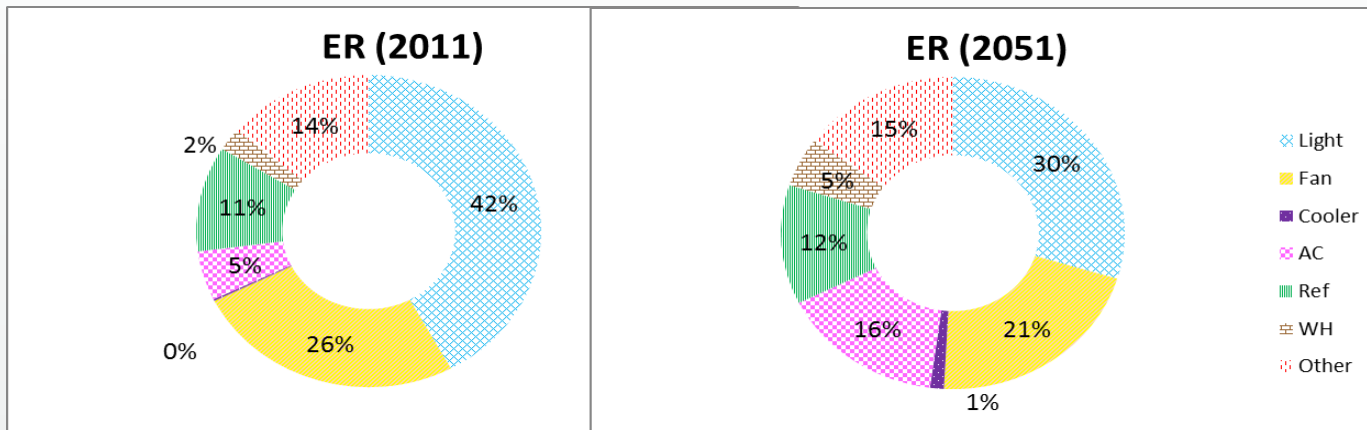
Legend: Poor, Middle, Rich

- Usage pattern of space conditioning technologies:
  - Rich households (HH) have the highest usage for all technologies
  - Poor HH have a higher usage for fans than middle HH
    - Middle HH have more options for substitution
    - Fans have a lower upfront cost
  - Order of usage across all income groups:
    - Fan> Cooler> AC

- Usage pattern of lighting technologies:
  - Average usage for lighting technologies is highest for poor HH
    - Poor HH have lesser number of light points
    - They also have poor ventilation (and less daylight)
    - For this income group, thick tube lights have the highest usage
  - Richer HH have more number of lighting points each of which is used for fewer hours throughout the day
  - Variation between rural and urban HH is observed to be low

- Income levels do play a significant role in level of comfort the HH try to attain; electricity consumption varies accordingly

- Variation in ownership is observed across income classes and regions, but not across rural and urban HH.

Electricity Consumption: Appliance-wise variation

- Share of space conditioning in electricity consumption increases from 27% (2011) to 38% (2051)

  - Share of AC becomes the highest in 2051: AC penetration increased from 7.7% to 11.5% between 2006-11 in urban and 1.9% to 3.4% in rural India

  - Share of fans declines (from 17% to 10%) while share of cooler increases slightly (from 1% to 4%)

- With introduction of technologies like LED, share of lighting declines from 32% to 17%

- Share of water heating in electricity demand increases from 11% to 16%

  - Catalyzed by increased ownership of appliances in rural households as well as shift from other fuels to electricity
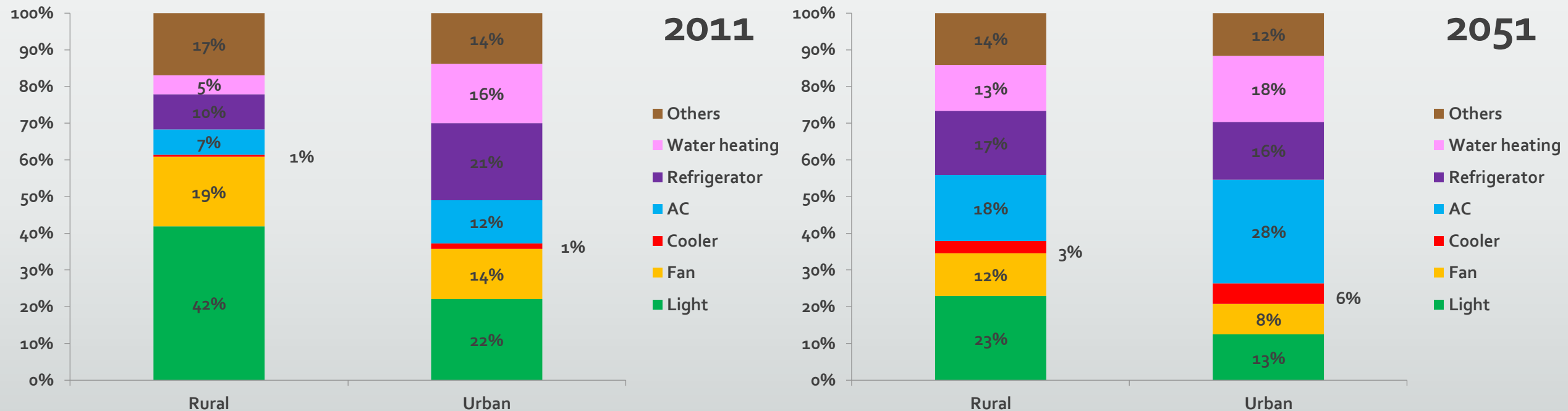
Electricity consumption: Regional variation

ER (2011) — Light 42%, Fan 26%, Cooler 0%, AC 5%, Ref 11%, WH 2%, Other 14%

ER (2051) — Light 30%, Fan 21%, Cooler 1%, AC 16%, Ref 12%, WH 5%, Other 15%

NR (2011) — Light 32%, Fan 17%, Cooler 3%, AC 10%, Ref 13%, WH 10%, Other 15%

NR (2051) — Light 22%, Fan 12%, Cooler 9%, AC 18%, Ref 12%, WH 12%, Other 15%

Legend: Light, Fan, Cooler, AC, Ref, WH, Other

- Electricity usage pattern varies across regions
  - Factors leading to variation include income, climatic condition, etc.
- In both cases, share of lighting declines
- In both cases, share of space conditioning increases
  - Share of fans declines
  - Share of ACs and coolers increases
- Water heating has a higher share in NR in both 2011 and 2051
- Share of refrigeration increases in ER but declines in NR between 2011 and 2051

Electricity consumption: Rural-Urban variation

- Electricity usage pattern between rural and urban areas differ significantly in both 2011 and 2051
  - Both rural and urban households spend a larger share of electricity on lighting in 2011
    - Decline in share of lighting in rural areas is starker between 2011 and 2051 (42% to 23%)
- Share of lighting and fans declines while that of ACs and coolers increase between 2011 & 2051 in both rural and urban areas
- Share of water heating increases in rural areas but remains nearly same in urban areas between 2011 & 2051
- Share of refrigeration increases in rural areas but declines in urban areas between 2011 & 2051

Electricity Consumption: Variation by income class

- Poor households have highest share of electricity for lighting ; rich households have the same highest for ACs

- Poor: Share of lighting and fan declines; share of coolers and refrigerators increases

- Middle: Share of lighting and fan declines; share of ACs, coolers, and water heating increases

- Rich: Share of lighting, fan and refrigerators declines; share of ACs and water heating increases

- Electricity consumption pattern of poor and middle income groups is similar to that of rural areas
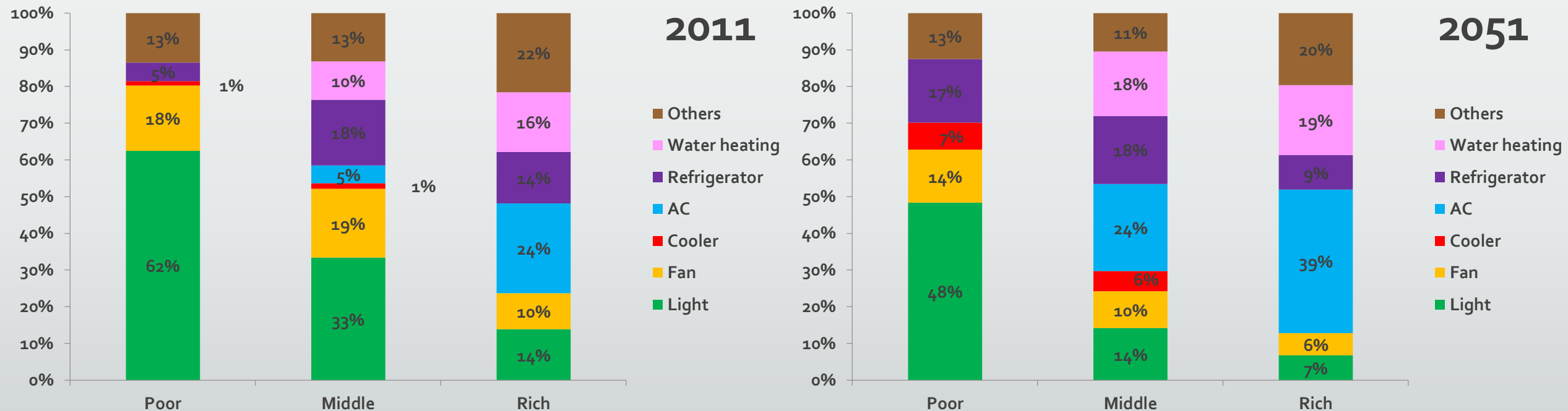
Summary

- Electricity consumption pattern varies by region, income groups, and urbanization

- The two key end-uses that consume electricity in the current period are lighting and space conditioning

  - Lighting has the higher share for rural HH as well as poor and middle income HH

    - It is expected that as new technologies penetrate, share of lighting will decline

  - Space conditioning has similar share in both rural and urban HH, but higher share in rich HH

    - Within space conditioning, fan has the higher share in poor and middle HH

    - AC has a higher share in rich HH

    - It is expected that ACs will dominate electricity consumption by 2051 in rich and middle income HH as well as in urban HH

      - Rural HH are also projected to have a higher share of AC, but lighting is projected to have a higher share

- Share of water heating and refrigeration (rural HH, poor & middle income HH) is also expected to increase as more households purchase these appliances

Thank You!!

Swapnil Shekhar
Research Associate
Swapnil.shekhar@teri.res.in
Integrated Assessment and Modeling Division, TERI