Rumi: An open-source bottom-up demand-oriented energy systems model

Prayas (Energy Group)

September, 2020

Outline

- Brief overview of Rumi
  - Approach
  - Methodology

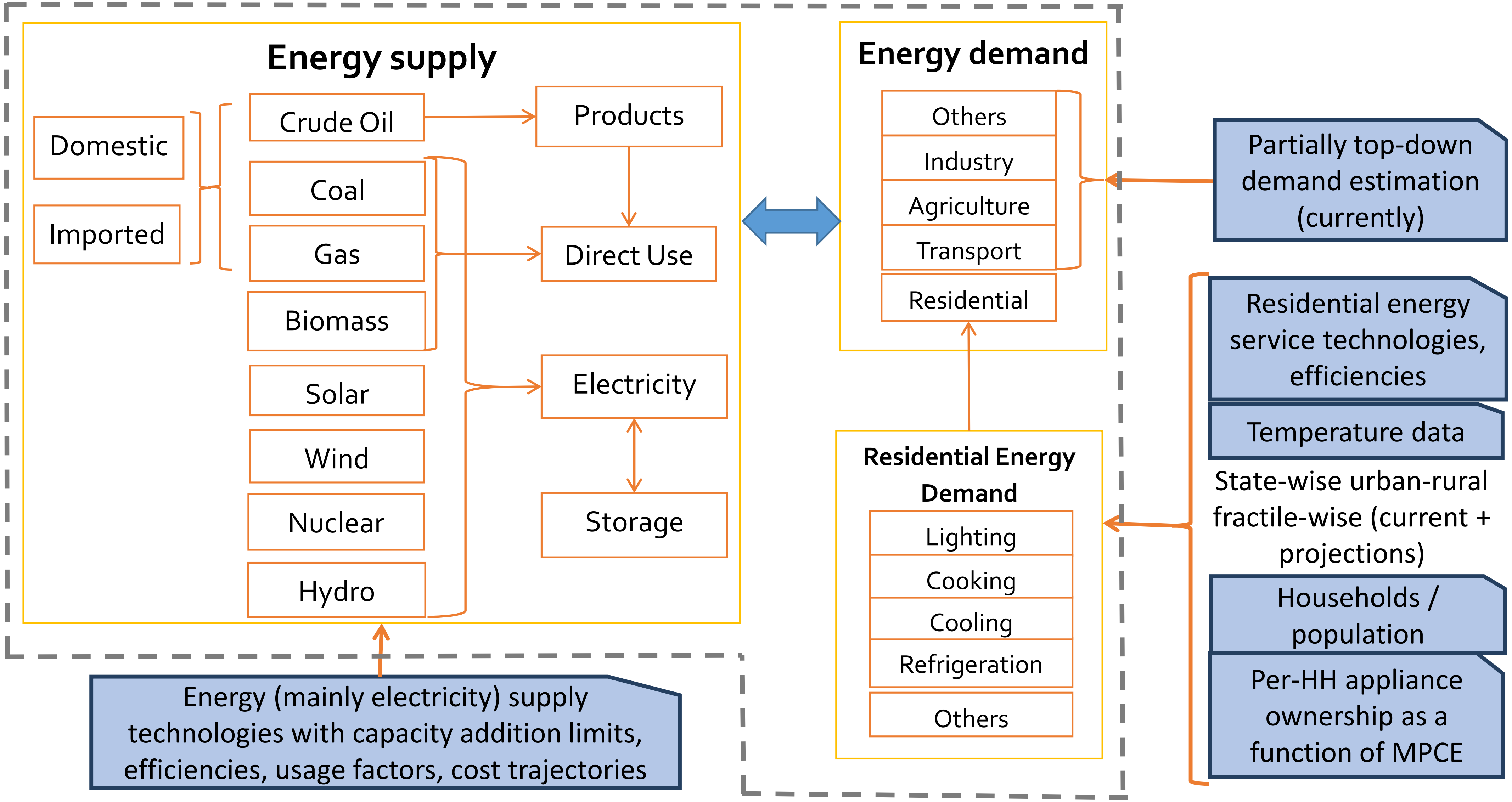
- Rumi India model
  - Scenarios
  - Insights from scenarios
  - Comparison with some other model results

Rumi approach, design features

- Transparent, open source energy modelling platform / model
- Demand focused
  - Bottom-up energy service oriented
  - Spatial / temporal / consumer-type disaggregation
- Optimised electricity capacity addition to meet demand
  - Account for diurnal and seasonal variations in demand and generation
- Enable policy-relevant analysis
- Support easy interfacing and integration with other models

- Built de-novo to support desired features
  - Mostly in python/pyomo, some R

Rumi-India model architecture



Current Rumi-India model configuration

- Period: 2019-20 to 2030-31

- Geographic disaggregation
  - 25 'states' including a grouping each of UTs and non-Assam NE states
  - Each state broken down into rural-urban geographies

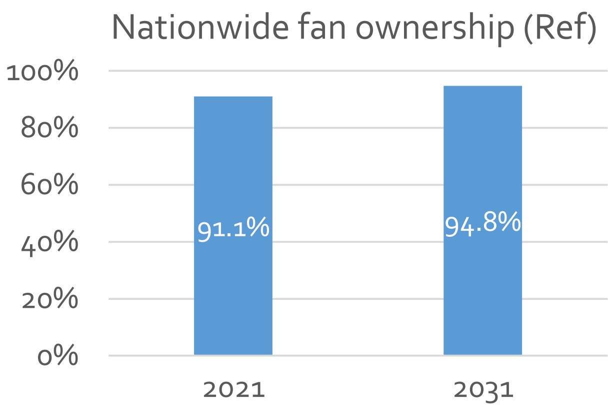
- Electricity
  - Temporal resolution: 5 seasons and 6 slices in a typical day of each season
  - Generation: coal, OCGT, CCGT, nuclear, hydro, solar, wind, biomass
  - Storage: 4-hour and 6-hour batteries
  - One 'balancing area'

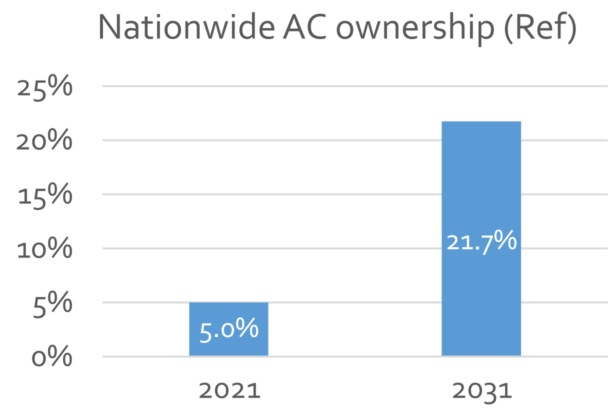
Scenarios

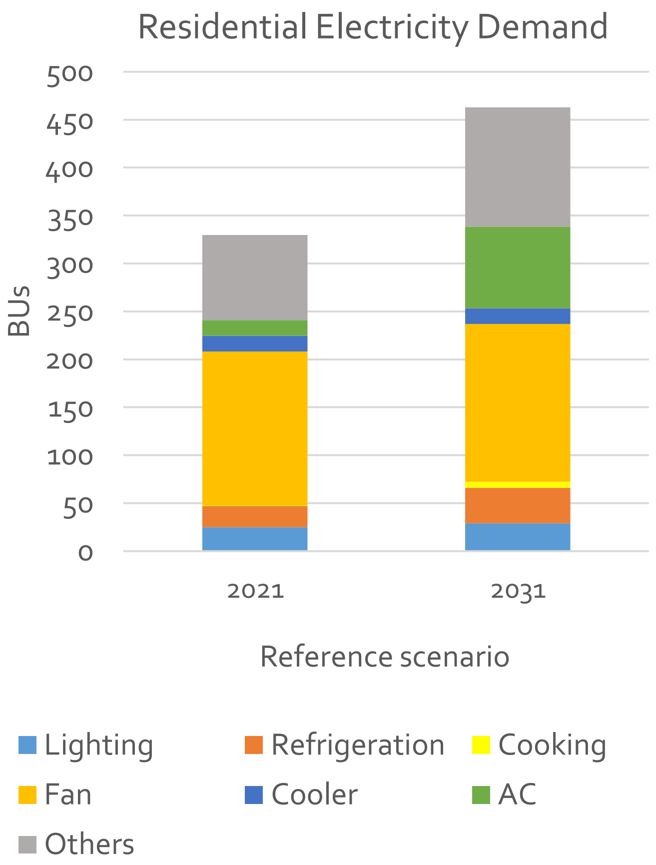
- Reference
  - Covid-19 related impacts not yet factored in
- High efficiency
  - Faster improvement in efficiency, increased electrification
  - Technological, economic and behavioural changes
  - Affects most demand sectors, electricity generation and T&D losses
- Equity: More equitable India
  - Urban-rural, inter-state and cross-quintile MPCE inequities reduce
- Load-shift
  - Residential electricity cooling service demand shifted to evening/night to account for occupancy

INSIGHTS FROM RUMI-INDIA MODEL RUNS

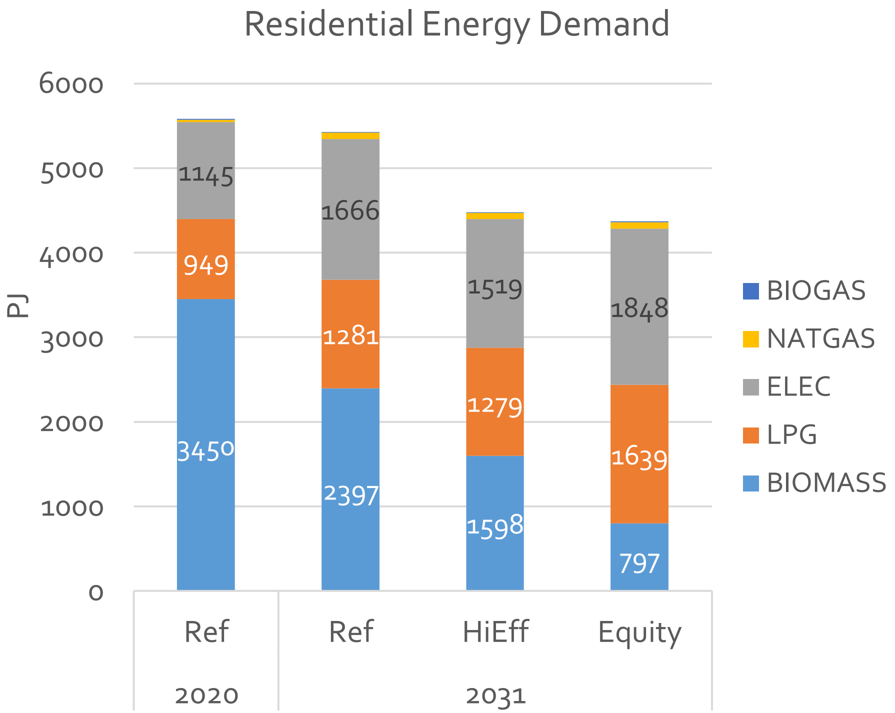
Demand from fans continues to be the single largest contributor to residential electricity demand in FY31, but ACs are rapidly catching up.





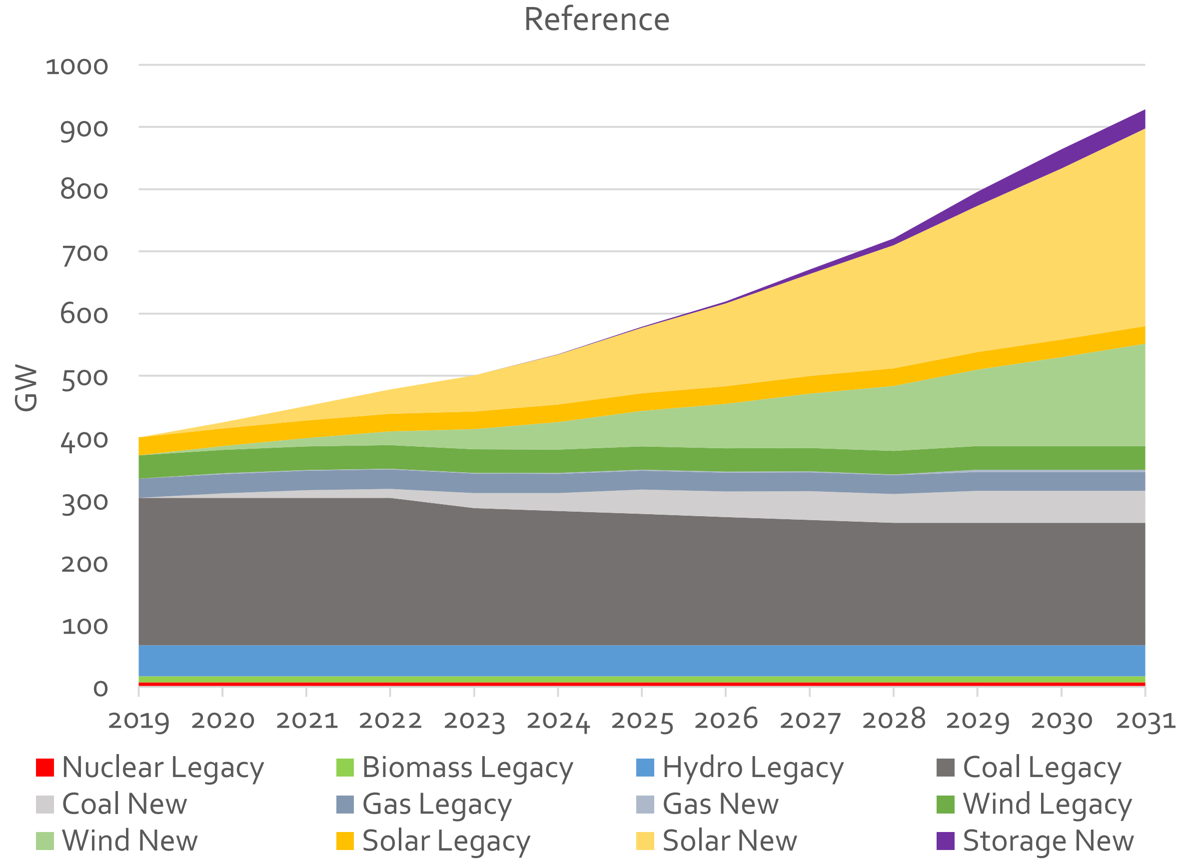


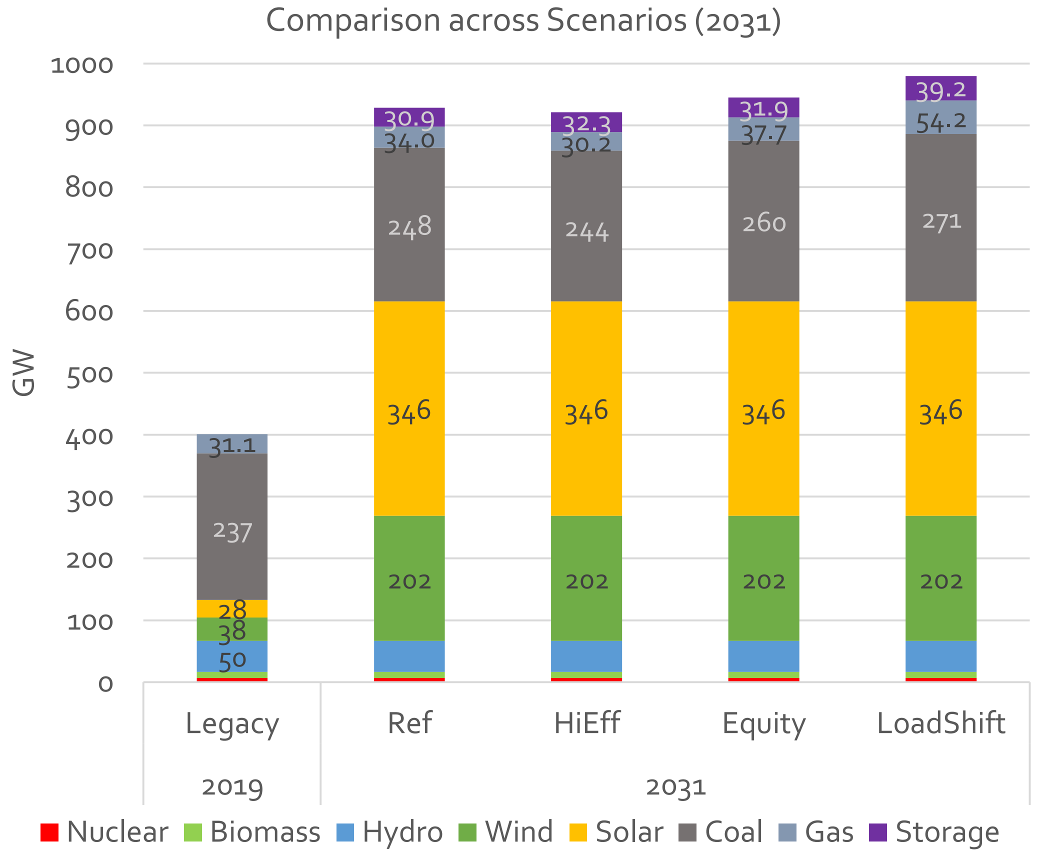
Meeting clean cooking goals needs special effort.



Highlights importance of strong AC and fan efficiency and clean cooking programs for health and wellbeing

Installed capacity more than doubles by FY31. ~90% of the capacity added is solar and wind – together about 550GW. ~30 GW of storage added.





Robust modelling studies needed to determine appropriate siting of RE and storage projects and grid strengthening

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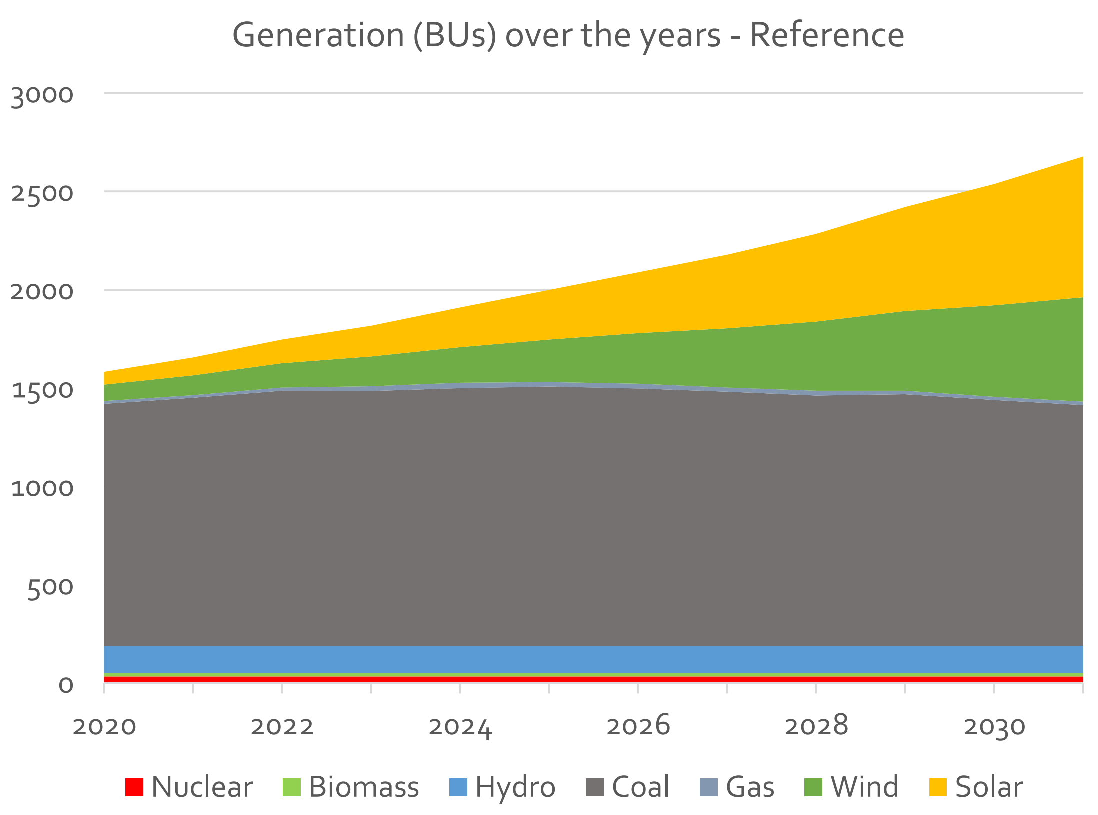
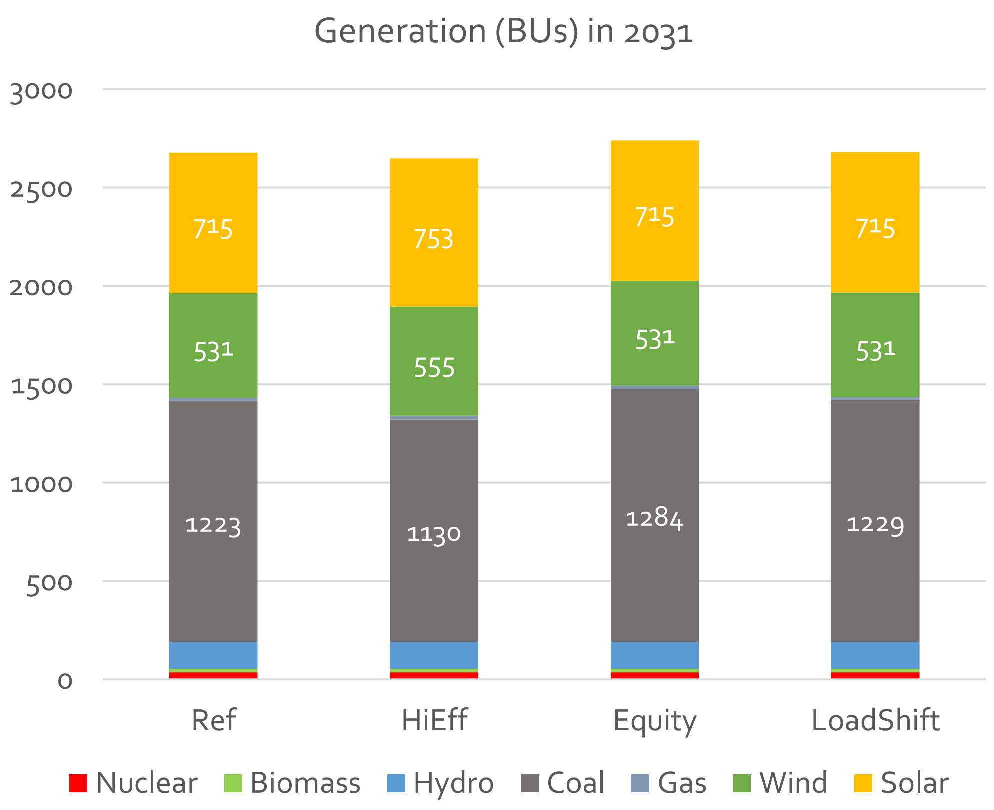
Most of the incremental generation between FY20 and FY31 is from wind and solar. Yet, 45-50% of the generation in FY31 is from coal.





Peak coal-based power generation could happen during the decade. Prepare for reduced coupling of coal and power sectors

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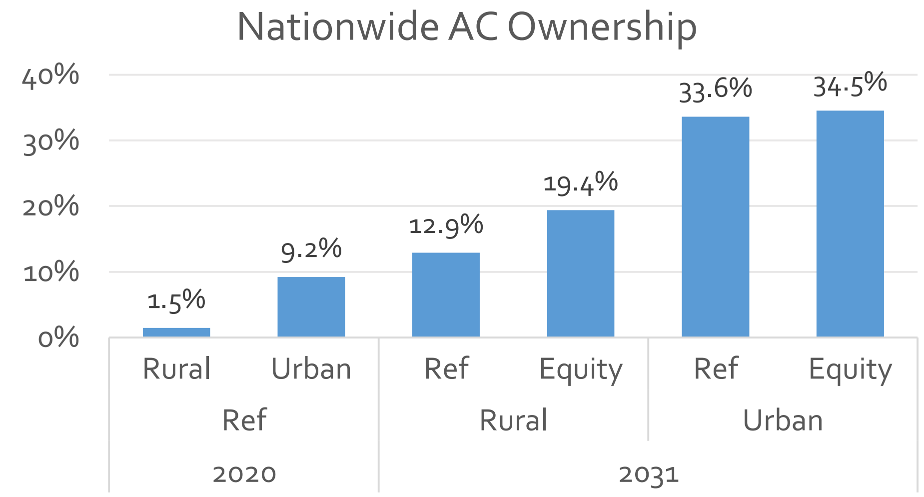
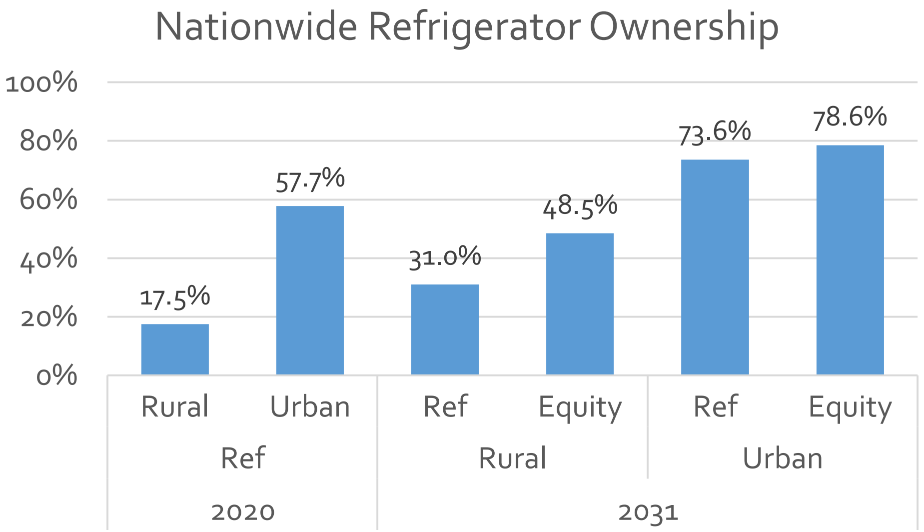
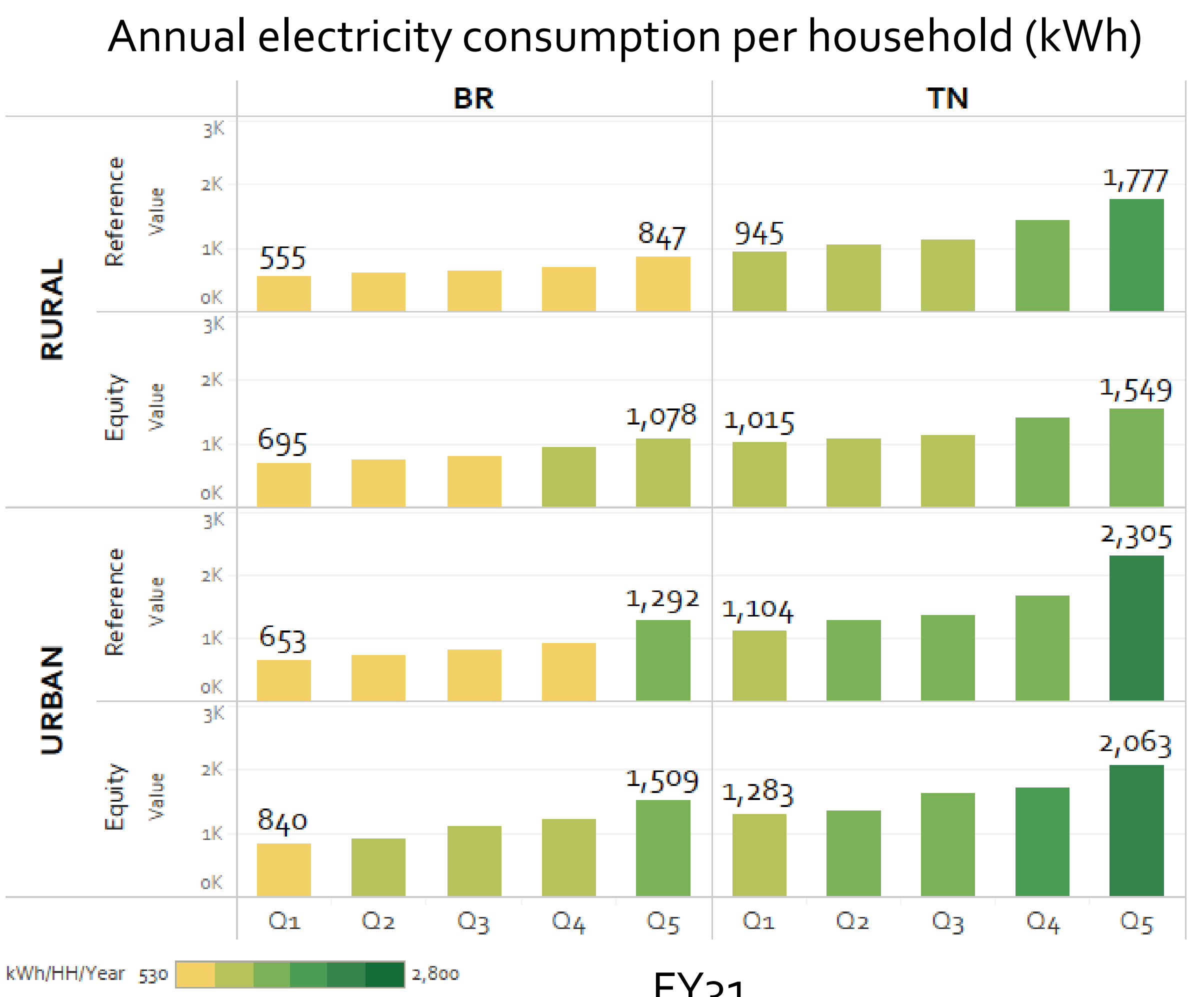
Reduced inequity could result in higher appliance penetration and subsequently higher demand







FY31

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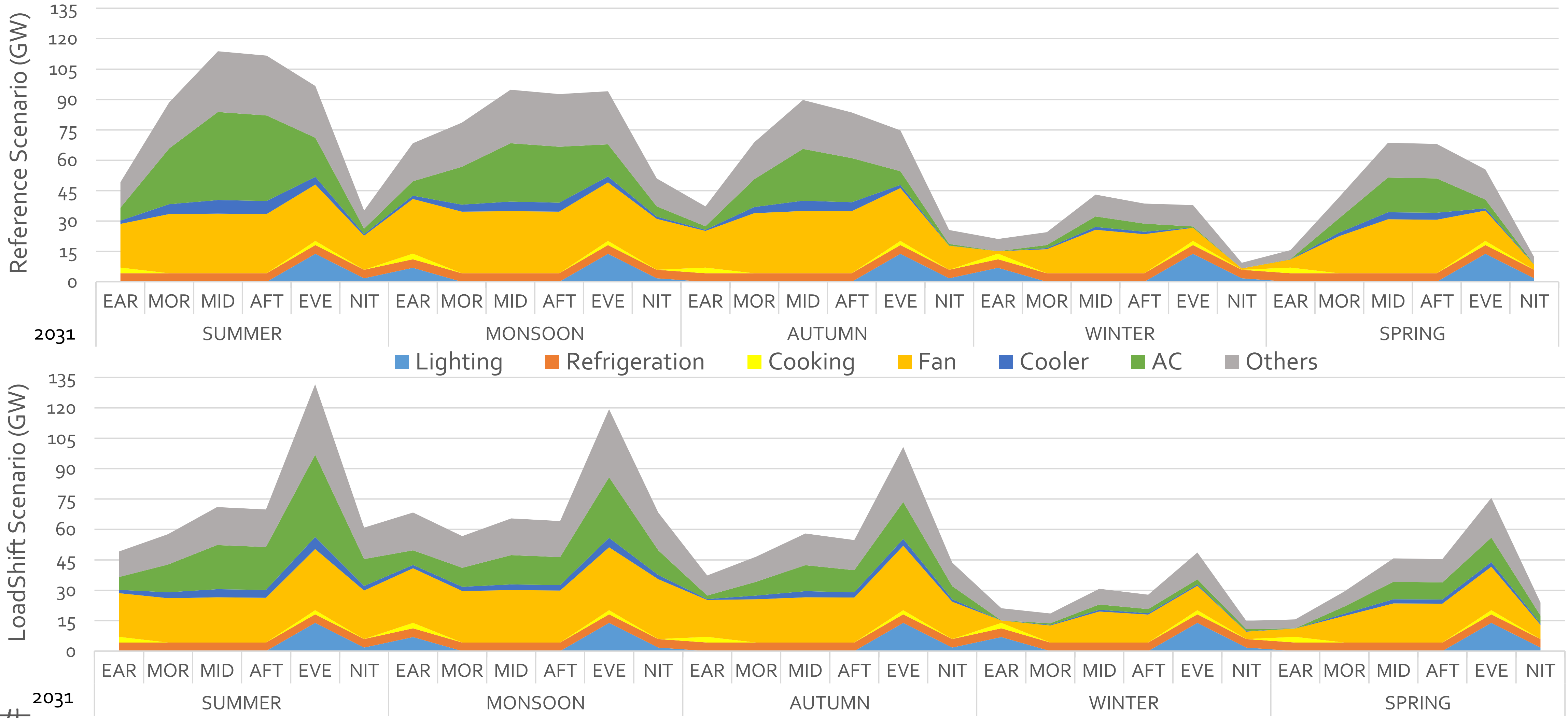
Due to higher occupancy during evening/night, residential demand could have a significant evening peak, when there is no solar energy



Note: Time slices are of different duration

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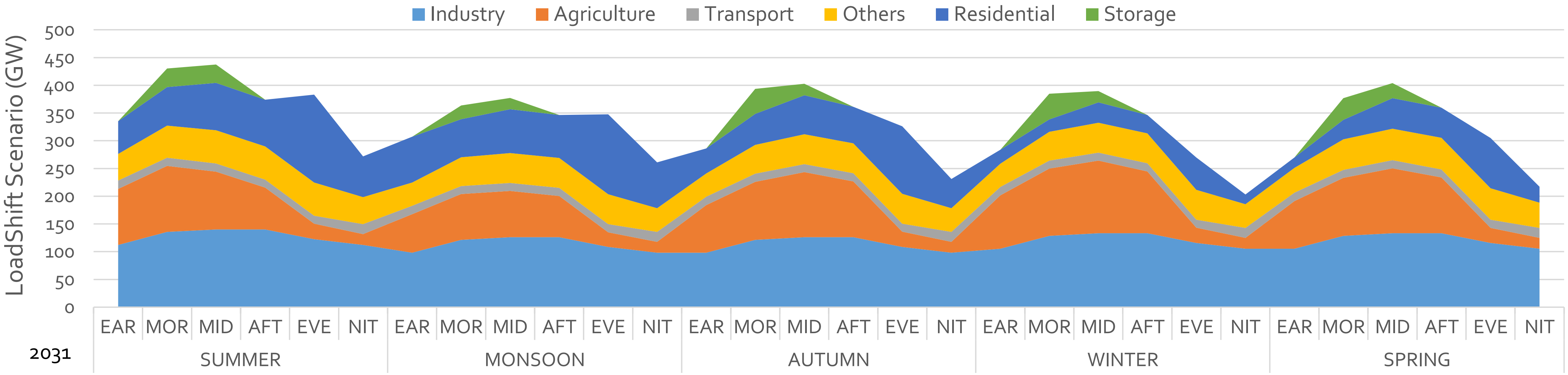
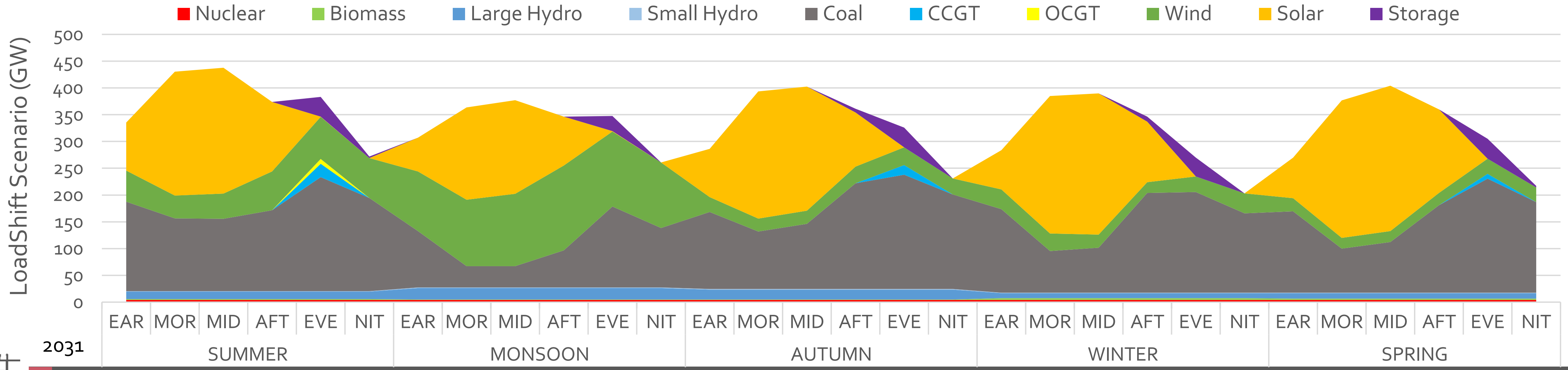
However, the overall evening peak is not as pronounced, but still may need significant balancing support from dispatchable generation





Note: Time slices are of different duration

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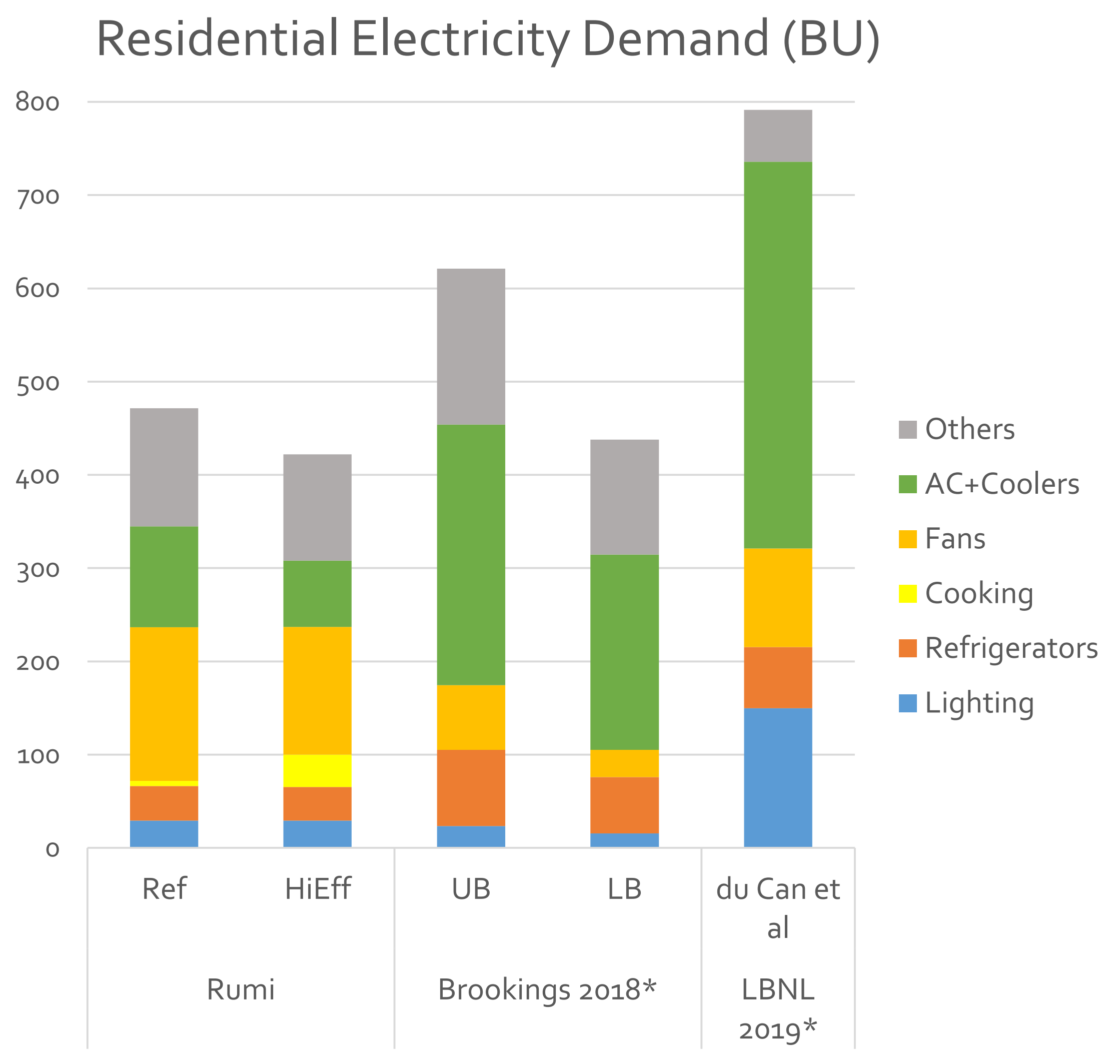
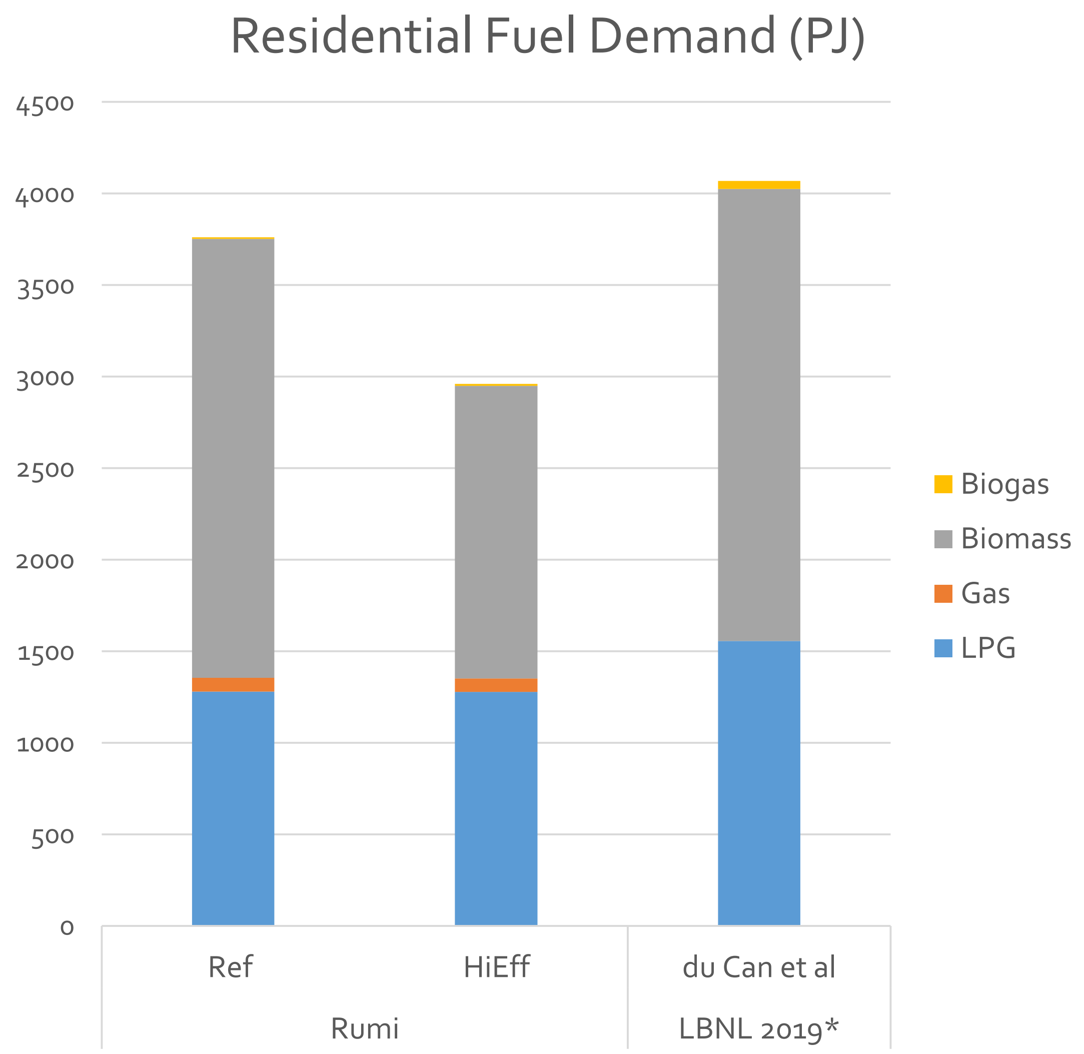
COMPARISON WITH OTHER MODELS: RESULTS

Residential energy demand – FY31





LBNL and Brookings studies refer to ACs only

**Closest Comparable FY or CY*

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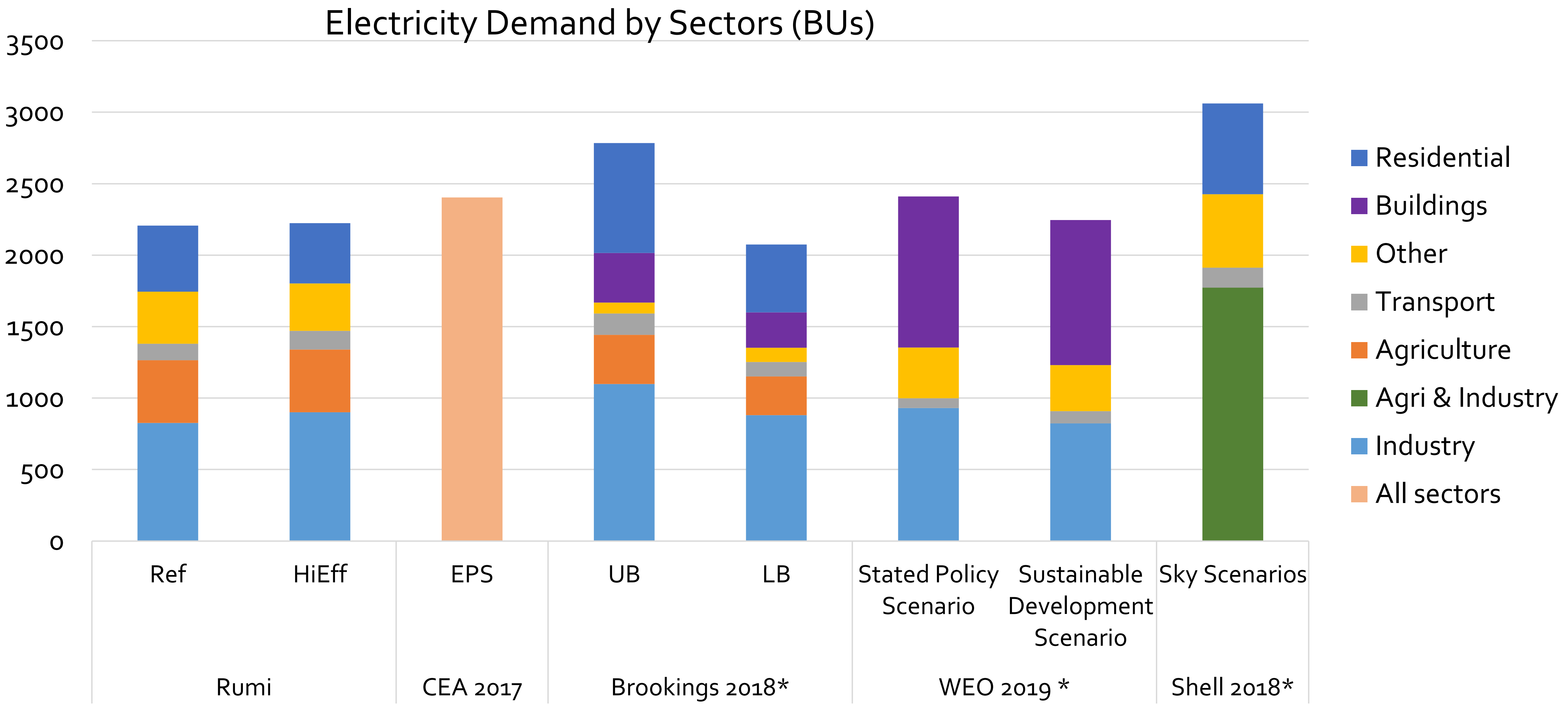
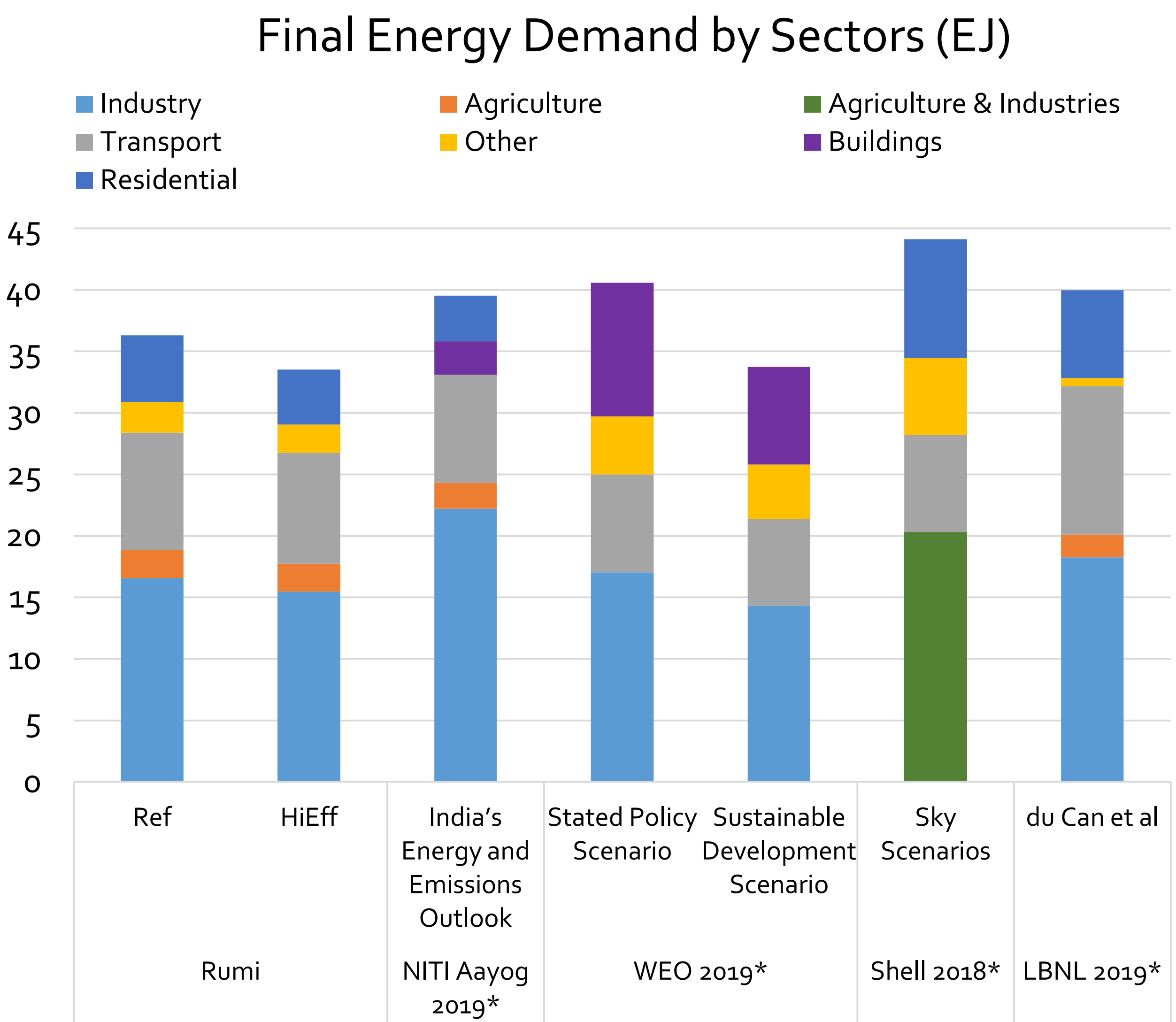
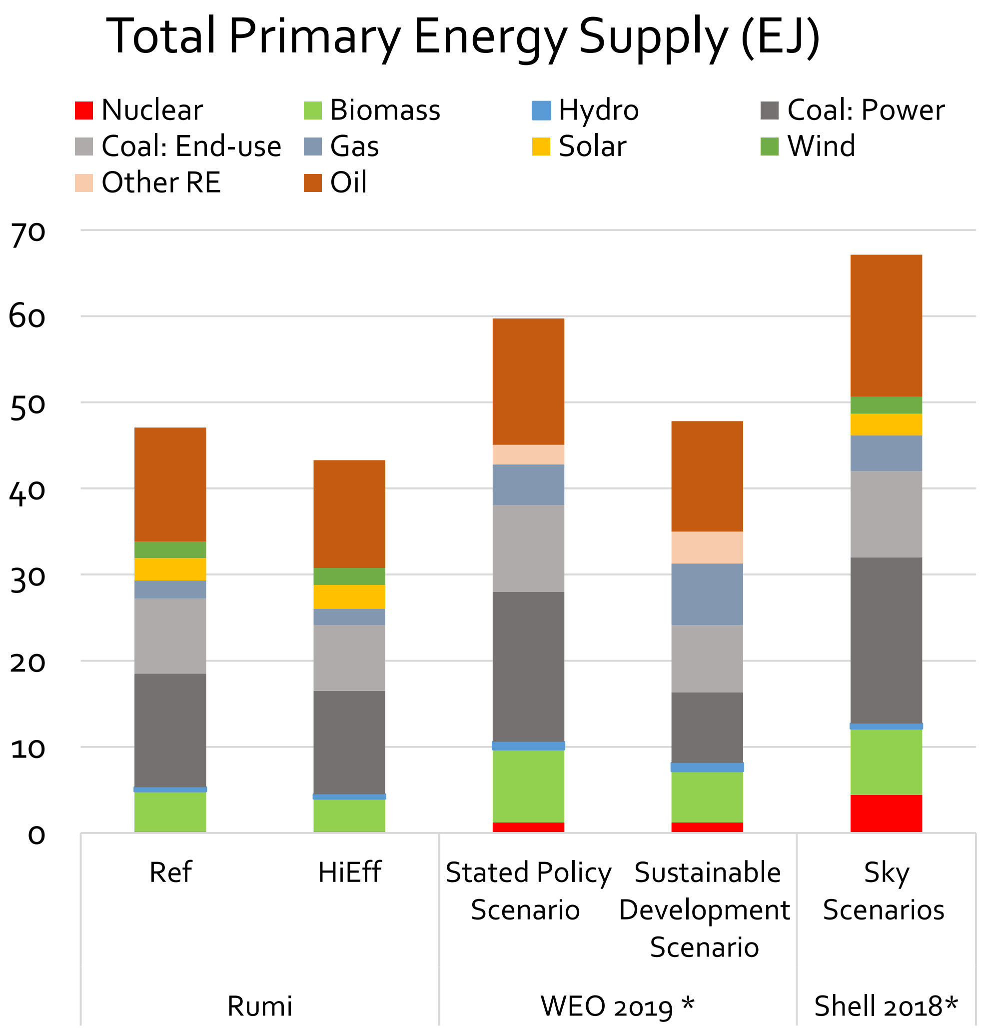
Electricity demand – FY31



Closest Comparable FY or CY

Energy Demand and Supply – FY31





**Closest Comparable FY or CY*

Appendix: Details of Rumi

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September 2020

THE RUMI MODELLING PLATFORM

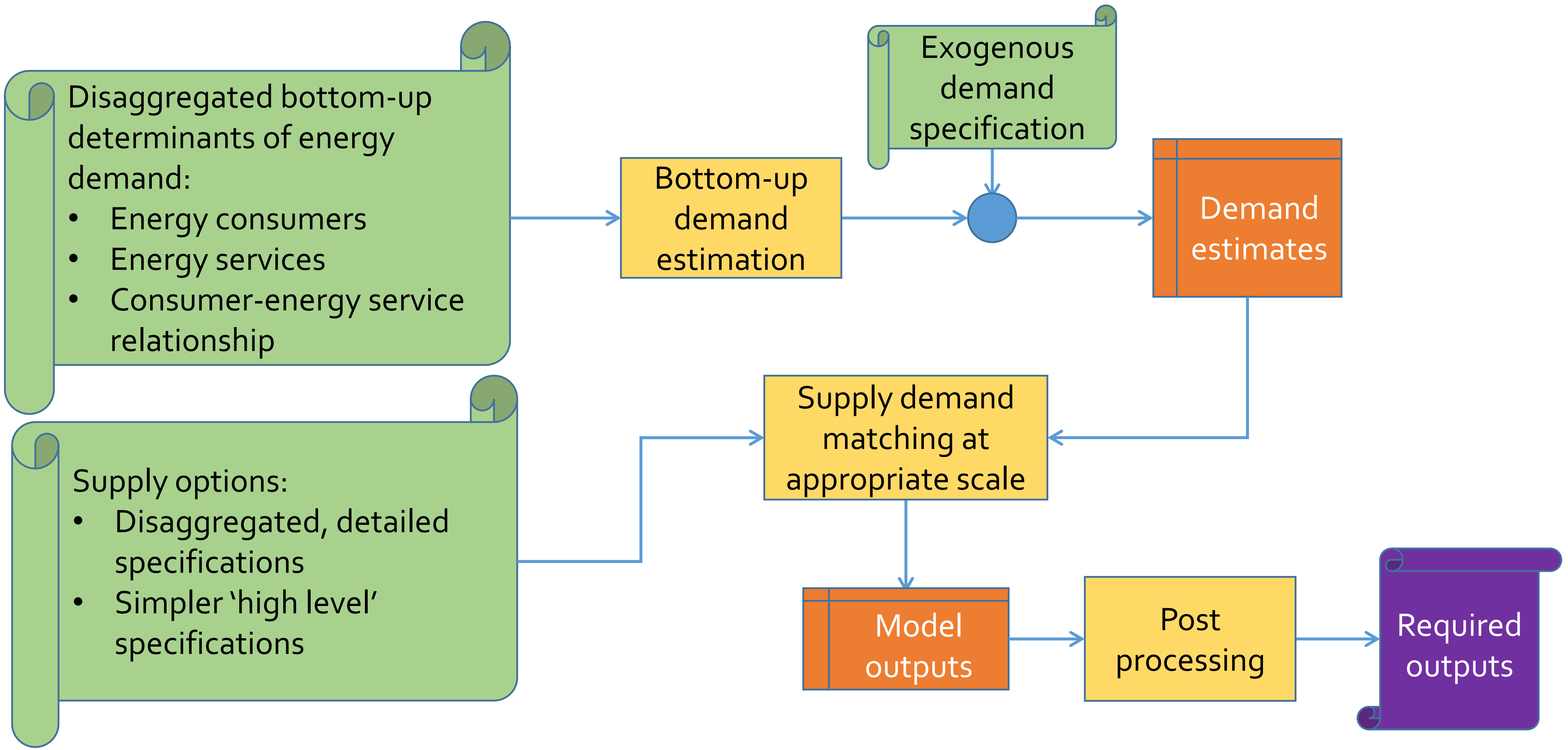
About the Rumi platform

- Complements, enriches eco-system of available modelling platforms such as TIMES-MARKAL, MESSAGE, and OSEMOSYS
- Explicit focus on detailing out demand
  - But will progressively include various forms of demand-supply matching
- Making it freely available for download and use: a crucial objective
  - Data sets will also be made available in addition to source and documentation
  - MESSAGE and TIMES-MARKAL made open source after Rumi development well under way ☺
- Plan to provide easy ways to link to other models
  - Simple, clean text-based interfaces

Rumi and other similar platforms

- Many similarities in capabilities but also some differences
- Demand
  - Rumi supports greater level of detail more easily: e.g. geographically disaggregated temperature driven cooling demand
  - Other platforms support demand as a function of price: currently not supported in Rumi
- Supply
  - Rumi supports disaggregated CUFs based on which production is modelled
  - Other platforms support many more technologies currently than Rumi
- Technology adoption pathways currently not supported in Rumi
- Interface
  - Many other platforms have a GUI which Rumi does not have
  - Rumi: text-based simple and intuitive inputs

Rumi model structure



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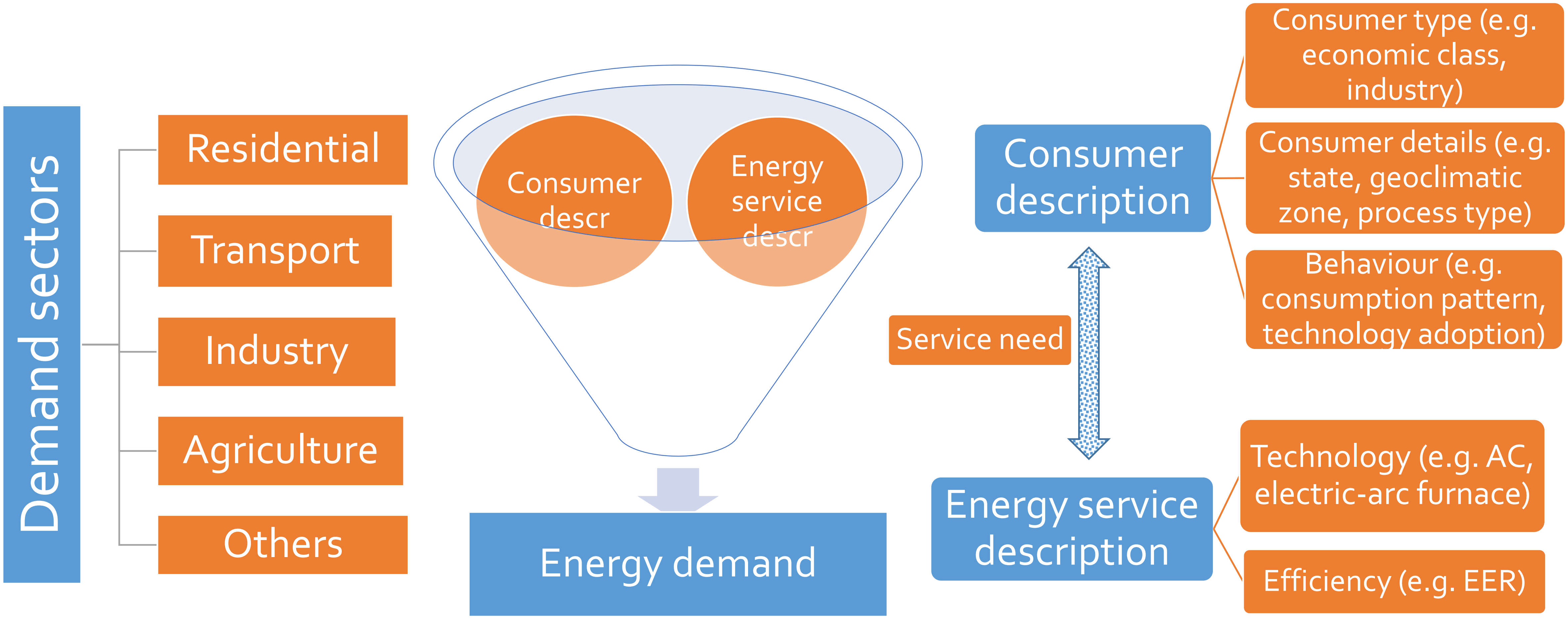
Demand specification in Rumi



Demand currently not a function of energy carrier prices

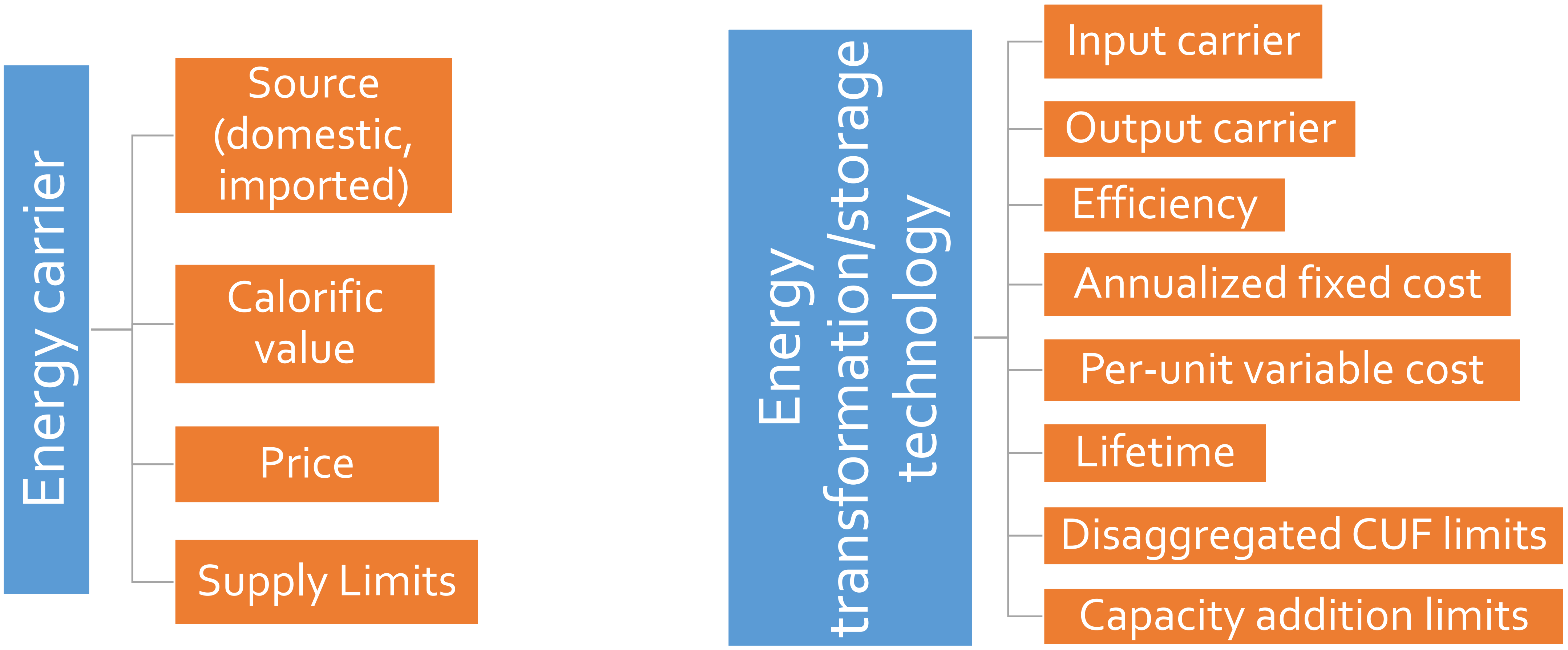
Temporally disaggregated

Rumi: disaggregation of demand

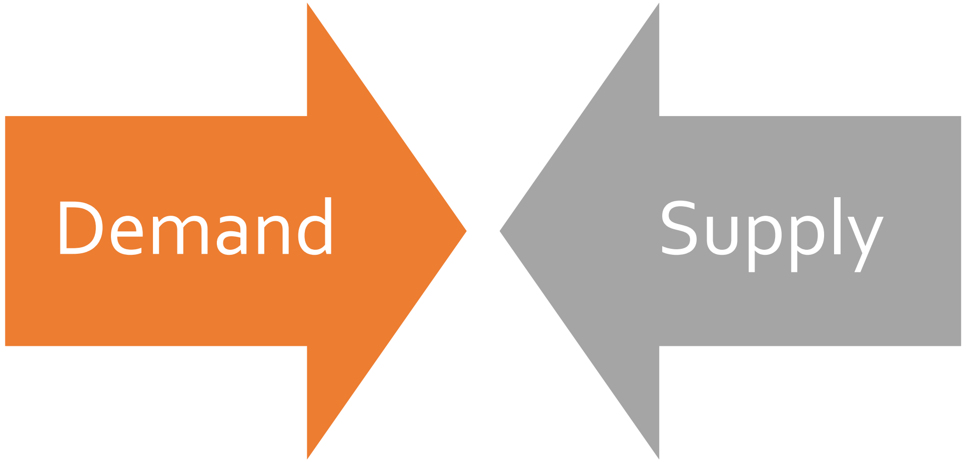
- Residential sector can be detailed out now
- Other sectors to be added in due course

- Types of disaggregation supported
  - Geographic
    - States and urban-rural
  - Economic class
    - Fractiles within the geographic disaggregation
  - Temporal
    - Time-slices consisting of seasons with representative days and slices within a day
  - Weather
    - Temperatures at sub-state level

Supply specification in Rumi



Demand-supply matching



- Demand and Supply matched at specified time granularity
- Optimises with perfect foresight
    - Optimised typically for cost

- Modeller can provide inputs at preferred level of detail
- Current implementation of Rumi supports detailed specification of
    - Demand: Residential sector
    - Supply: Electricity generation
- Other sectors, technologies to be added/detailed out in future

RUMI-INDIA MODEL

Basic model elements

- Model period: Financial year 2019-20 to 2030-31
- Geographic disaggregation
  - 25 'states' with UTs and non-Assam NE states grouped as one state each
  - Each state further sub-divided into urban and rural regions
- Temporal resolution (only relevant for electricity)
  - 5 seasons
    - Summer (Apr-May), Monsoon (Jun-Aug), Autumn (Sep-Oct), Winter (Nov-Jan), Spring (Feb-Mar)
  - 6 slices in a typical day of each season:
    - Early (06-09), Morning (09-12), Mid-day (12-15), Afternoon (15-18), Evening (18-22), Night (22-06)
- Demand sectors: Residential , industry, transport, agriculture and others
- Supply options: Coal, crude oil, petroleum products, natural gas, electricity, biomass, biogas

Major data sources

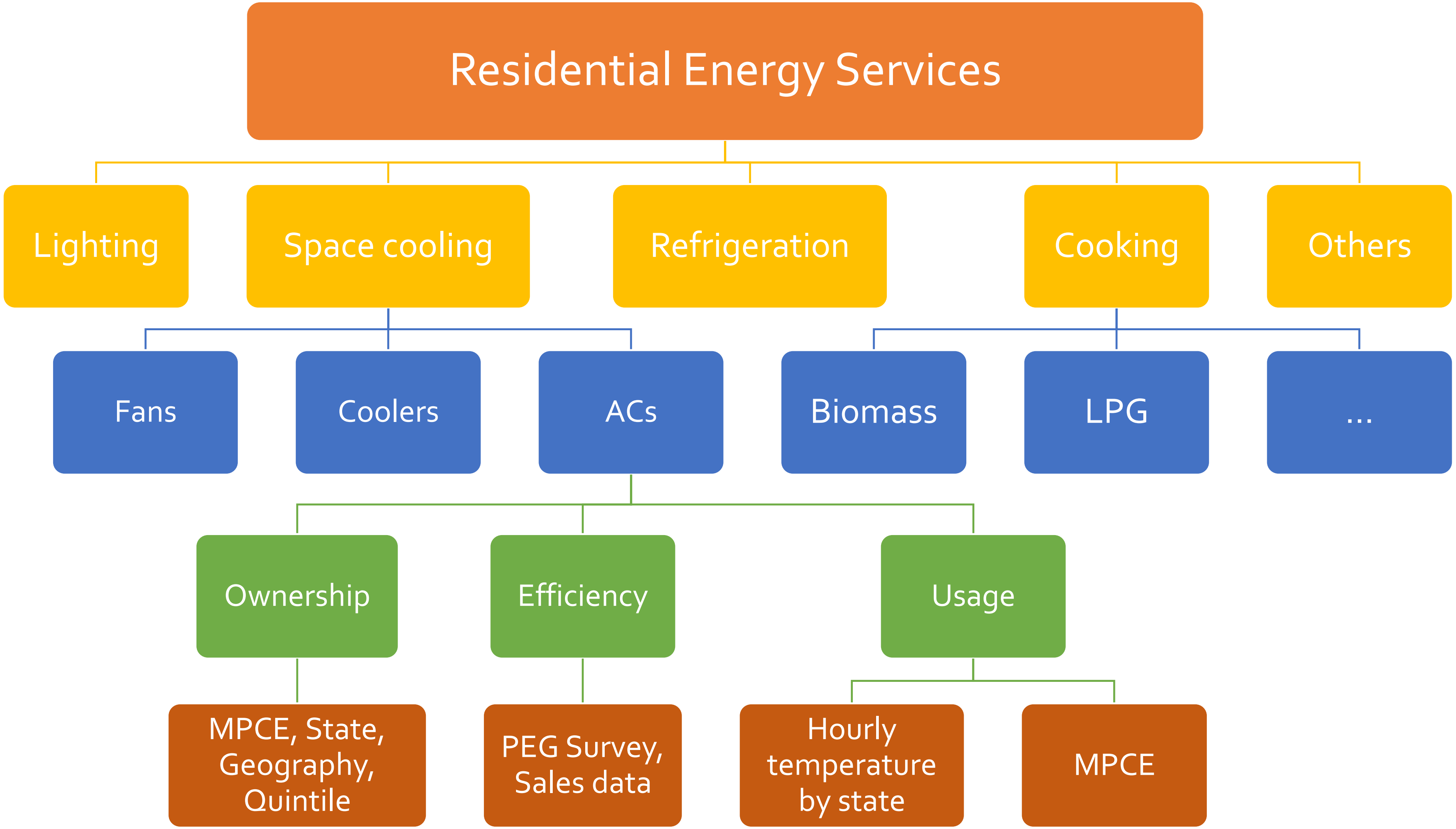
Source	Data used
NSSO expenditure surveys, IHDS, PEG residential survey	MPCEs, appliance ownership, household characteristics
IIASA	State-wise, urban-rural population projections
RBI/CSO	Inflation indices / price deflators
BEE, ELCOMA, e-commerce sites	Appliance sales by efficiency category
CMIP and OpenWeather	Temperature projections and hourly profile
IMF	GDP projections
State and CERC regulatory orders	Electricity prices: base year + projections for conventional sources
Regulatory orders, literature	Renewable price projections and CUFs
CEA	Historical demand, installed capacity, T&D losses, aux consumption, heat rates, CUFs …
MoC, MoPNG	Domestic coal, oil, gas production, prices; usage by demand sector …
World Bank	Imported coal, gas + all petroleum prices

Rumi demand model

- Non-residential sectors [Transport, Industry, Agriculture, Others]
  - Annual energy-carrier-wise demand projected based on past GDP-elasticity
    - National GDP used as no reliable projections of sectoral GDP available
    - Elasticity slightly adjusted to account for increasing efficiency and for “reasonableness”
  - Elasticity adjusted to account for likely structural changes that may occur
    - Increased electrification of transport
    - Solarization of agriculture demand and consequent shifting to day time
  - Granularity of demand input
    - Non-electricity demand at national, annual level
    - Electricity demand at state, time-slice level
    - Load shapes roughly approximated based on a few sample load shapes from EESL

- Residential demand: Detailed bottom-up demand estimation
  - Transport and industry to be added next

Residential demand detailing: AC example



Residential demand model – 1

- Five energy services modelled: lighting, cooking, cooling, refrigeration, others
- Except cooking, all others served only by electricity
- Modelled for every state, urban-rural region, expenditure quintile, time-slice

- % of HHs of each state, region, quintile using electrical appliances of a type
  - Obtaining by regressing over these variables from the NSSO 66th round expenditure survey 2011-12, and projecting MPCE values based on past trends
- Distribution of different efficiency ratings within HHs using an appliance
  - Based on PEG consumer survey of ~3000 HHs in 2 states
- # electrical appliances of each type per household of each quintile estimated by
  - Combining IHDS II data (to map quintiles to # of rooms) and PEG survey data (to map # of rooms to # of appliances)
- One size of ACs and refrigerators assumed based on most popular models in use

Residential demand model – 2

Energy Service	Description
Lighting	• 100% HHs assumed electrified, and hence 100% lighting met through electricity • Three technologies (efficiencies) modelled: incandescent, CFL, LED • Efficiency: 60W, 15W, 9W in initial year with LED efficiency improving over time • Daily use: 6 PM – 11 PM; and 1.5 hours of morning lighting in monsoon and winter
Refrigeration	• Three efficiency ratings modelled based on sales and survey: 3, 4 and 5 star • Based on sales and survey, on average, 200 L direct-cool refrigerators modelled • Efficiency: Average of BEE mandates since Dec 2016 and improving over time • Usage: 24 hours
Cooling	• Three technologies modelled: fans, air coolers and (room) air conditioners • Fans: Only one efficiency level (70 W) but improving fast over time due to mandates • Coolers: Only one efficiency level (180 W), improving gradually over time • ACs: 3, 4, 5 star modelled, current efficiencies taken from average of BEE ratings • Future AC efficiencies increase at a fast pace due to improvement in efficiency as well as rapid increase in ownership and usage • Time-slice wise usage based on temperatures – explained in a later slide

Residential demand model – 3

Energy Service	Description
Others	• For each state, likely total residential demand for FY20 is estimated by extrapolating from past CEA data • The difference between the extrapolated FY20 value and the bottom-up value estimated for the other 4 services is used to approximate the share of ‘Others’ • This share is kept constant over the model years for each state • This share is applicable to each time-slice
Cooking	• State, region, MPCE based regression used to estimate %-HHs using traditional (biomass) fuel or modern fuels • Values obtained from regression adjusted to account for the effects of Ujjwala based on the NSSO 76th round washing and sanitation survey • Modern fuel share split into LPG (the dominant share), PNG (urban areas), biogas (rural areas) and electricity (both urban, rural) based on PEG’s CEFTI model • Useful per-capita energy required assumed based on literature (2.2 MJ / cap / day) • Efficiency: LPG, PNG and biogas stoves have 58% efficiency, (induction) electric stoves have 82% efficiency, biomass stoves have 14% efficiency. • All efficiencies except biomass gradually improve over time • Usage time: One hour between 6 AM – 9 PM and one hour between 6 PM – 10 PM

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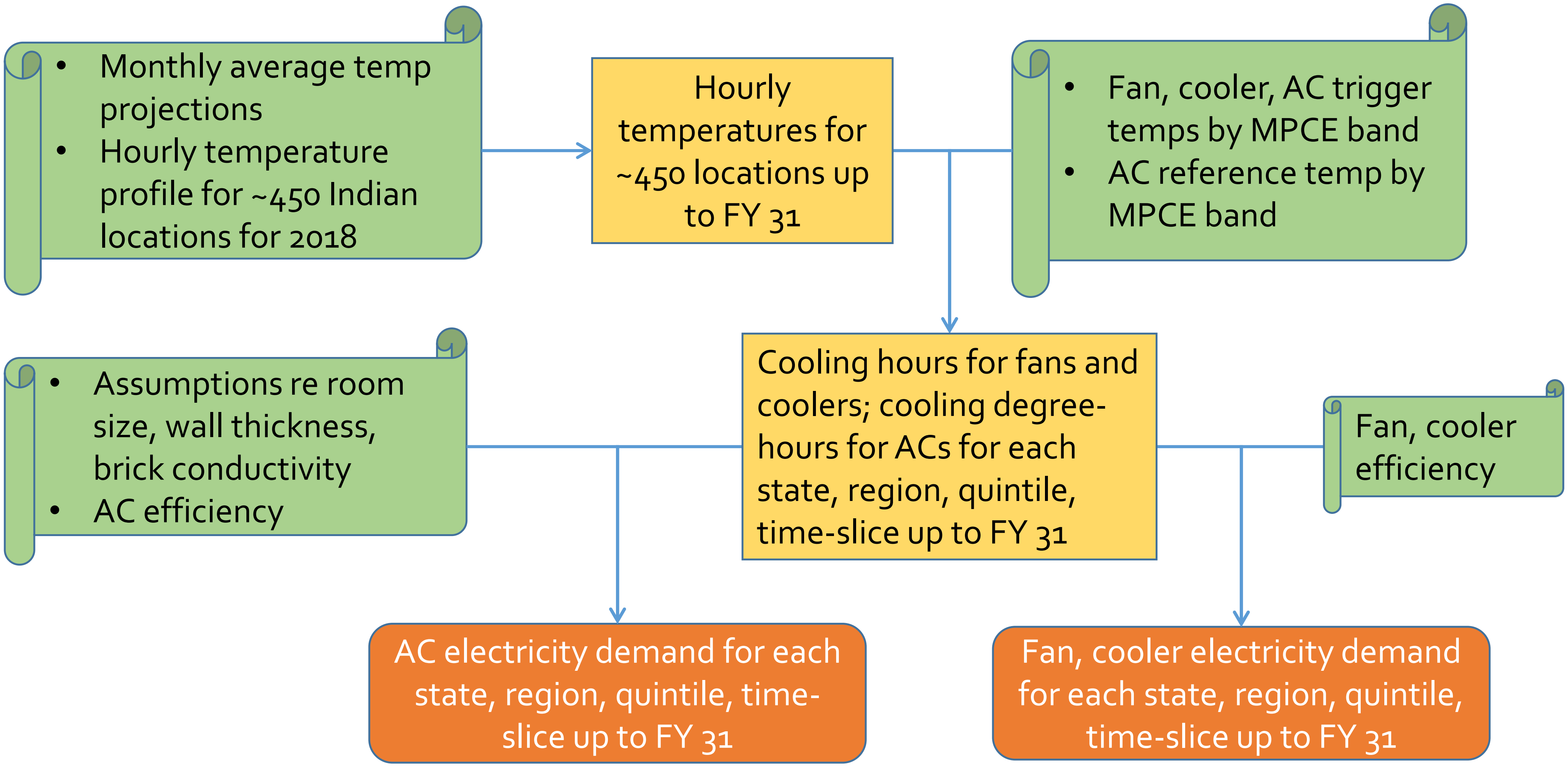
Residential cooling demand – 1

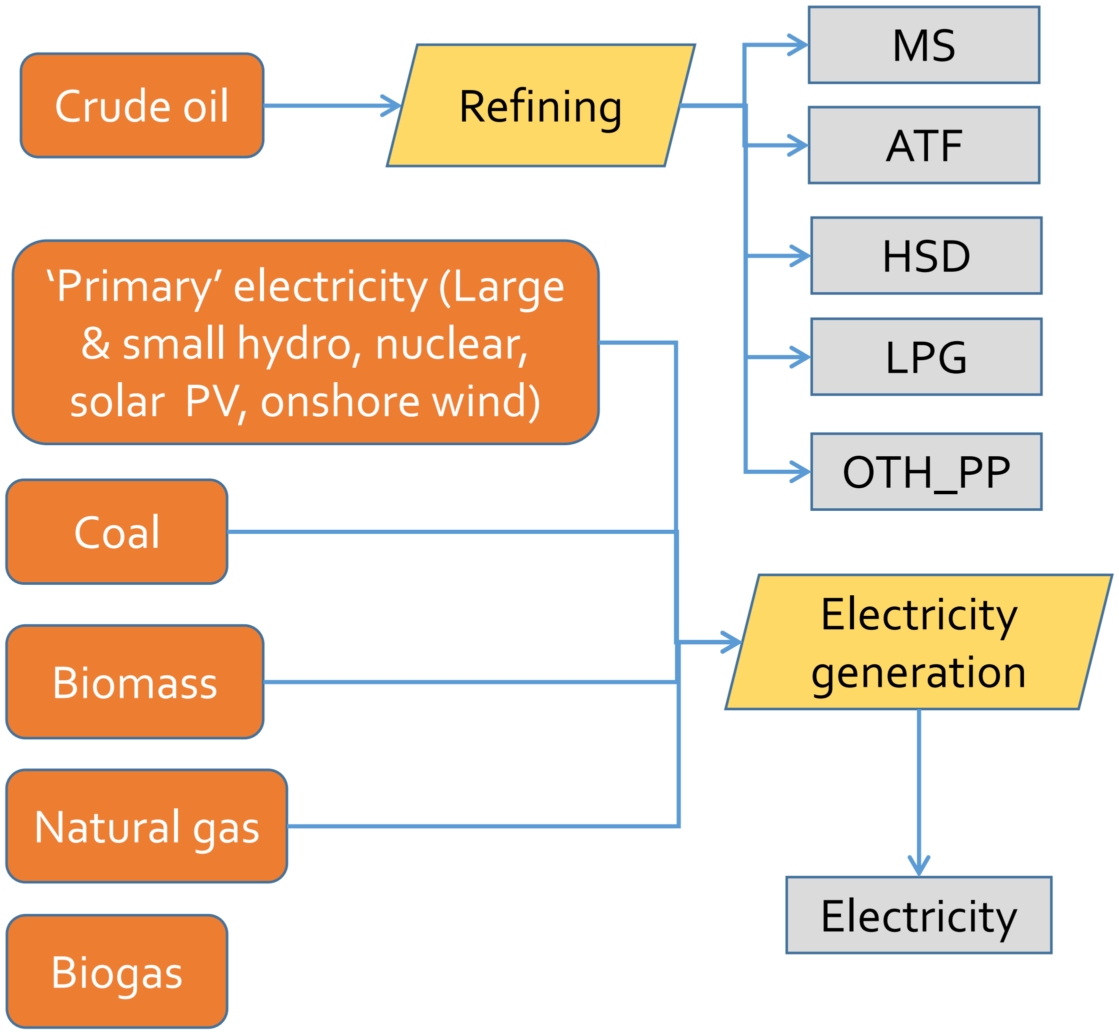
- NSSO expenditure survey only gives combined ownership/use of ACs and coolers
  - IHDS used to split this between ACs and coolers in 2011-12
  - Share of ACs in ACs+coolers in FY31 assumed for each state and region based on climatic zones
    - Ranges from 50% (rural Bihar, J&K etc.) to 90% (urban Delhi, Haryana, Goa etc.)
  - Actual AC and cooler use penetration estimated from the above

- Residential cooling electrical energy demand estimated as a function of temperatures
  - Fans and coolers: Based on numbers of hours of usage and wattage
  - ACs: Based on cooling degree hours, EER efficiency and assumptions about room characteristics

Residential cooling demand – 2



Rumi supply model



- Primary sources of energy
  - Coal, crude, natural gas, biogas, biomass, hydro, nuclear, solar PV, onshore wind
- Two conversion technologies
  - Electricity and refineries
  - Electricity modelled in detail
- Electricity storage also modelled
- Final use energy carriers
  - Petroleum products, electricity, coal, natural gas, biogas, biomass
- All costs in real 2018 prices

Non-electricity energy carriers – 1

- Annual domestic production limits for all primary fuels
  - Based on past production and trends for coal, crude, natural gas
  - Constant over the years for biomass and biogas
- Price
  - Different domestic and imported prices for coal, natural gas
  - Only imported price for crude (and hence petroleum products)
  - Only domestic price for biomass, biogas
- Price escalation
  - Domestic coal, natural gas price escalation based on past trends
  - Crude, petroleum products, imported coal and imported natural gas based on World Bank escalation rates

Non-electricity energy carriers – 2

- Fuel price only relevant for end-use fuels
  - Cost of fuel used to generate electricity included in the price of electricity
- Calorific value
  - Different calorific values for domestic and imported coal
  - Uniform calorific value for all other fuels
- Refinery efficiency/throughput
  - To estimate crude requirement (and hence import dependence) from fuel demand
  - Fuel demand specified only for petroleum products and not crude

Electricity in Rumi – 1

- Demand-supply matching done per time-slice per balancing area
  - Currently only one balancing area (all of India)
  - But can be state or region-wise

- Electricity generation technologies
  - Coal, CCGT, OCGT, Nuclear (PHWR), Large Hydro, Small Hydro, Biomass, Solar PV, Onshore Wind
- No separate treatment of distributed / rooftop solar PV currently
- No other nuclear technologies, offshore wind, geothermal etc. currently
- Only one coal-based technology as all new coal capacity will be super-critical
- No transmission constraints or bottlenecks assumed – 'copper plate model'
- No separate treatment of captive generation capacity – treated same as rest

Electricity in Rumi – 2

- Costs
  - Two part tariff: fixed costs (Rs / MW / year) and variable costs (Rs / kWh)
  - Variable costs include the cost of the fuel
  - Costs considered for utility scale capacity

- Coal and gas based technologies: Both fixed and variable costs
- Other technologies: only fixed costs – implicitly zero variable cost

- Fixed costs levelized over the lifetime of the generation capacity
- Fixed costs of new installations may vary by year of installation
  - Based on available data, trends, regulatory orders and literature
  - Constant across installation years for all except solar PV and onshore wind
  - Solar PV costs decline at 2% per year, wind costs decline at 1% per year

Electricity in Rumi – 3

- Separate variable costs for domestic or imported fuel
- Variable cost escalation
  - As per CERC norms for domestic fuel
  - As per fuel price escalation rate for imported fuel

- Heat rates / conversion efficiency
  - Existing coal plants: as per CEA General Review
  - Existing gas plants: as per CERC tariff regulations 2019
  - New coal plants: as per CERC tariff regulations 2019
  - New gas plants: as per literature
  - Biomass plants: as per CERC tariff regulations 2017

Electricity in Rumi – 4

- CUF / Usage factors
  - Specified as maximum CUF by each time-slice for each model year
  - Coal, gas plants: Flat 85% through the year
  - Nuclear: Flat 66% through the year based on recent past data
  - Large hydro, small hydro, biomass: Seasonal CUF based on recent past data

- Solar and wind
  - Installation year FY20 annual average CUFs of 21% and 28% respectively based on regulatory orders
  - Increasing to 26% and 35% respectively by FY31 based on literature
  - Solar profile taken from NREL SAM model for a few locations in MH
  - Wind profile taken from actual wind generation in FY18 from MH SLDC

Electricity in Rumi – 5

- Lifetime of generation capacity
  - Specified for each generation technology
  - Enables annualization of costs and facilitates retirement

- T&D Losses
  - State-wise past trends used to project state-wise T&D losses
  - Lower limit of 12% for a state and 15% nationally
  - State-wise demand for each time-slice bumped up by corresponding T&D losses to get busbar demand

- Auxiliary consumption
  - Specified for each technology based on CERC regulations
  - Auxiliary consumption subtracted from total electricity generated to obtain the supply that can meet busbar demand

Electricity in Rumi – 6

- For each electricity generation technology – two types of capacity
  - Legacy capacity ‘inherited’ by the model, i.e. installed prior to FY20
  - New capacity chosen by the model, i.e. installed between FY20 and FY31
  - Slightly different treatment of legacy and new capacity
  - Currently, no special consideration for capacity ‘in the pipeline’
    - Model treats the future as a clean slate and adds capacity that it finds appropriate

- Legacy capacity
  - State-wise technology-wise capacity data
  - State-wise fixed and variable costs based on most recent regulatory orders
  - Retirement of legacy capacity as per CEA retirement schedule in NEP
    - Only for coal and gas

Electricity in Rumi – 7

- New capacity addition decided by the model to minimise costs while meeting load
  - Determined by fixed and variable costs, CUFs, auxiliary consumption etc.

- New capacity added in a year constrained by maximum possible capacity addition for each technology
- For all technologies except solar and wind, typically the maximum capacity that was added in any year historically
- For newer technologies solar and wind
  - Initial year max capacity 10 GW and 6 GW respectively
  - FY30 max capacity addition ~80% of max annual capacity added by China already: 40 GW and 20 GW respectively
  - Linear interpolation in between

Electricity parameters installation year 2020 (Ref)

Technology	Efficiency (Heat rate)	Annual Maximum CUF	Remarks
Coal	38.1%	85%	• Domestic VC escalation as per CERC • Imported VC escalation as per World Bank coal prices • Fixed cost escalation 0% • Costs of new MoEFCC emission norms not included
CCGT	55.7%	85%	Similar to coal
OCGT	38.6%	85%	Similar to coal
Nuclear	NA	66%	Fixed cost escalation 0%
Large Hydro	NA	32.8%	Fixed cost escalation 0%
Small Hydro	NA	20.6%	Fixed cost escalation 0%
Solar PV	NA	21%	Fixed cost escalation -2%
Onshore wind	NA	28%	Fixed cost escalation -1%
Biomass	23.9%	23.1%	Fixed cost escalation 0%

Electricity storage in Rumi

- Two types of storage modelled
  - Four-hour and six-hour battery storage
  - Pumped storage not modelled as does not appear to be cost-competitive
    - But can easily be added

- Annualized fixed costs expressed as (Rs 000 / MWh / year)
  - Based on NREL 2019 Annual Technology Baseline including BoS costs
  - 4-hour battery: $306 / kWh in FY20 falling to $160 / kWh in FY31
- Round-trip efficiency taken from NREL ATB for Reference scenario
- Constraints on maximum capacity of any storage that can be added in any year
- Depth of discharge, lifetime etc. based on literature
  - Lifetime constrained by both # of charging cycles as well as by # of years
  - Storage charged after accounting for efficiency loss

Electricity demand-supply matching

- For each time-slice of each day ‘Required electricity’ = ‘Available electricity’ in a balancing area
  - Each day considered separately because, though demand is similar across representative days of a season, storage state may vary across days

- Required electricity
  - Sum of state-wise electricity demand in that time-slice increased by T&D losses
  - Any storage charging requirement in that time-slice including storage losses
- Available electricity
  - Total electricity generated from various sources minus auxiliary consumption
  - Electricity available in storage subject to depth-of-discharge constraints

- Capacity addition optimised to minimise cost of making electricity available to enable such matching in each time-slice of each year

Rumi optimization

- Optimizes for total cost to meet the specified demand at the specified time-granularity with perfect foresight

Choices to be made by the model

- Capacity of each generation technology and storage technology to install in each year
- Generation technologies to schedule in every time-slice to meet electricity demand
  - Including domestic or imported coal/gas based generation
- Storage technologies to charge/discharge in every time-slice
- Quantity of domestic or imported coal/gas for end-use
  - Related to choice of domestic or imported coal/gas based generation

Post-processing

Additional information can be computed from model outputs. For example,

- Per-capita energy consumption
- State-region-quintile-wise energy costs incident upon each HH for each year
  - Including cost of purchasing traditional biomass for cooking
- GHG emissions from the energy sector
- Energy intensity
- Import dependence for each fuel and purpose (end-use, electricity generation)
- Quantities of fuel required for electricity generation
- Quantity of electricity generated from each fuel

Scenarios – 1

- Three scenarios in addition to Reference

- High efficiency scenario
  - Affects all aspects as efficiency improved along various dimensions
  - Faster improvement in average appliance efficiency over the years
  - ↑ share of higher efficiency (star rating) appliances of same technology
  - ↑ trigger / reference temperatures for cooling appliances: behaviour change
  - Greater electrification in all sectors
    - Electric cooking in residential, greater electrification in industry, agriculture, transport
  - Reduced GDP elasticity of demand for non-residential sectors
  - Reduced T&D losses – lower limits of 10% per state and 12% nationally
  - Improved CUFs for solar, wind and heat rates for coal, gas at higher costs
    - Cost increase lower than CUF/efficiency increase

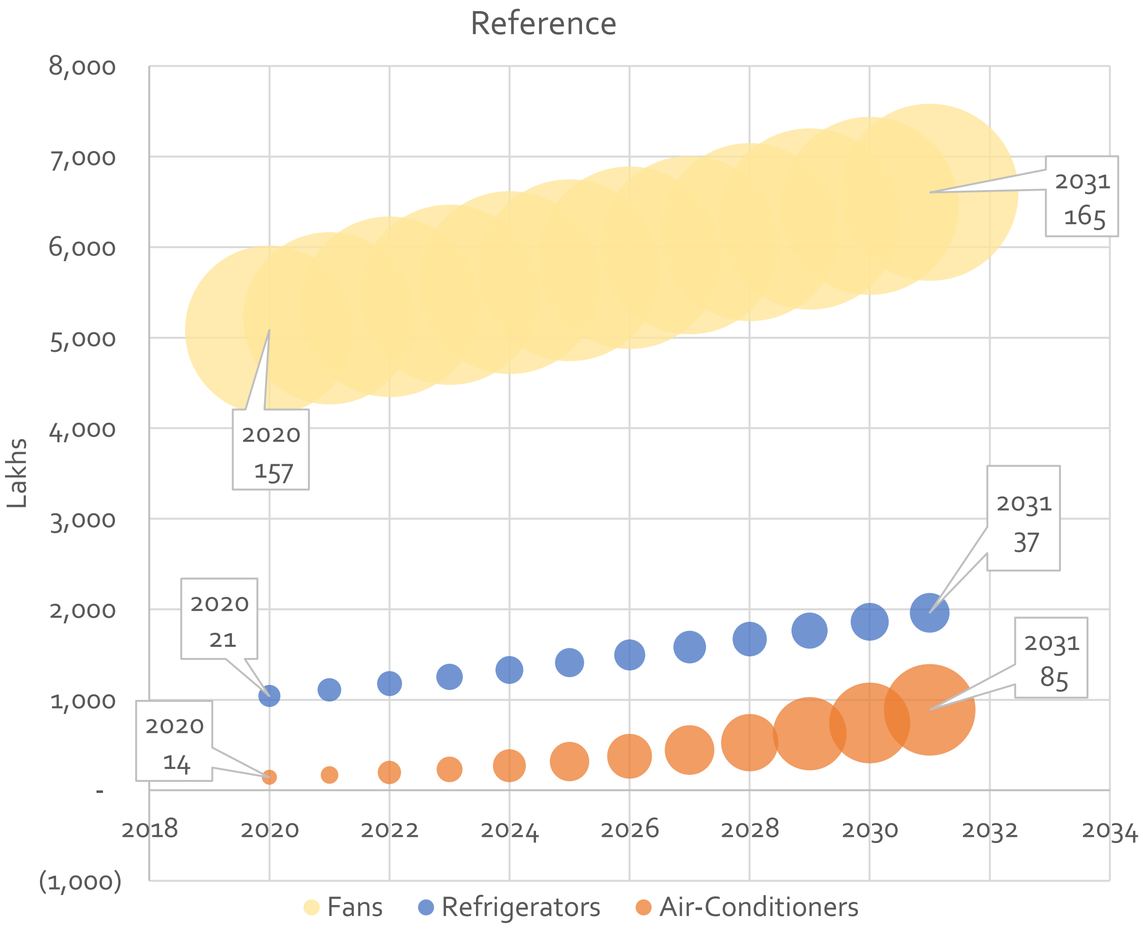
Scenarios – 2

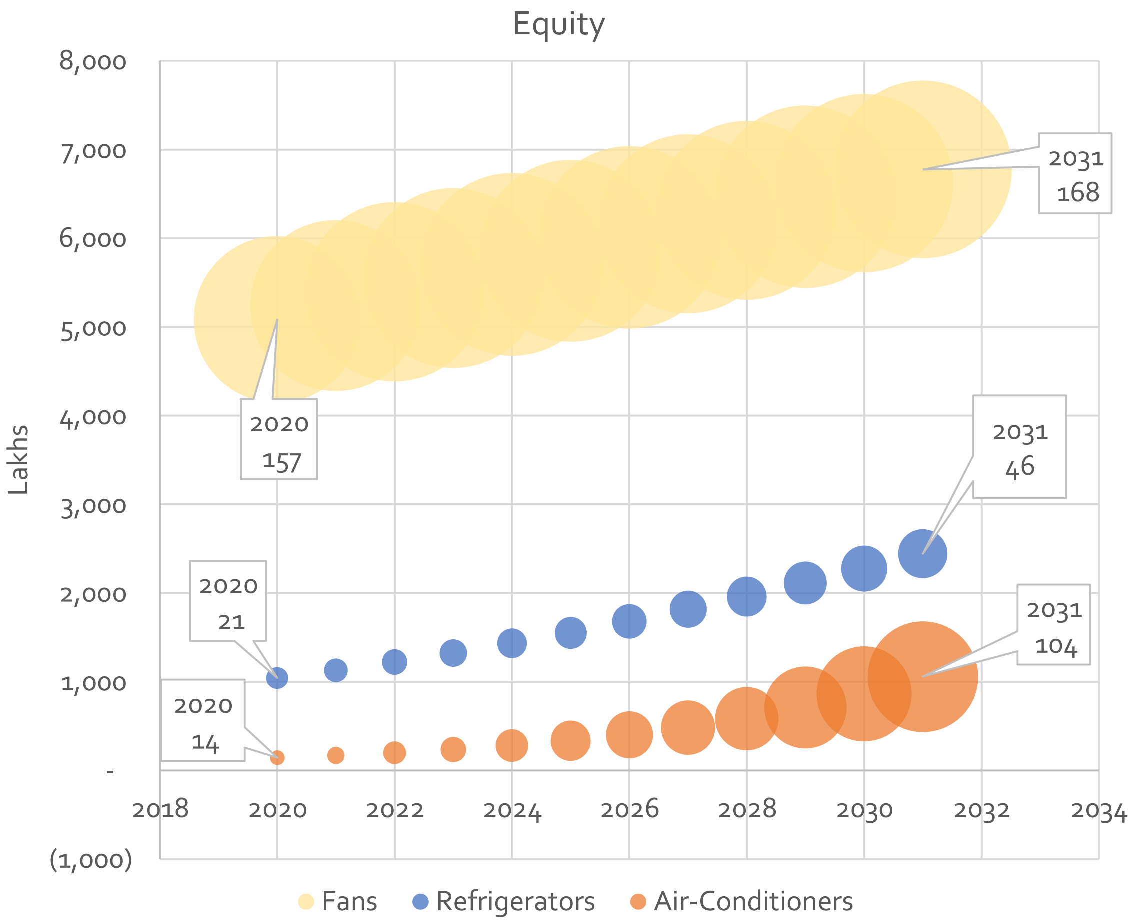
- Equity scenario
  - More equitable India where MPCE divergence is lower while keeping national average MPCE roughly the same as Reference
  - Urban-rural, inter-state and cross-quintile MPCE inequities reduced
  - Ensuring that no state-region-quintile gets poorer over time
  - Affects residential energy demand and cost of energy per HH as a share of the household's average consumer expenditure

- Load-shift scenario
  - Reference scenario models cooling demand as a function of temperature – hence it mostly manifests during the day
  - Load-shift scenario shifts some of this load to the evening/night to simulate cooling behaviour based on house occupancy
  - Affects only residential electricity demand

MORE RESULTS FROM THE RUMI-INDIA MODEL

Appliances in use: number and consumption

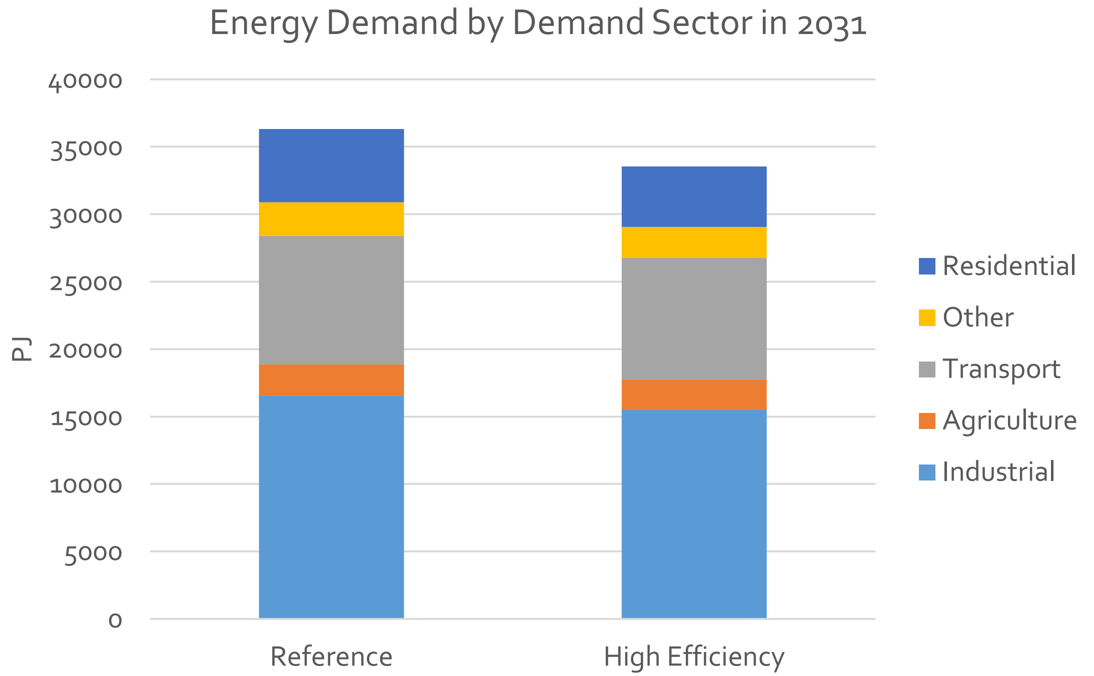


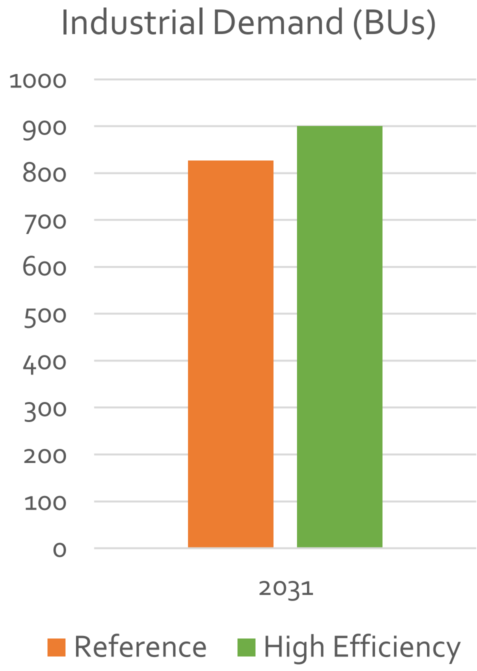


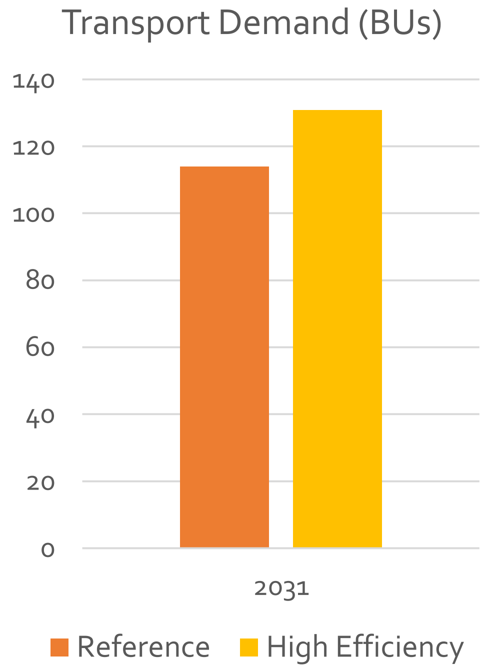
Bubble-size represents consumption in BU (shown in the call-out data labels); y-axis represents count of appliances in use in lakhs.

Fans remain the largest consuming appliance in FY31, though AC consumption increases fast

Energy demand in the High Efficiency scenario



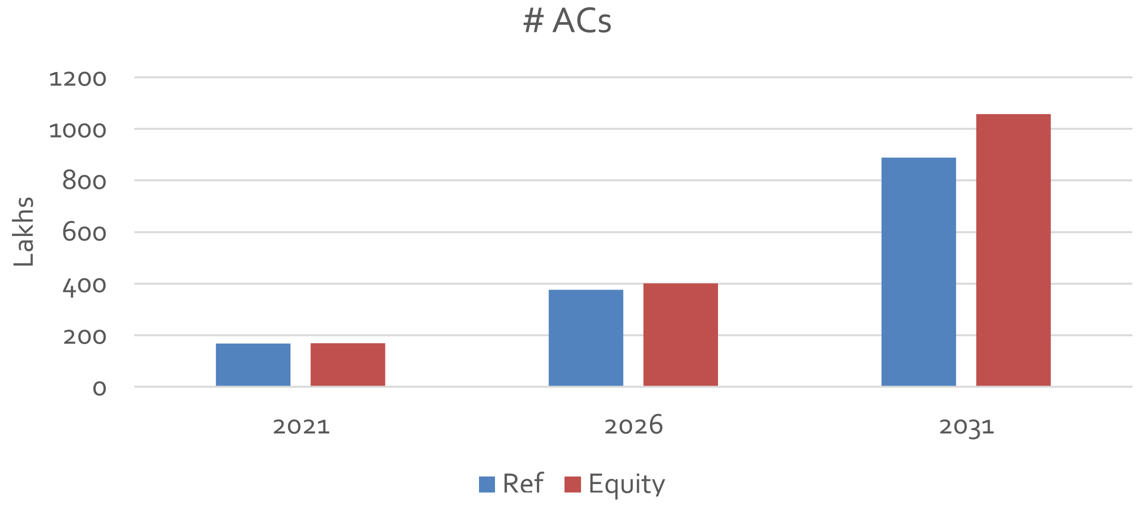


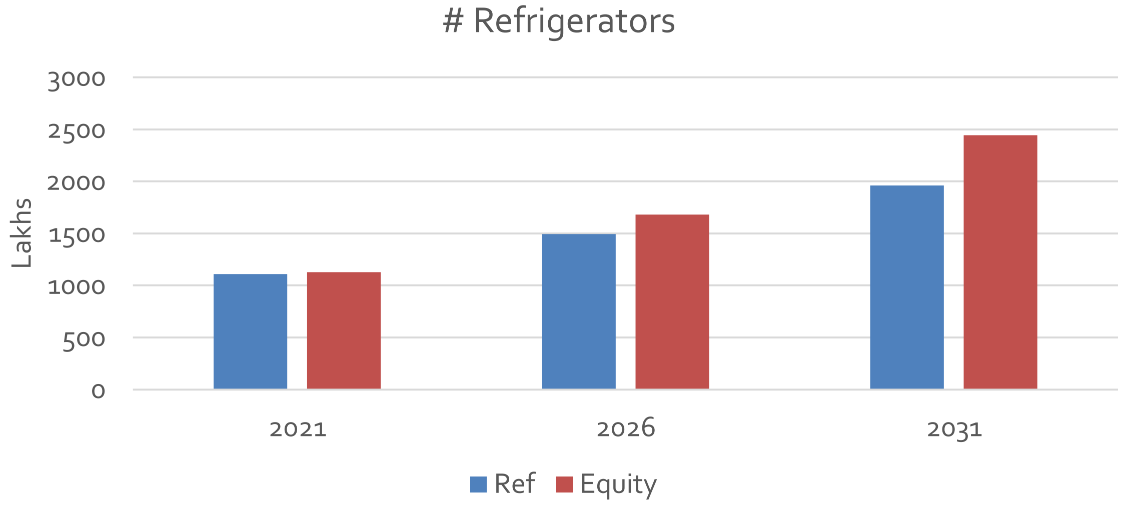


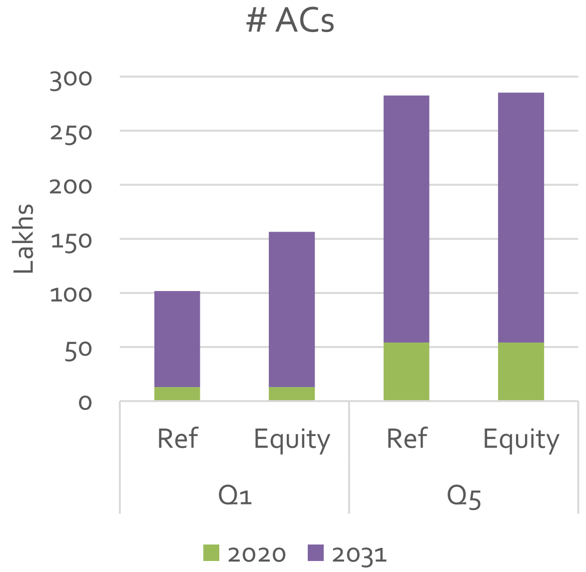
- Total energy demand in 2031 lower by ~8% in the HiEff scenario compared to Ref
  - In spite of Industrial and Transport electricity demand being higher due to greater electrification of the sectors
- Solar+wind generate more than Ref due to better CUF
  - Marginal increase in storage capacity added

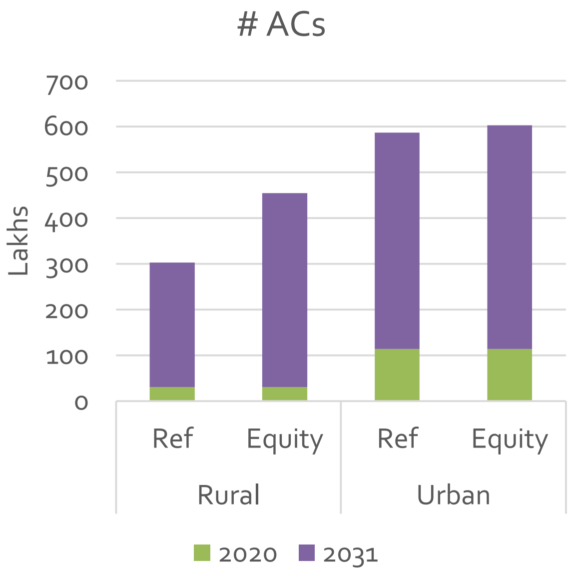
Prayas (Energy Group)

Equity scenario – appliances in use









- Greater ownership of ACs and refrigerators compared to Ref
- Greater increase in ownership among poorer quintiles, regions

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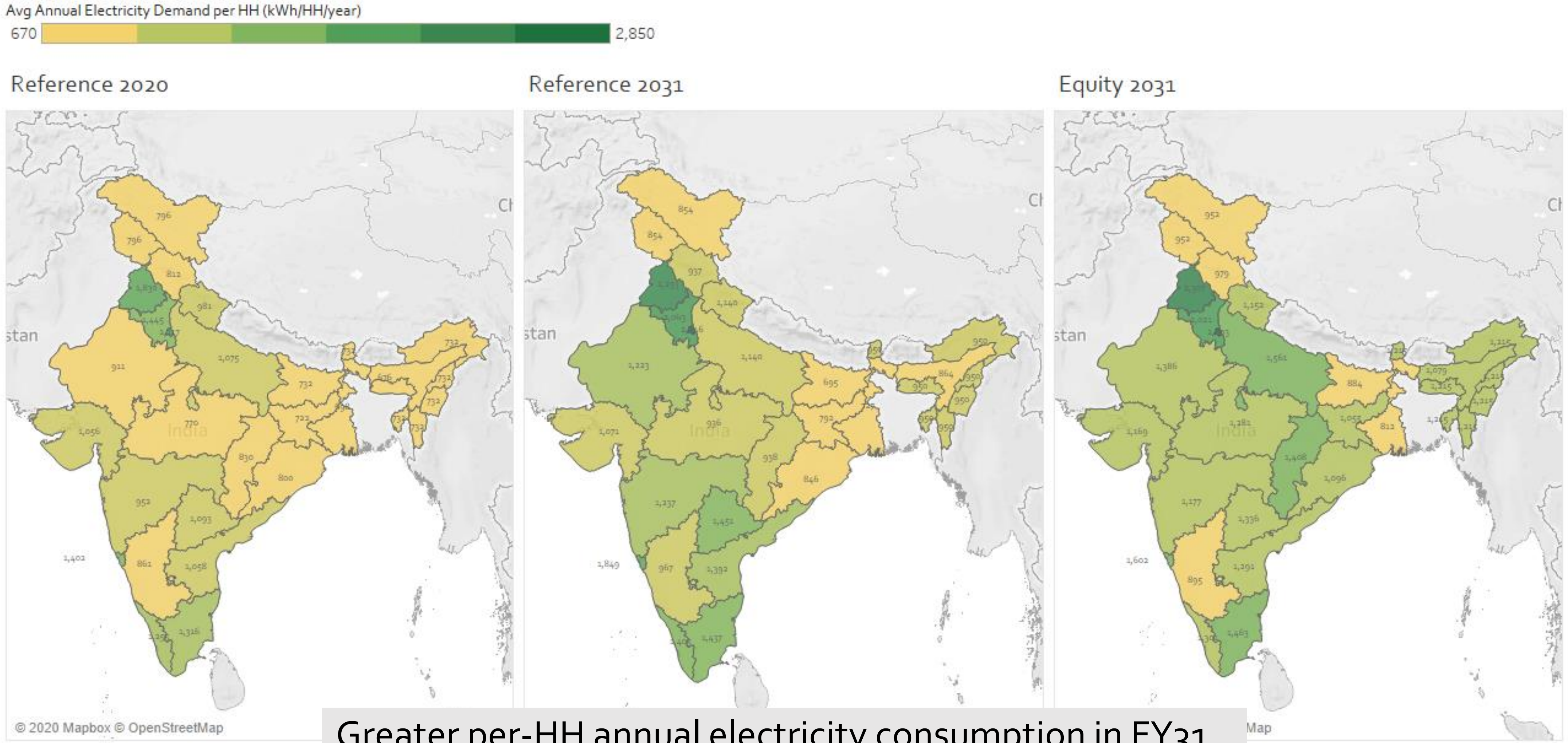
Per-HH annual electricity consumption



Greater per-HH annual electricity consumption in FY31 in poorer states in Equity scenario as compared to Ref

Energy cost as % of HH expenditure – FY31

- Cooking fuel has a bigger expenditure share than electricity in most quintiles / states
- Affordability significantly better for poorer quintiles / states in the Equity scenario compared to Ref

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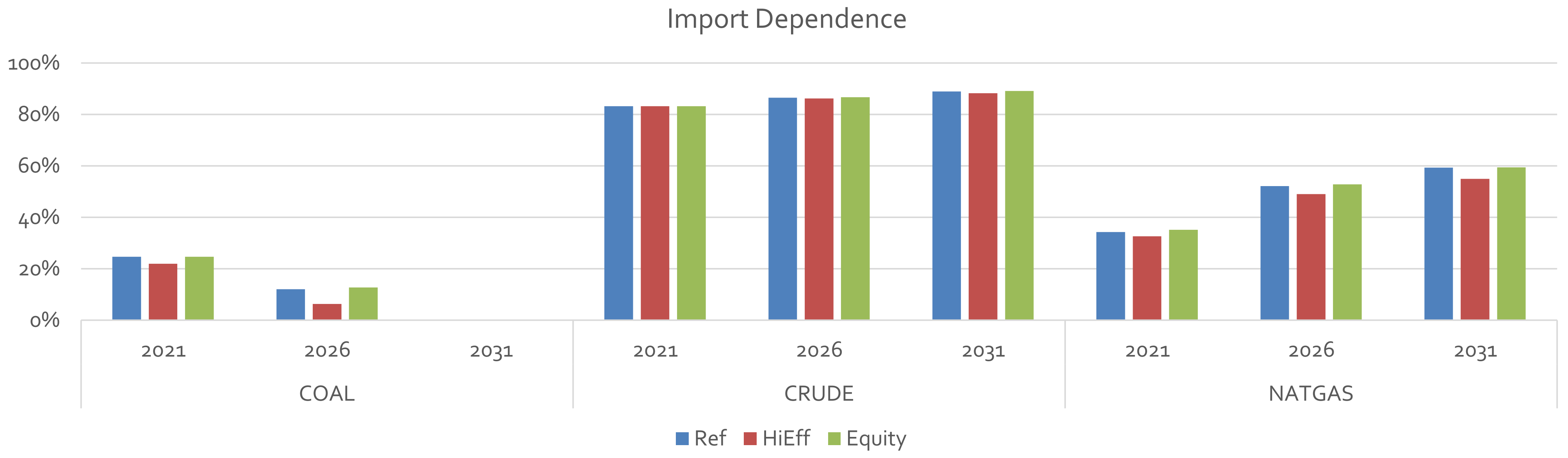
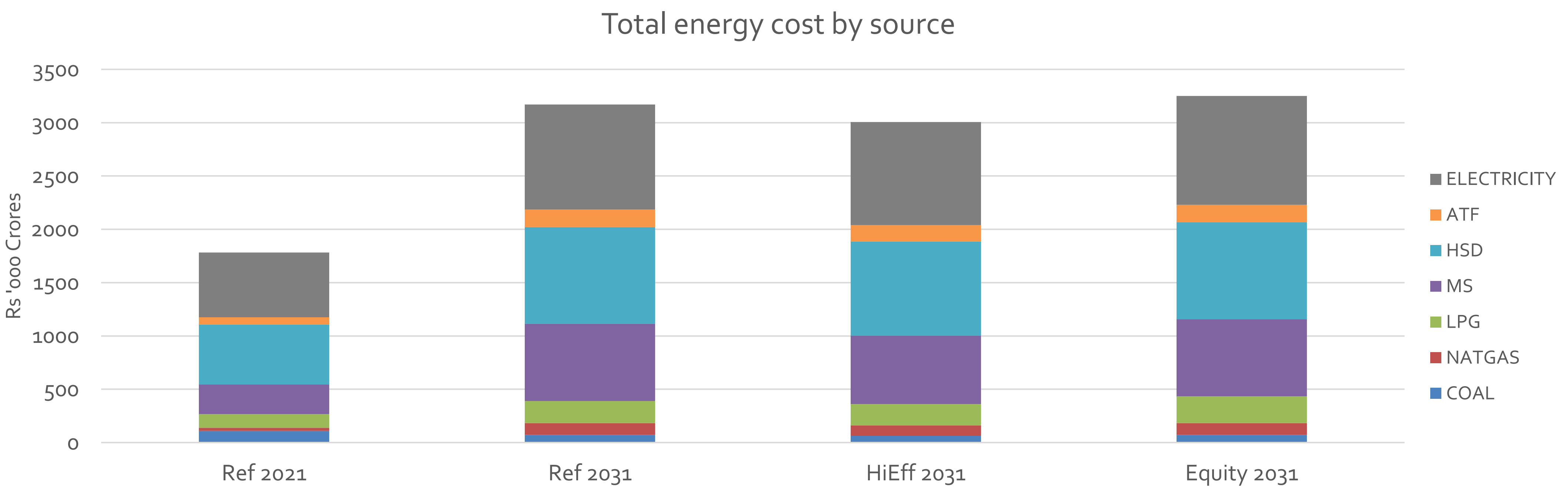
Fuel Quantity and Import Dependence

	COAL (MT)	NATGAS (BCM)	LPG (MT)	MS (MT)	HSD (MT)	ATF (MT)
Ref 2021	1084	28	24	34	90	10
Ref 2031	1237	56	36	81	133	21
HiEff	1112	50	35	72	129	20
Equity	1271	56	44	81	133	21



Energy-carrier-wise costs

Rs '000 Cr	COAL	NATGAS	LPG	MS	HSD	ATF	ELECTRICITY
Ref 2021	108	30	128	280	559	70	606
Ref 2031	71	112	207	723	908	164	986
HiEff 2031	62	98	200	642	883	155	964
Equity 2031	71	113	251	723	908	164	1021



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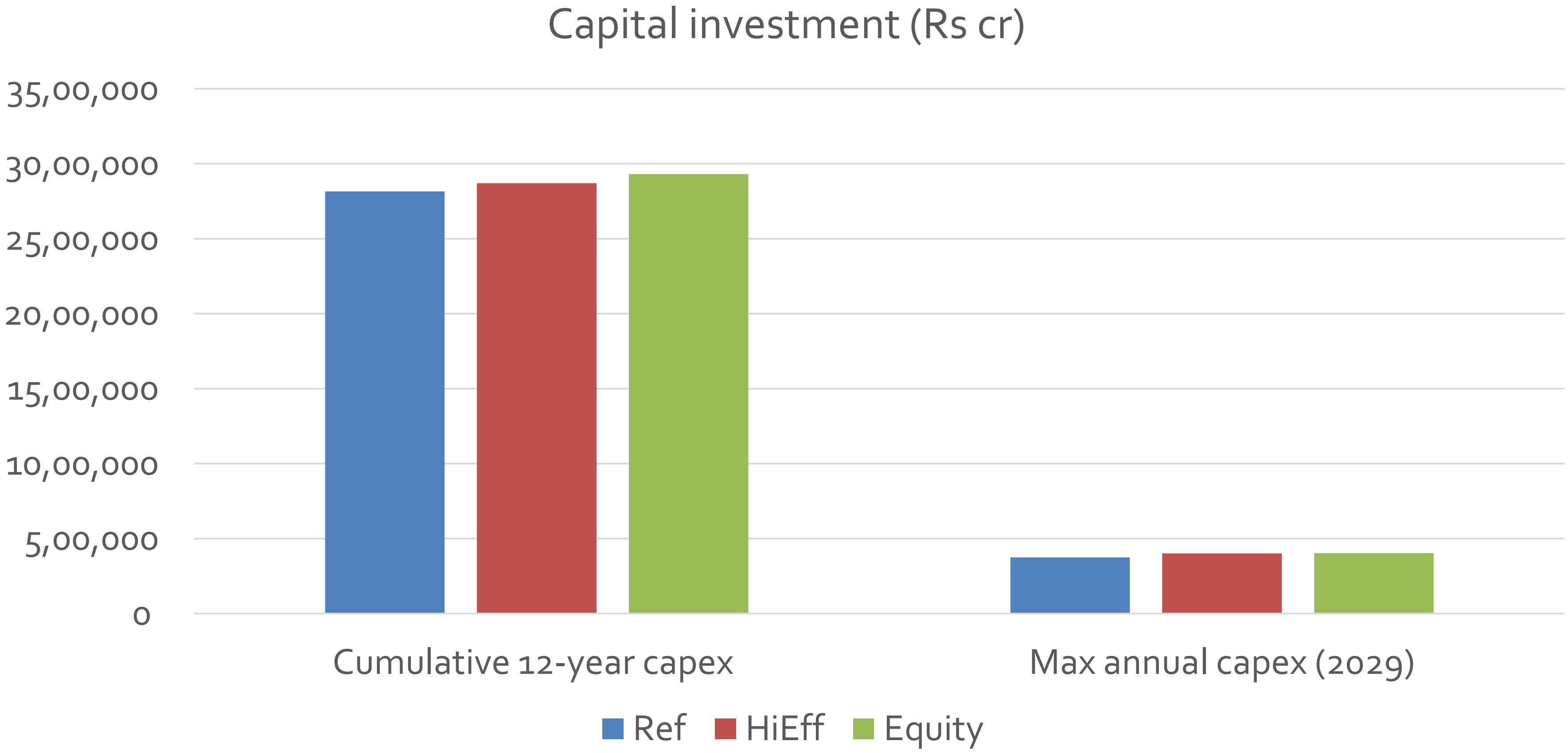
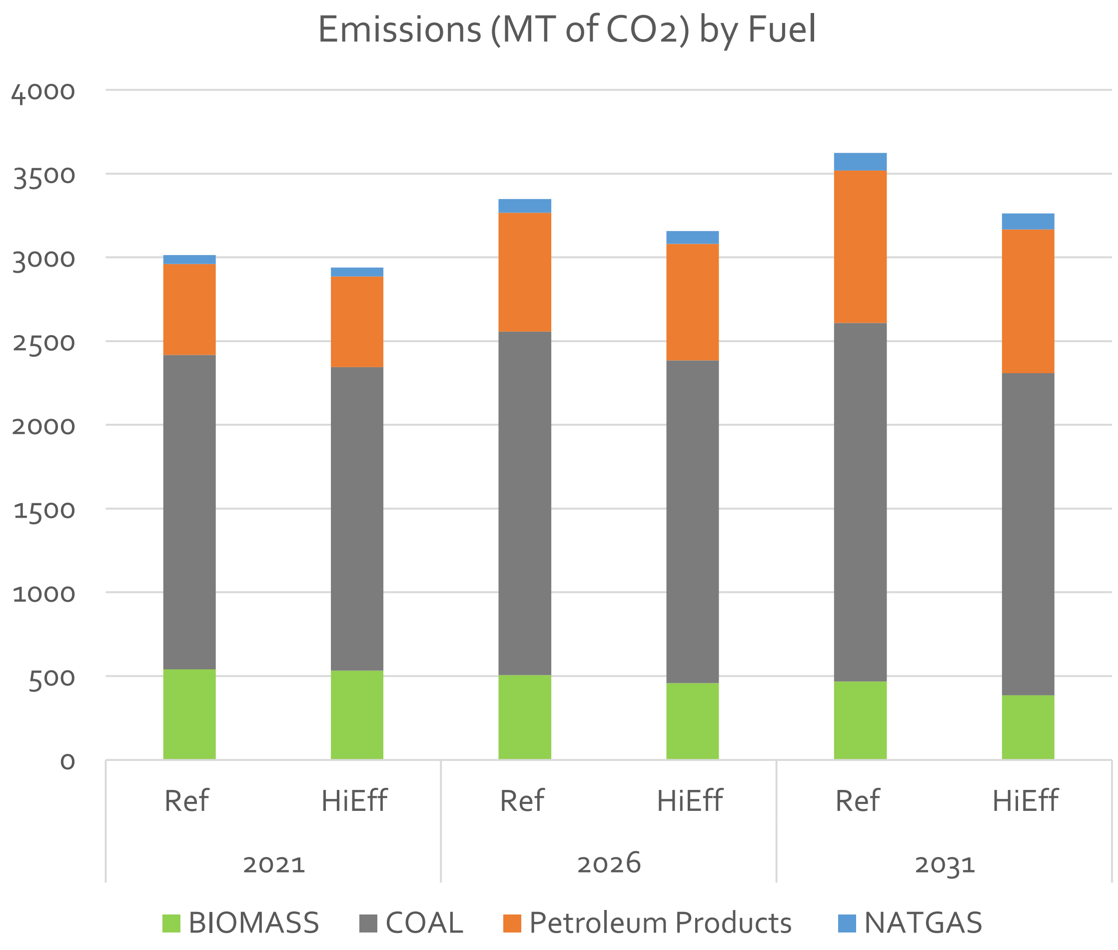
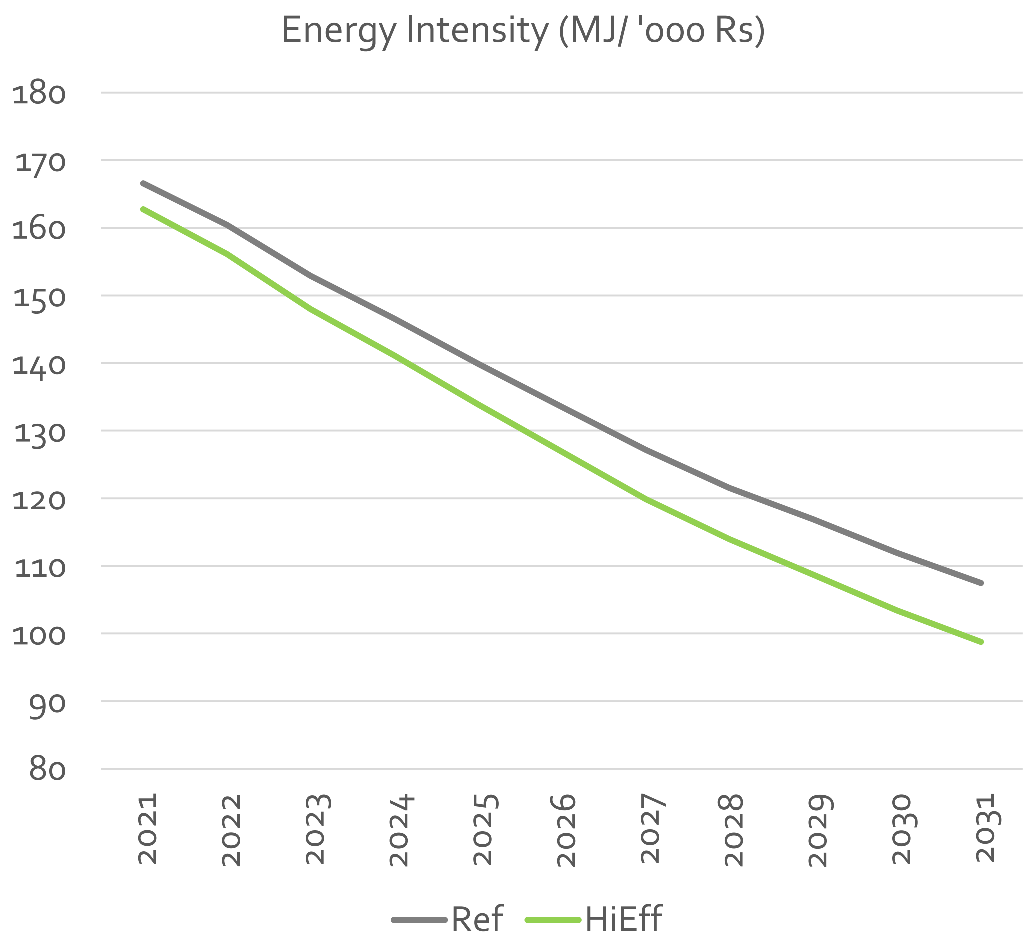
Capital investment requirements

Rs. Cr	Ref	HiEff	Equity
Cumulative 12-year capex	28,15,158	28,70,149	29,30,551
Max annual capex (2029)	3,75,019	4,01,030	4,03,132



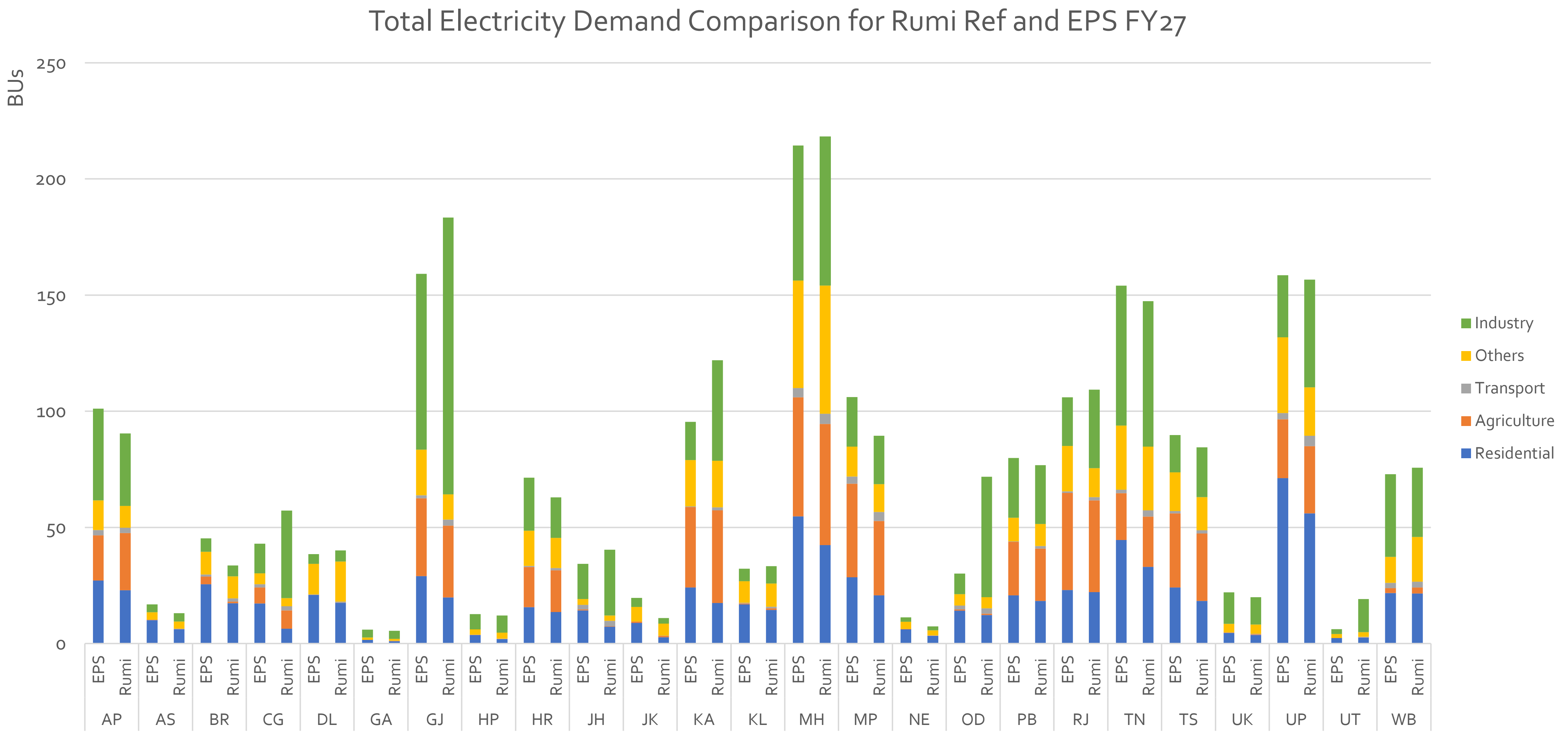
GHG emissions, Energy & GHG emissions intensity





SOME MORE COMPARISON WITH OTHER MODELS

State-wise sector-wise electricity demand – FY27



Please note that EPS state-wise, sector-wise estimates are available only till FY27. Moreover, the EPS industry demand depicted here does not include demand from captive industry.

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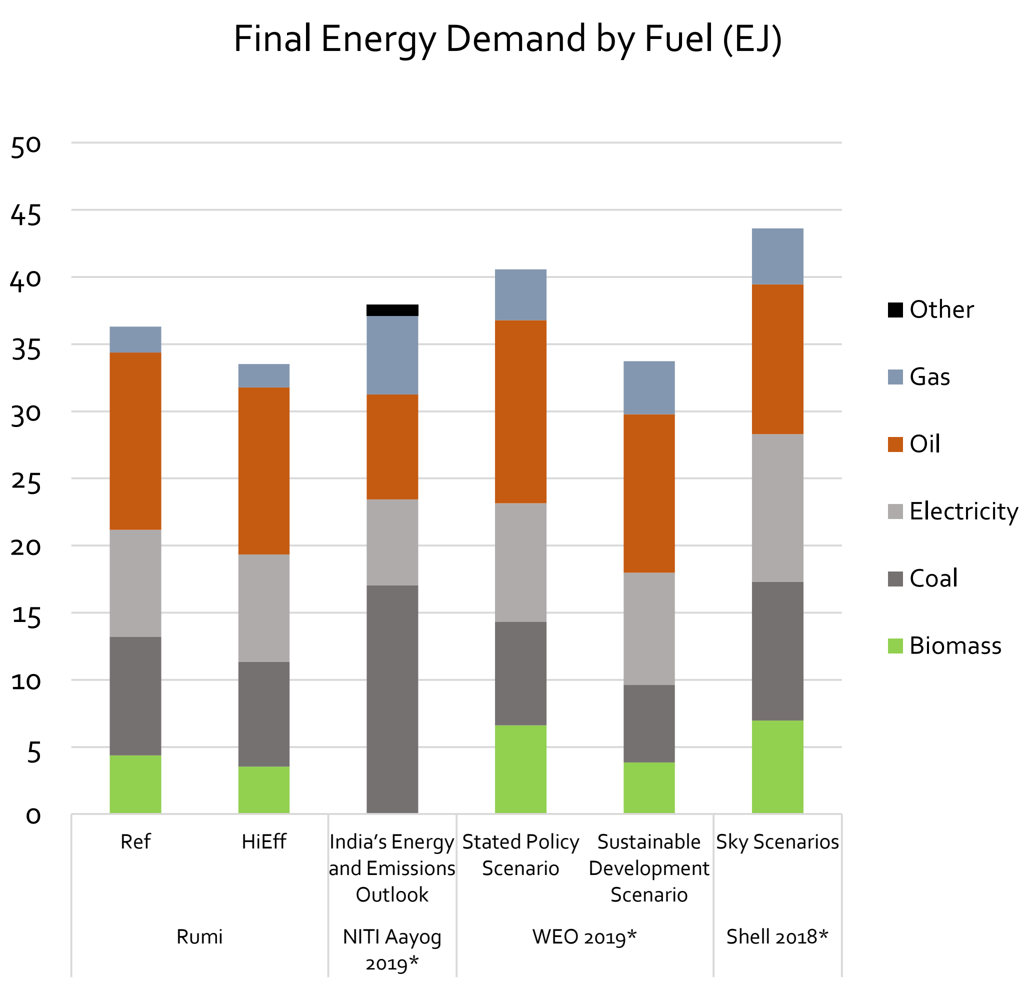
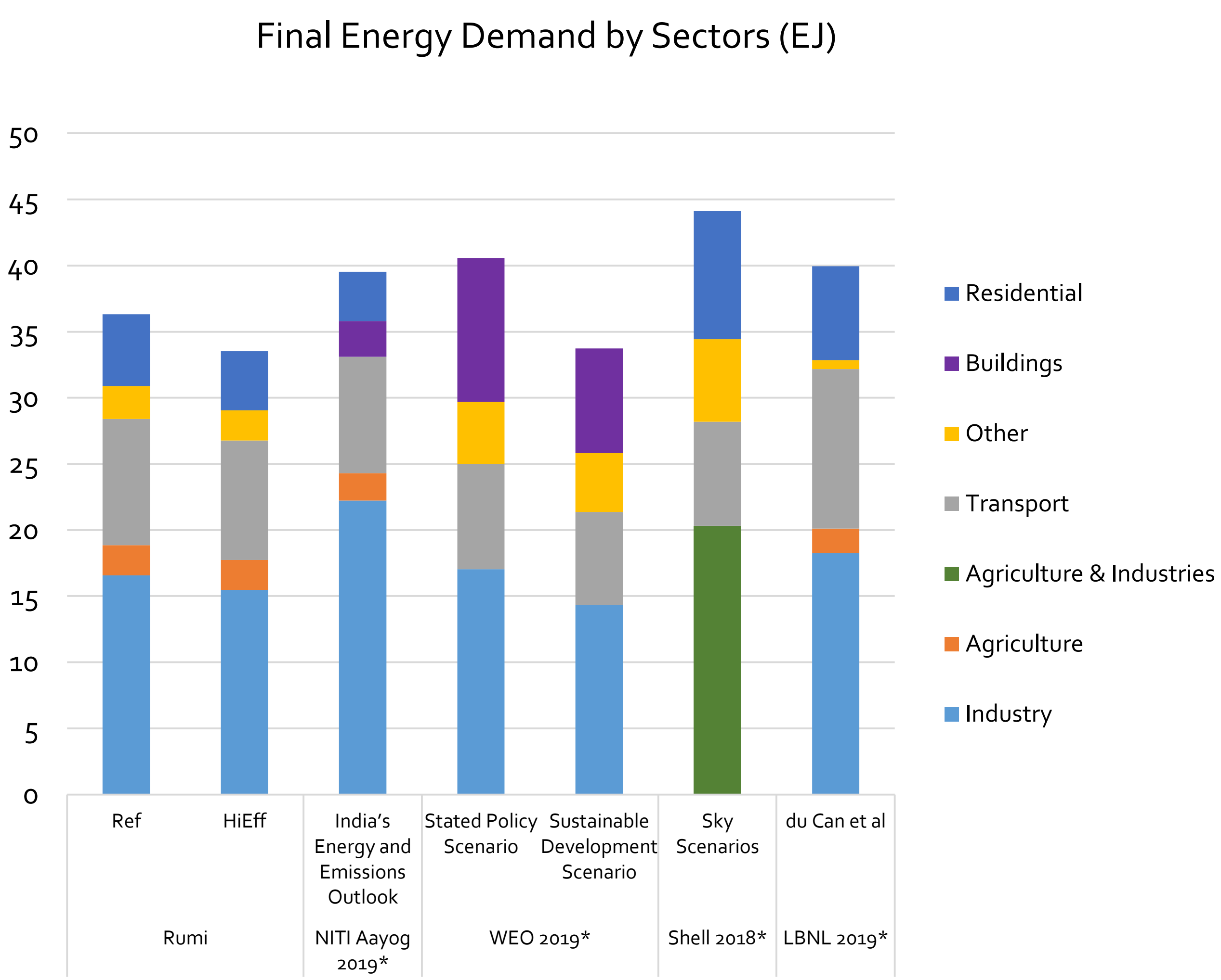
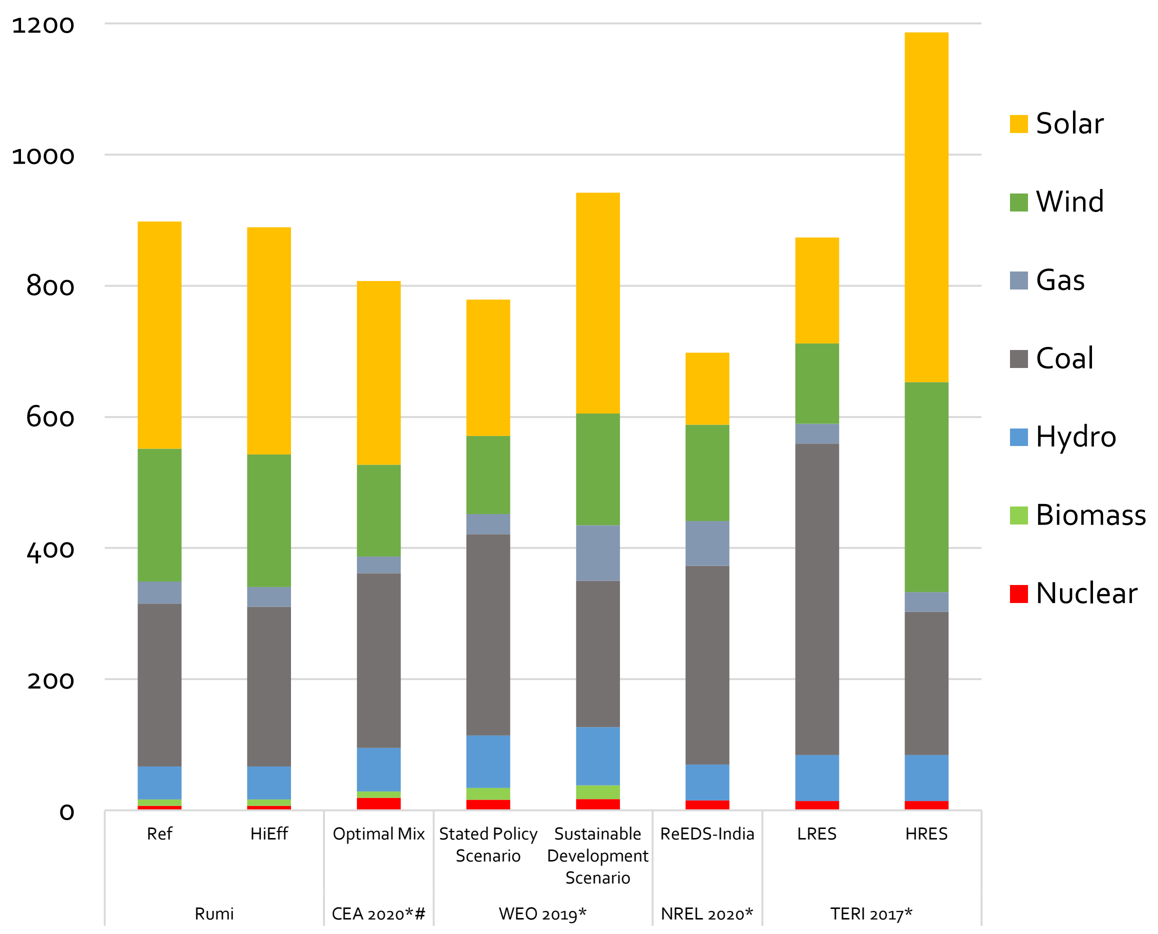
Final energy demand – FY31

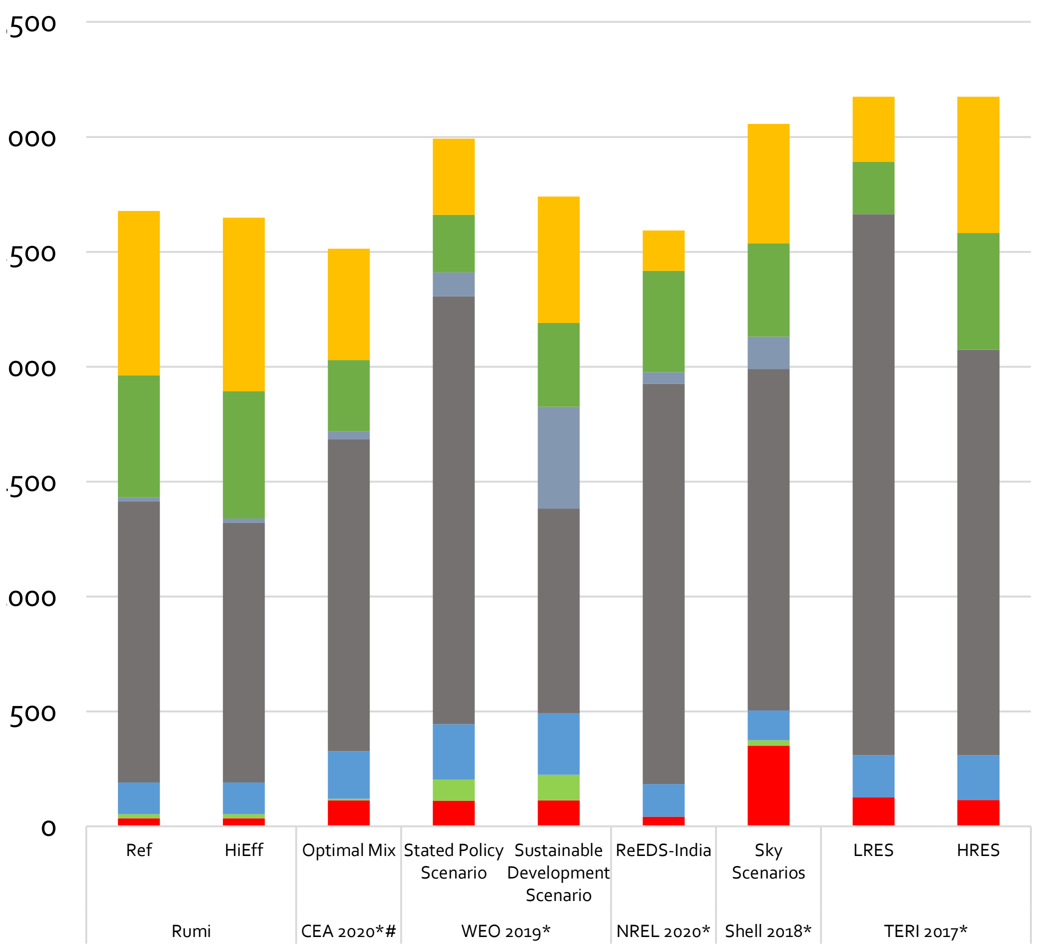




**Closest Comparable FY or CY*

Capacity and generation mix – FY31





Closest Comparable FY or CY
 # Captive industry not included

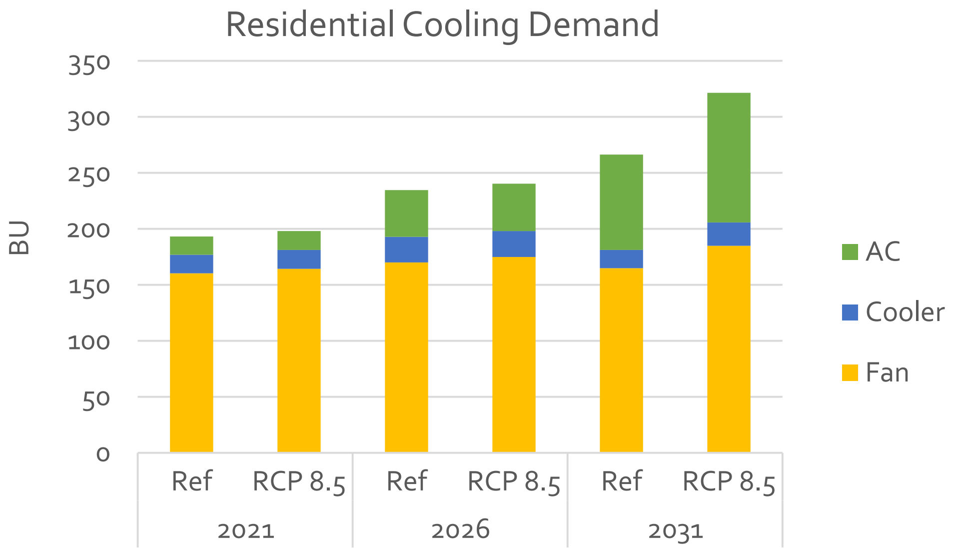
Prayas (Energy Group)

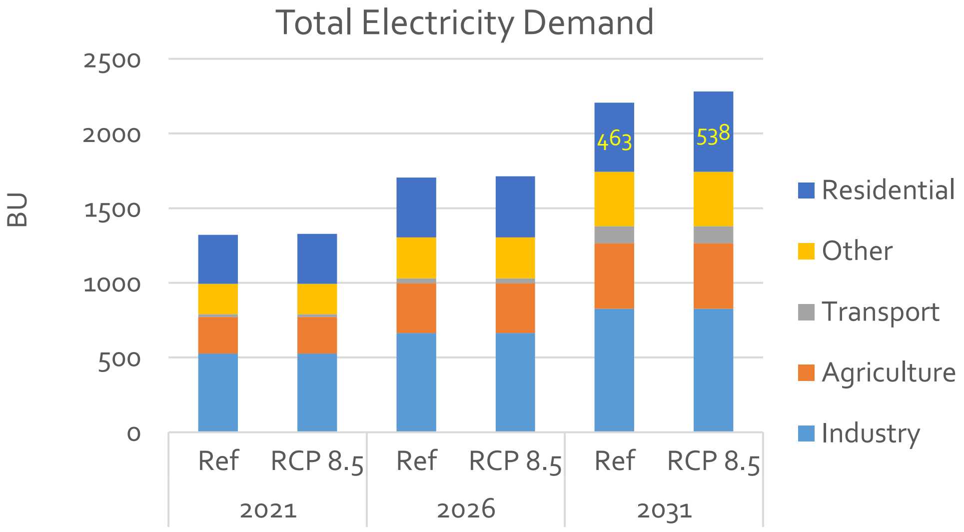
SENSITIVITY ANALYSIS

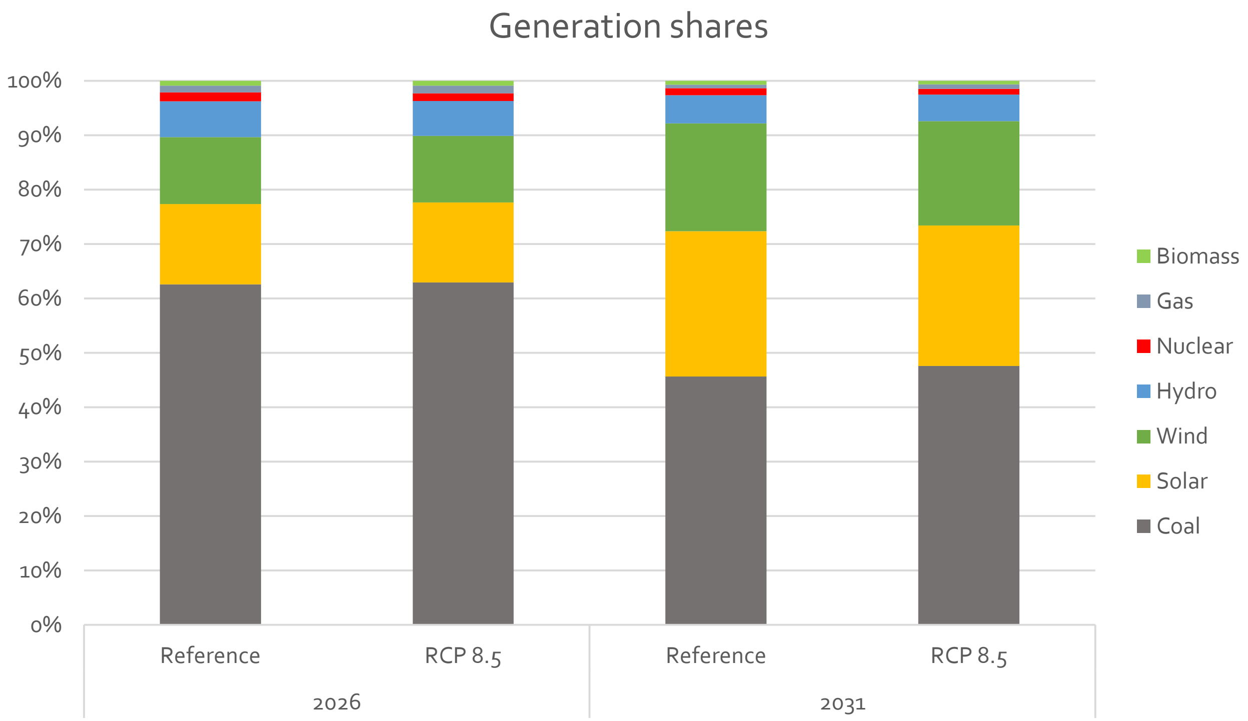
Sensitivity Analysis

- Four sensitivity analyses to check robustness of insights to changes in input assumptions
- Different temperature projections => different cooling electricity demand => service with greatest residential electricity demand
- Two different RE generation profiles => time-sensitivity of contribution of RE to overall generation
- Different cost assumptions => mix of choices made by the optimizer
- No noticeable difference in the high level results/insights under any of these runs

Sensitivity 1: RCP 8.5 temperature projections instead of RCP 4.5

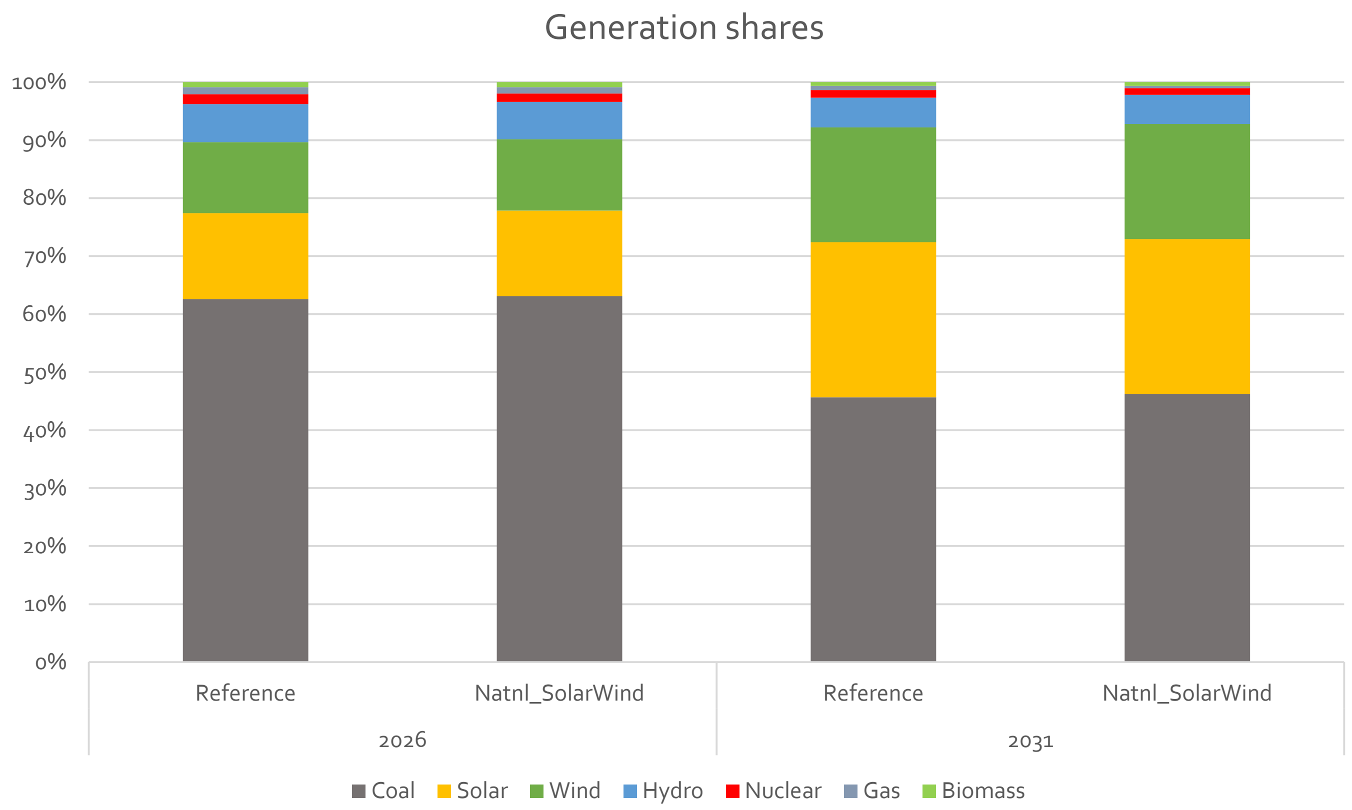






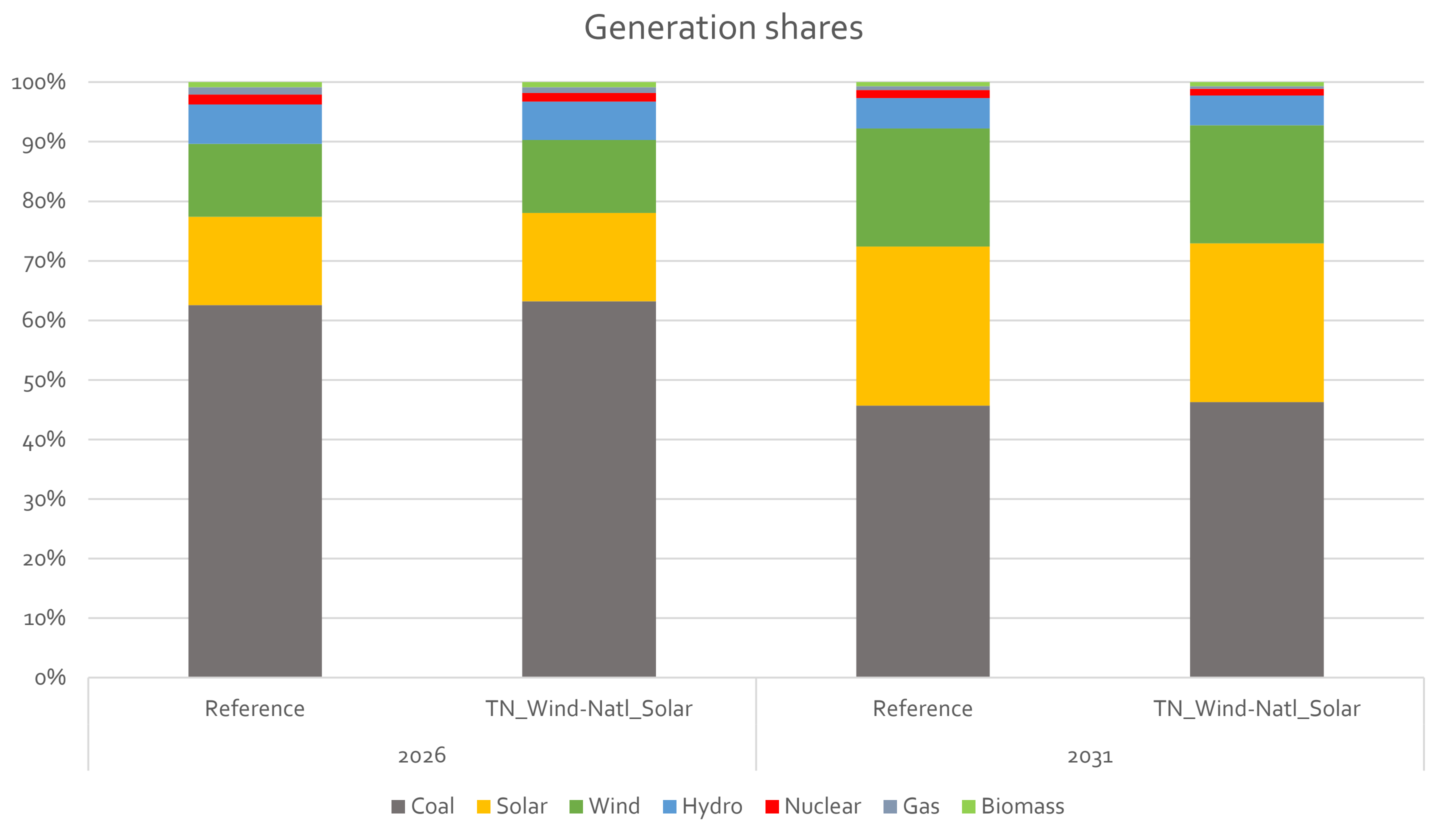
Greater cooling demand in FY31 under RCP 8.5 due to increased temperatures. But no significant difference in overall demand or generation shares

Sensitivity 2: National composite solar, wind profiles



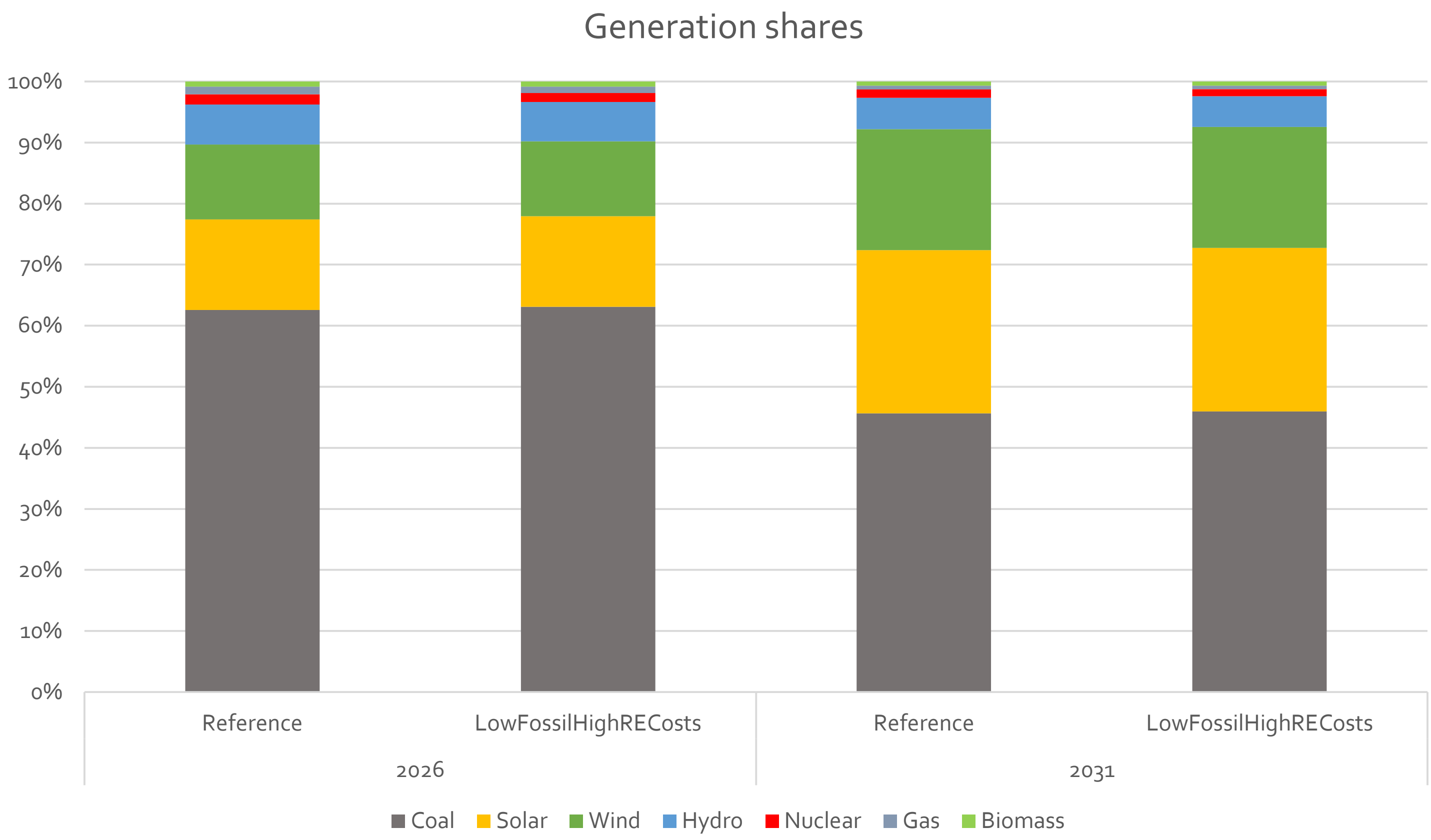
Changing the solar and wind profiles from MH to national average generation-based profiles has negligible impact on the generation mix

Sensitivity 3: National solar profile and TN wind profile



Changing the solar and wind profiles from MH to national average generation-based profile for solar and the profile of a major wind state (TN) has negligible impact on the generation mix

Sensitivity 4: 10% cheaper fossil fuels, 10% costlier RE



The generation mix is not impacted by changing the technology cost assumptions: making fossil fuel based generation 10% cheaper and renewable based generation 10% costlier

THANK YOU

Email us at energy.model@prayaspune.org