PIER 2.0: India's energy demand until 2040-41

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

Prayas (Energy Group)

January, 2025

Rumi: An open-source Energy Systems modelling platform

Background

What is this presentation about?

What it contains

- Overview of the PIER 2.0 demand model
- Key results, insights and observations

What it does not contain

- Details of the methods, approaches used
- Many details available in individual presentations within the respective demand sectors *[See https://doi.org/10.5281/zenodo.14603083 Files/Docs.zip]*
- Other details available within the various 'source' files and documentation released with the model

Forthcoming

- PIER 2.0 Supply model
- A consolidated documentation of PIER 2.0 (Demand+Supply) inputs, assumptions, scenarios

PIER 2.0 demand model

Improved/enhanced version of PIER 1.0 released earlier

Open-data model freely available for download, use and enhancement

Built on Rumi 2.0 – an open-source modelling platform

Improved features in Rumi 2.0 for energy service technology modelling

PIER 2.0 demand model...

Detailed bottom-up modelling of Residential, Transport and the 3 biggest energy-consuming Industrial sectors Iron & Steel, Cement and Aluminium

Model time horizon: Financial Year 2023-24 to 2040-41

Usage of latest data sources available

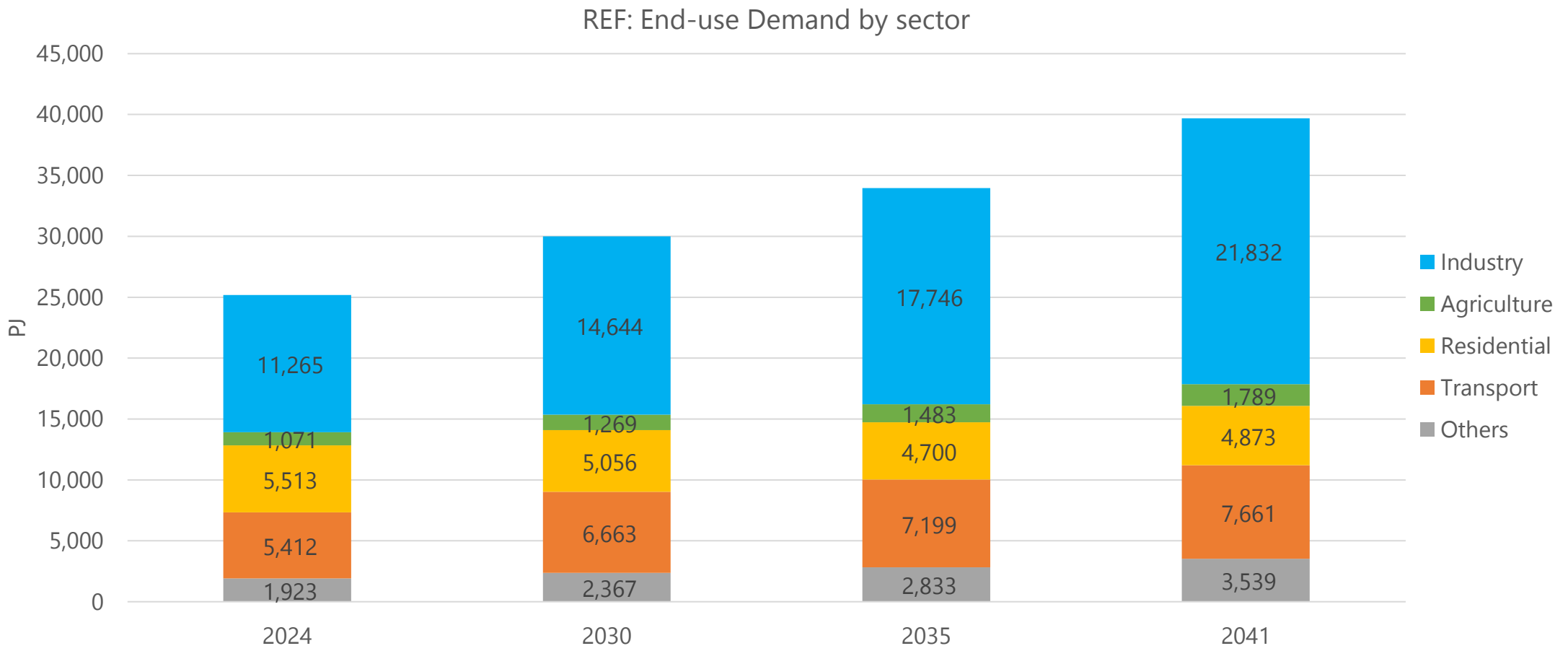
Temporal granularity (mainly for electricity): Each year divided into 12 months, each of which is represented by a typical day broken into 24 hours

Geographic granularity: India represented as 25 "states" where the north-eastern states except Assam are combined into one, and union territories are treated as part of their surrounding/nearest states with Ladakh being considered part of J&K

Electricity load shapes reconciled based on actual state-wise load profiles

Reference Scenario Results

Reference scenario results by sector



Total end-use demand grows from ~25 EJ to ~40 EJ from FY24 to FY41 growing at 2.7% p.a.

Note that end-use energy demand includes Green H2 used as feedstock in industry

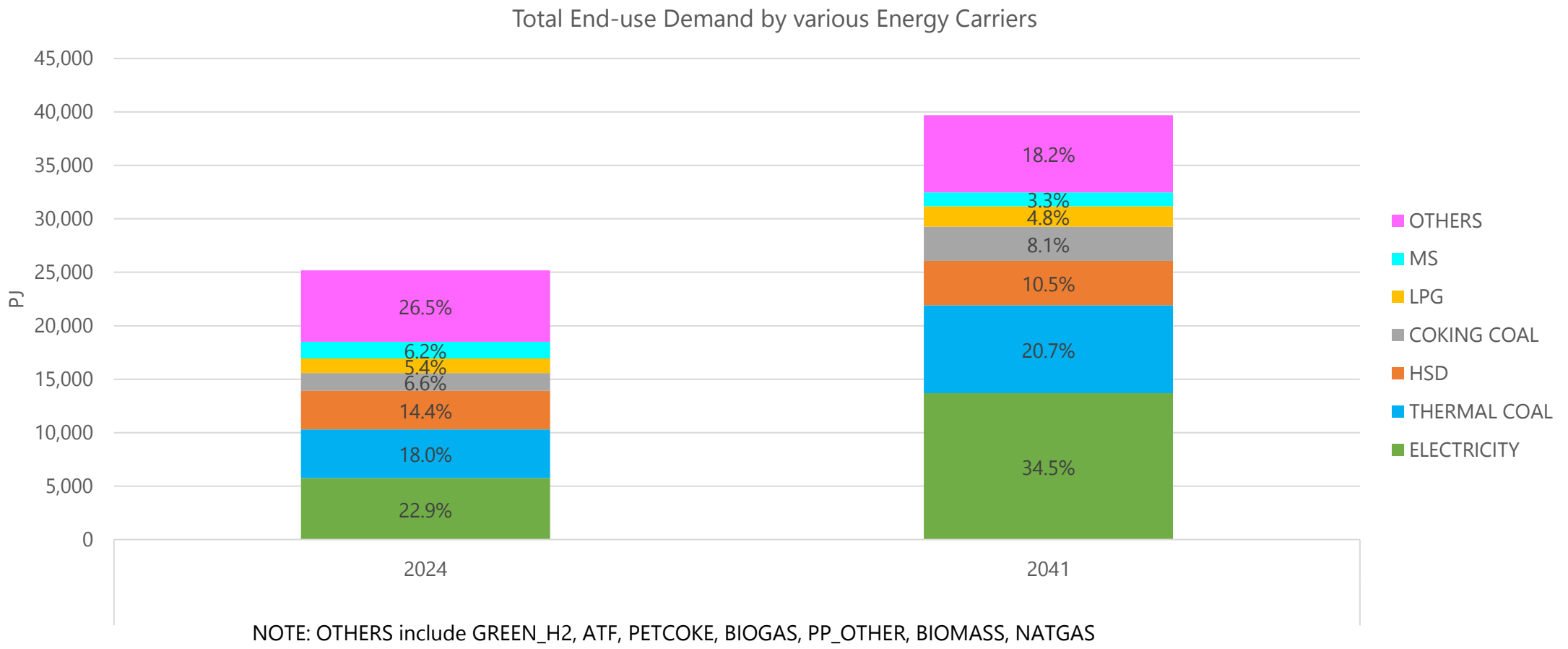
2024 refers to FY23-24, 2041 refers to FY40-41 etc

Reference scenario results by sector …

- Industry accounts for the highest share of demand – growing from ~11 EJ (45% share) in FY24 to ~22 EJ (55% share) in FY41 at 3.7% p.a
- Residential sector end-use demand *reduces* slightly from FY24 to FY41
  - Despite significant increase in appliance ownership and use
  - Mainly due to drastic reduction of inefficient biomass use in cooking: its use going down from 3.0 EJ in FY24 to just 0.6 EJ in FY41
  - Slight *increase* in residential demand from FY35 to FY41 as biomass use reduction plateaus while uptake of electric appliances continues
- Transport sector demand grows slowly at 2.1% p.a.
  - Despite significant growth in passenger km (4.1% p.a.) and freight ton km (4.9 % p.a.)
  - Mainly due to rapid electrification of transport and greater efficiency of electric vehicles
- Agriculture accounts for ~4% of end-use demand through the model period
- "Others" sector – comprising mainly commercial establishments – grows at 3.7% p.a and accounts for only ~9% of total demand
- Considering only 'commercial energy' (i.e. without traditional biomass)
  - Overall demand grows at 3.3% p.a. from 22.2 EJ to 39 EJ
  - Residential demand *grows* through the model period at 2.9% p.a.

Note that end-use energy demand includes Green H2 used as feedstock in industry

Reference scenario results by energy carrier



NOTE: OTHERS include GREEN_H2, ATF, PETCOKE, BIOGAS, PP_OTHER, BIOMASS, NATGAS

Points to greater electrification of various sectors – as expected

Note that end-use energy demand includes Green H2 used as feedstock in industry

2024 refers to FY23-24, 2041 refers to FY40-41 etc

Reference scenario results by energy carrier …

- Electricity, thermal coal and diesel (HSD) are the most prominent
  - FY41 demand of these carriers > FY24 demand of all carriers put together
- Electricity
  - Has the highest share (23%-35%) and the highest growth rate (5.2% p.a.), if one leaves aside Green H2 that starts from a negligible base
  - Driven by increased electrification in Transport, Agriculture and Industry, and aided by greater ownership and use of Residential electrical appliances
  - Electricity overtakes coal (thermal+coking) to become the largest carrier by FY41

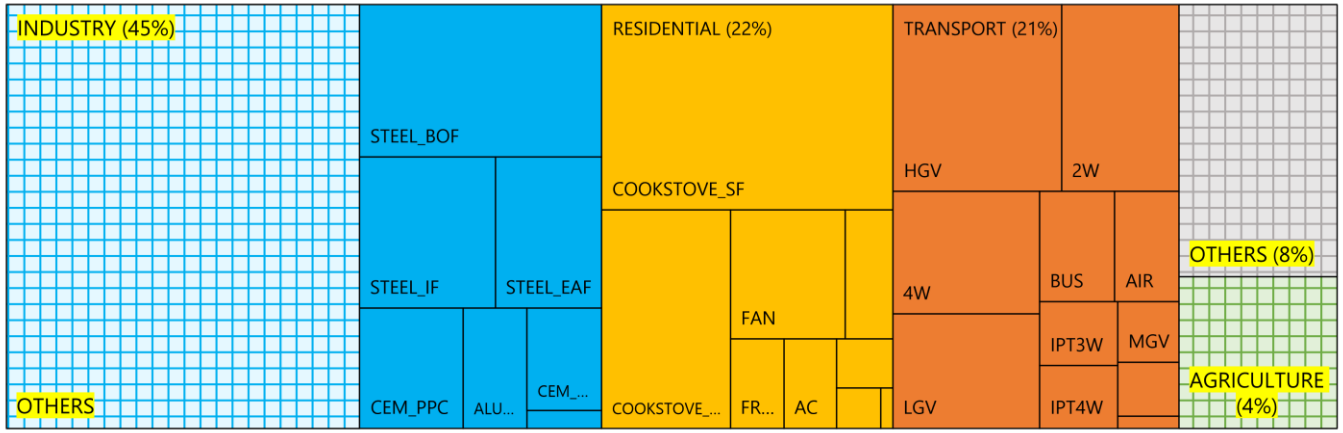
- Petroleum products
  - Their share *declines* from 31% in FY24 to 24% in FY41 – primarily driven by Transport electrification
  - HSD remains the most prominent petroleum product – but with a reducing share in the overall basket due to electrification of Transport and Agriculture. Its demand is sustained by its use in road freight, which is harder to electrify
  - Demand for MS (petrol) *declines* in absolute terms – from 1.6 EJ to 1.3 EJ
  - LPG grows with increasing uptake of clean cooking fuels – but growth is limited by expanding PNG networks and uptake of electric cooking
  - ATF grows fastest among petroleum products (4.7% p.a.) in the absence of viable alternatives to aviation
  - Petcoke grows at 4.3% largely driven by growth in cement production

Reference scenario results by energy carrier …

- Thermal and coking coal
  - Their demand grows faster than overall energy demand. Their share together increases from 25% to 29%.
  - Points to their use being primarily in hard-to-abate Industrial sectors such as iron and steel, and cement. Petro-product reduction is mainly due to Transport electrification.
- Other carriers
  - As expected, traditional biomass sees a sharp fall. Its demand falls from the 4th highest (~3 EJ) in FY24 to 12th highest (~0.6 EJ) in FY41 – even ATF and green H2 have higher demand.
  - Green H2 demand, including feedstock used in Industry, grows from a negligible value to about 0.9 EJ
- MS (petrol) and ‘other petroleum products’ (mostly the heavy distillates) are the only modern fuels whose demand falls in absolute terms between FY24 and FY41

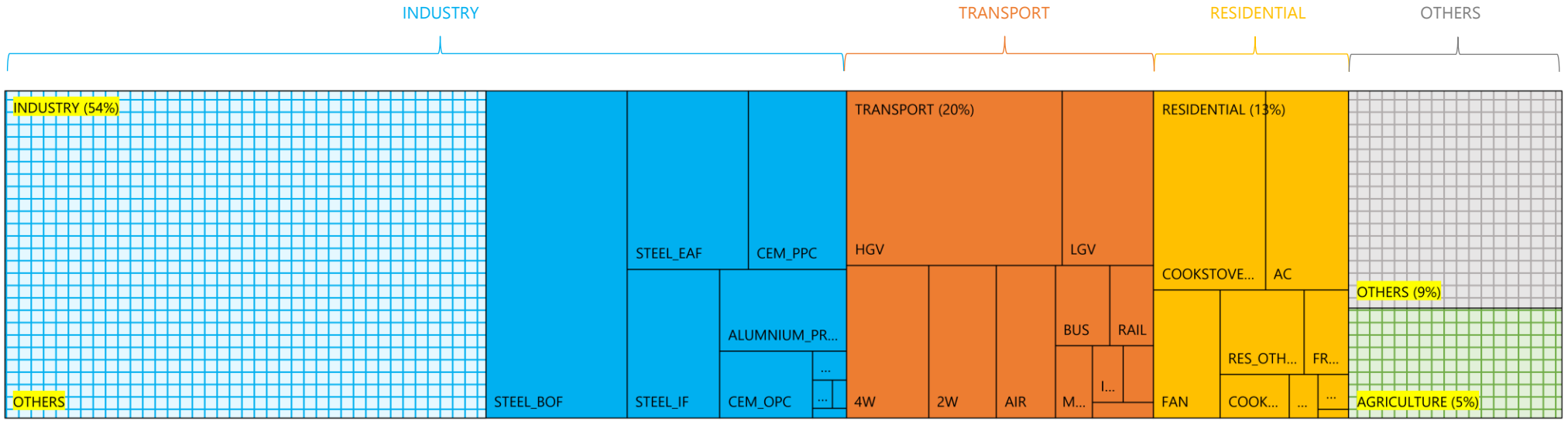
Total Energy Demand growth by Sectors/Sub-components between 2024 & 2041

2024
~25 EJ



- Residential Energy demand in FY24 is almost same as Transport Energy demand, however by FY41, transport is much higher than residential.
- Within Transport, HGV energy demand increases disproportionate to other segments, owing to lesser electrification within the road segments.
- In energy terms AIR can be seen to be comparable to 2W segment by the end of FY41. This is despite 2W serving 3310 BPKM as opposed to only ~450 BPKM served by AIR
- STEEL BOF more than doubles in the model period

2041
~39 EJ

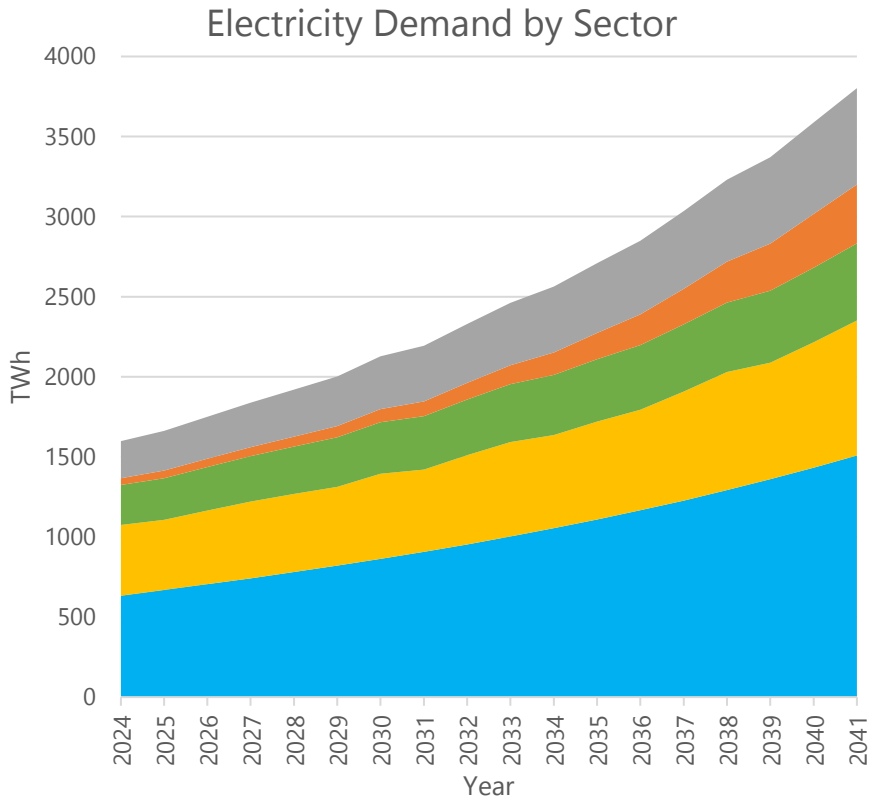


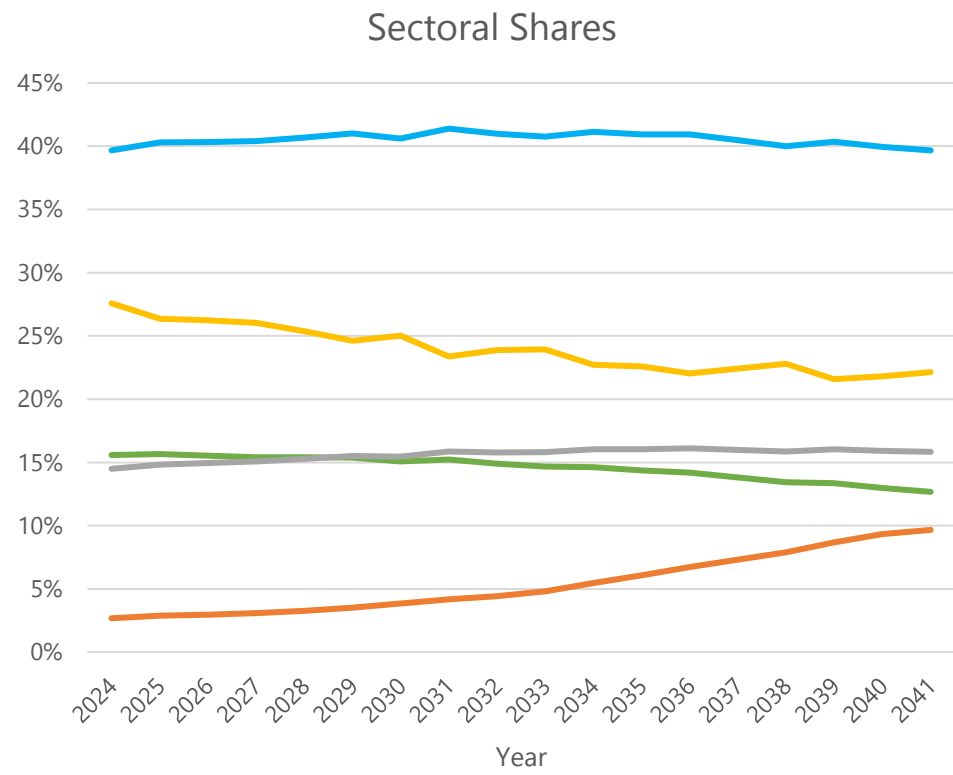
Shaded : Modelled bottom-up Hatched : Modelled Coarser

2024 refers to FY23-24, 2041 refers to FY40-41 etc

Deep dive into Electricity demand in the Reference scenario

Total Electricity Demand by Sectors



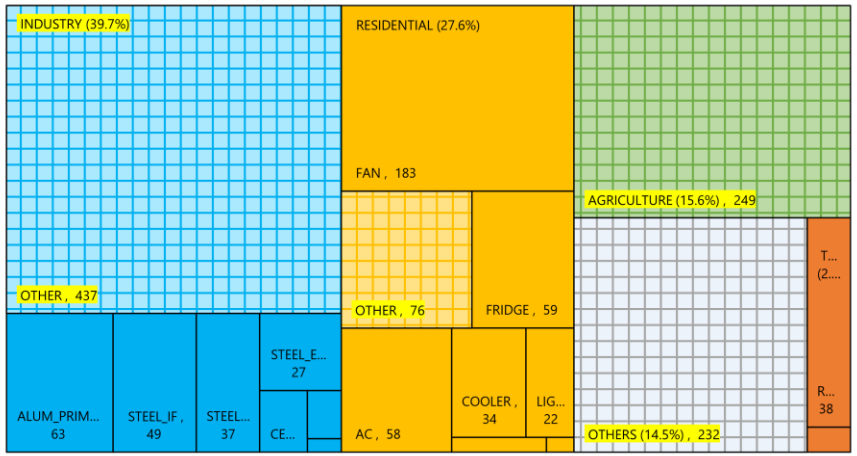


- Electricity demand grows at ~5.2% CAGR, with Transport being the fastest growing sector at ~13.5% CAGR
- While Residential share steadily drops across the years due to increased efficiency, the share of Transport increases owing to increased electrification

2024 refers to FY23-24, 2041 refers to FY40-41 etc

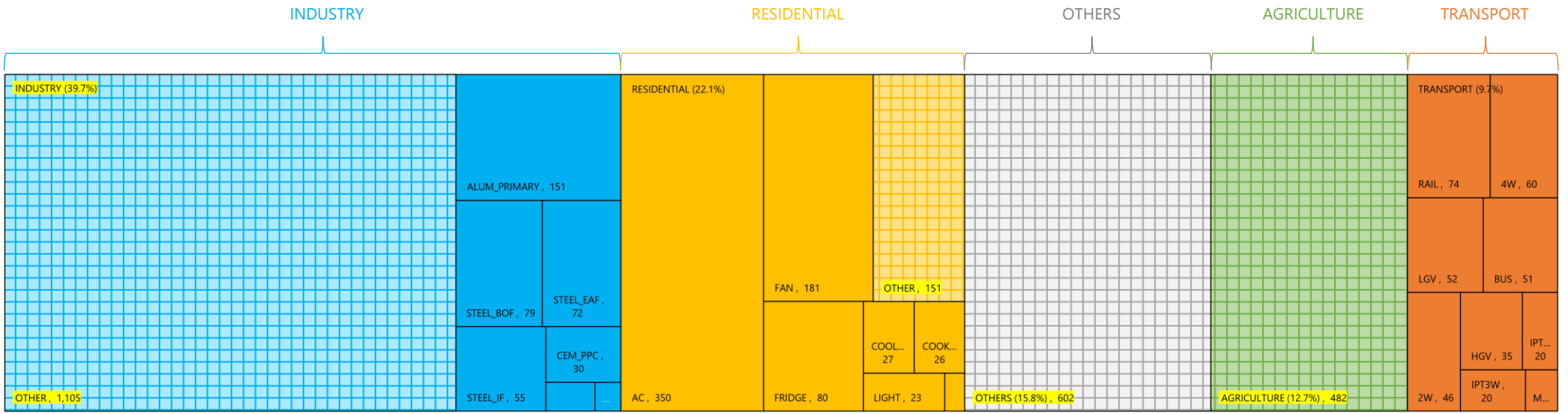
Total Electricity Demand growth by Sectors/Sub-components between 2024 & 2041

2024
1599 TWh



- Significant growth of sub-components of Residential (AC) and Transport (Increased Electrification of road and rail) can be seen
- All of electricity demand in FY24 is comparable to just the Industry demand in FY41
- In FY41, Residential ACs consumption is comparable to all of Transport despite ~99% of total vehicle sales in FY41 being EVs, further this is about same as the electricity demand of Steel+Cement+Alumnimium
- Despite 79% of buses stock in FY41 being electric, the electricity required for them is less than that required for refrigerators or any single steel manufacturing process

2041
3802 TWh



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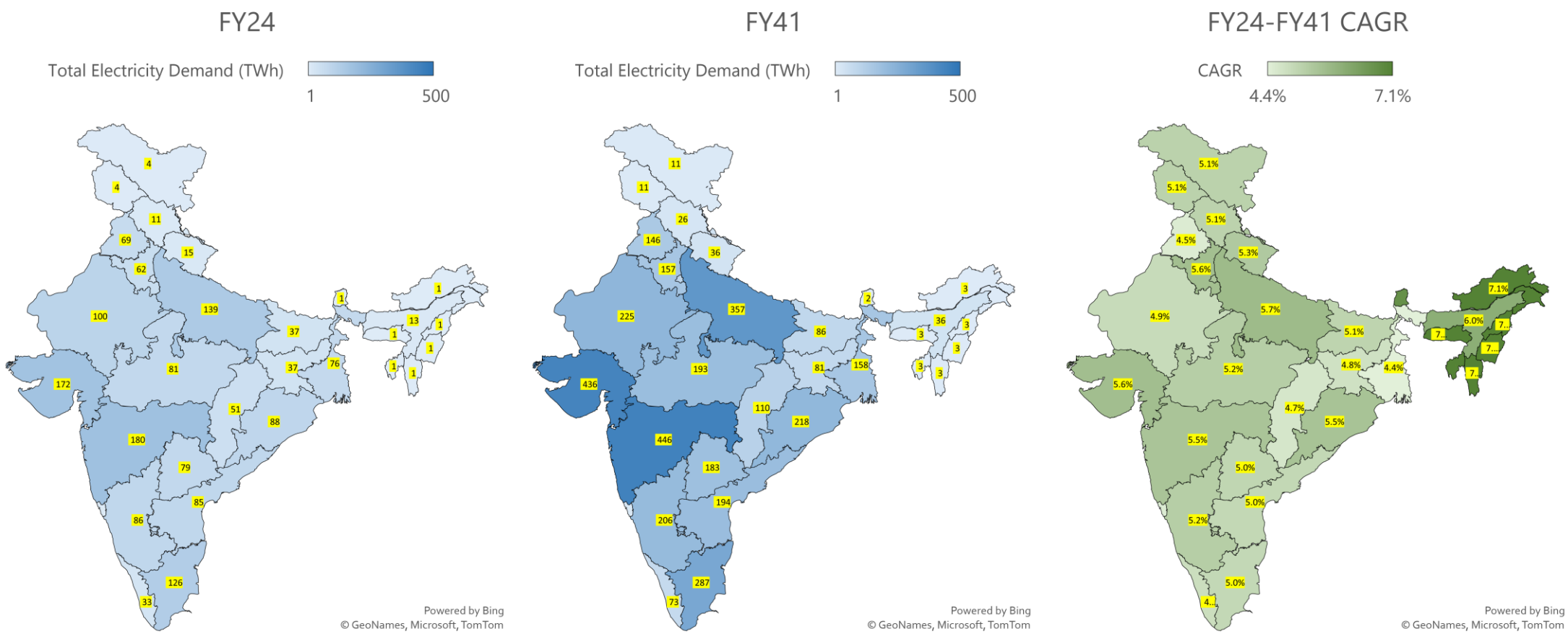
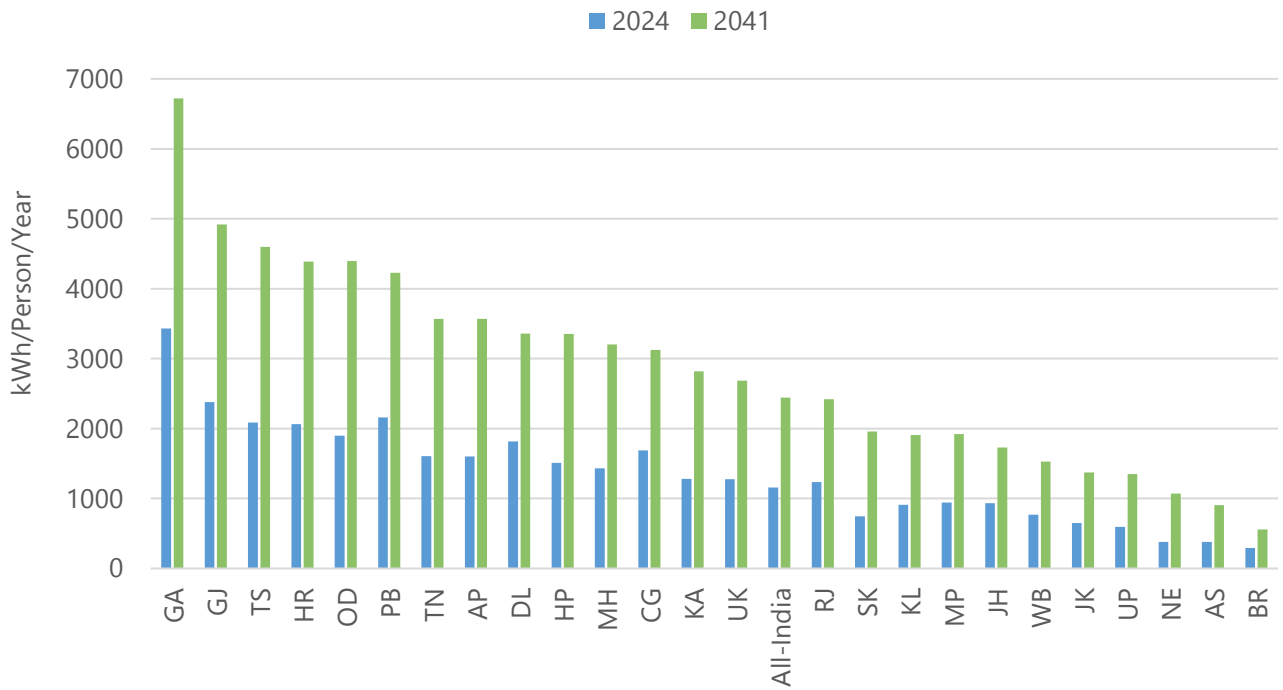
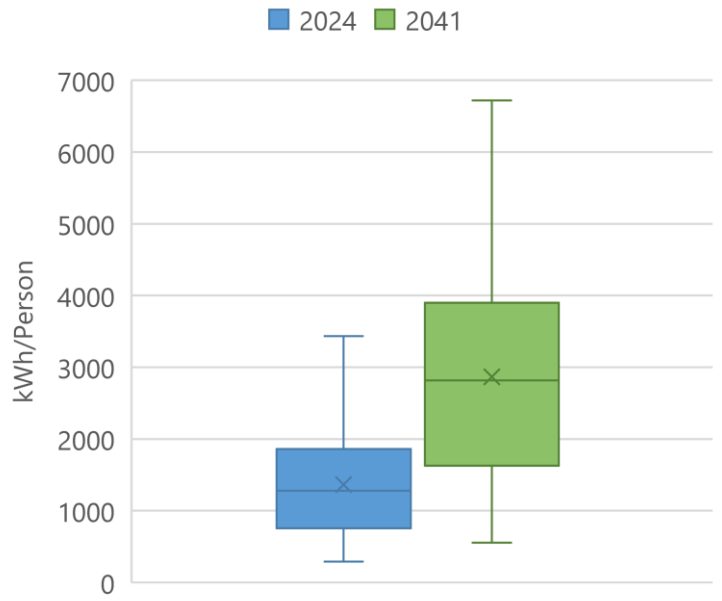
Growth of Electricity Demand in States



- Except North-eastern states, most states' electricity demands grow under/around 5.5% p.a
- Top states in terms of electricity demand (absolute terms) are Maharashtra, Gujarat, Uttar Pradesh

Growth of Per-capita Electricity Demand in States

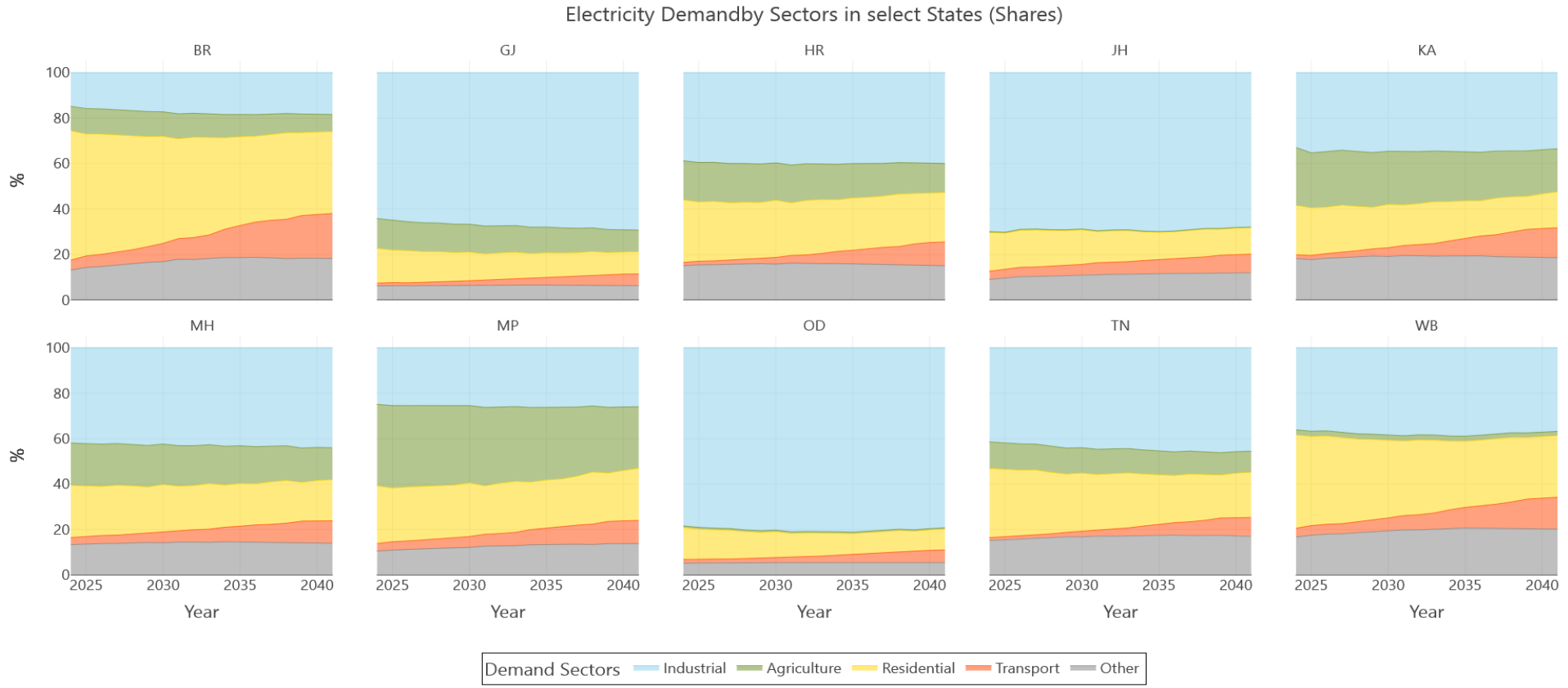




- Goa, Gujarat and Telangana are the states with high per-capita Electricity consumption and Uttar Pradesh, Bihar and North-eastern states including Assam have low per-capita electricity consumption
- Relative positions of states remain more or less same between 2024 and 2041
- However, there is a major variation across states (556 kWh – 6722 kWh in FY41), and the variation increases over years

2024 refers to FY23-24, 2041 refers to FY40-41 etc

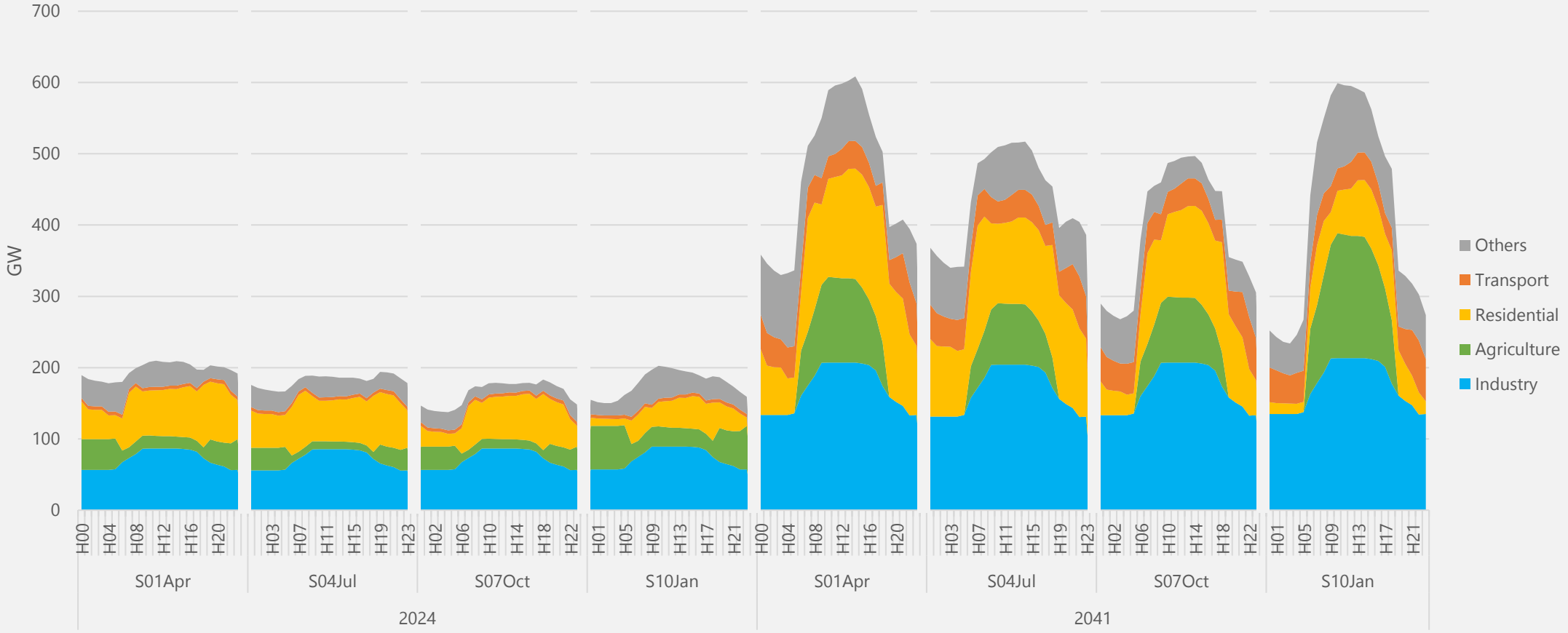
Growth of electricity demand in select states



- Geographically and sectorally diverse set of states depicted
- Industry dominates the demand in heavily industrialised or resource rich states such as GJ, JH and OD
- Agriculture plays a very significant part in states such as MP
- In contrast, the Residential sector dominates in an unindustrialised and naturally irrigated state such as BR

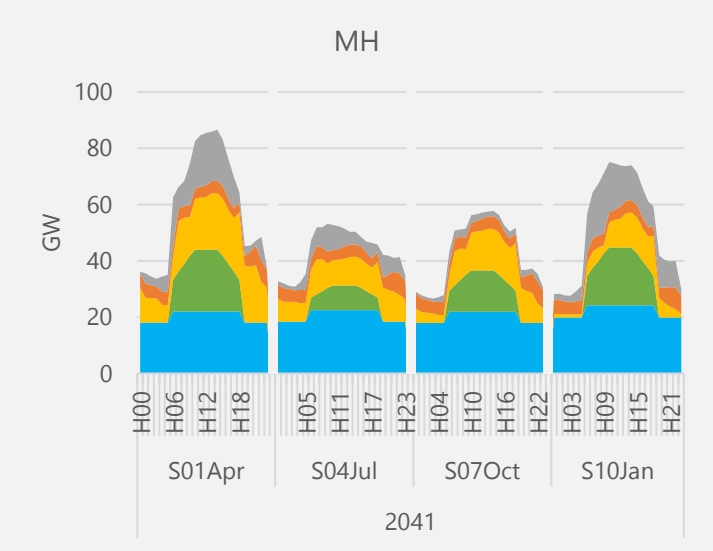
2024 refers to FY23-24, 2041 refers to FY40-41 etc

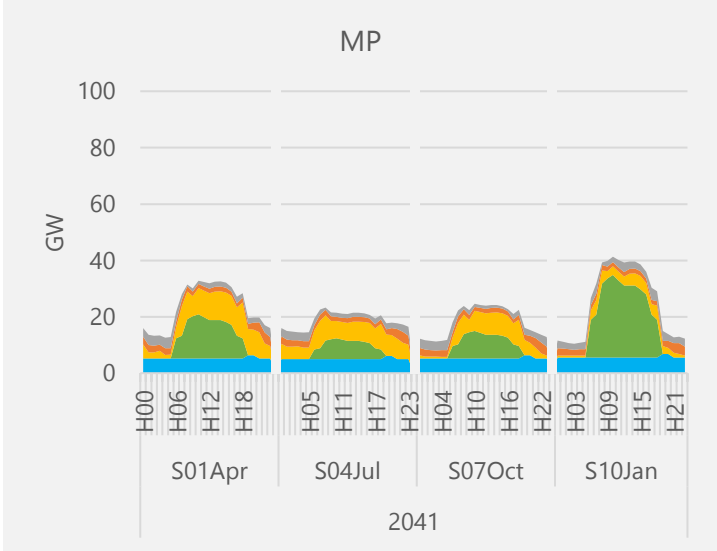
End-use electricity load shapes by sector in 2024 and 2041

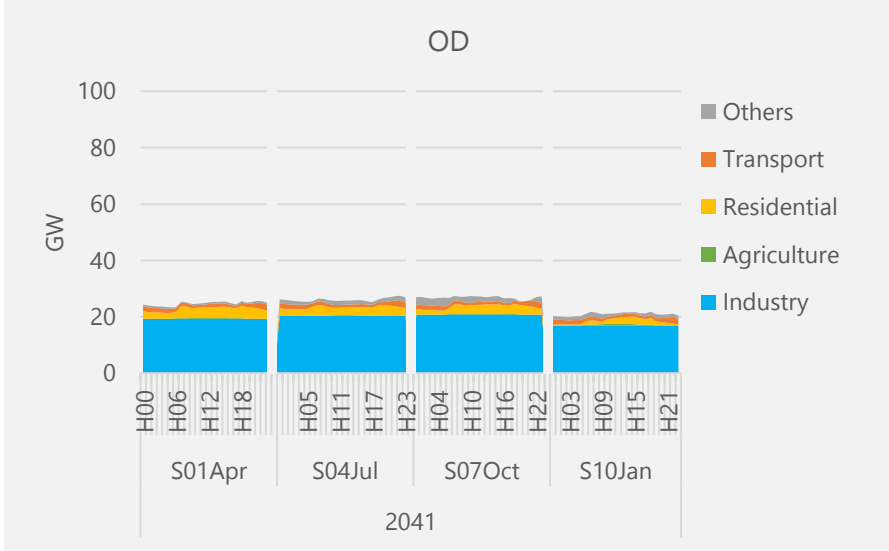


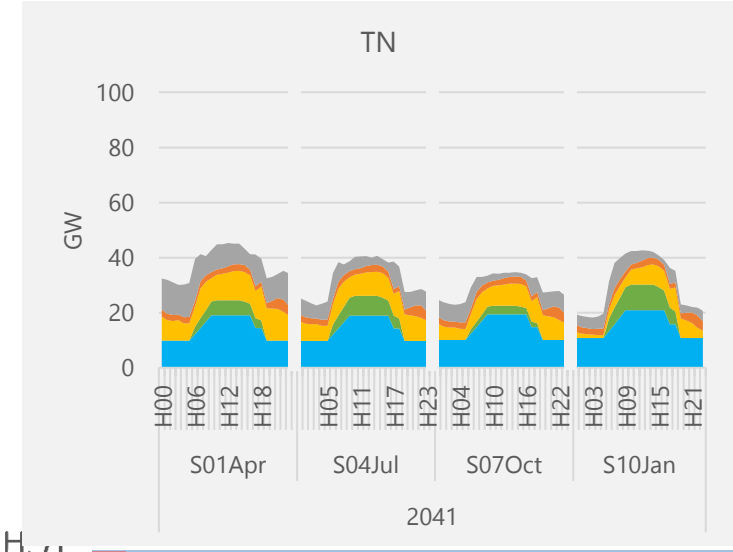
- Load shape gets distinctly peakier by FY41 with a predominant day-time peak. Annual Peak load of electricity demand ~614 GW at 10 AM in Feb 2041.
- Factors including Agriculture load shift to day-time, greater use of cooling appliances, and Transport charging demand, contribute to the change of overall load shape between FY24 and FY41

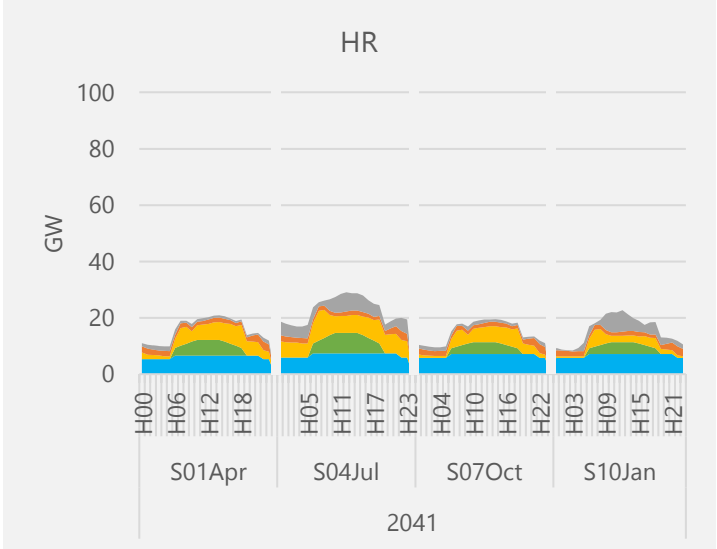
End-use electricity load shapes in FY41 for few states







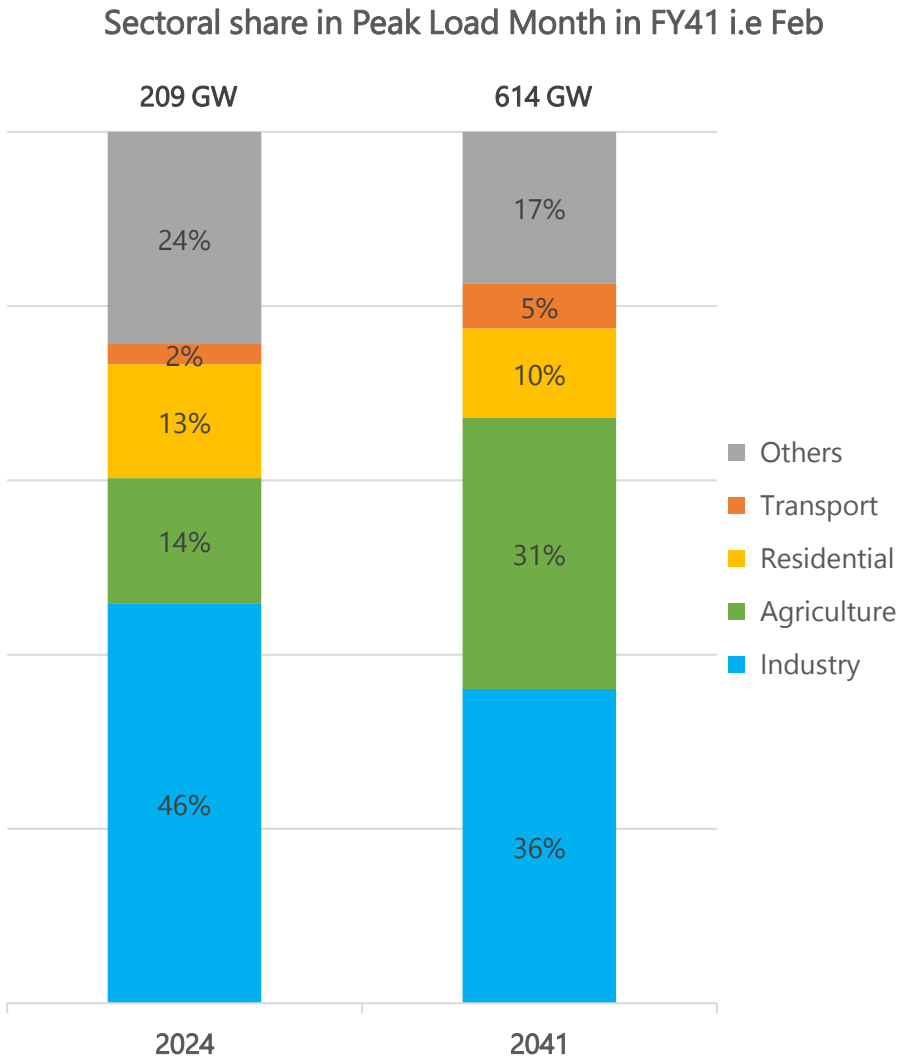




- Large differences in load-shapes are observed across states.
- States with predominantly industrial load tend to have flatter load curves (e.g. OD)

2024 refers to FY23-24, 2041 refers to FY40-41 etc

Changing composition of Peak load



- Though the annual national peak occurs at 10 AM in Feb in all model years, its composition changes due to shifting Agriculture supply to day-time and Transport electrification
- Day-time supply of electricity for Agriculture, enhanced appliance efficiency in Residential sector, electrification of Transport drive this change in peak-load composition

2024 refers to FY23-24, 2041 refers to FY40-41 etc

Cross-scenario comparison

Scenarios in PIER 2.0 demand model

Reference

- Based on past trends, known targets and likely changes

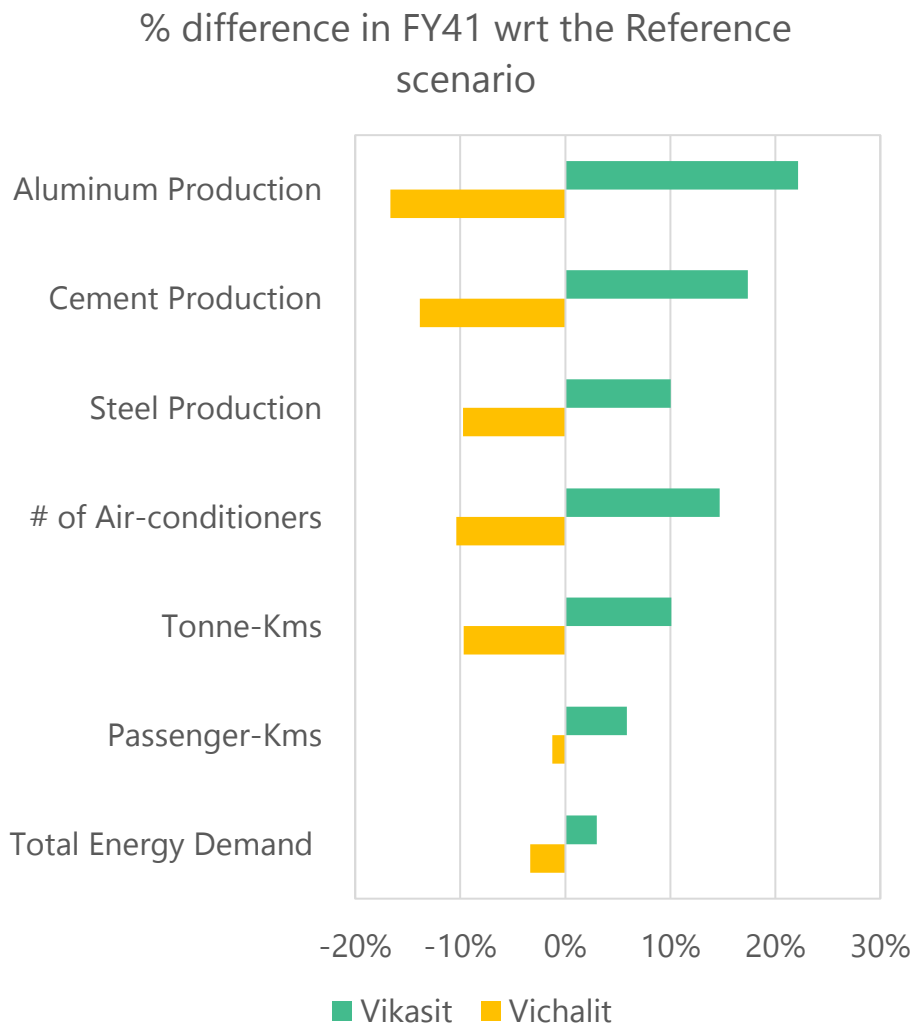
Vikasit Bharat

- Assuming significant improvement in incomes by 2047
- Greater Economic growth than Reference
- Significantly higher energy service demand than Reference
- Accompanied by efficient and effective policies
- Adoption of sustainable lifestyles
- Increased electrification & investments in newer technologies

Vichalit Bharat

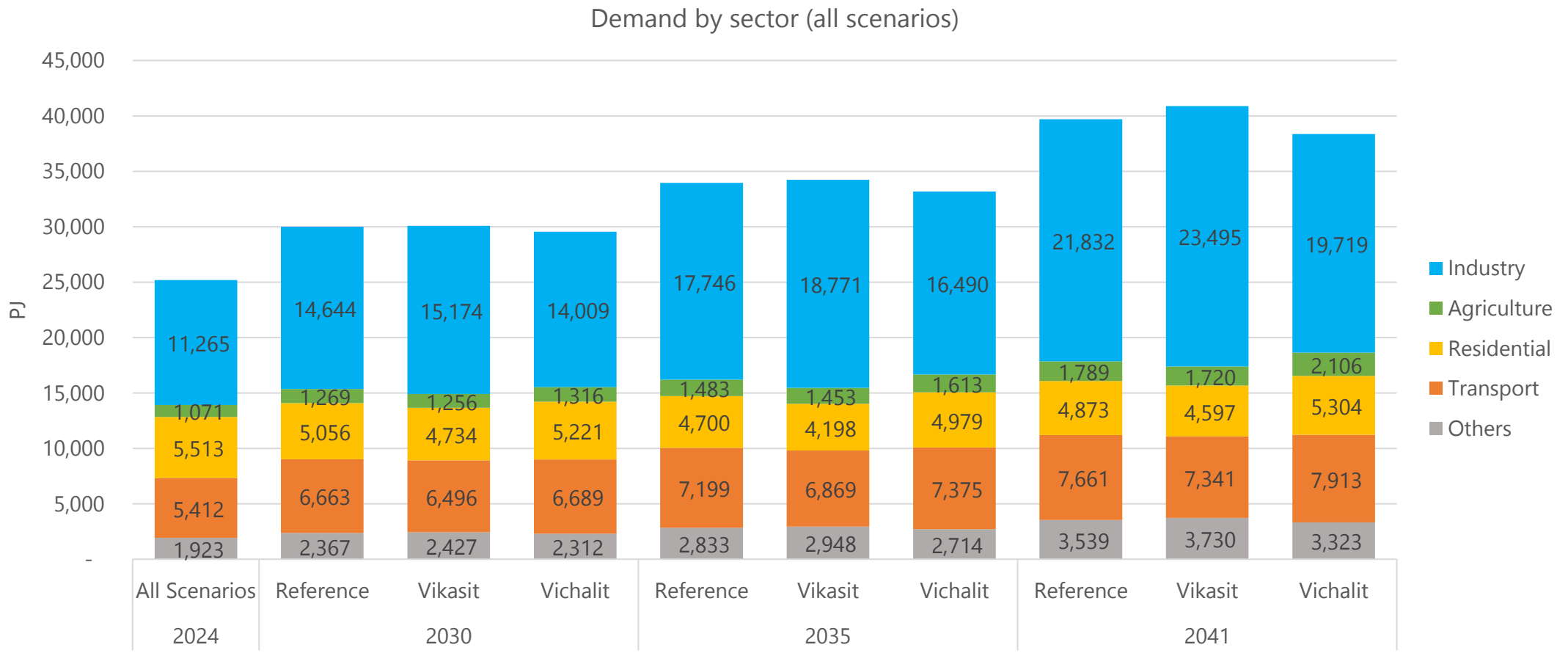
- A ‘shaken’ or ‘disturbed’ future
- Slower economic growth and than Reference
- Significantly lower energy service demand than Reference
- Less effective policies and governance
- Less sustainable lifestyles
- Lower investments in new technologies

Cross-scenario comparison by energy service in FY41



- FY41 demand in Vikasit scenario is only 3% more than Ref
  - Despite significantly higher energy services in the form of higher adoption and use of modern appliances, greater transport activity and greater Industrial production
  - Due to a combination of modal shift and higher electrification in Transport, greater efficiencies in all sectors and greater investment in newer technologies
  - Industry demand in this scenario is lower than Ref until ~2030 despite higher production. As a result, total energy demand in Ref is more than Vikasit until 2035
- The opposite scenario prevails with Vichalit: 3.1% lesser demand than Ref in FY41 despite significantly lower energy services and adoption of modern appliances

Cross-scenario comparison of demand estimates (by sector)



In most years energy demand (in terms of PJ) in Vikasit Bharat scenario is the highest and Vichalit Bharat scenario is the lowest, with Reference being in between

Note that end-use energy demand includes Green H2 used as feedstock in industry

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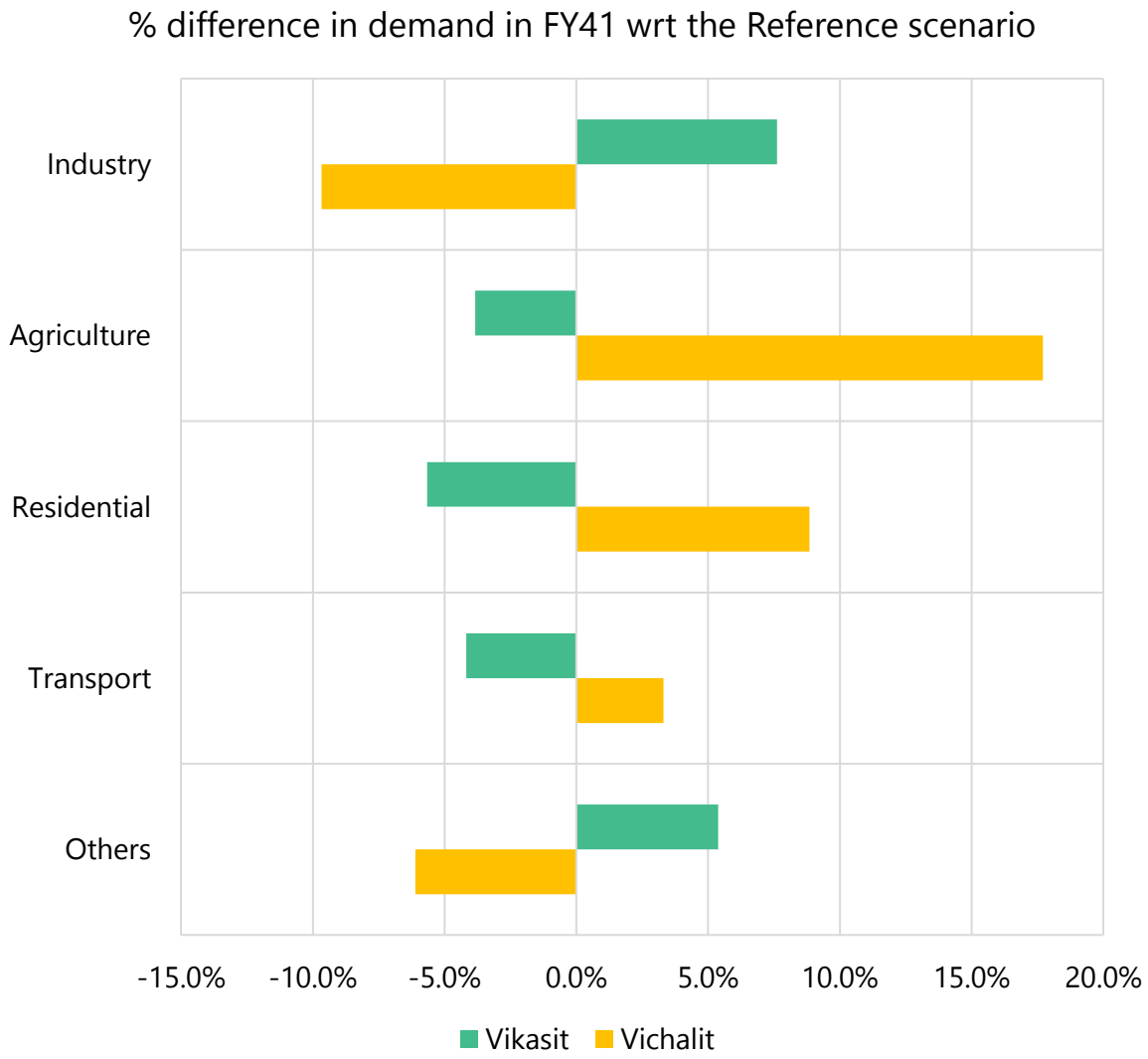
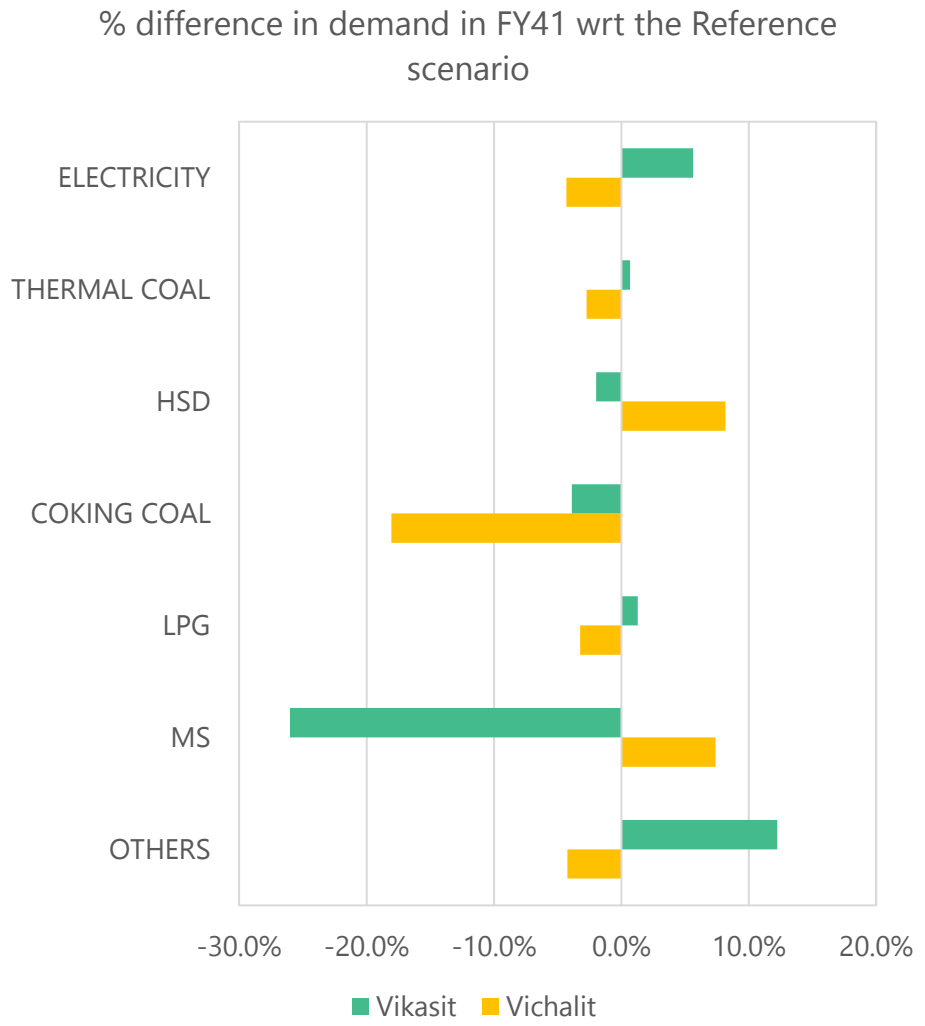
Cross-scenario comparison by sector in FY41



- Vikasit: Compared to Ref, Residential, Transport and Agriculture sector demands ↓ in FY41, while Industry and others demand ↑
- Vichalit: Exactly the opposite
- Biomass use, efficiency and electrification more relevant than amount of energy service in Residential, Transport and Agriculture
- Industry and others closely related to GDP: amount of energy service more important than efficiency and technology adoption

Cross-scenario comparison by energy carrier in FY41

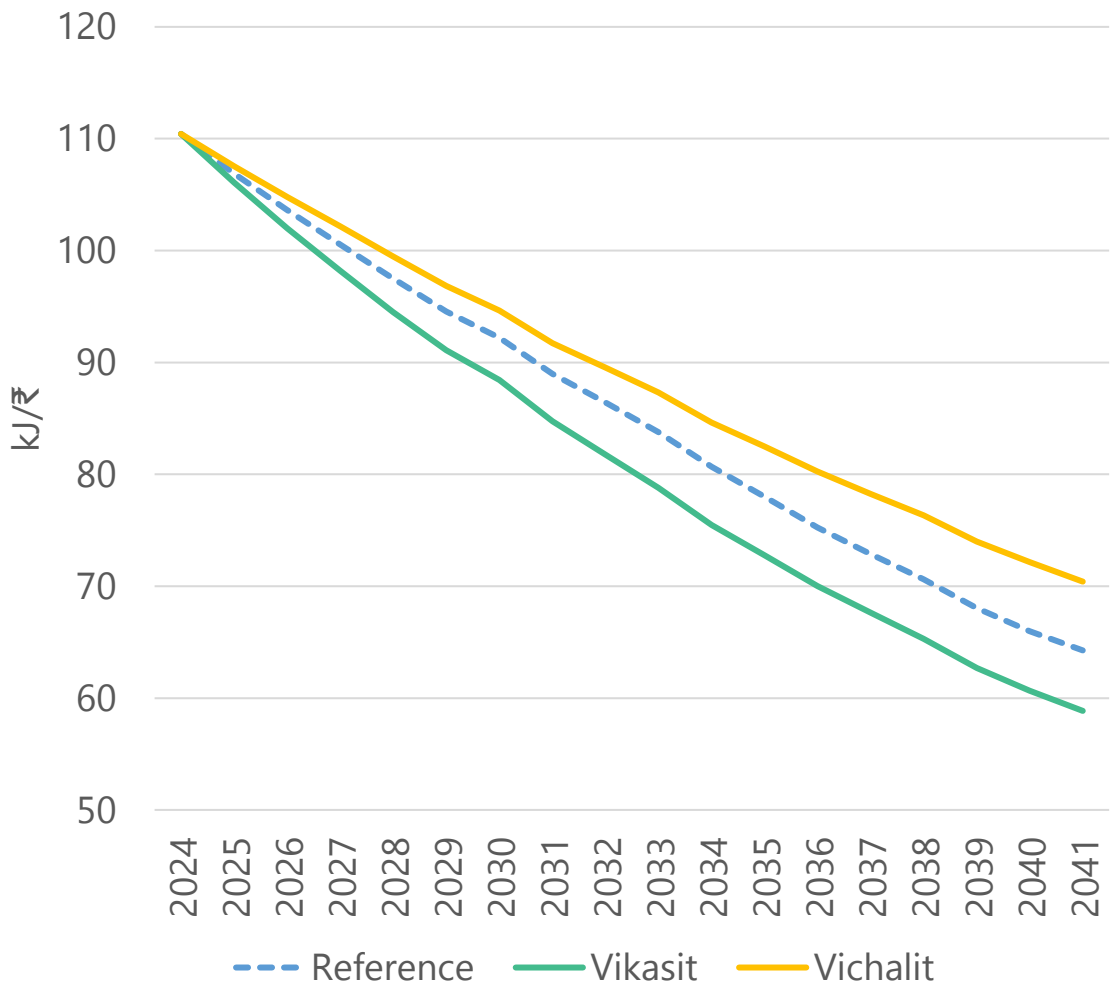


NOTE: OTHERS include GREEN_H2, ATF, PETCOKE, BIOGAS, PP_OTHER, BIOMASS, NATGAS

Carrier-wise Demand (vs. Ref FY41):

- "Clean carriers" Electricity, Commercial Biomass+Waste & Green H2: ↑ in Vikasit; ↓ in Vichalit
- Coking+Thermal Coal: ↓ in both owing to higher efficiency & decarbonisation in Vikasit; lower production in Vichalit
- For thermal coal, the faster economic growth is counter-balanced by greater efficiency and investment in decarbonization options leading to a small net growth in Vikasit compared to Ref
- Carriers being phased out like Biomass, MS & other PPs: ↓ in Vikasit; ↑ in Vichalit for similar reasons
- ATF: Slight ↓ in both (modal shift in Vikasit; lower activity in Vichalit)
- NATGAS: ↑ in Vikasit (mix of greater uptake of PNG, CNG & decarbonisation) and reduces in Vichalit (due to lower uptake and decarbonisation)

End-use energy demand intensity of GDP

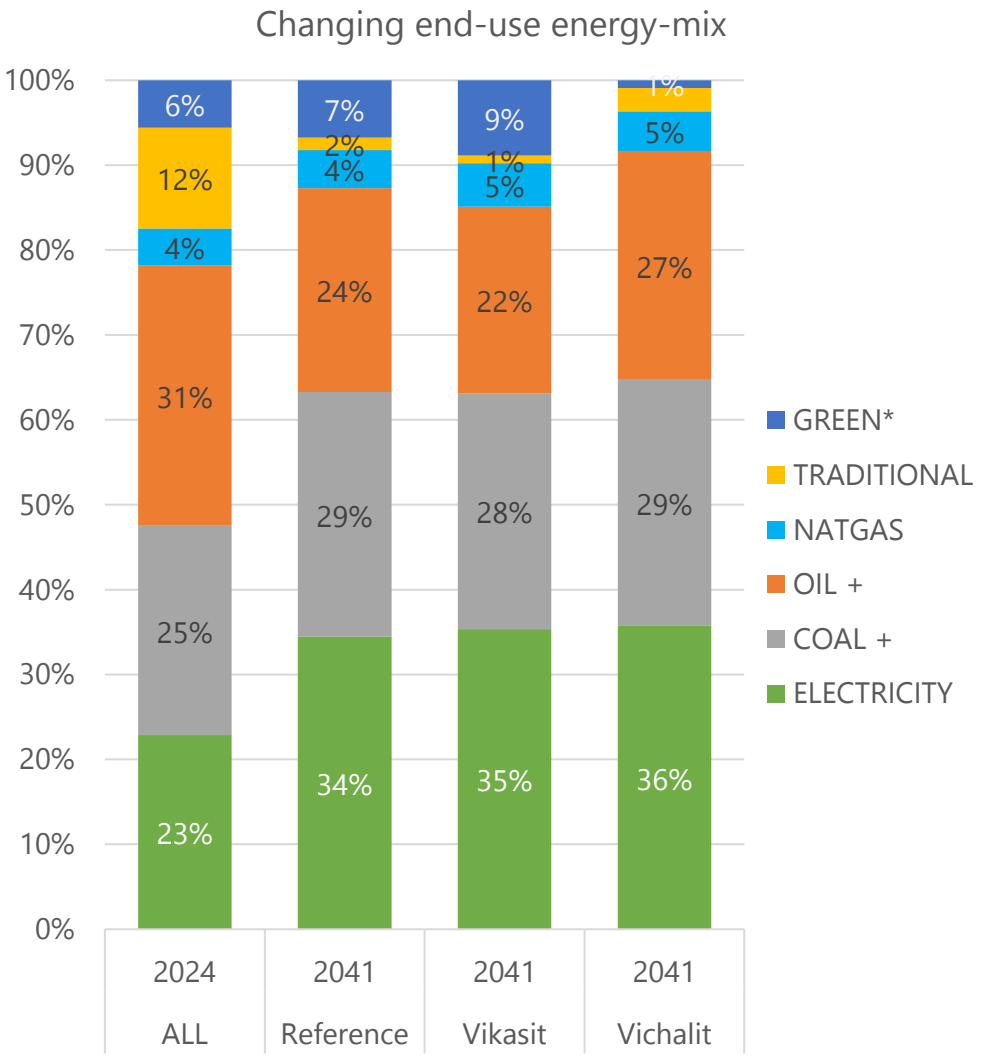


Please note the truncated Y-Axis for emphasis

- Greater difference in end-use energy intensity across sectors though only +-3% change in energy demand in FY4
- End-use energy demand intensity of GDP is ~9.6% greater in Vichalit when compared to Reference
- And ~8.5% lower in Vikasit when compared to Reference

2024 refers to FY23-24, 2041 refers to FY40-41 etc

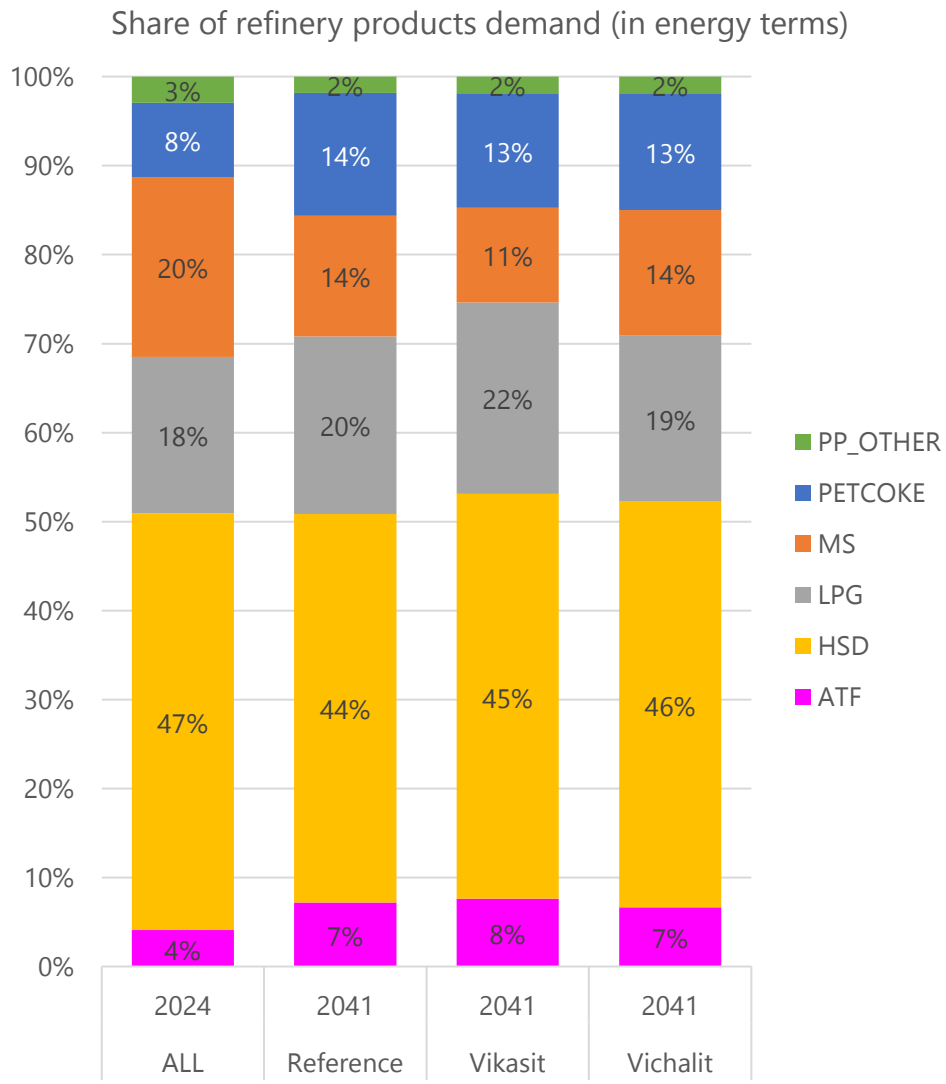
Changing end-use energy mix



- Petroleum products have the highest share (31%) in the end-use energy mix in FY24 – but are not so in FY41, going down to just 22% in Vikasit
- Electricity's share increases from 23% in FY24 to 35-36% across scenarios in FY41 – to become the leading energy carrier in end-use
- Coal's share in end-use increases marginally from 25% in FY24 to 28-29% in FY41
- The share of "traditional" fuels (traditional biomass + biogas) comes down from 12% in FY24 to just 1-3% in FY41
- The share of "green" fuels (commercial biomass + green H2) increases from 6% to 7-9% in Ref/Vikasit scenarios but falls to just 1% in Vichalit scenario due to non-adoption of new technologies and green options

2024 refers to FY23-24, 2041 refers to FY40-41 etc

Changing role of refineries



- The differing growth rates in demand for different petroleum products will have an impact on the product mix from refineries
- While HSD's share in the petroleum product mix remains more or less similar in FY41 compared to FY24 (across scenarios), shares of other products change
- Most significantly the share of MS is likely to go down from 20% in 2024 to 11-14% in FY41 across scenarios
- LPG's share goes up from 18% in FY24 to 20-21% in FY41 in Ref and Vikasit scenarios
- ATF's share goes up from 4% in FY24 to 7-8% across scenarios in FY41
- The change would be gradual – but is likely to require investments and planning by refineries

2024 refers to FY23-24, 2041 refers to FY40-41 etc

PIER 2.0 Energy Carrier Demand outputs at a glance

Sl no	Energy Carrier	Unit	Scenario	2024	2030	2035	2041
1	ELECTRICITY	TWh	Reference	1599	2127	2709	3802
			Vikasit		2161	2801	4016
			Vichalit		2094	2626	3638
2	THERMAL COAL*	MT	Reference	264	336	401	478
			Vikasit		344	403	481
			Vichalit		331	390	465
3	HSD	MT	Reference	84	85	90	96
			Vikasit		84	89	94
			Vichalit		86	93	104
4	COKING COAL*	MT	Reference	81	111	135	156
			Vikasit		113	147	150
			Vichalit		102	116	128
5	LPG	MT	Reference	29	34	38	40
			Vikasit		36	40	41
			Vichalit		33	36	39
6	MS	MT	Reference	35	50	47	31
			Vikasit		46	39	23
			Vichalit		50	48	34
7	ATF	MT	Reference	7.1	10.6	12.6	15.5
			Vikasit		10.6	12.6	15.4
			Vichalit		10.5	12.3	14.8

Sl no	Energy Carrier	Unit	Scenario	2024	2030	2035	2041
8	BIOGAS	BCM	Reference	0.5	0.5	0.4	0.3
			Vikasit		0.5	0.4	0.3
			Vichalit		0.4	0.4	0.3
9	BIOMASS	MT	Reference	191	128	82	38
			Vikasit		105	47	24
			Vichalit		141	103	64
10	COMMERCIAL BIOMASS + WASTE	MT	Reference	102	111	119	133
			Vikasit		113	126	151
			Vichalit		109	116	126
11	GREEN HYDROGEN	MT	Reference	0.1	2.9	4.7	7.2
			Vikasit		5.0	8.3	13.0
			Vichalit		1.1	1.8	2.7
12	NATGAS	BCM	Reference	29	41	44	47
			Vikasit		41	45	56
			Vichalit		41	46	46
13	PETCOKE	MT	Reference	19	26	32	39
			Vikasit		25	30	34
			Vichalit		25	31	39
14	OTHER PETROLEUM PRODUCTS	MT	Reference	5.6	5.0	4.6	4.4
			Vikasit		4.9	4.4	4.1
			Vichalit		5.1	4.8	4.6

* Assuming domestic energy density of THERMAL COAL as ~4,110 kCal/kg and COKING COAL as ~4,910 kCal/kg

Note that end-use energy demand includes Green H2 used as feedstock in industry

2024 refers to FY23-24, 2041 refers to FY40-41 etc

Key takeaways

Role of increased electrification

- Electricity becomes the most used carrier accounting for over a third of end-use demand
- Large efficiency gains in Transport and Agriculture
- ACs alone consume as much as all of transport in FY41 despite 99% of vehicle sales being EVs
- Load gets peakier during the day due to agricultural load shifting, combined with other uses such as transport charging, space cooling etc.

Other energy carriers

- Coal continues to play an important role in end-use due to its hard-to-abate nature
- Significant change in petroleum product mix in future along with slower growth of products in general needing rethink from refineries

Key takeaways…

State-wise variations

- Across the years divergence between states in terms of per-capita consumption of electricity increases
- Similar pattern is observed in per-capita consumption of all energy as well, across scenarios

Scenario insights

- Policies/measures determining adoption of efficiency and decarbonisation techniques have big impact on energy services that can be supported
- Vikasit provides much more energy services than Reference at just 3% energy cost
- Conversely Vichalit provides much lesser energy services than Reference at only 3% lower energy cost

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

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