PIER 2.0: India's Residential Energy Demand until 2040-41

Perspectives on **I**ndian **E**nergy based on **R**umi **(PIER)**

Prayas (Energy Group)

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Rumi: An open-source Energy Systems modelling platform

A quick guide to PIER 2.0 Model Documentation

- Please use this document as a primary reference for sector-specific modelling methodology, sources, assumptions, model-results and insights
- Access the "Source Workbooks" for more detailed documentation
- In this document, Source Excel Workbook names are given in Courier New font along with a folder path
    - Example: "`D_RES/NumInstances.xlsx`"
- Access the PIER 2.0 files from Zenodo https://doi.org/10.5281/zenodo.14603083
    - Refer Rumi documentation for folder structure (https://github.com/prayas-energy/Rumi/tree/main/Docs)
- Follow the 'FileInfo' Sheet in the workbook and respective sheets to access further documentation of assumptions and validation along with citations of sources

Introduction

Residential energy

- Aspirations and quality of life
- Universal electrification
- Ujjwala
- Changing weather patterns

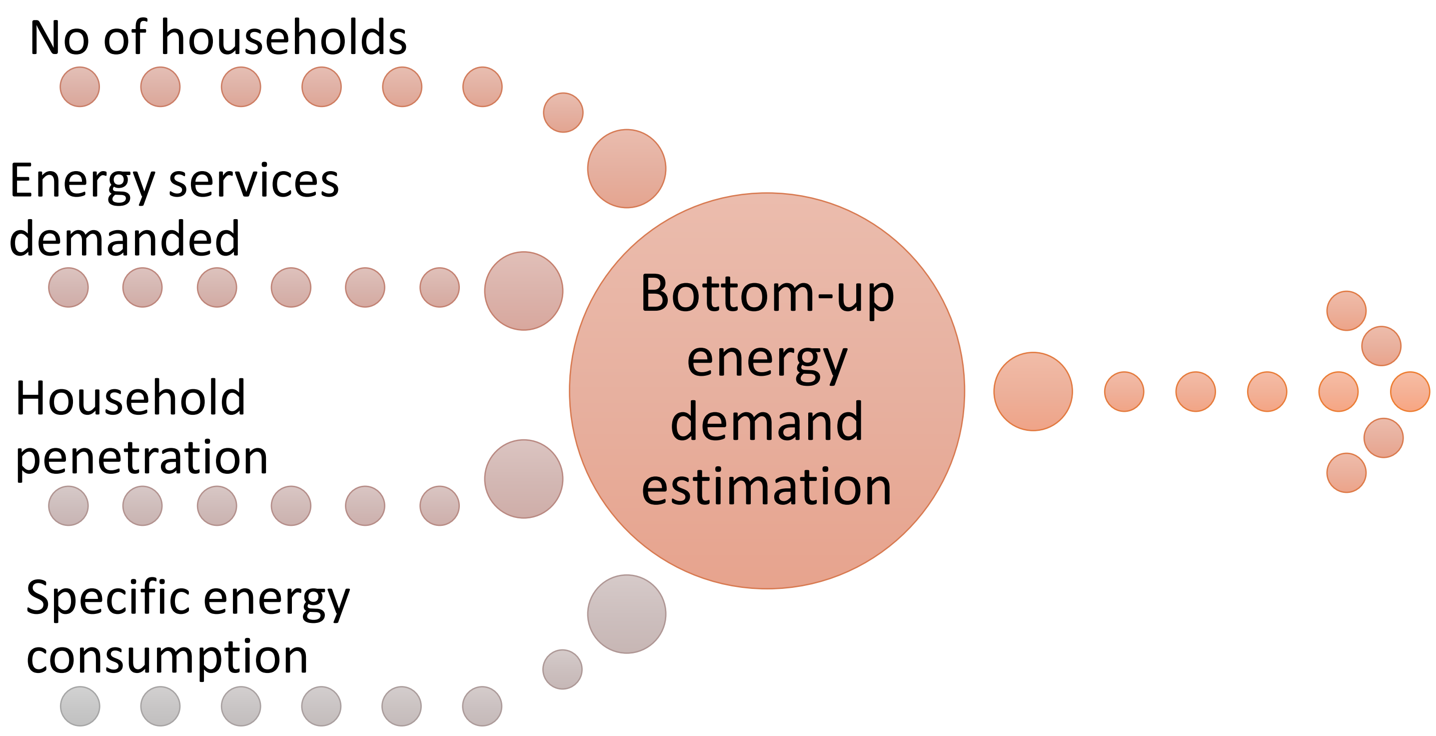
PIER

- Open-data model
- Built on open-source Rumi
- Detailed bottom-up model
- Disaggregated

Overview

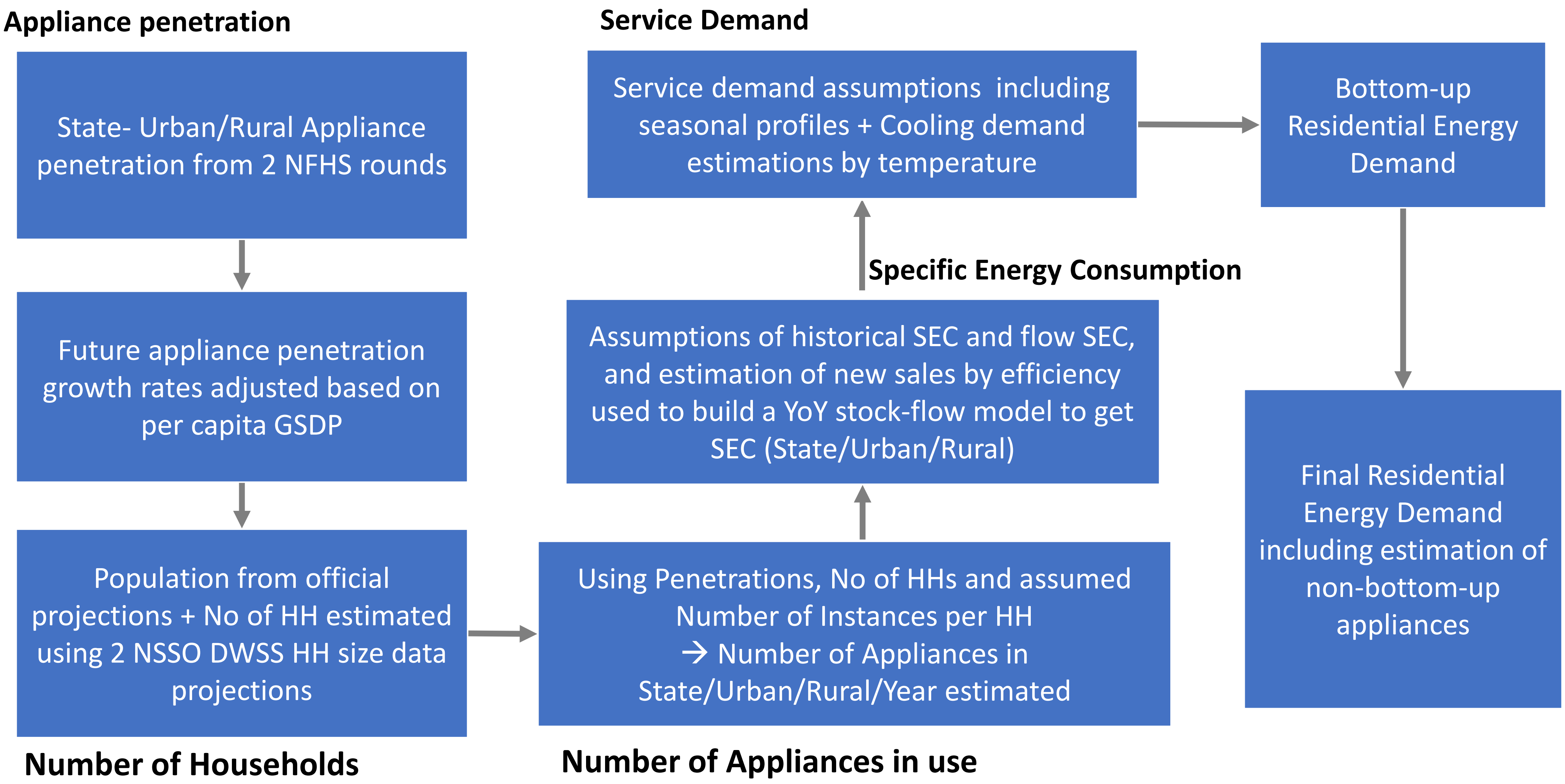
- Model set-up
- Model results
- Insights

Bottom-up residential energy demand estimation



- Energy demand for each energy carrier at requisite granularity
- Geographic: State and urban-rural for all carriers
- Time:
  - FY2024 – FY2041
  - Annual for all except electricity
  - Electricity: 12 seasons (months) per year; 1 typical day per season; 24 hours per day

Overview of the bottom-up residential demand model



Inputs to PIER residential model

Primary drivers of residential energy demand

Demographics	Appliance penetrations	Appliance breakup	Specific Energy Consumption (SEC)	Energy service demand
• Population • # HHs	• Fans, coolers, ACs • Refrigerators, TVs • Modern cooking	• By technology (Direct Cool & Frost Free refrigerators) • By efficiency (star rating of ACs and refrigerators)	• Efficiency of appliance stock	• Hours and patterns of usage

All at state + urban/rural granularity – each combination is a 'consumer type'

Location of all input data files shown relative to `PIER/Default Data/Demand/Source/D_RES` unless otherwise mentioned. The same file may also exist in the corresponding location in a scenario folder

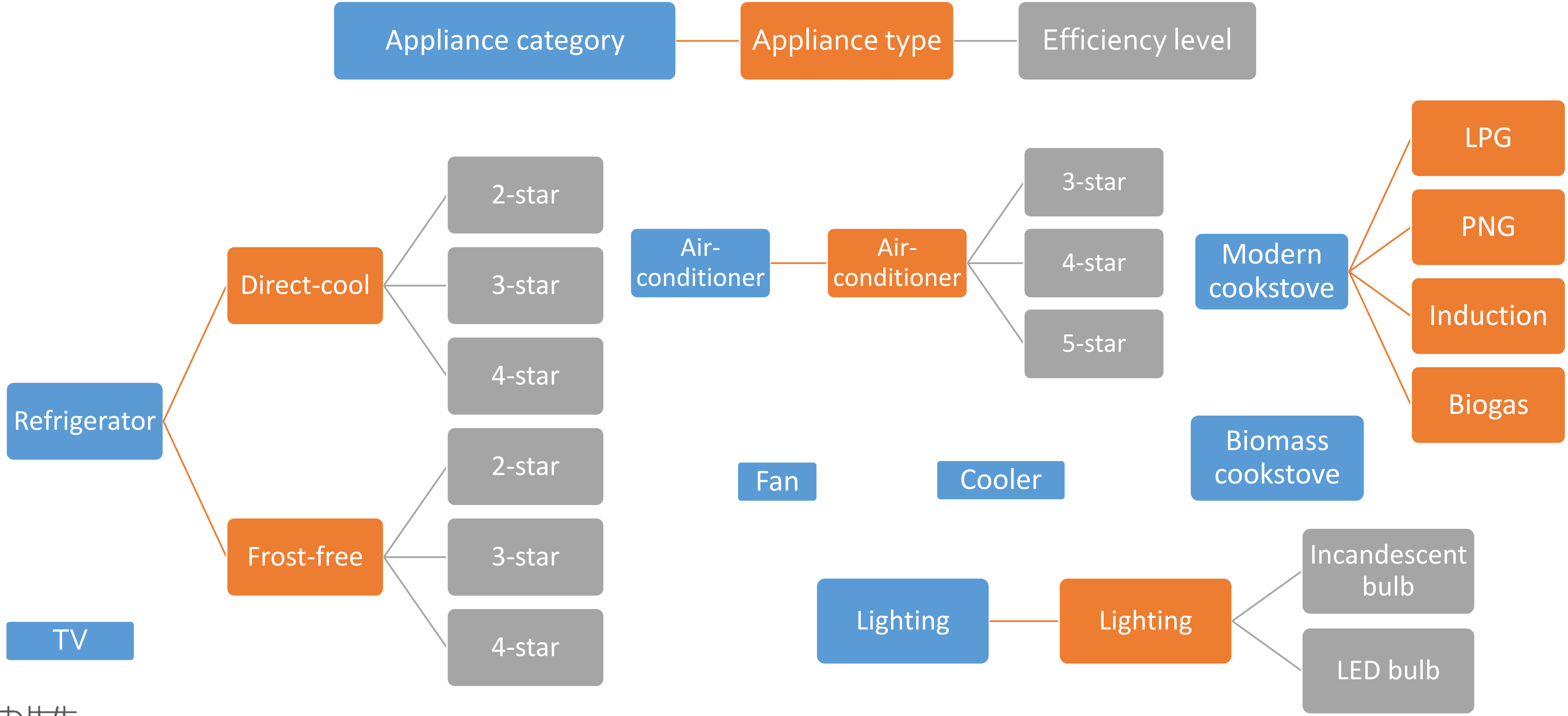
Demographics

- Latest state-wise and urban-rural population projections from MoHFW
  - Accounts for falling fertility rates etc.
  - By CY up to 2036: CY n assumed to FY n+1
  - Growth Rate between 2030 and 2036 used to project to 2040
  - Doesn't include household count / size projections

- Latest source for household size: NSSO Drinking Water & Sanitation Survey
  - 2013 and 2019 rounds used to estimate change in HH size for each geography
  - Project HH size forward based on that
  - # HHs calculated from population and HH size

- Data file: "`PIER/Default Data/Demand/Source/Demographics+ResNumConsumers.xlsx`"

Appliances modelled in PIER 2.0



Appliance penetrations

- Penetrations for appliance category for each consumer type
- Latest source with data at required granularity: NFHS-5 (FY2021)
  - Previous NFHS: round 4 (FY2016)
- Lighting assumed to be universally electric post *Saubhagya* programme and near 100% household electrification
- Other appliances projected forward based on growth rate between NFHS-4 and NFHS-5
  - Elasticity of growth rate to per-capita state GSDP growth rate also considered
  - Extreme values adjusted – for both GSDP growth rates and elasticity

- Data file: ”`D_RES UsagePenetration.xlsx`”

Appliance penetrations: Challenges

- ACs and coolers not distinguished in NFHS (and in many surveys)
  - NSSO 78th round (FY2021) multi-indicator survey distinguishes them
  - Depending on approximate agroclimatic characteristic of each consumer type, target AC share in AC+cooler assumed for FY2041
  - AC and cooler shares within cooling appliances projected for each consumer type using NSSO-78 and target

- Modern / biomass cooking penetration
  - NFHS has data for LPG, PNG etc. but also a big ‘other’ category
  - Categorized as modern or biomass depending on location / assumption

Appliance break-up

- To track by appliance type and efficiency level
- Almost no data available – particularly re stock/sales by efficiency level
- Modelled based on detailed stock flow calculation for each consumer type
- Number of instances of each appliance in a household broadly based on PIER 1.1
    - Data file: ”`NumInstances.xlsx`”

- Stock of appliances of each appliance category for each consumer type
    - From appliance penetration, # HHs and number of appliances per HH
- Some data published by BEE in the past on production by appliance type and star-rating
    - Used to split initial appliance category stock into appliance type and efficiency level

Appliance break-up …

- Assumptions re
  - Initial split of lighting into incandescent bulbs and LEDs
  - Shares of different appliance types and efficiency levels in purchase of appliance category in each year
  - No incandescent bulbs purchased after 2030
  - Split of modern cooking across HHs over the years based on likely rollout of CGD networks, uptake of induction cooking etc.
- Stock and flow of each appliance type and efficiency level for each consumer type calculated based on the above to get the required break-up
- Data file: ”`Res-ST-stock-flow-TSR-ELS.xlsx`”

Specific Energy Consumption (SEC)

- Little data available and large variance possible
- Appliance categories with mandatory BEE efficiency standards:
  - ACs, refrigerators and TVs
  - Fans – introduced recently
- For appliance categories with mandatory efficiency standards
  - Category specific assumptions: refrigerator size; TV size; room size and wall characteristics for ACs
  - Assumption about 'real life' SEC as a % of notified BEE efficiency
  - SEC of the initial stock of each appliance type / efficiency level based on past BEE efficiency standard notifications
  - SEC of future appliance purchases based on simulation of BEE's efficiency standard revision process
  - Stock SEC for each consumer type, appliance type and efficiency level for each year calculated based on all of the above and detailed stock-flow calculations

Specific Energy Consumption …

- For other appliances: assumptions about either purchase or stock SEC
  - SEC of new cooler and LED purchase assumed to improve at 2% per year
  - SEC of modern cookstove stock assumed to improve at 1% per year
  - No improvement in SEC of new purchases for ‘outdated’ appliance types such as biomass stoves and incandescent bulbs
- Stock SEC calculated for these appliance types based on the above for each consumer type
- Data file: “`Res-ST-SEC.xlsx`”

Energy service demand

- Given for each appliance category
- Almost no data available – hence mostly based on assumed behaviour

Category	Energy service demand	Unit
Lighting	4 – 4.5 hours in the evening; 0.5 – 1 hr in the morning depending on the month	Hours
Fan, cooler, AC	Based on temperature projections (obtained from CMIP6), assumed ‘trigger’ temperature, set-point temperature for ACs and slight modifications for humidity and urban-rural differences [see next slide]	Cooling hours for fan & cooler; cooling degree hours for AC
Refrigerators	Assumed to run through the year	Hours
TVs	Six hours per day – consistent with BEE’s assumptions – spread across two afternoon hours and four evening hours	Hours
Cooking	• Useful energy required per household estimated based on per-capita useful energy requirement from literature • Electric cooking spread across 2 hours each in the morning and evening	Useful MJ, with additional input to give load profile for electric cooking

Energy service demand estimation for cooling

CMIP6 Temp projections from IPCC models

Daily average temperature projections for 0.25° X 0.25° lat-long resolution available till year 2100

→

OpenWeather proprietary data
450 locations in India 2018 at hourly granularity.
Used to distribute daily temp projections from CMIP6

→

CH/CDH calculated for 450 locations based on Trigger temperature assumptions

State CH, CDH estimated using locations within state weighted by population

Average hourly CH, CDH calculated for each State/Urban-Rural/Month/Year

↓

Occupancy Adjustment

Hourly profiles (denoting usage fractions) for each cooling appliance are applied to adjust for house occupancy and hence appliance usage.

←

Energy service demand of Cooling Appliances

Specific hours when fans/coolers used
Cooling degree hours of AC use per hour

- Data files for energy service demand:
  - `"Res-cooling-service-demand (1-Load-shifting).xlsx"`
  - `"Res-cooling-service-demand (2-Parameter prep).xlsx"`
  - `"Res-non-cooling-service-demand.xlsx"`

Energy demand for unmodelled energy services

- Energy demand estimation for services not modelled bottom-up
  - E.g. washing machines, computers, water heating etc.
  - Electric vehicle charging not included as part of residential energy
  - All provided by electricity
- Provided as an exogenous input
- Based on calibration against state-wise FY23 residential electricity demand published by CEA
  - Difference between CEA published data and bottom-up computed value plus estimated home-charging of EVs as estimated from the PIER transport model
  - Some adjustments for the FY23 value for each state to account for anomalies
  - Split between urban-rural based on relative shares of modelled demand
- Future values based on the growth rate of bottom-up demand for each consumer type
- Load profile based on assumptions about four types of services covered by this: water pumping, water heating, washing machines and other appliances
- Data file: "`OtherResElecDemand.xlsx`"

Scenarios modelled

Residential only scenarios

Following scenarios modelled only for D_RES - these are apart from the three scenarios (REF, Vikasit and Vichalit) modelled across demand sectors

- Four main scenarios modelled based on varying the 3 most critical parameters
  - SEC, appliance penetration, and usage (energy service demand)
  - LikelyEfficiencyTrend: Reference / base case scenario
  - DesiredEfficiencyTrend: Higher efficiency than LikelyEfficiencyTrend
  - HighConsumption: Higher penetration and energy service demand
  - HighConsumptionDesiredEfficiency: Higher penetration and energy service demand with higher efficiency
- Two other 'scenarios'
  - Calibration-run: To calibrate against FY23 data to get exogenous input for unmodelled services
  - LET_CMIP5: Same as LikelyEfficiencyTrend but with CMIP5 temperature projections – to examine impact of different temp trajectory

- All scenario folders under `Scenarios/D_RES` folder
- `scenario-description.pdf` in each scenario folder describes the scenario

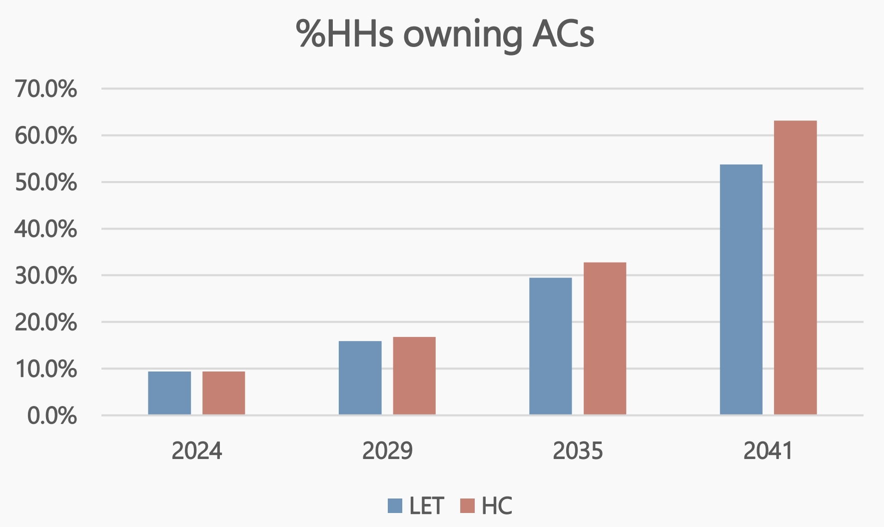
Details of major scenarios modelled

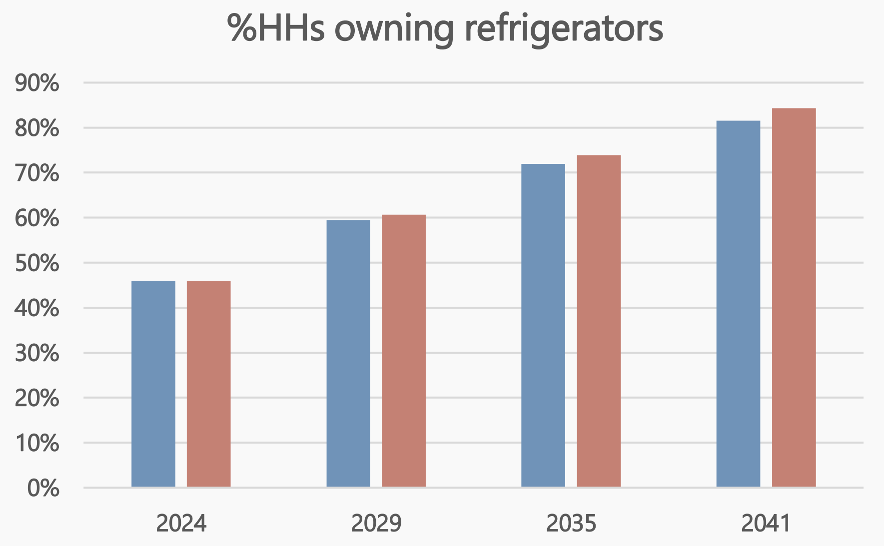
Scenario	SEC	Ownership	Usage
Likely Efficiency Trend (LET)	• Efficiency standards revised every 4 years for all appliances except fans (6 years) • 'Actual' appliance efficiency 70% of notified, 80% for fans • Gradual shift to higher star-rated appliances	Standard	Standard
Desired Efficiency Trend (DET)	• All efficiency standards revised once in four years • 'Actual' appliance efficiency 80% of notified, 90% for fans • Faster shift to higher star-rated appliances • Slower growth of exogenous "other appliances" demand	Standard	Standard
High Consumption (HC)	Similar to Likely Efficiency Trend	Greater uptake of appliances	• Greater usage of appliances • Cooling trigger temps 2°C lower
High Consumption Desired Efficiency (HCDE)	Similar to Desired Efficiency Trend	Same as High Consumption	Same as High Consumption

Model results

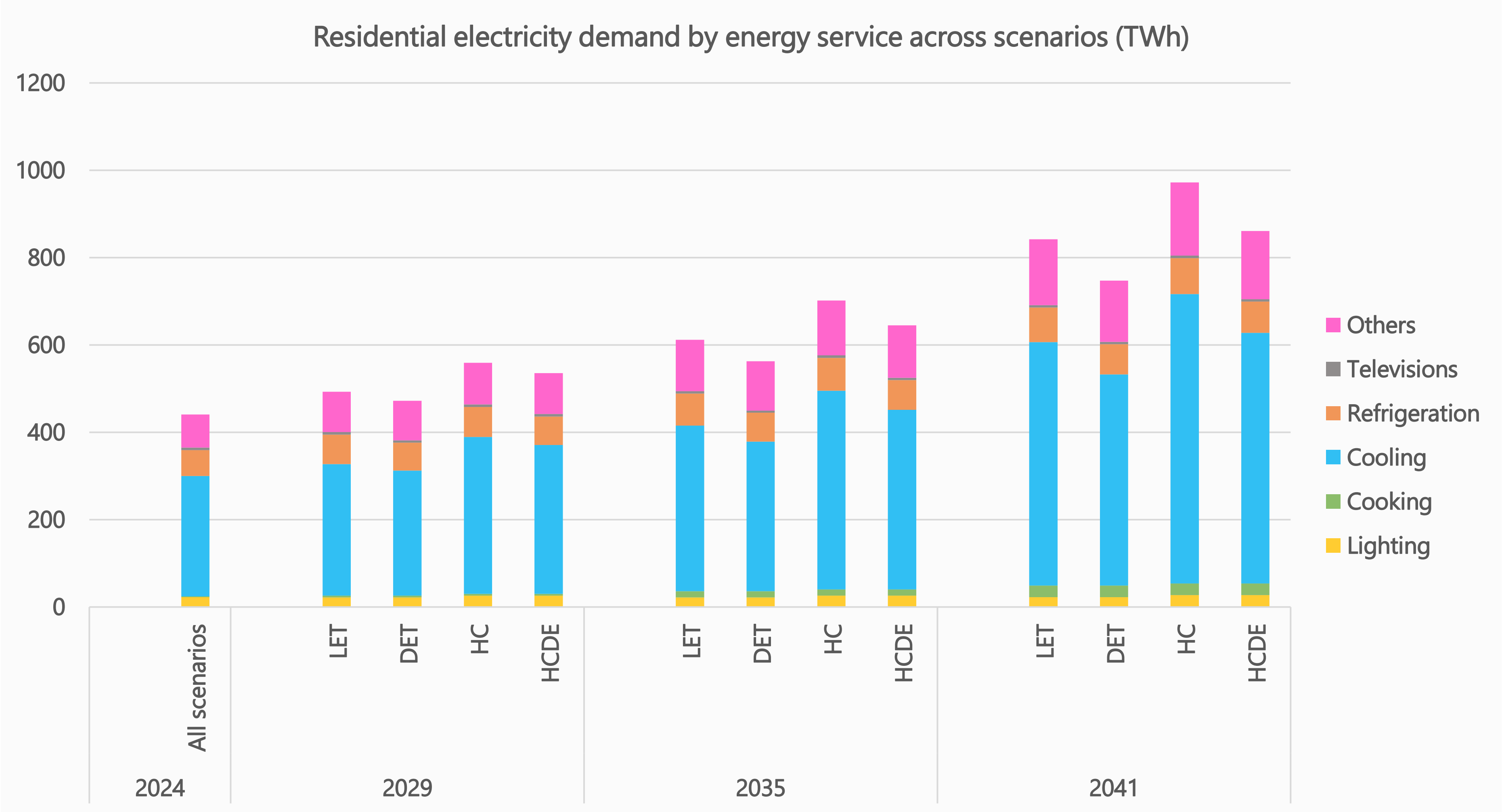
Significant ‘welfare’ increase by FY2041

- All HHs own fans, almost all own TVs by FY2041 in all scenarios
- AC penetration ↑ from ~9% in FY24 to
  - 54%-63% in FY2041 across scenarios
  - 11% CAGR in LET/DET scenarios
  - Rural ↑ from 2.5% in FY2024 to 35.5%-47.2% in FY2041 across scenarios
- Refrigerator penetration
  - 81.5%-84% in FY2041 across scenarios





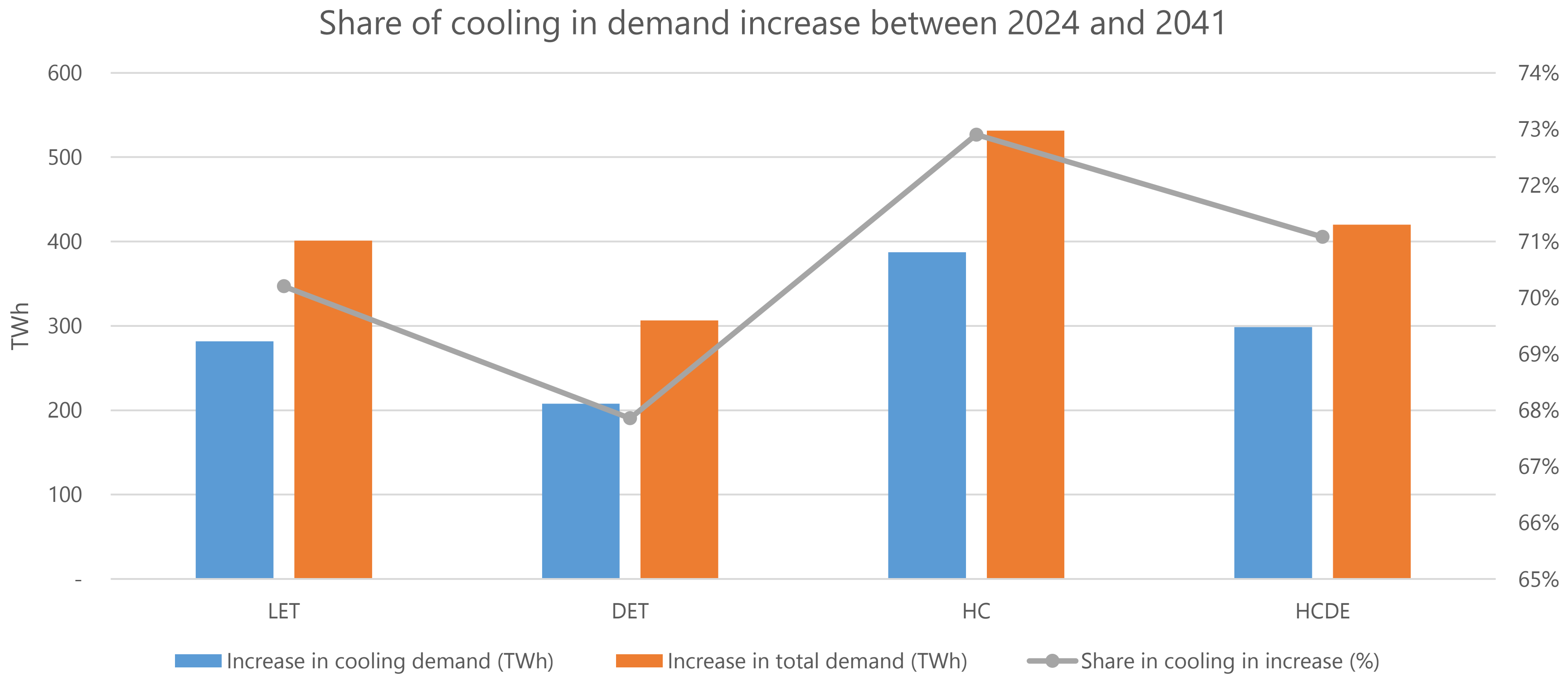
Model results #1: Electricity demand across scenarios



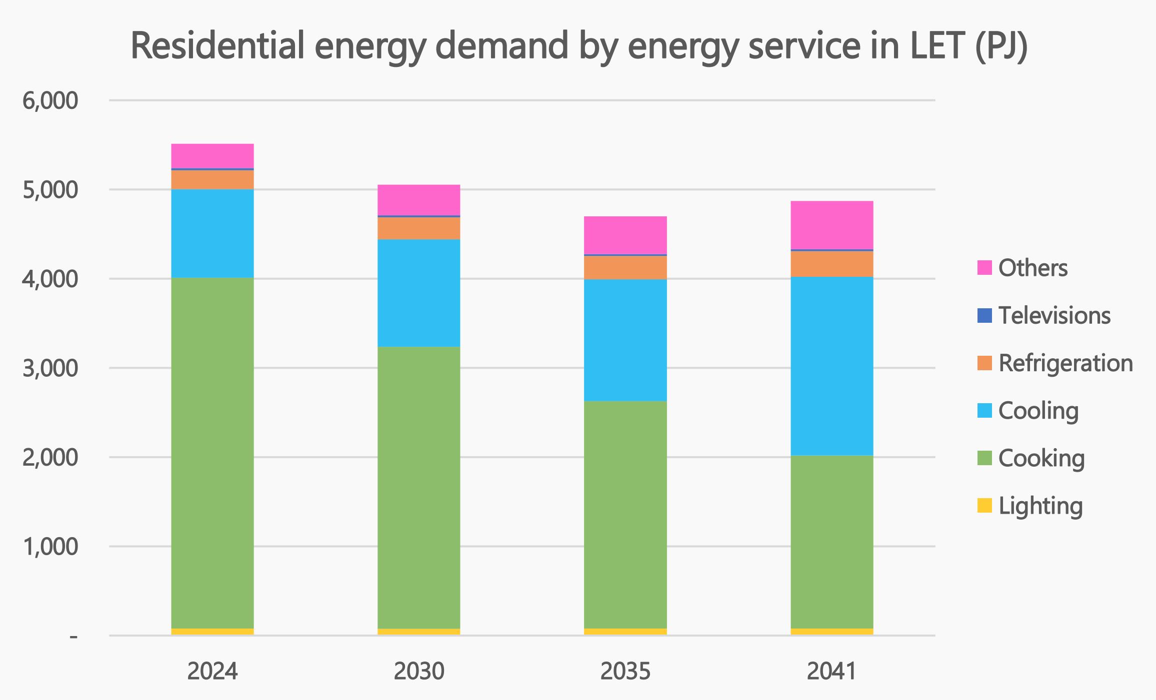
- DET < LET < HCDE < HC
  - HCDE ≅ LET in FY41
- ↑ from 441 BU in FY24 to
  - 842 BU in FY41 in LET
  - 972 BU in FY41 in HC

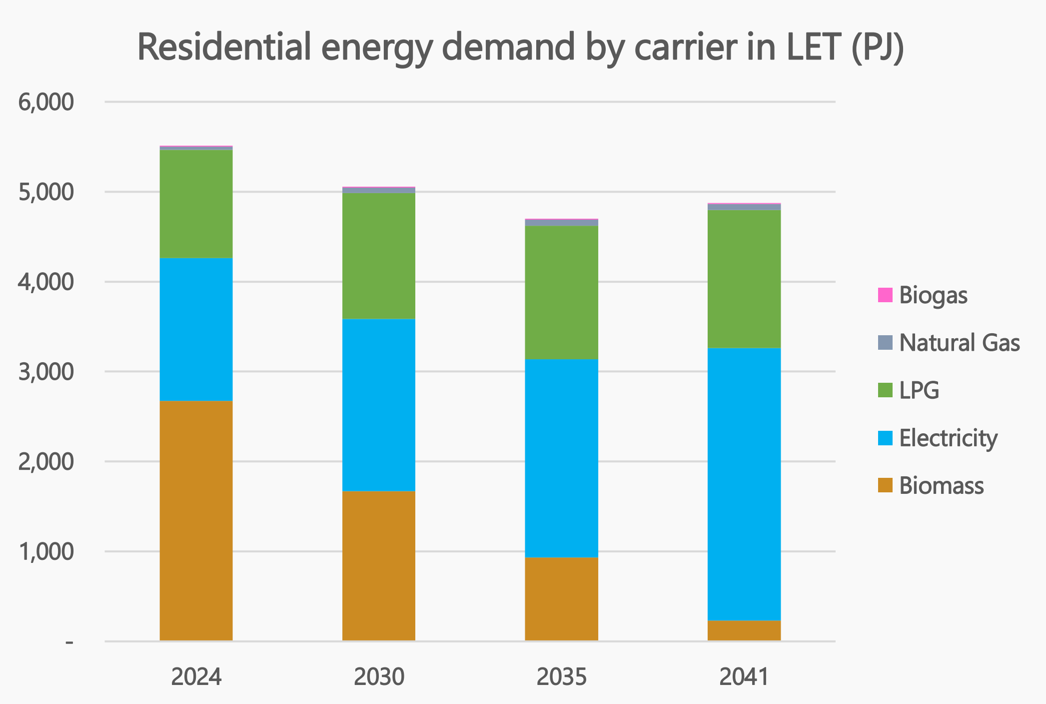
Model results #2: Role of space cooling

- Share of space cooling in residential electricity demand 61% - 68% across scenarios and over the years
- It contributes to over 68%-73% of the demand increase between 2024 and 2041 across scenarios



Model results #3: Total residential energy demand

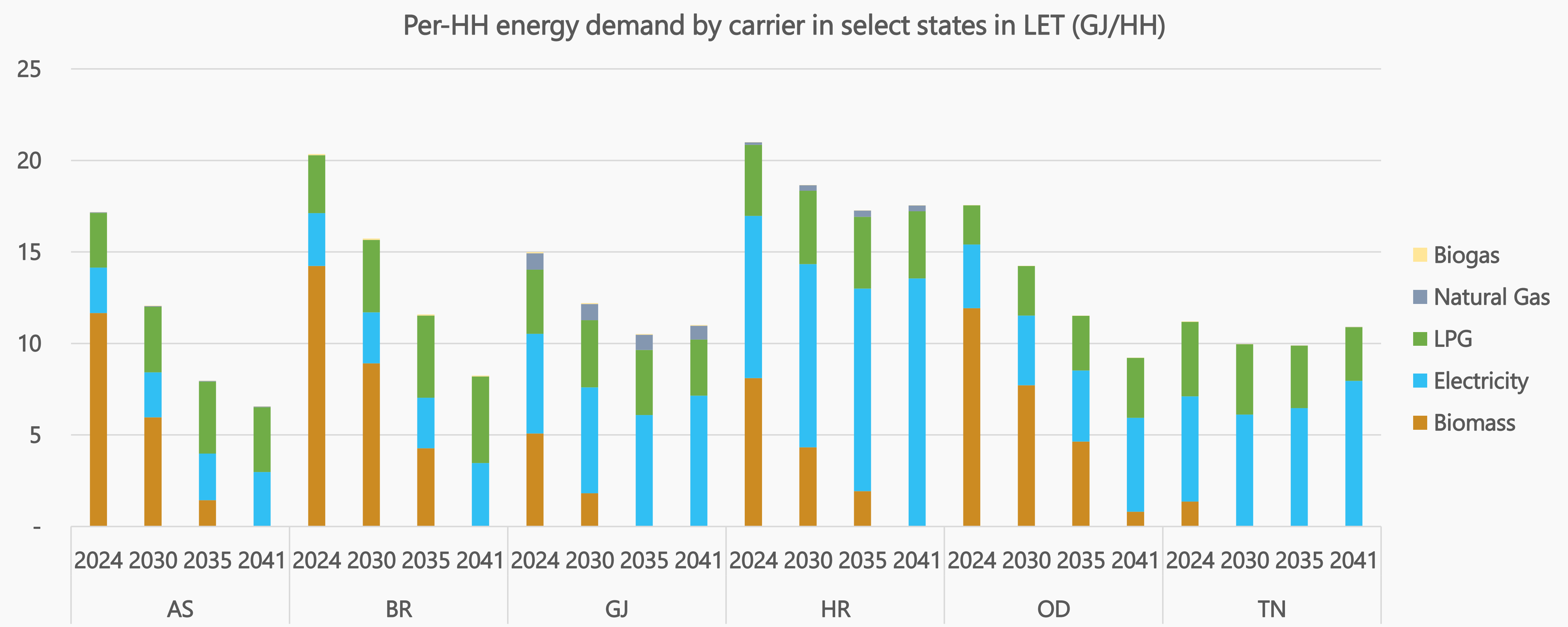




- Cooking consumes the most energy in most years – cooling overtakes cooking by the end
- Total demand decreases over the years (~5513 PJ to ~4873 PJ in LET)
  - Due to huge efficiency gains from moving away from biomass cooking
  - Slight increase between 2035 and 2041 as electricity increase outpaces biomass reduction
- Share of biomass ↓ from 49% to 5% between FY24 and FY41 in LET
- Share of electricity ↑ from 29% to 62% in the same period in LET

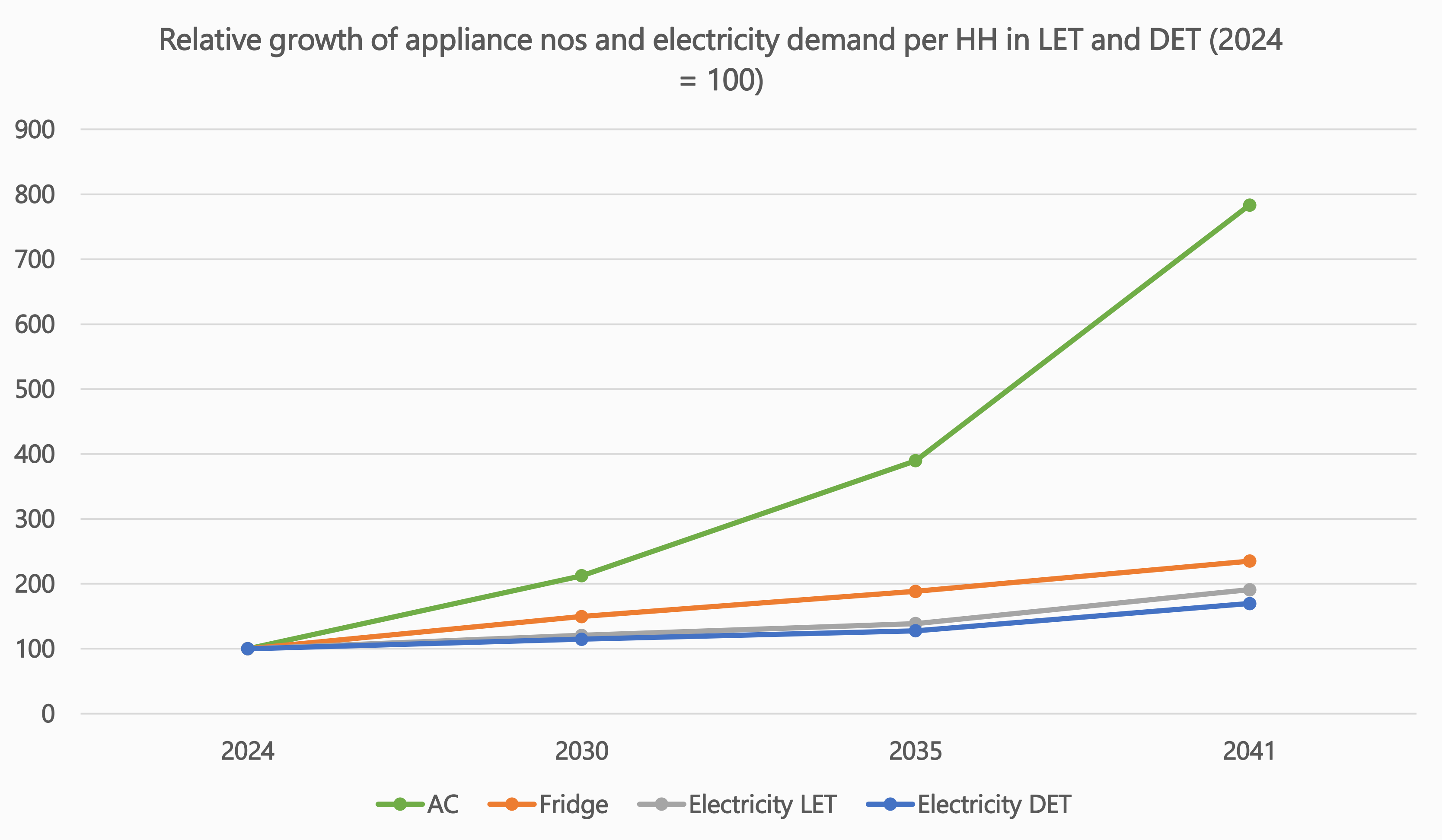
Model results #4: Wide disparity across states

- Major differences across states in per-HH energy demand
  - Higher per-HH energy demand typically indicates greater biomass use for cooking
  - Energy demand tends to ↑ in states once they attain full modern cooking (e.g. TN, GJ)



Model insights

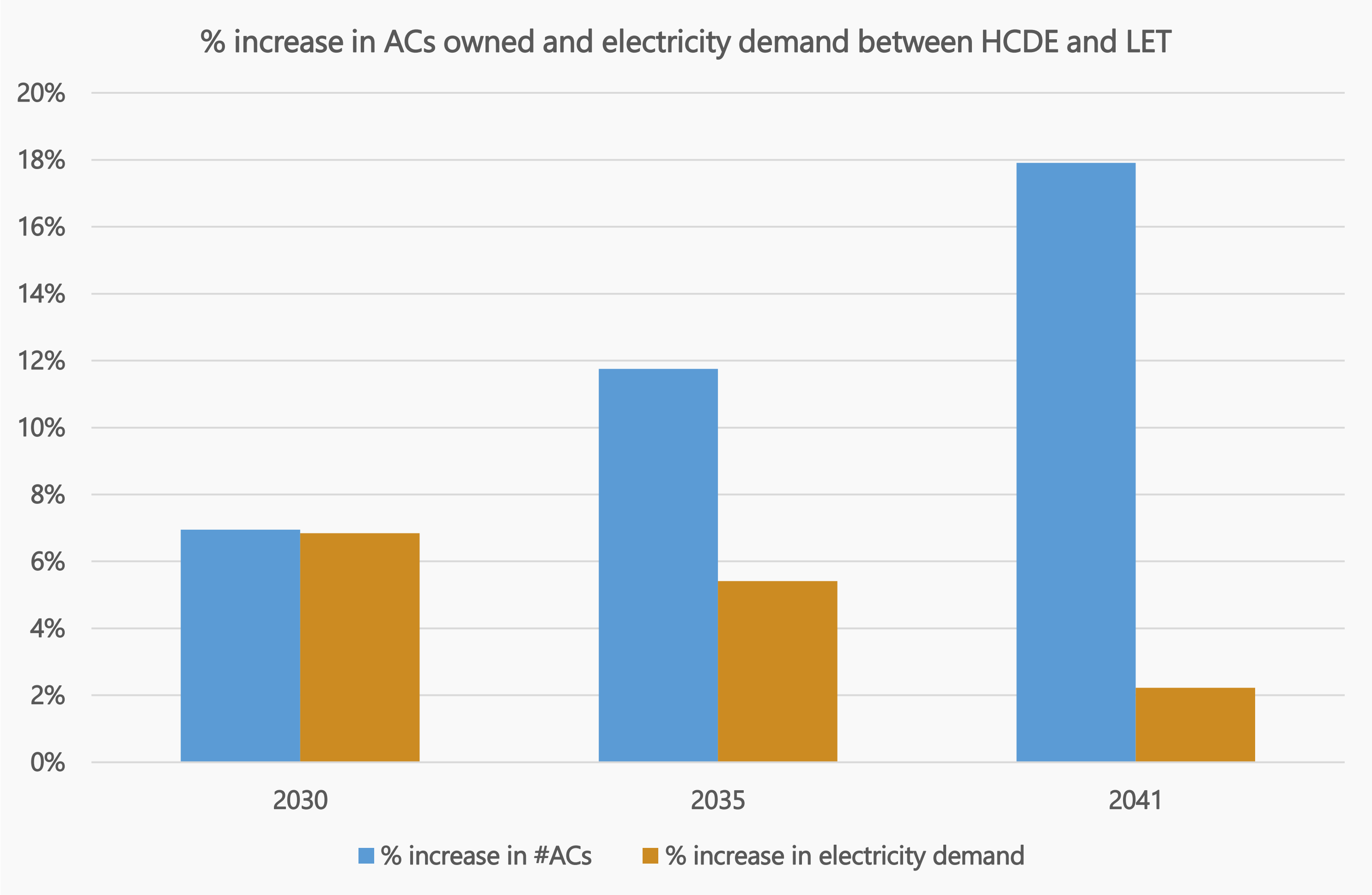
Insight #1: Increased appliance use ≠ increased electricity demand



- 6.8x ↑ in #ACs
- 1.35x ↑ in #refrigerators
- LET: 0.9x ↑ in electricity demand
- DET: 0.7x% ↑ in electricity demand
- Per-HH demand ↑ even lower

Demand estimation purely based on past trends is risky

Insight #2: Energy efficiency major determinant of electricity demand

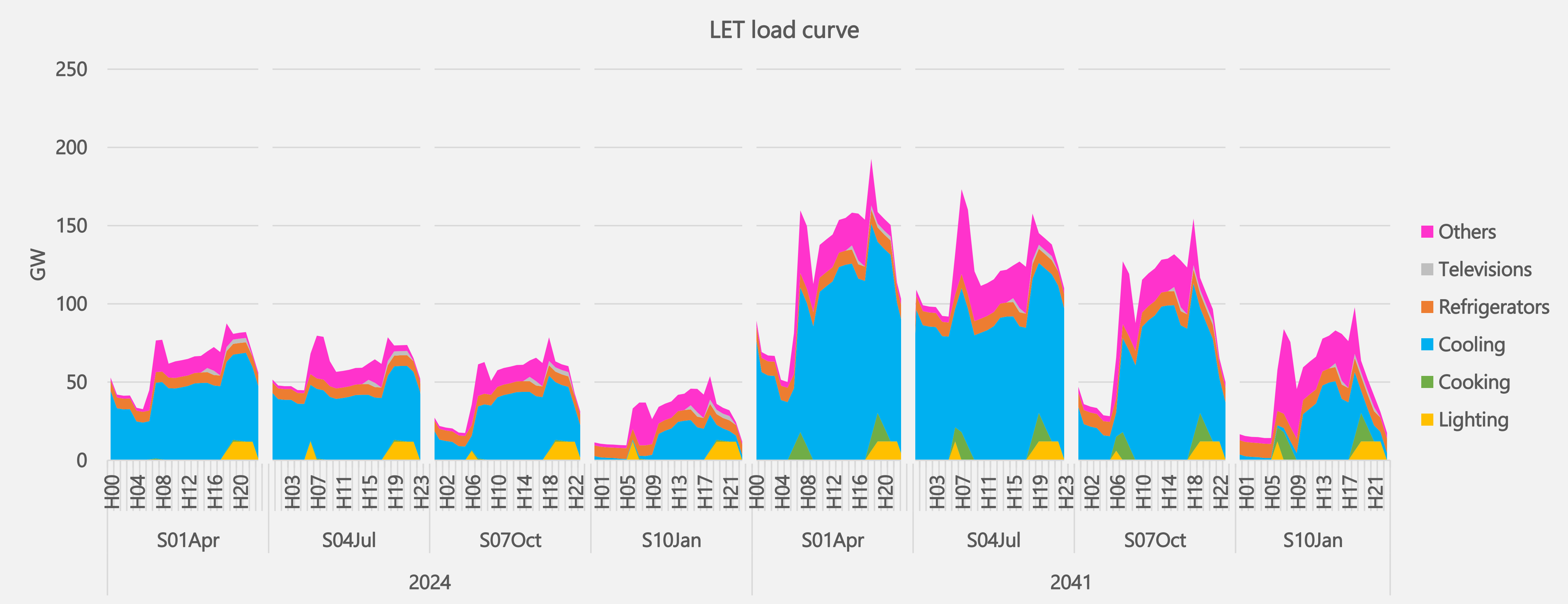


- Efficiency regime
  - 51 million extra ACs (18%) in 2041 in HCDE compared to LET
  - But only 2% more electricity demand in HCDE than LET in 2041
- Technology shift
  - Shift to more efficient electric cooking
  - TN achieves 100% clean cooking before 2030 but its per-HH energy demand still decreases between 2030 and 2035 despite increased appliance use – due to shift to electric cooking

An effective energy efficiency regime can play a vital role

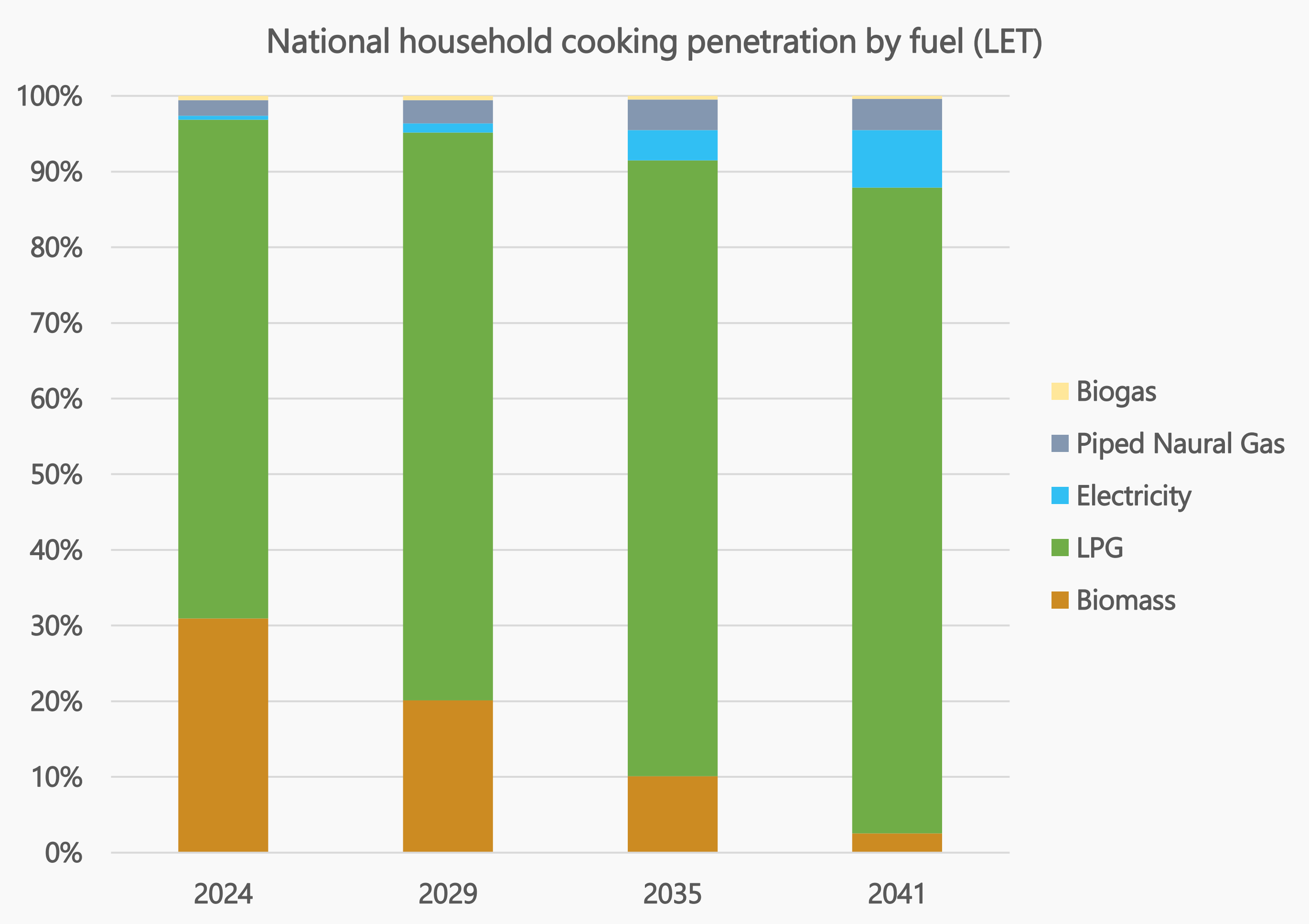
Insight #3: Residential load shapes will get peakier

- Peak load of residential electricity demand ~201 GW in May 2041
- Driven by cooling, cooking and water heating co-occurring in the morning hours



Importance of power procurement, network planning and DSM strategies

Insight #4: Cooking energy



- Clean cooking use ↑ from 69% in FY24 to 97.5% in FY41 in LET
- LPG use penetration ↑ from 66% to 85%
- Induction-based electric cooking grows fastest: 0.5% to 7.6%
- 11.4 million HHs still use solid fuels even in FY41
  - Rural areas of 6 states (CG, JH, MP, OD, RJ, WB)

Good progress, but need for targeted interventions to eliminate solid fuel use for cooking

Conclusions

Model findings

- Large growth in appliance ownership and use
- No commensurate increase in energy demand
- Quantification of the role of space cooling
- Large diversity across states

Useful policy insights

- Need for detailed demand estimation methodology
- Importance of an effective efficiency regime
- Need to manage peak load
- Targeted interventions to adopt clean cooking

Download PIER 2.0 from:
https://doi.org/10.5281/zenodo.14603083

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