PIER 2.0: India's Transport 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

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: “`Freight/(Frt-Base) TechSplitRatio (RoadStockFlow).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

Outline of this document

- Drivers of Transport Demand
- Passenger Model in detail; Inputs, Results and Insights
- Freight Model in detail; Inputs, Results and Insights
- Combined Transport; Results, Scenarios and Insights
- Conclusions

For ease of reference, slides are marked as below

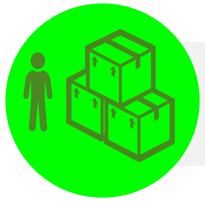
Passenger transport

Freight transport

Total Transport

Glossary

ATF	:	Aviation Turbine Fuel
BPKM	:	Billion Passenger-kilometres
BTKM	:	Billion Tonne-kilometres
BU	:	Billion Units of Electricity (same as TWh)
G-H2	:	Green Hydrogen
GHG	:	Greenhouse gases
GVW	:	Gross Vehicle Weight (Kerb weight +Maximum permissible payload)
HGV	:	Heavy Goods Vehicle
HSD	:	High-speed diesel, commonly known as Diesel
IPT	:	Intermediate public transport
LDT	:	Long-distance Passenger transport
LGV	:	Light Goods Vehicle
MGV	:	Medium Goods Vehicle
MS	:	Motor-spirit, commonly known as Petrol or Gasoline
MT	:	Million Tonne (or million metric-tonne)
PJ	:	Petajoules
SDT	:	Short-distance Passenger transport
SEC	:	Specific energy consumption
ST	:	Service Technology
STC	:	Service Technology Category



Transport overview

- Transportation sector forms ~10% of India's final energy demand making it the third largest sector after Industry and Residential
- Almost all of this demand is today met through fossil fuel sources
- It is further estimated that 90% of passenger travel demands are met by road transport and 67% of the freight traffic is met by road
- Further, ~10% of India's GHG emissions come from the transport sector, of which 90% comes from road alone
- Transport is crucial in the energy as well as environment story
- Our interests: Changing nature of the sector due to electrification and increased travel demands, impact on grid/planning, import dependency, GHG emissions etc.

Primary drivers of transport energy demand

Vehicle Stock and Flows	Vehicle tech breakup	Energy Service and Vehicle segments	Specific Energy Consumption (SEC)	Energy service demand (or Activity)
• Detailed stock-flow tracking for road transport • 2W, 4W, IPT3W, IPT4W, BUS: road passenger transport • LGV, MGV, HGV: road freight transport • Stock-flow tracking not meaningful for RAIL, AIR and WATER (freight only)	• Break-up by fuel: E.g. buses can be diesel, CNG, or electric • Break-up by energy service: E.g. bus fleet used for short and long distance • Break-up by type: E.g. Buses for educational and non-educational use in short-distance transport	• Passenger transport: Short (all except air) and long distance (bus, taxi, rail and air) • Similarly for freight • Also account for international passenger and freight originating in India	• Efficiency of vehicle stock (for road vehicles) or vehicle type • Based on Historic SEC for Rail • Other modes: actual consumption and activity used for SEC	• Road: Activity per day, days per year, and load factors • Non-road: Based on historic data

Road segment at state geographic granularity, non-road at national level

Inputs are calibrated and verified with respect to FY22-FY24 MS and HSD demand data

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

Road (Passenger and Freight): Stock and flow (1/2)

Stock-flow: Below datasets used to build state-wise stock flow from FY13 to FY23

- State-wise, Category-wise, Vehicle Registrations *[MoRTH, 2010-2019]*
- State-wise, Category-wise, Commercial Vehicles in Use *[MoRTH, 2010-2019]*
  - FY13 values is the starting point for both the above, so that FY13-FY23 can be used to retire older stock
  - Thereby the start year FY24 data is much more calibrated
- State-wise, Category-wise, Class-wise, Fuel-wise New Vehicle Sales *[MoRTH, VAHAN database, 2014-2023]*
- Reasonably reliable flow data of vehicles from the VAHAN portal – though painstaking
- Sketchy stock data since retirements are not accounted for in official stock statistics – hence assumptions needed
- Future stock projections are considered based on FY14-20 growth-rates upon FY23 base (estimates using latest available data) along with reasonable tempering across the model period; thus assuming a normalcy post-Covid
- Future sales and retirements follow based on the lifetime and stock assumptions

- Data file: "`Passenger/(Pass-Base) TechSplitRatio (RoadStockFlow).xlsx`"
- Data file: "`Freight/(Frt-Base) TechSplitRatio (RoadStockFlow).xlsx`"

Road (Passenger and Freight): Stock and flow (2/2)

The guiding formula is

Stock (Y, ST, S) = Stock (Y-1, ST, S) + Sales (Y, ST, S)- Retirements (Y, ST, S)

Where Y is year, ST Service Tech and S is State

Since MoRTH tracks year-on-year vehicle registrations and not necessarily retirements, the actual legacy stock in use has to be estimated.

State-wise legacy stock for FY2013 is derived from vehicle registration data

−

From FY14 onwards, 1/lifetime of the legacy stock is retired annually. Depending on the vehicle variant, the legacy stock is fully exhausted by FY2023 (FY2013+10 years) or FY2033 (FY2013+20 years)

+

Sales data from FY13 to FY23 is sourced from the VAHAN portal, with projections based on assumptions.

−

A vehicle purchased in year X retires in year X+n, where n is the vehicle's lifetime.

Road (Passenger and Freight): Activity

Activity: No authoritative surveys/data available – hence assumption based with rough validation against following sources

- Census 2011: Table B-28 'Other Workers' By Distance From Residence To Place Of Work And Mode Of Travel To Place Of Work *[ORGI, 2011]*
  - *The same could not be used comprehensively as the dataset is limited to 'other worker' and there is no subsequent Census*
- Wilbur Smith & Associates: Study on Traffic and Transportation Policies And Strategies in Urban Areas in India, survey of 30 cities *[MoUD, 2008]*
- Comprehensive Mobility Plans of Pune 2008, Gulbarga 2009, Davangere 2016, Bangalore 2020, Jammu 2017, Nagpur 2018, Mumbai 2018
- India's Electric Vehicle Transition: Can Electric Mobility Support India's Sustainable Economic Recovery Post COVID-19? *[CEEW, 2020]*
- Scraped speedometer data from used vehicles listicles to understand the activity
- Per STC demand is considered constant across the model-period

- Data file: "`Passenger/(Pass-Base) NumInstances, ES_Demand & UsagePenetration.xlsx`"
- Data file: "`Freight/(Frt-Base) NumInstances, ES_Demand & UsagePenetration.xlsx`"

Road (Passenger and Freight): SEC and others (1/2)

SEC

- ICCT compilation of India's EV market and parameters *[ICCT, 2020]*
- 2W, 4W Fuel Economy Declaration *[SIAM, 2017-18, 2018-19]*
- 4W market split by manufacturer in FY18-19, FY20-21 *[ICCT, 2021]*
- Product reviews on CarDekho.com to ascertain real-world efficiency
- Major Bus manufacturer model specifications *[Eicher, Mahindra, Tata, BharatBenz, Volvo, AshokLeyland]*
- SRTU Fleet Statistics, State-wise, Category-wise, STU wise *[MoRTH, 2010-2019]*
- Similar approach for freight SEC
- Factors for 'real-world efficiency' are assumed

Others

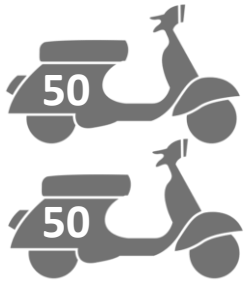
- Passenger Load Factors are roughly based on OECD model *[OECD data, TERI model]*
- SRTU data-based assumptions for breaking up bus fleet into short and long distance

- Data file: "`Passenger/(Pass-Base) ST_SEC.xlsx`"
- Data file: "`Freight/(Frt-Base) ST_SEC_payload.xlsx`"

Road (Passenger and Freight): SEC and others (2/2)

An illustrative example for the Stock SEC methodology (SEC = 1/mileage)

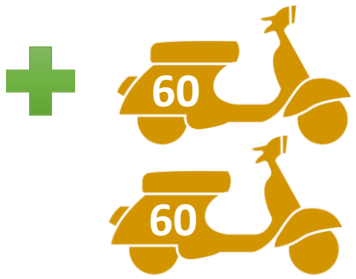
2025



Initial Stock =2

- 2 Vehicles of 50 kmpl
- Average stock mileage (50+50)/2 =
- **50 kmpl**

2026



Stock = 2+2= 4

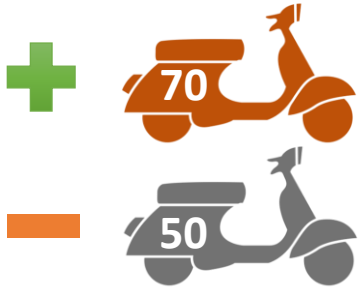
- 2 vehicles of 60kmpl added
- Stock mileage = (50*2 + 60*2)/4 =
- **55 kmpl**

2027

Stock = 4+1 = 5

- 0 retirements
- 1 vehicle of 65kmpl added
- {(Previous year Stock Mileage*Previous year stock) + (New Sales Mileage *New sales)}/ New Stock
- = (55*4+65*1)/5 =
- **57 kmpl**

2028



Stock = 5+1-1= 5

- 1 50kmpl vehicle retires
- 1 70kmpl vehicle added
- (OldStockMileage*OldStock – RetiringMileage*Retirement+NewSalesMileage*NewSales)/NewStock
- (57*5-50*1+70*1)/5 =
- **61 kmpl**

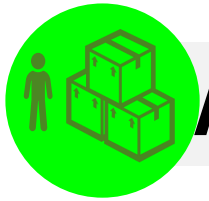
Rail (Passenger and Freight)

Activity

- Indian railways published data on train and engine kilometrage pertaining to Steam, Diesel and Electric Locomotives *[Indian Railways, 2010-2020]*
- Indian railways data on load of Trains (passenger and goods) *[Indian Railways, 2010-2020]*
- Monthly Evaluation Report *[Indian Railways, 2023]*
- Parliamentary standing committee report on implementation of metro rail projects for metro ridership in the country
    - The metro and non-metro service demand share in SDT is assumed as 10:90
- Future activity projections are considered based on FY14-20 growth-rates upon FY23 base (estimates using latest available data) along with reasonable tempering across the model period ; thus assuming a normalcy post-Covid
- Data file: Same as road

SEC

- Indian railways data on fuel consumption by classes of services *[Indian Railways, 2010-2020]*
- Delhi metro rail data for three years used, as data from other metro systems not available *[DMRCL, FY14-FY16]*
- Data file: Same as road



Air (Passenger and Freight)

Activity

- Handbook of Civil Aviation Statistics *[DGCA, 2014-23]*
- Monthly Traffic And Operating Statistics of Indian Carriers (Scheduled and Unscheduled Domestic Services) *[DGCA, 2013-23]*
- Country-wise International Traffic (Scheduled) Statistics, Pax and Frt *[DGCA, 2015-23]*
- Future activity projections are considered based on FY14-20 growth-rates upon FY23 base (estimates using latest available data) along with reasonable tempering across the model period; thus assuming a normalcy post-Covid
- Data file: Same as road

SEC

- Petroleum and natural gas statistics: Consumption (end use) of Aviation Turbine Fuel (ATF) *[MoPNG, 2015-2022]*
- Data file: Same as road

Water (Freight only)

Activity

- All Inland Waterways cargo and Coastal Cargo are considered to be Domestic cargo.
- Non-coastal 'overseas cargo' split into 'Export cargo' using the EXIM shares of all goods expressed in MT.
- Activity data from publications by Inland Waterways Authority and Shipping Ministry
- Since the lead of the entire sector is not known, the whole of the cargo is clubbed into Freight-WATER *[Dept of Commerce, 2014-2023]*
- Future activity projections are considered based on FY14-20 growth-rates upon FY23 base (estimates using latest available data) along with reasonable tempering across the model period; thus assuming a normalcy post-Covid
- Data file: Same as road

SEC

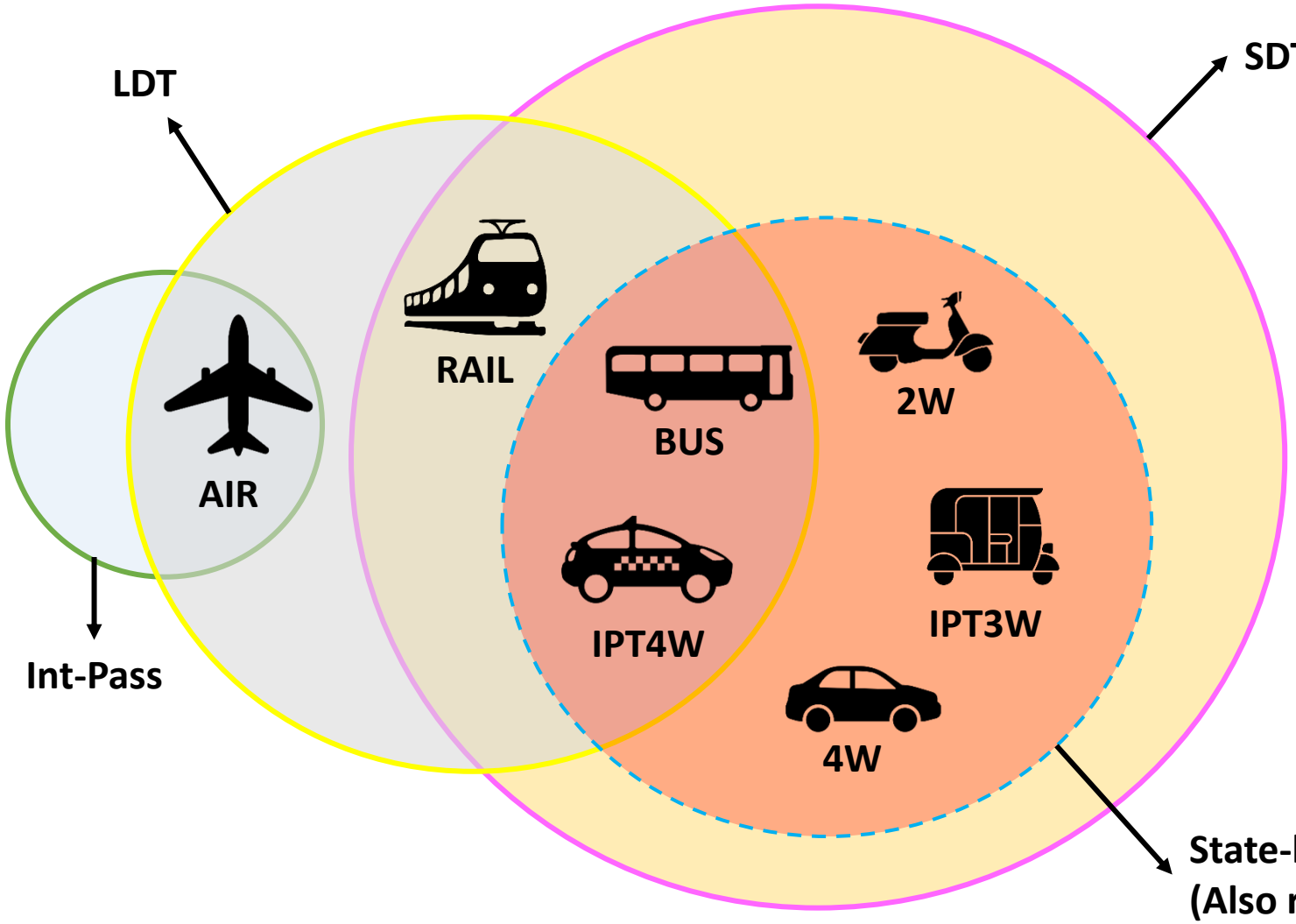
- Petroleum and natural gas statistics: Sector-wise Consumption (end use) Diesel and Heavy Oil *[MoPNG, 2015-2022]*
- Data file: Same as road

Passenger Model in detail

Pass: Model overview

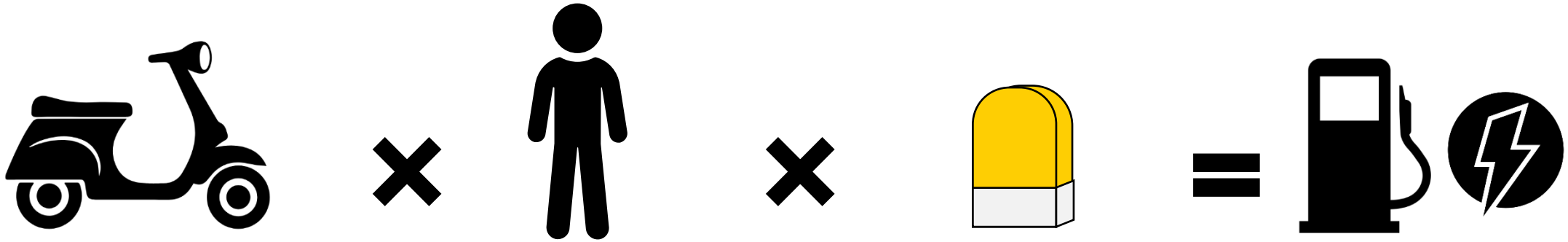
- Only Motorised transport modelled; FY2024-FY2041
- Three energy service: Short-distance, long-distance (SDT, LDT) and International Air Passenger
- 7 Vehicle segments (ServiceTech Category): AIR, RAIL, 2W, 4W, IPT3W, IPT4W, BUS (IPT= Intermediate Public Transport). Water is not considered- sparse, less prevalent, data
- 2W, 4W: Privately owned; IPT3W, IPT4W: can have mixed ownership
- One 'AVERAGE' efficiency-level for every ST considered, except for buses to differentiate from EDU/nonEDU for SDT and AVERAGE for LDT
- Hybrids NOT considered in the model. H2 buses NOT considered at this stage.
- Blending
  - MS-Ethanol blending: E20 implemented from 2025, E10 assumed before that
  - Sustainable Aviation Fuels (SAF): are considered as 'some' blending in ATF, and becomes relevant after 2035. This is due to absence of clear roadmaps or industry outlooks
  - Both these 'blending' on the demand-side is simulated using Fuel-efficiency losses
  - Blending also reflects in changing energy density in MS

Pass: Service Technologies



STC	ST
AIR	ATF
RAIL	HSD, ELEC
BUS	HSD, ELEC, CNG
IPT4W	HSD, ELEC, CNG, MS
2W	MS, ELEC
IPT3W	HSD, ELEC, CNG, MS
4W	HSD, ELEC, CNG, MS

Pass: Road – energy demand



- Number of vehicles
- Technology of vehicle
- SEC (energy/km)

- LoadFactor: Number of persons per vehicle (trip)

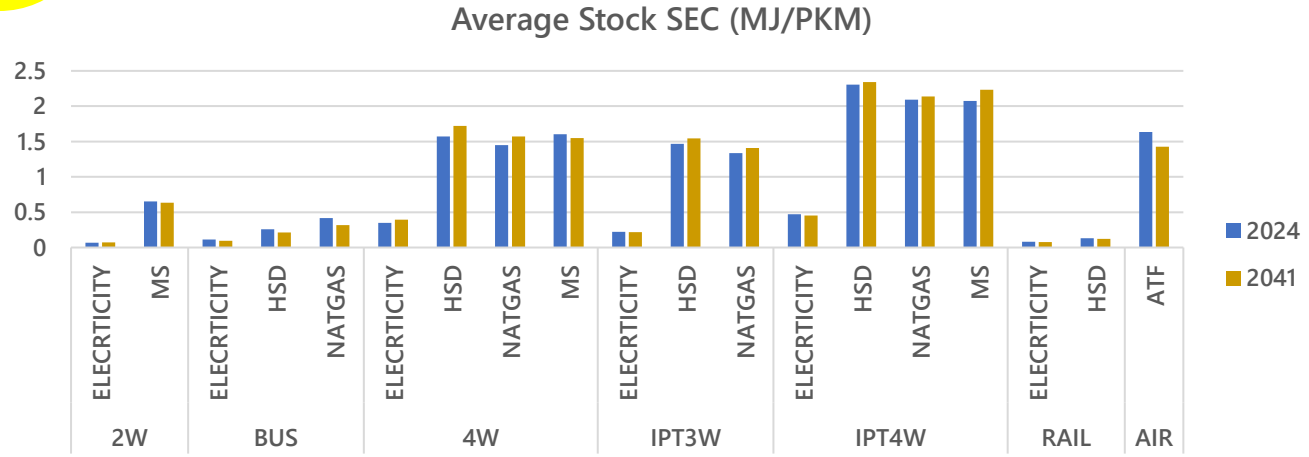
- Distance travelled
- Number of trips
- Number of days

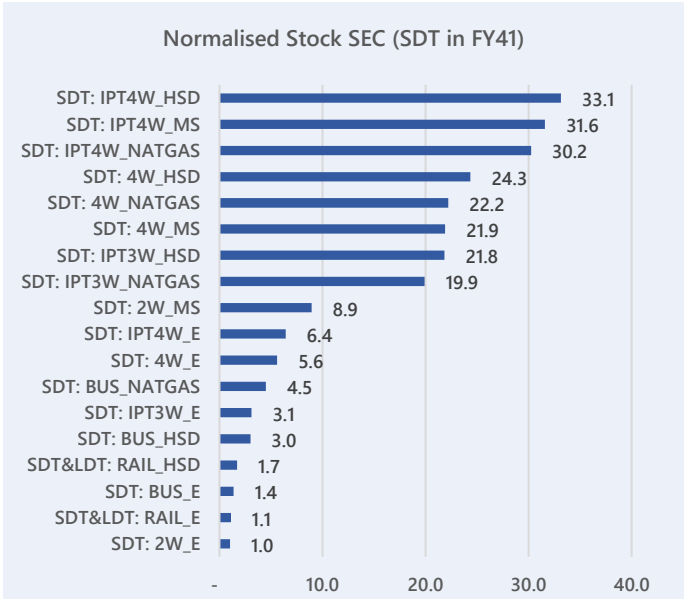
- Passenger-kms
- Fuel used

Road ES Demand (stc, st, s, y, es) = Stock (stc, st, s, y, es) * Km per day (stc) * Number of travelling days (stc) * Load factor (stc, es)

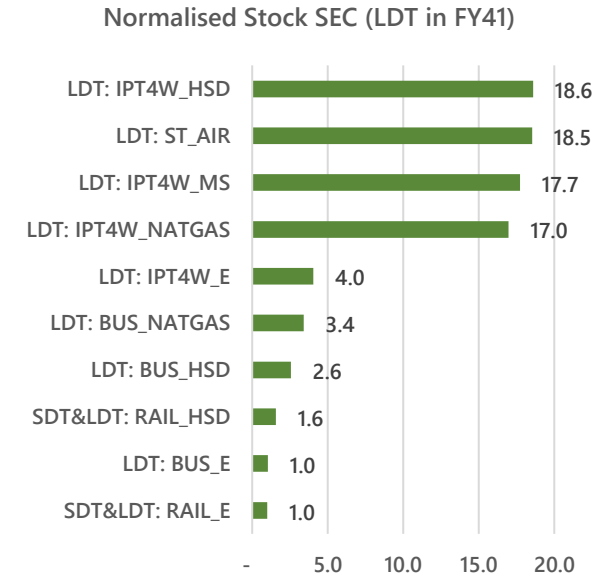
Where stc- Service Tech Category, st- Service Tech, s- State, y- year, es- energy service

Pass: Inputs – SEC





With respect to most efficient mode i.e 2W EV



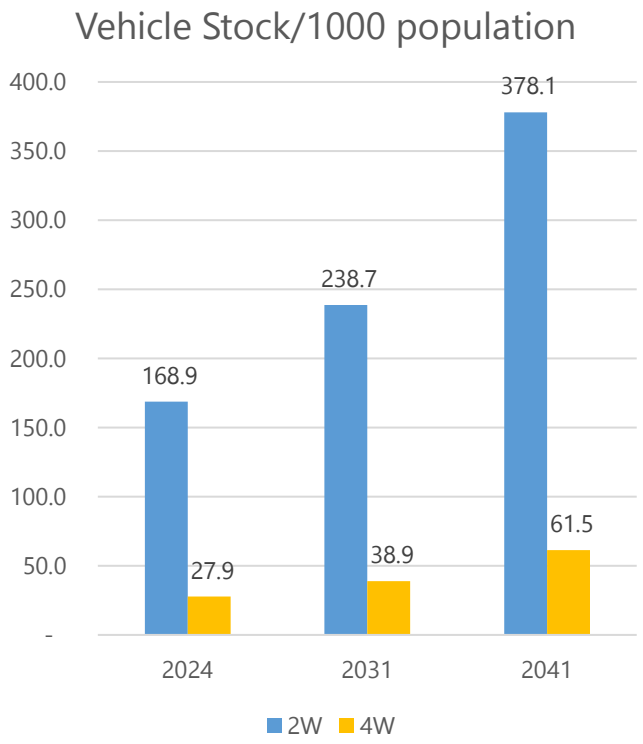
With respect to most efficient mode i.e RAIL Electric

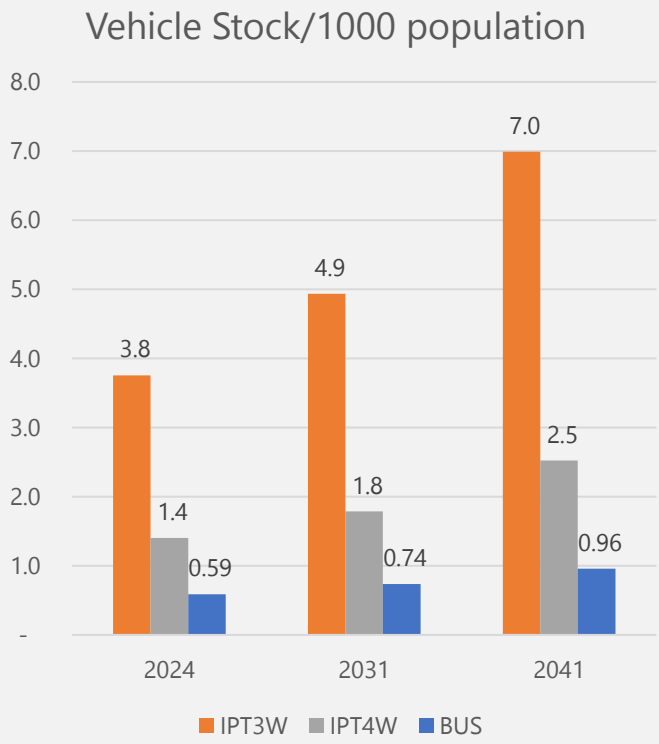
Flow Mileage FY24, FY41	2W	IPT3W	IPT4W	4W	BUS
MS (Km/l)	56-60.5	28-30.5	19-20.4		NA
HSD (Km/l)	NA	27.8-28.5	18.8-19		5.2-5.9
CNG (Km/Kg)	NA	40-41	27-27.5		4.5-5.2
Electricity (Km/kWh)	45-47	15-16.9	7.1-7.3		1.1-1.3

- All flow SEC improvements are <1% CAGR, with majority pairs <0.5%
- Any SEC 'increase' during the model period are caused due to deteriorating LoadFactors

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

Pass: Inputs- Stock

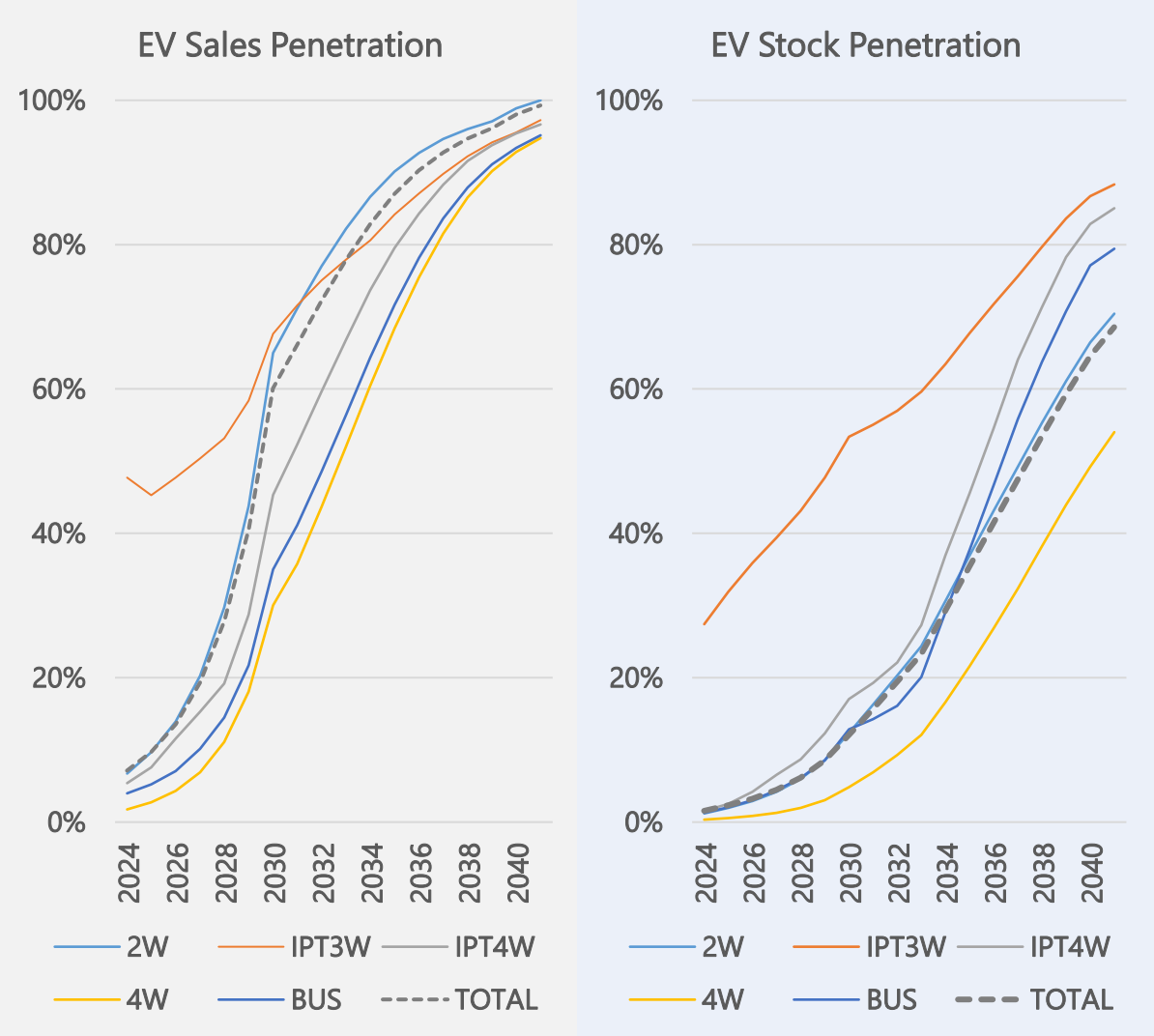




Vehicle Stock (Million)			CAGR
STC	**2024**	**2041**	**FY24-41**
2W	235.6	592.3	**5.6%**
IPT3W	5.2	11.0	**4.4%**
IPT4W	2.0	4.0	**4.2%**
4W	38.9	96.3	**5.5%**
BUS	0.8	1.5	**3.6%**
TOTAL	**283**	**705**	**5.5%**

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

Pass: Inputs- EV penetration

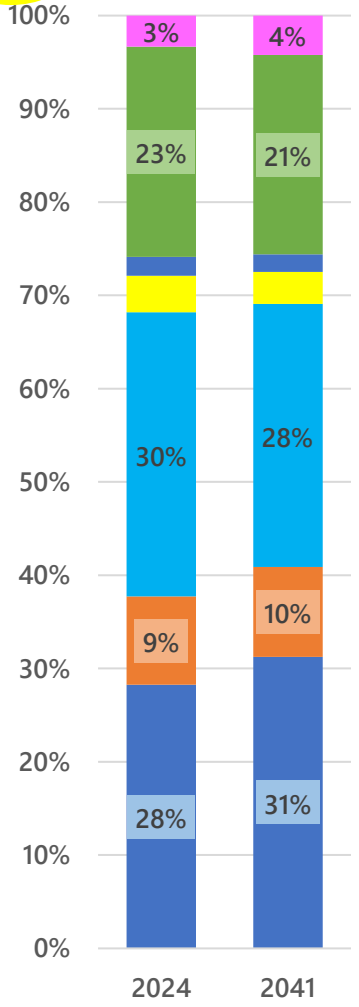


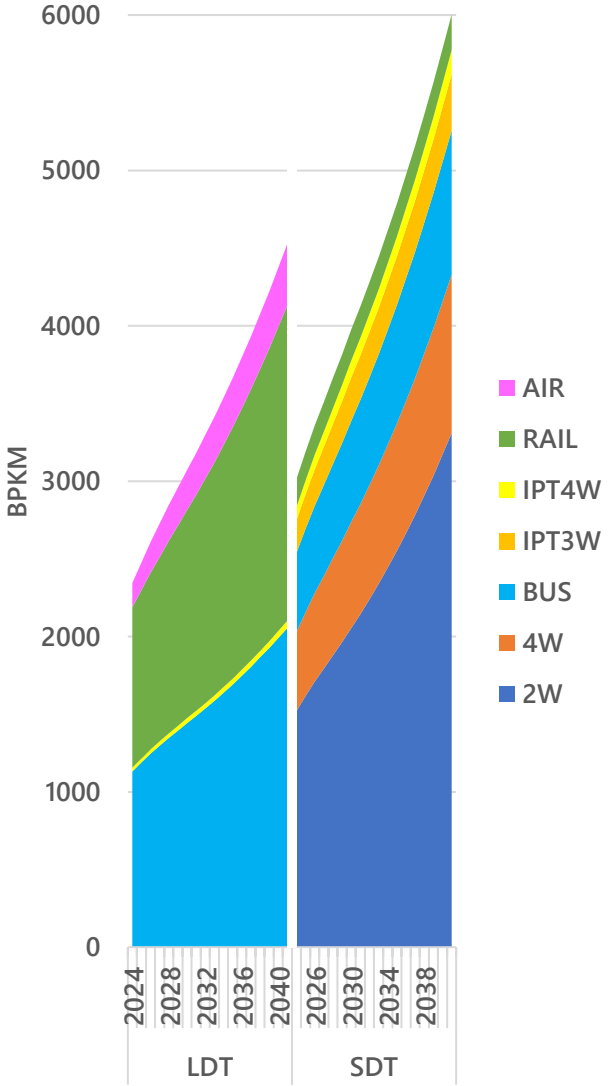
EV national sales penetration	2030 – 'target'	2041 assumption
2W	65%	100%
IPT3W	60% (higher if the State has already reached)	97%
IPT4W	45%	97%
4W	30%	95%
BUS	35%	95%
→ TOTAL	**60%**	**99%**

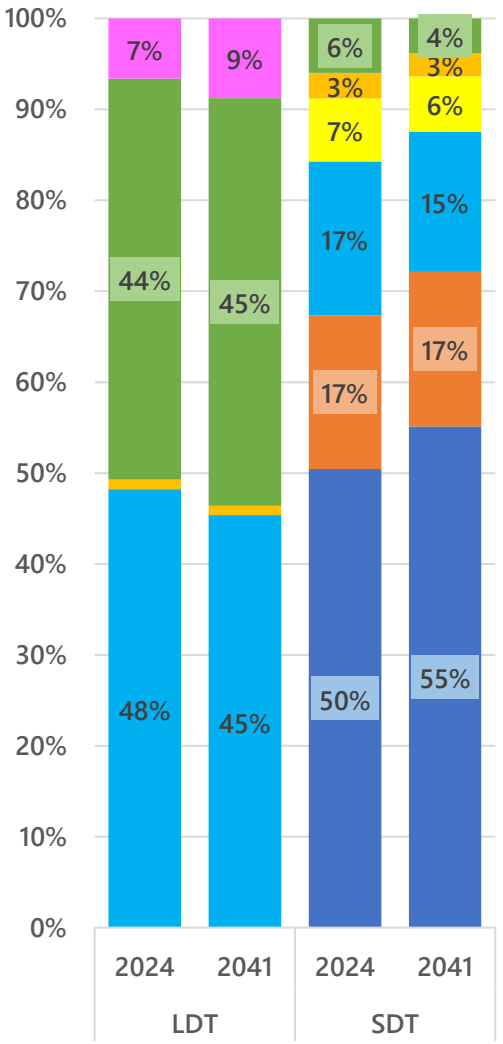
- In effect even though we have assumed > 90% sales penetration in all segments
- The Stocks end up differently because of lifetimes, legacy stock compositions
- No segment is 100% electrified in Stock in FY41

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

Pass: Intermediate outputs (BPKMs –by ES & Vehicle Segment)



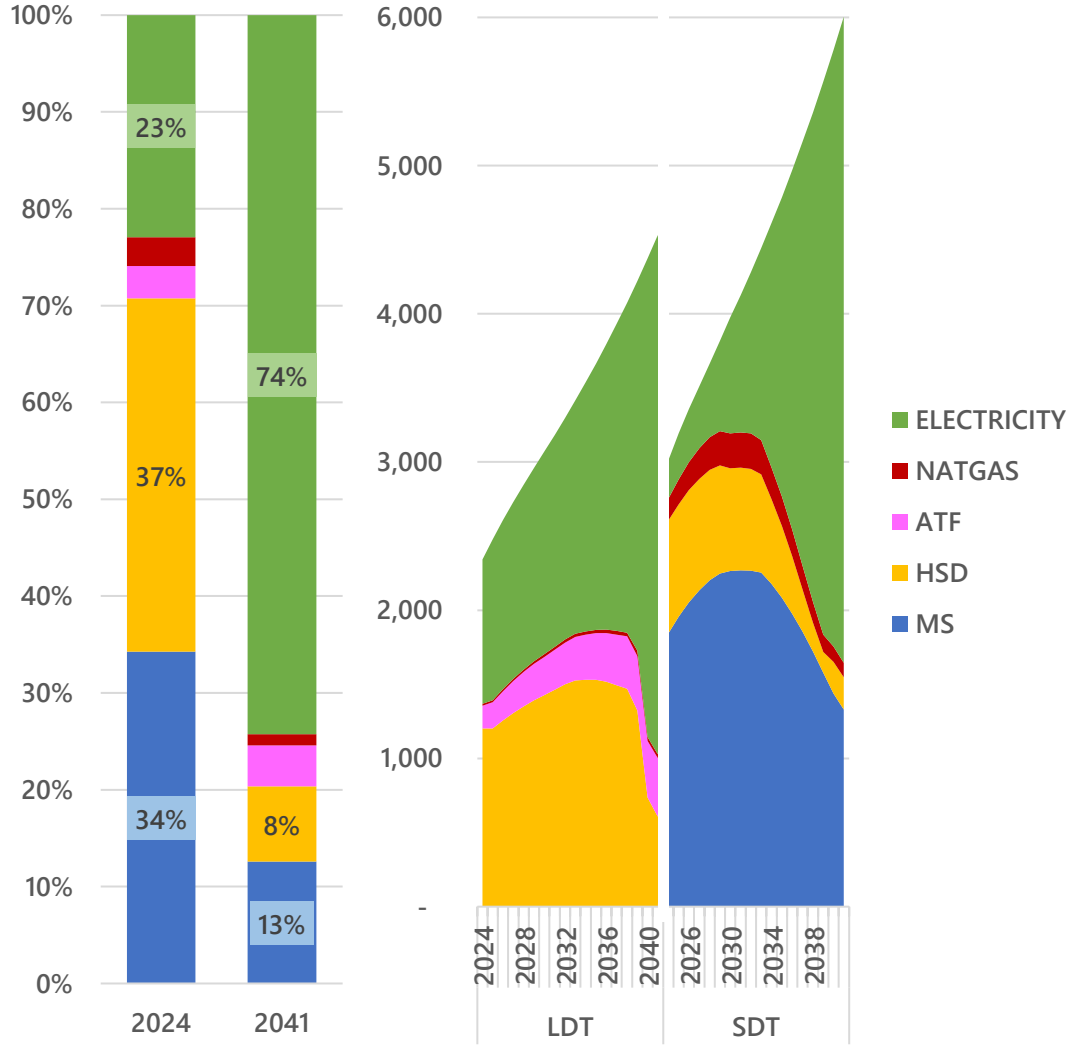


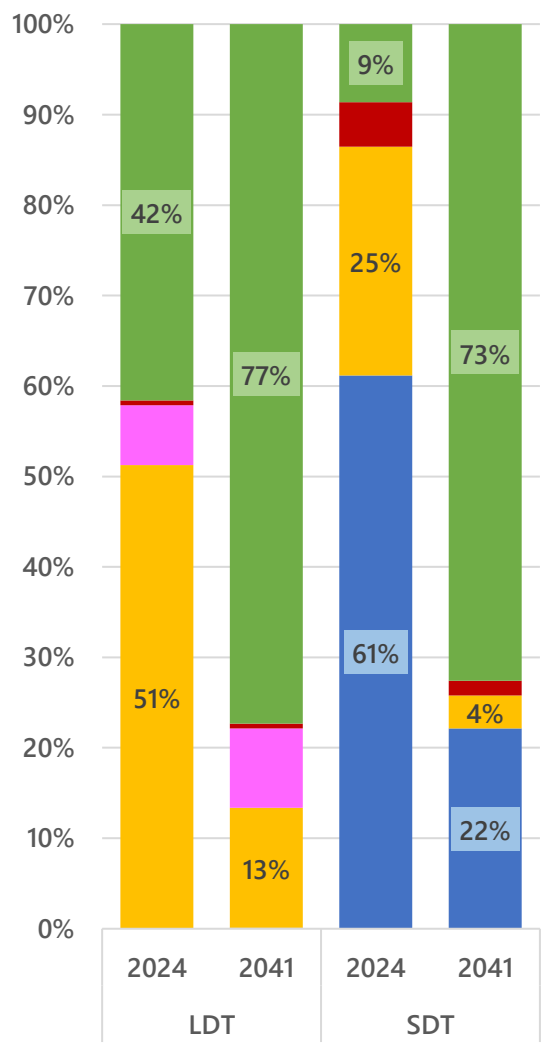


- Road dominates the Modal share among all motorised transport
- Road= 74%-75%
- SDT dominates demand (56-57%)
- In LDT, Rail and BUS shares are almost same
- In SDT 2W dominates, followed by 4W, and not far behind from 4W is BUS.

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

Pass: Intermediate outputs (BPKMs served by ES & Fuel)

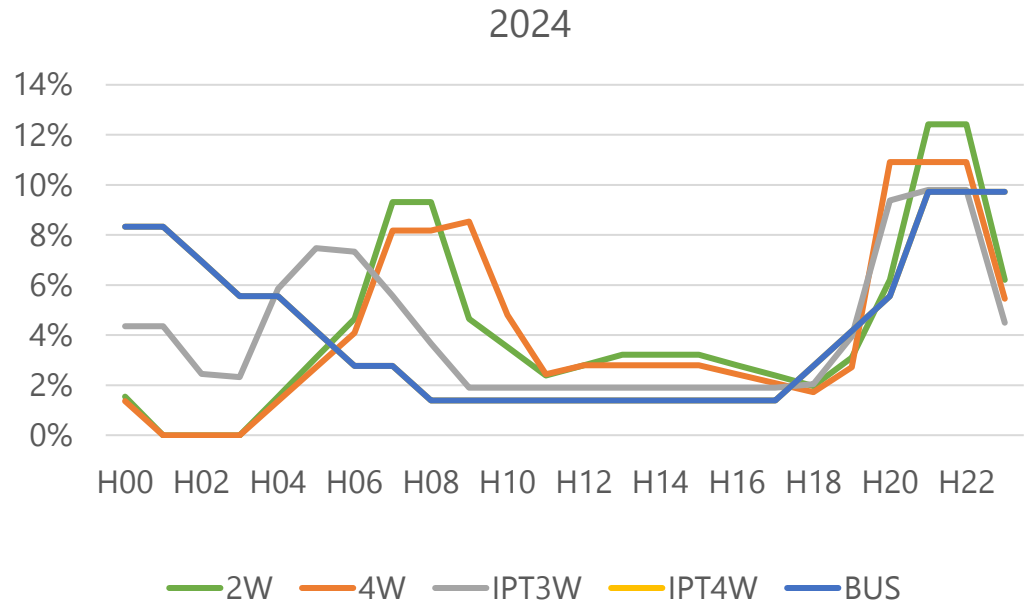


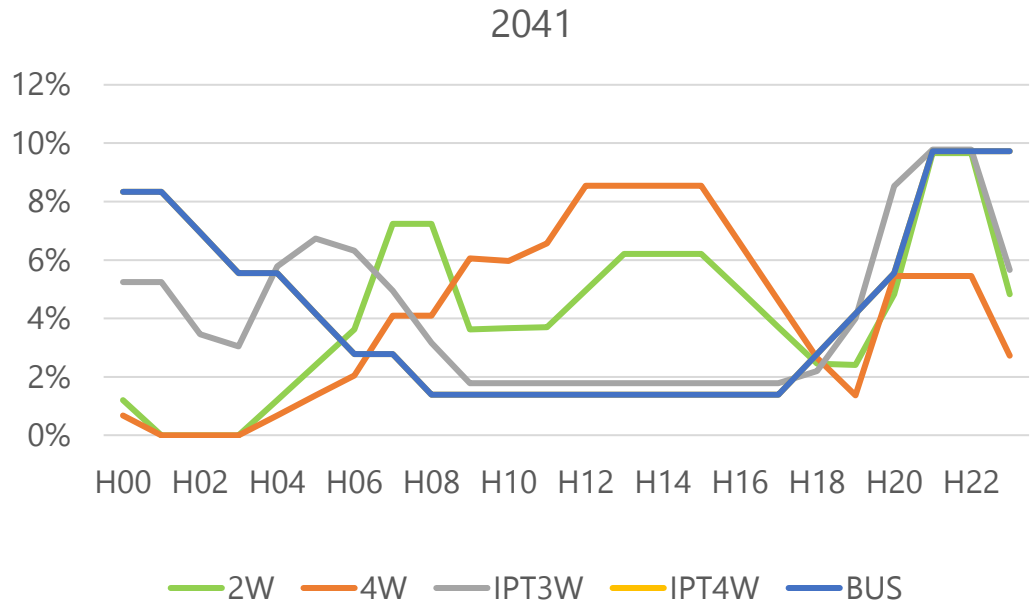


- By the end of the model period ~74% of the demand is served by Electricity-based modes
- Both in LDT and SDT, over 70% of the travel demand served is by Electricity in FY41
- LDT is already highly electrified because of RAIL
- Diesel dependence reduces from 25% to 4% in SDT, due to increased electrification in 4W and BUS

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

Pass: Charging profile assumptions



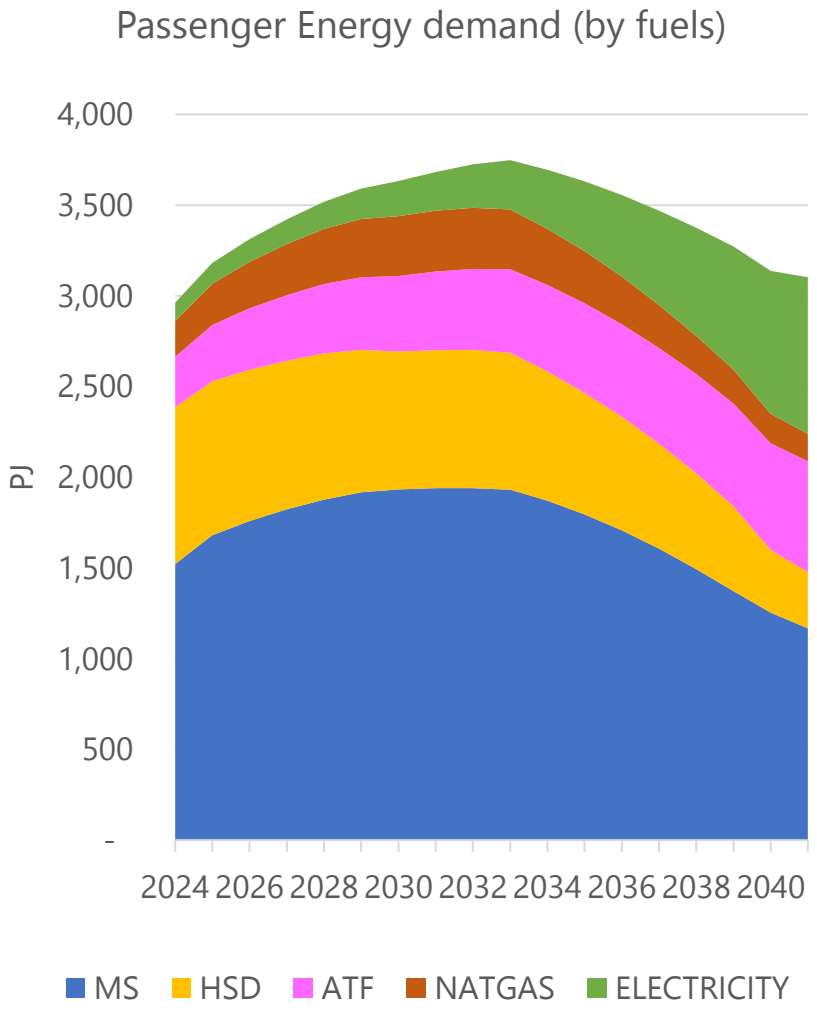


- 2W, IPT3W, 4W are assumed to have home-charging and public-charging options, hence two profiles for each of these vehicles
- Home:Public ratio is allowed to change over the years to account for more progress in public charging networks
- Home charging share FY24 → FY41= 2W: 90% → 70%, 4W: 90% → 45%, IPT3W: 90% → 70%
- Aggregate profiles are then applied
- Rail: while profile is considered 'flat', load is allocated to states based on Train-Kilometers. That is, Train-kilometers at Zonal level is translated to States based on the ratio of occurrence of the State of Division offices
- For example, 'Northeast Frontier' Zone has three Divisional heads in Assam and one each in Bihar and West Bengal. Hence the Train-kms for this Zone is allocated to Assam:Bihar:WB in the ratio of 3:1:1

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

Passenger Model Results and Insights

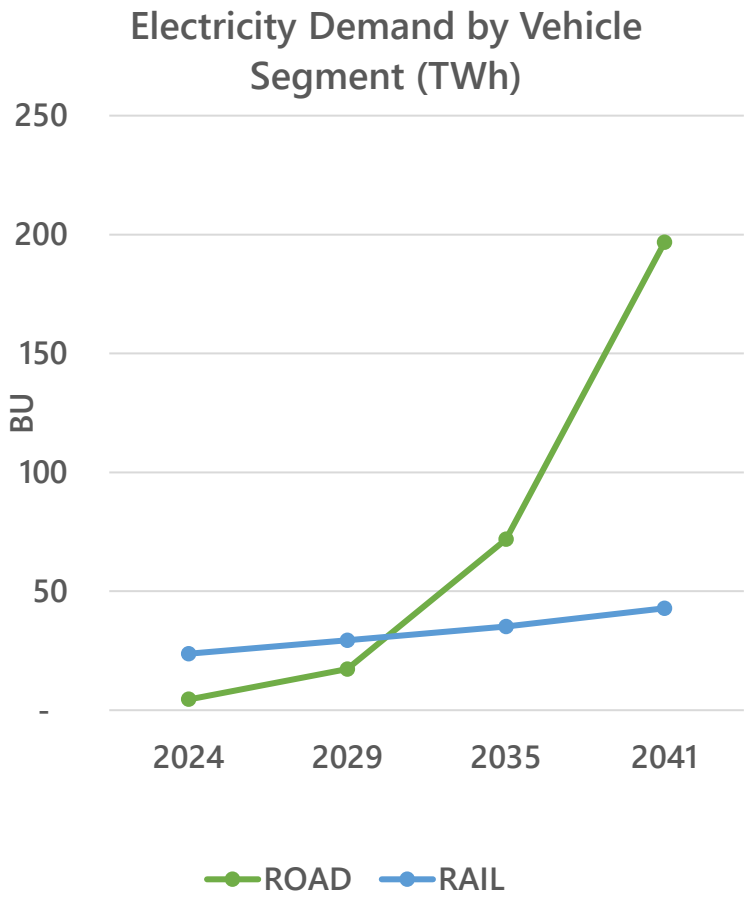
Pass: Main outputs (Energy demand by ES & Fuel)

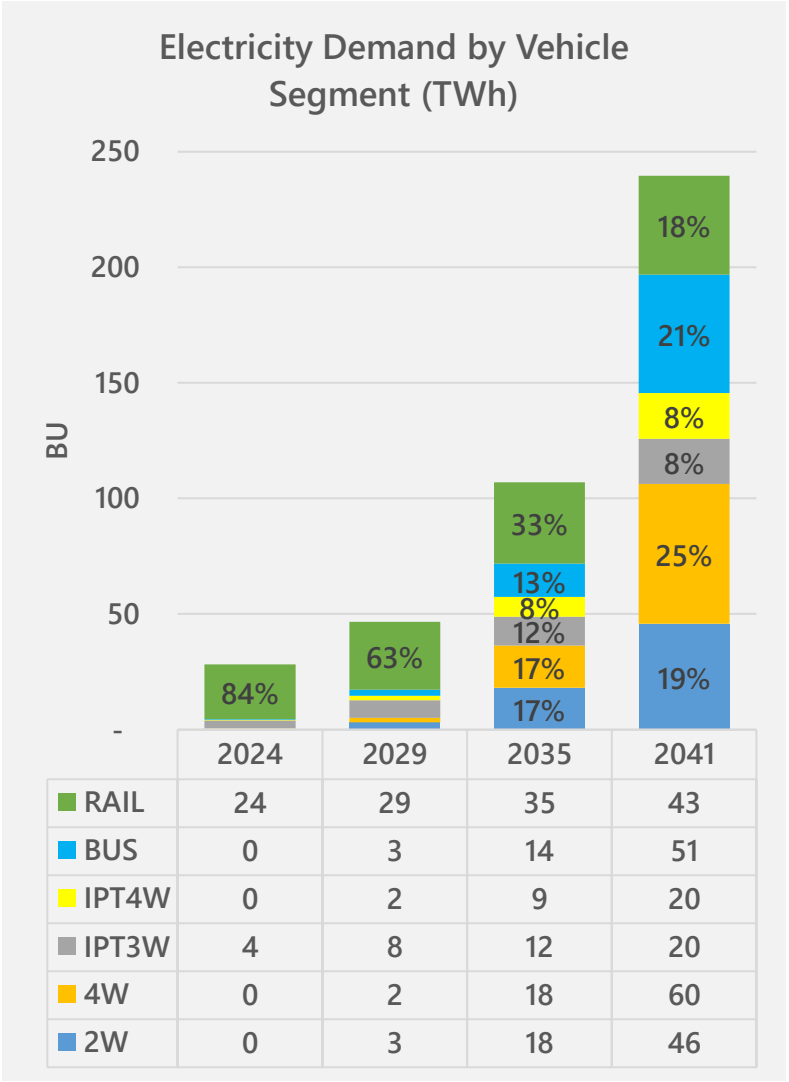


- Passenger energy demand first increases and starts reducing from 2033
- 2,963 PJ to 3,103 PJ from FY24-FY41
- Bulk of the energy demand continues to come from Short-distance services (67% in FY41 down from 78% in FY24)

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

Pass: Main outputs (Electricity demand)



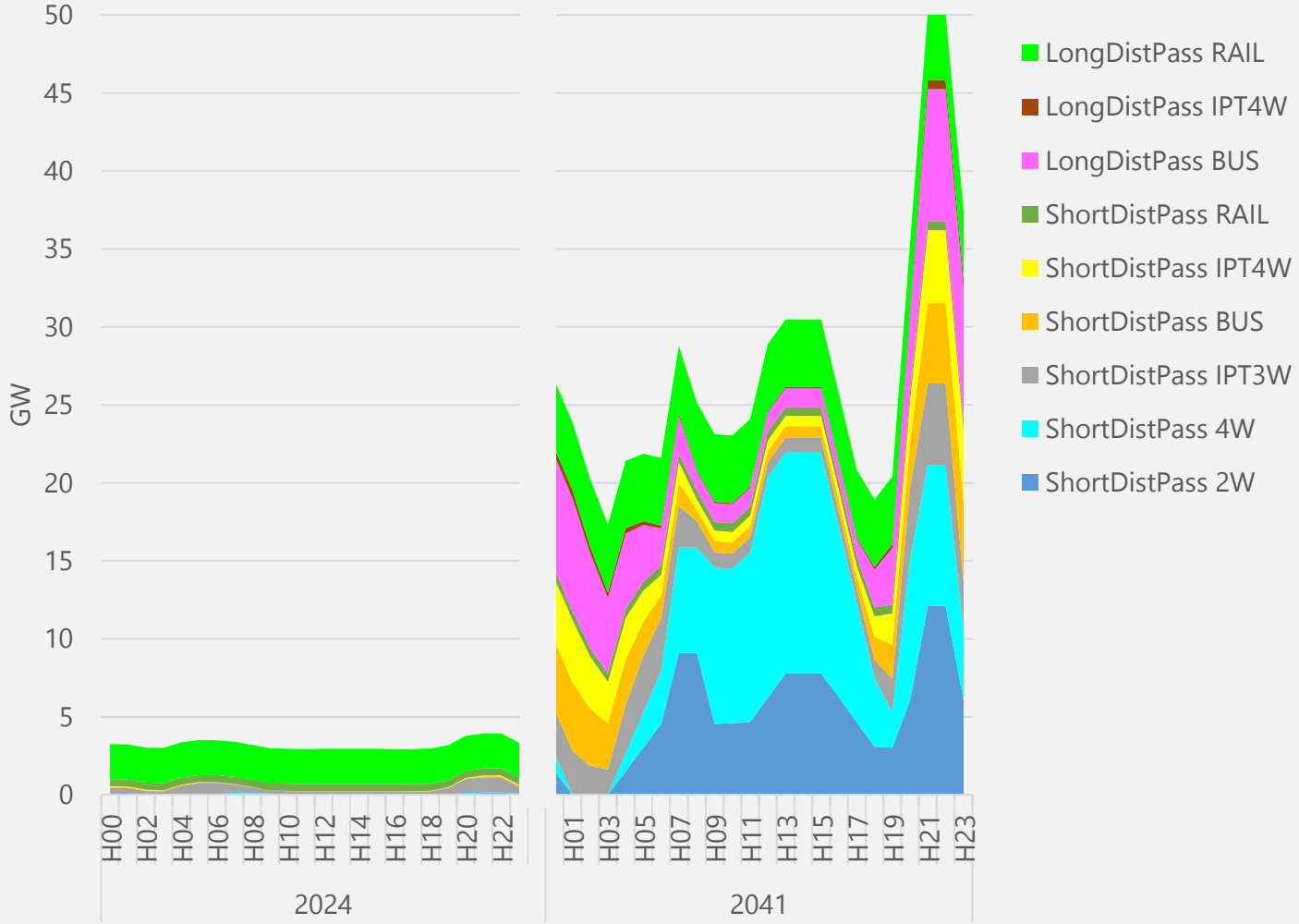


	2024	2029	2035	2041
RAIL	24	29	35	43
BUS	0	3	14	51
IPT4W	0	2	9	20
IPT3W	4	8	12	20
4W	0	2	18	60
2W	0	3	18	46

- Total Passenger transport Electricity demand grows the fastest among energy carriers (~13.4% CAGR)
- EV electricity demand, i.e 2W, 3W, 4W and BUS combined grows at 25% CAGR
- EV electricity demand (i.e non-Rail) overtakes Rail electricity demand in 2032
- While in the initial years 3W dominates the EV Electricity demand, by the end of the model period 4W, 2W, BUS form the bulk of demand

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

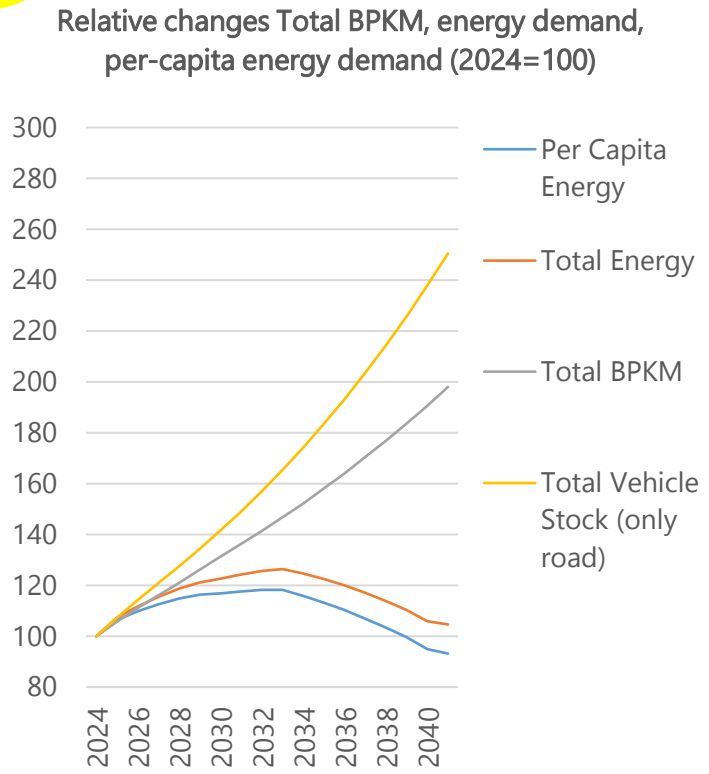
Main outputs (Electricity Load)

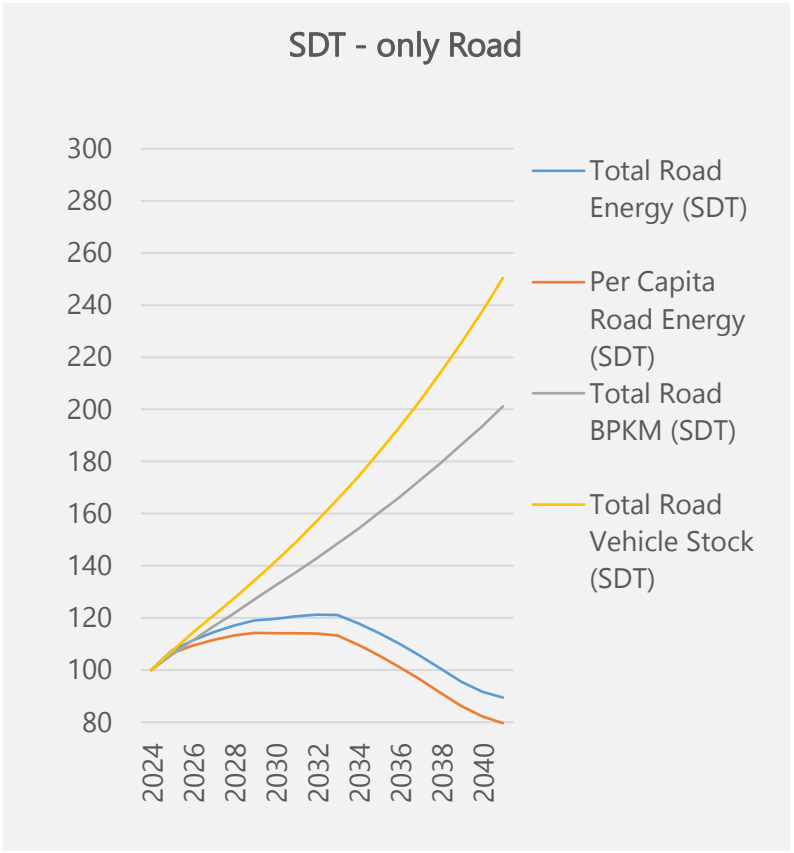


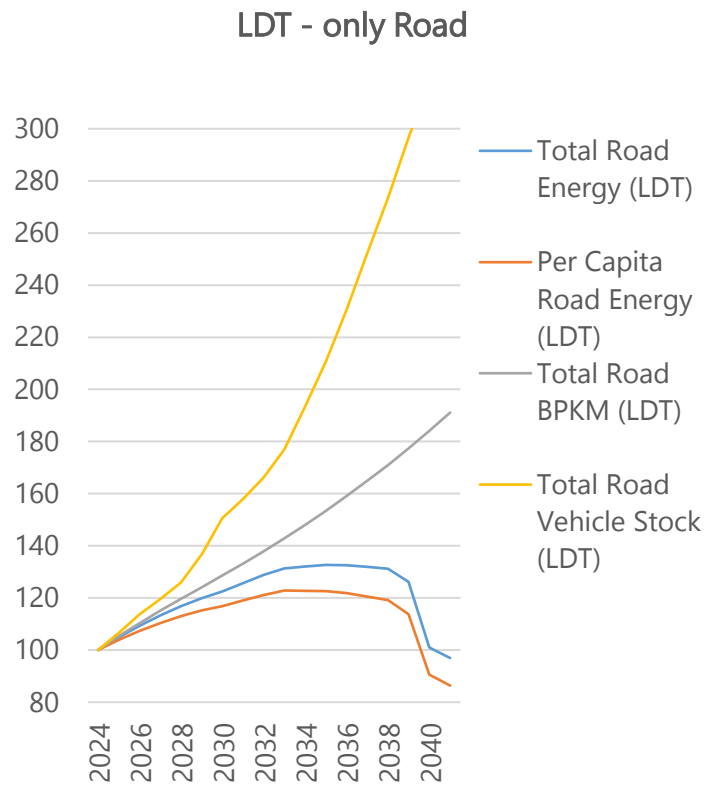
- FY41 Peak load for passenger is ~50GW
- Peak in FY41 is at night hours (H21, H22)
- As can be seen, Short-distance energy service forms the bulk of the load and peak-load
- Most of the day-time load is from Short-distance 4W followed by 2W
- Overall, four-wheelers (4W+IPT4W) contribute ~ 30% to the peak

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

Insight 1: Electrification ensures energy demand peaks, but also not at the cost of travel demands and vehicular growth



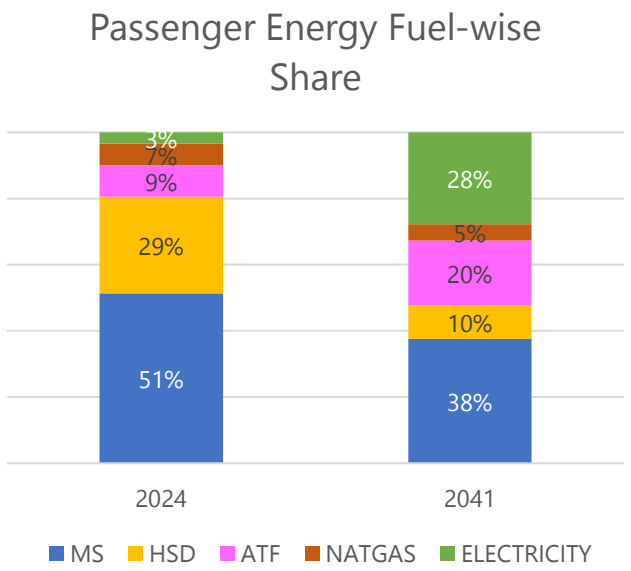


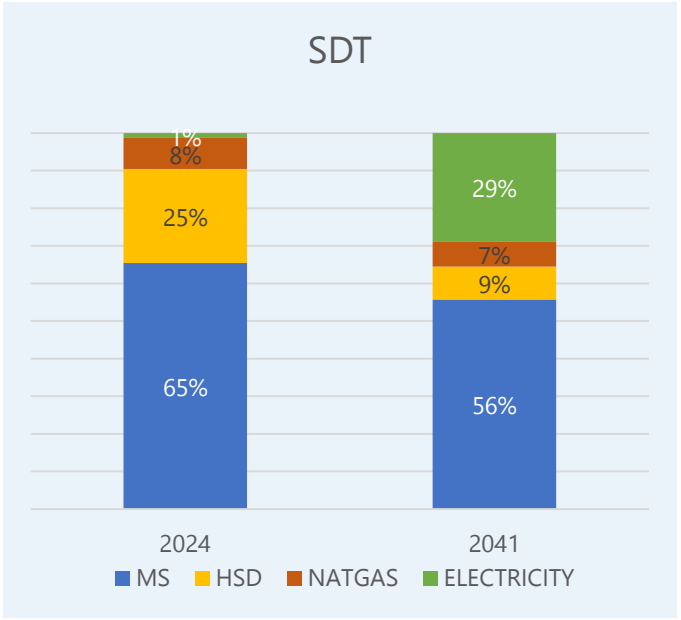


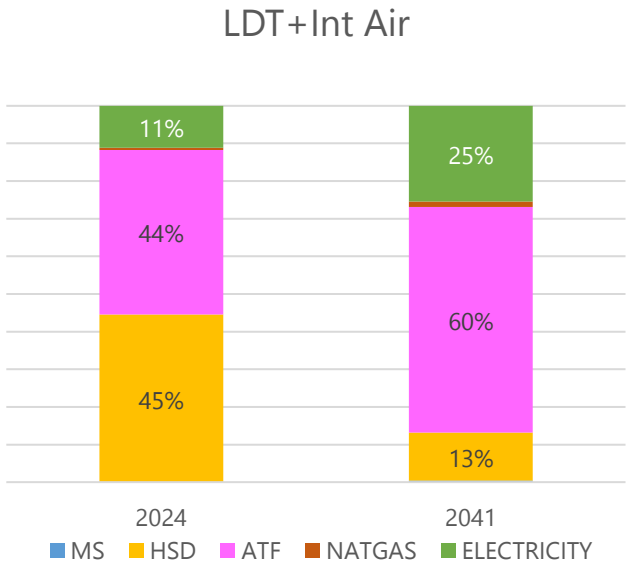
- As is clear from the graphs, even with the growing vehicle stock and travel demands, the energy demand is contained due to increased electrification
- In other words, the peaking passenger energy demand is not at the cost of travel demands or vehicular growth
- This trend holds in majority of the states

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

Insight 2: Petroleum based fuel mix in passenger changes dramatically







- Despite reduced share of MS in Travel Demand (from 34% to 13%) the decline in energy share is dragged out (51% to 38%)
- In absolute terms, MS demand peaks at around 2032 even with 100% E20 deployment in sales by 2025.
- At policy level, there appears to be less rationale for investing in higher Ethanol blends, in comparison to the push for electrification
- While HSD share reduces from 29% to 10%, the share of ATF increases from 9% to 20%, suggesting the need for more policy attention in the aviation sector when it comes to petroleum products

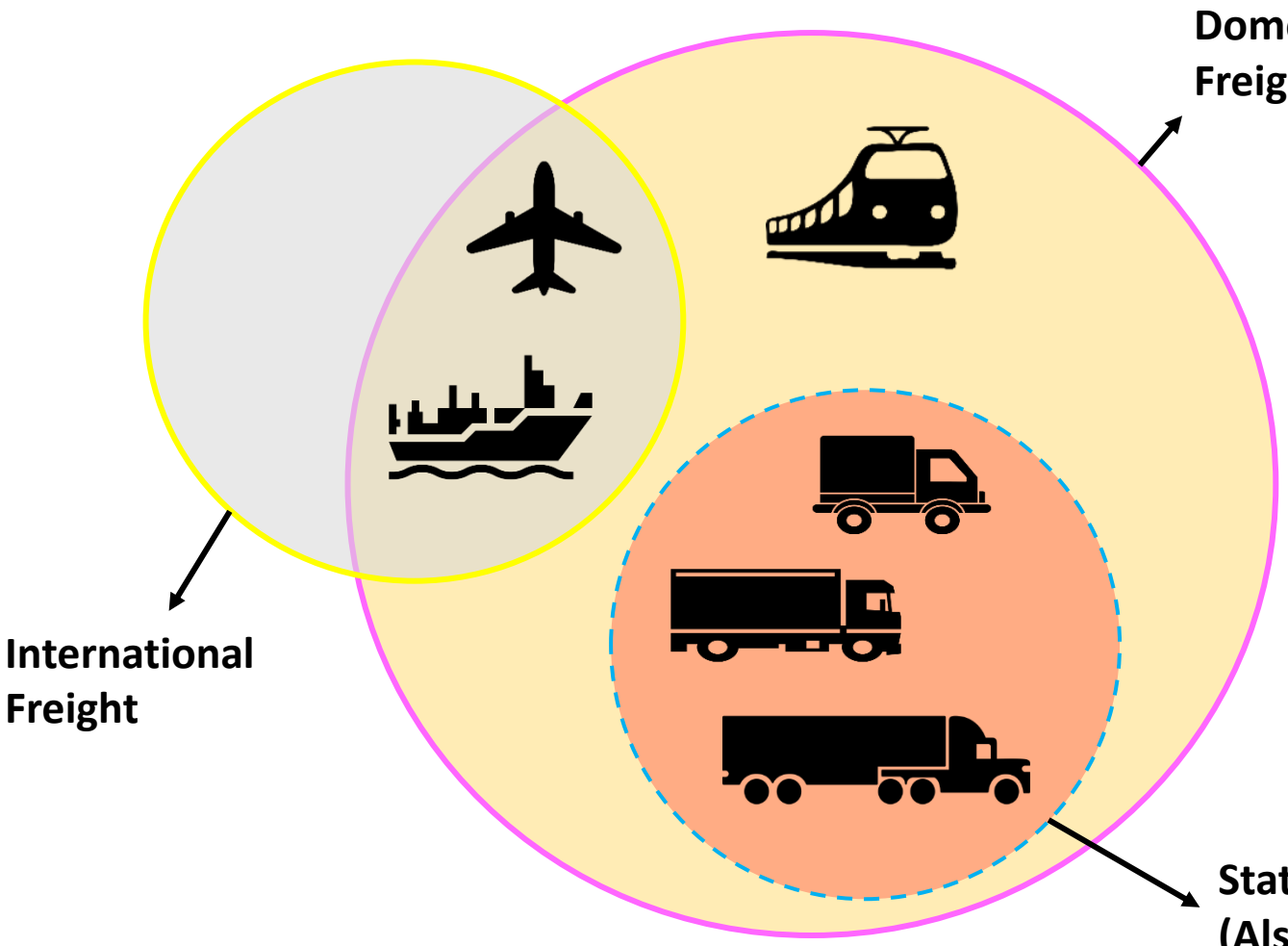
2024 refers to FY23-24, 2041 refers to FY40-41 etc

Freight Model in detail

Freight: Model overview

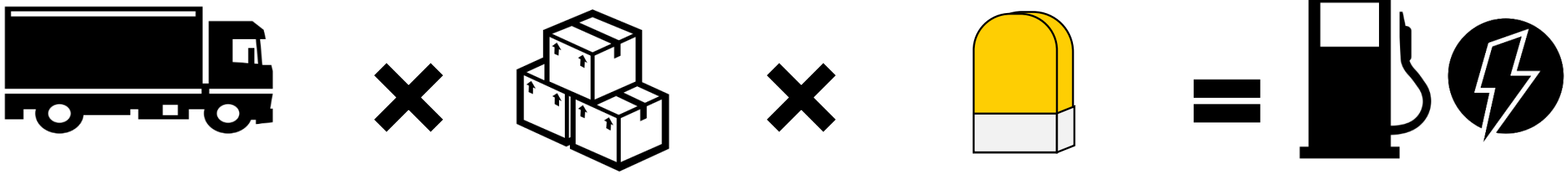
- Motorised transport modelled; FY2024-FY2041
- Two energy service: Domestic Freight and International Freight
- 6 Vehicle segments (STC): AIR, RAIL, LGV, MGV, HGV, WATER
  - LGV: Low duty/light goods vehicle (GVW <= 7.5 ton)
  - MGV: Medium duty goods vehicle (GVW 7.5ton- 12ton
  - HGV: Heavy-duty goods vehicle (GVW>12ton)
- MS and SAF same as Passenger

Freight: Service Technologies



STC		ST
AIR		ATF
RAIL		HSD, ELEC
LGV		MS, HSD, ELEC, CNG
MGV		HSD, ELEC, CNG
HGV		HSD, ELEC, CNG, GH2
WATER		HSD

Freight: Road – energy demand



- Number of vehicles
- Technology of vehicle
- SEC (energy/km)

- LoadFactor: Payload in Tonnes

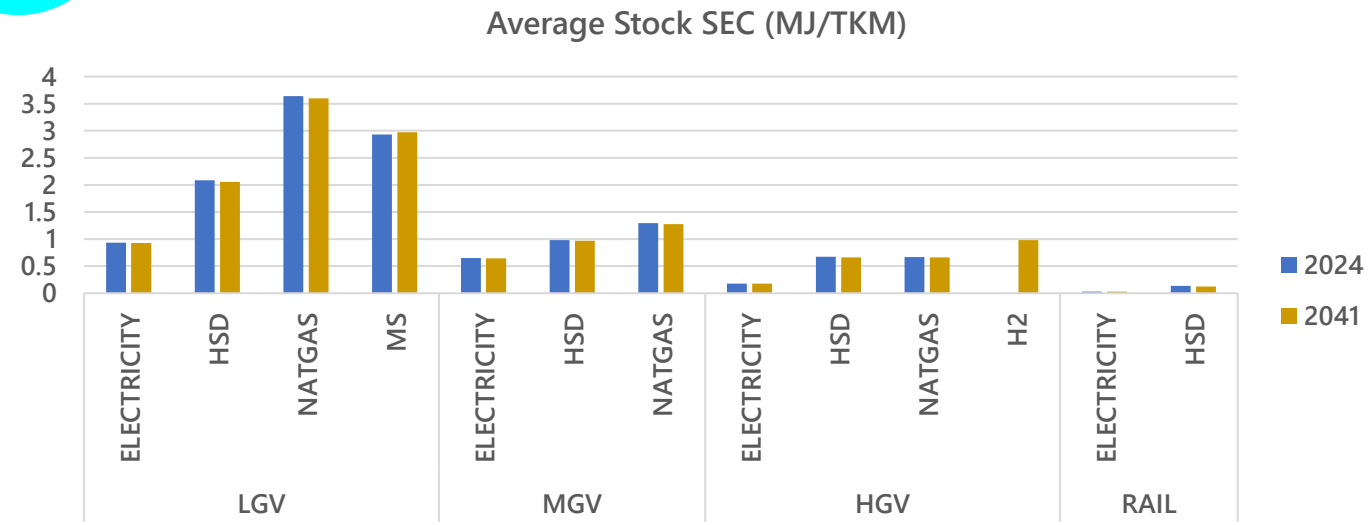
- Distance travelled
- Number of trips
- Number of days

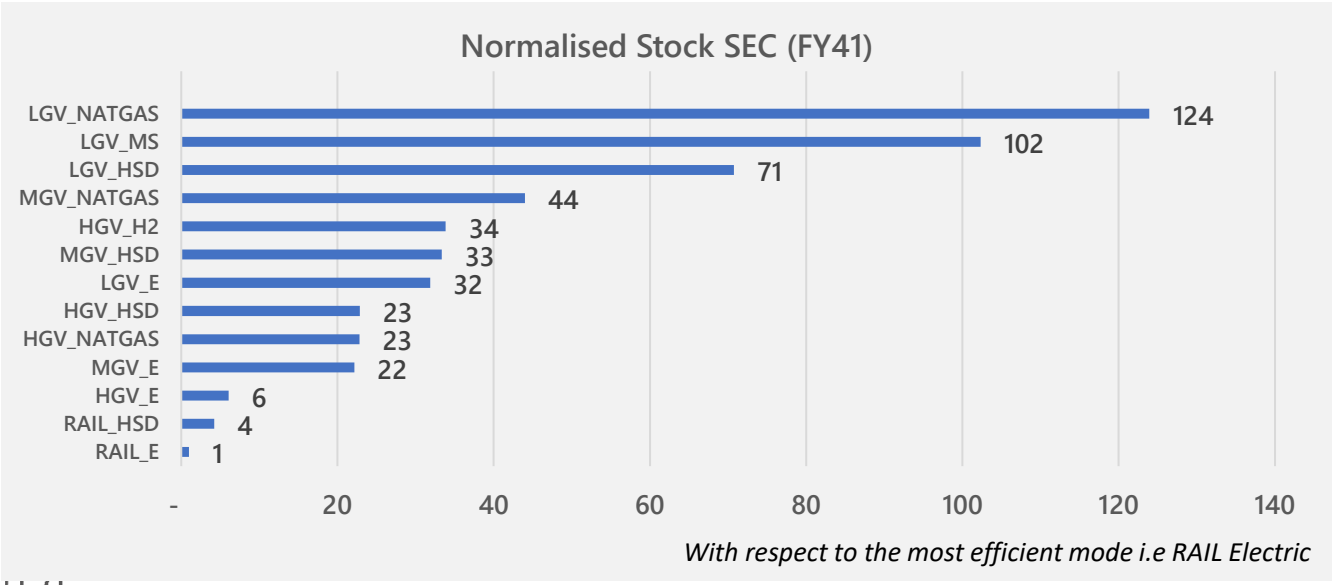
- Tonne-kms
- Fuel used

Road ES Demand (stc, st, s, y, es) = Stock (stc, st, s, y, es) * Km per day (stc) * Number of travelling days (stc) * Load factor (stc, es)

Where stc- Service Tech Category, st- Service Tech, s- State, y- year, es- energy service

Freight: inputs – SEC



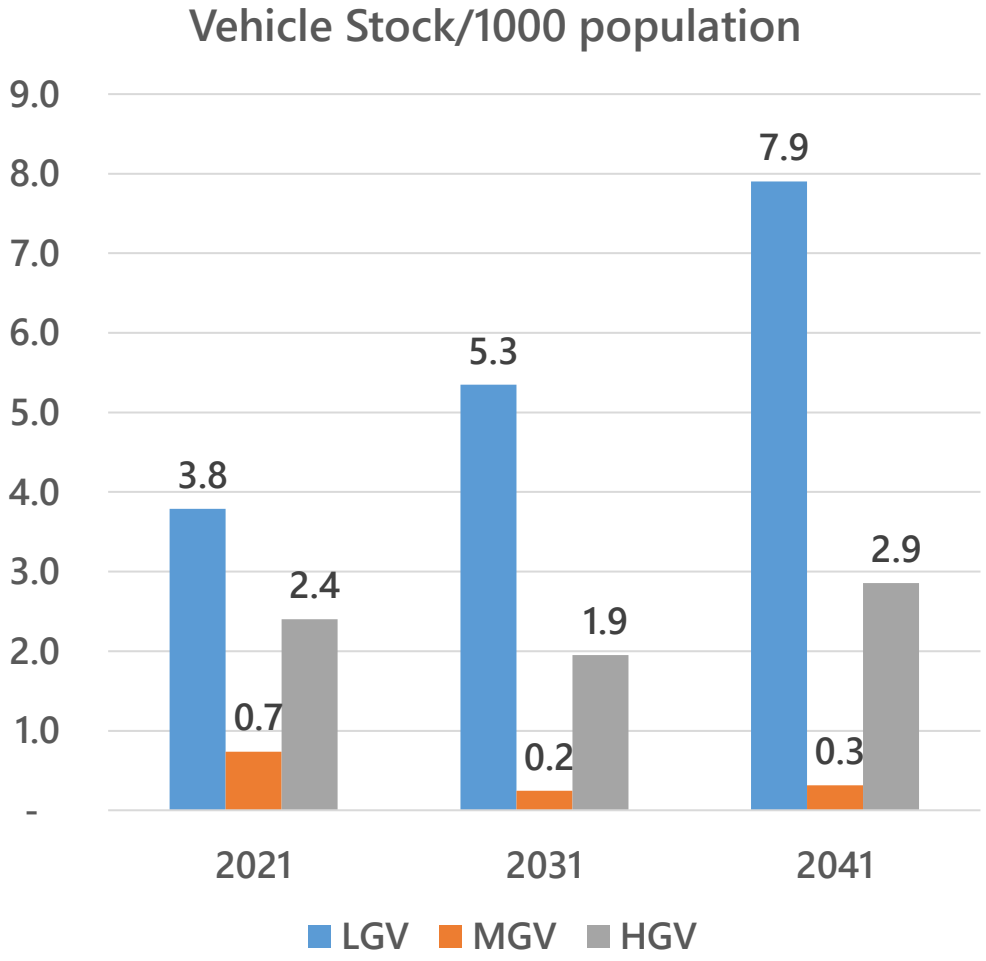


With respect to the most efficient mode i.e RAIL Electric

Flow Mileage FY24, FY41	LGV	MGV	HGV
MS (TKm/l)	10.85-10.99	NA	NA
HSD (TKm/l)	17.3-17.5	36.7-37.1	53.4-54.1
CNG (TKm/Kg)	12.97-13.14	36.5-37	70.4-71.3
Electricity (TKm/kWh)	3.8-3.9	5.5-5.6	20.27-20.5

- All flow SEC improvements are <0.1% CAGR

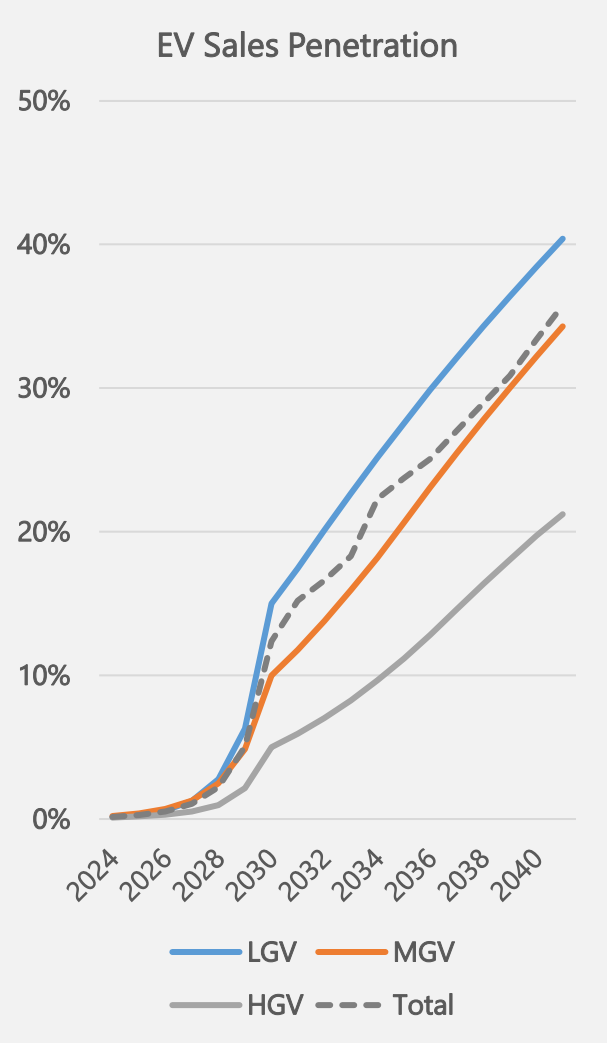
Freight: Inputs- Stock

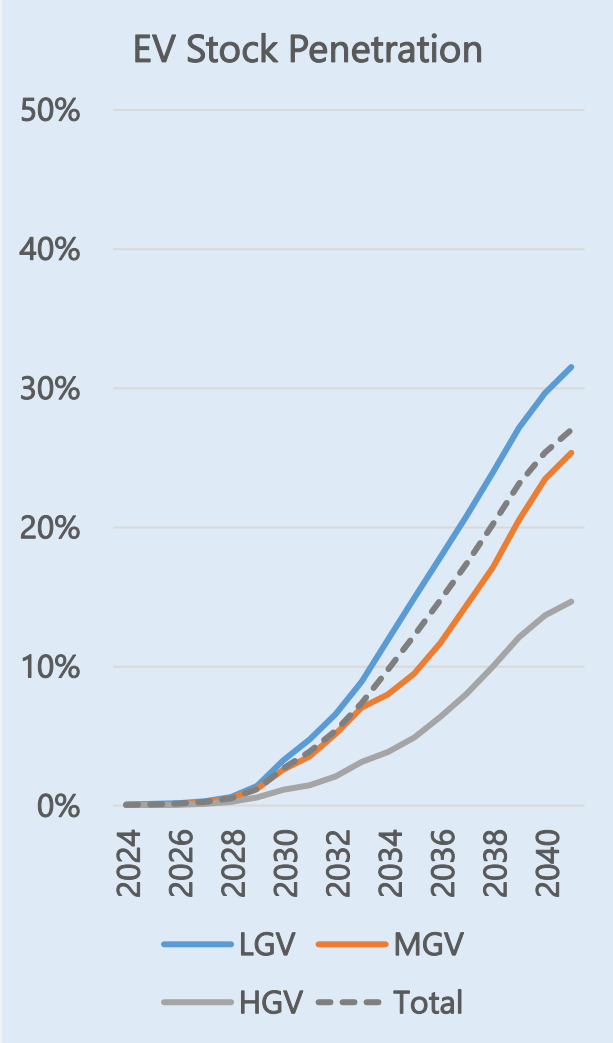


Vehicle Stock (Million)				CAGR
STC	2024	2041	Folds	FY24-41
LGV	5.63	10.72	1.9	**3.9%**
MGV	0.32	0.43	1.3	**1.7%**
HGV	2.39	3.88	1.6	**2.9%**
TOTAL	**8.34**	**15.02**	1.8	**3.5%**

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

Freight: Inputs- EV penetration



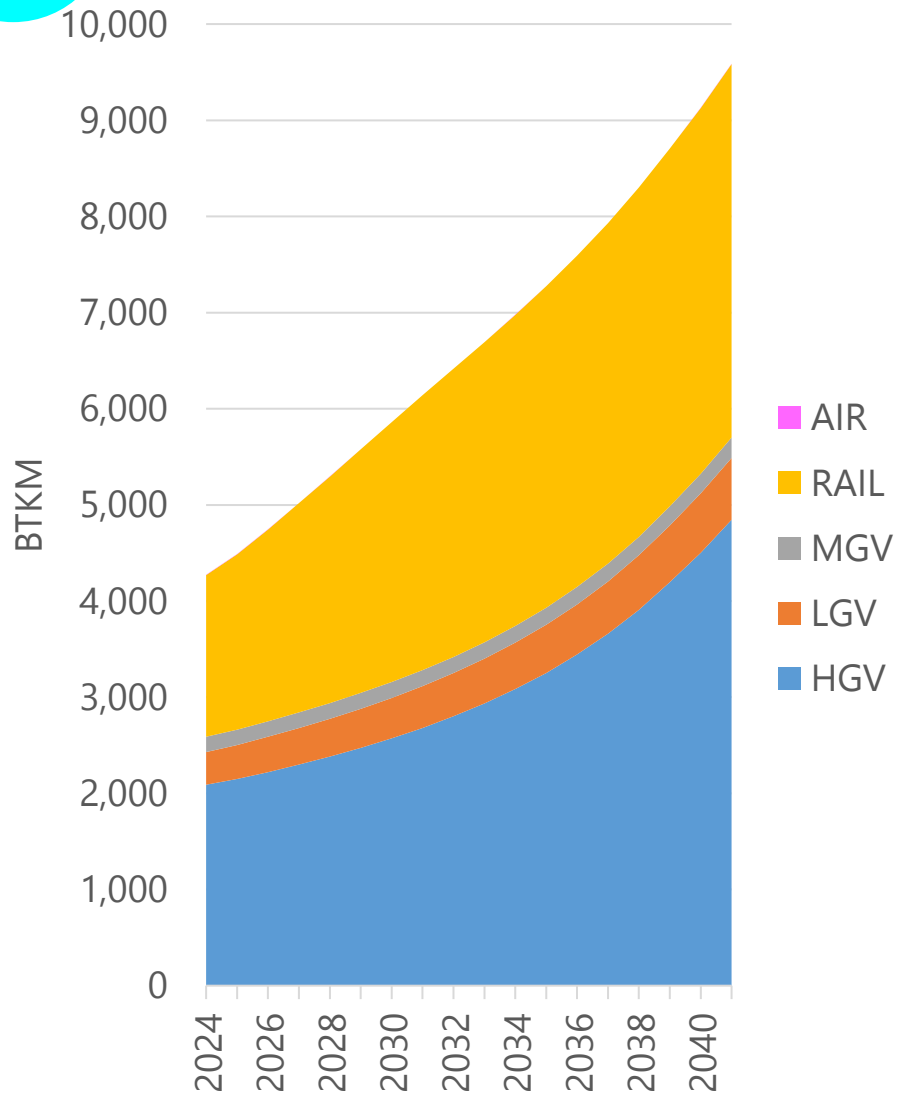


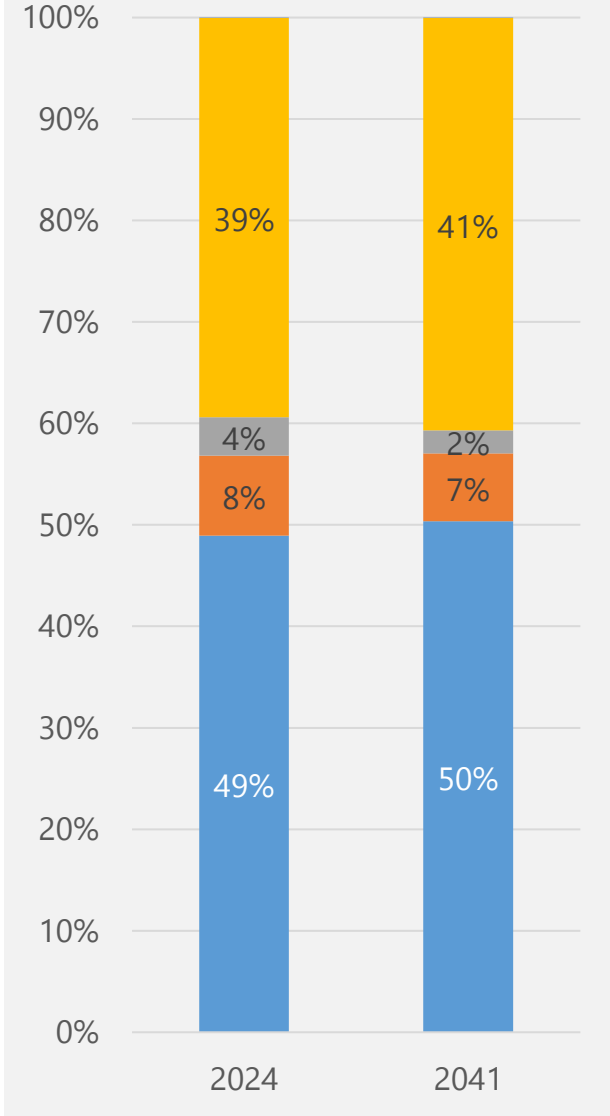
EV national sales penetration	2030 – 'target'	2041 assumption
LGV	15%	40%
MGV	10%	34%
HGV	5%	21%
→ TOTAL	**12%**	**36%**

- Higher electrification is considered in LGV given the technology and market trends

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

Freight: Intermediate outputs (BTKMs –by Vehicle Segment)

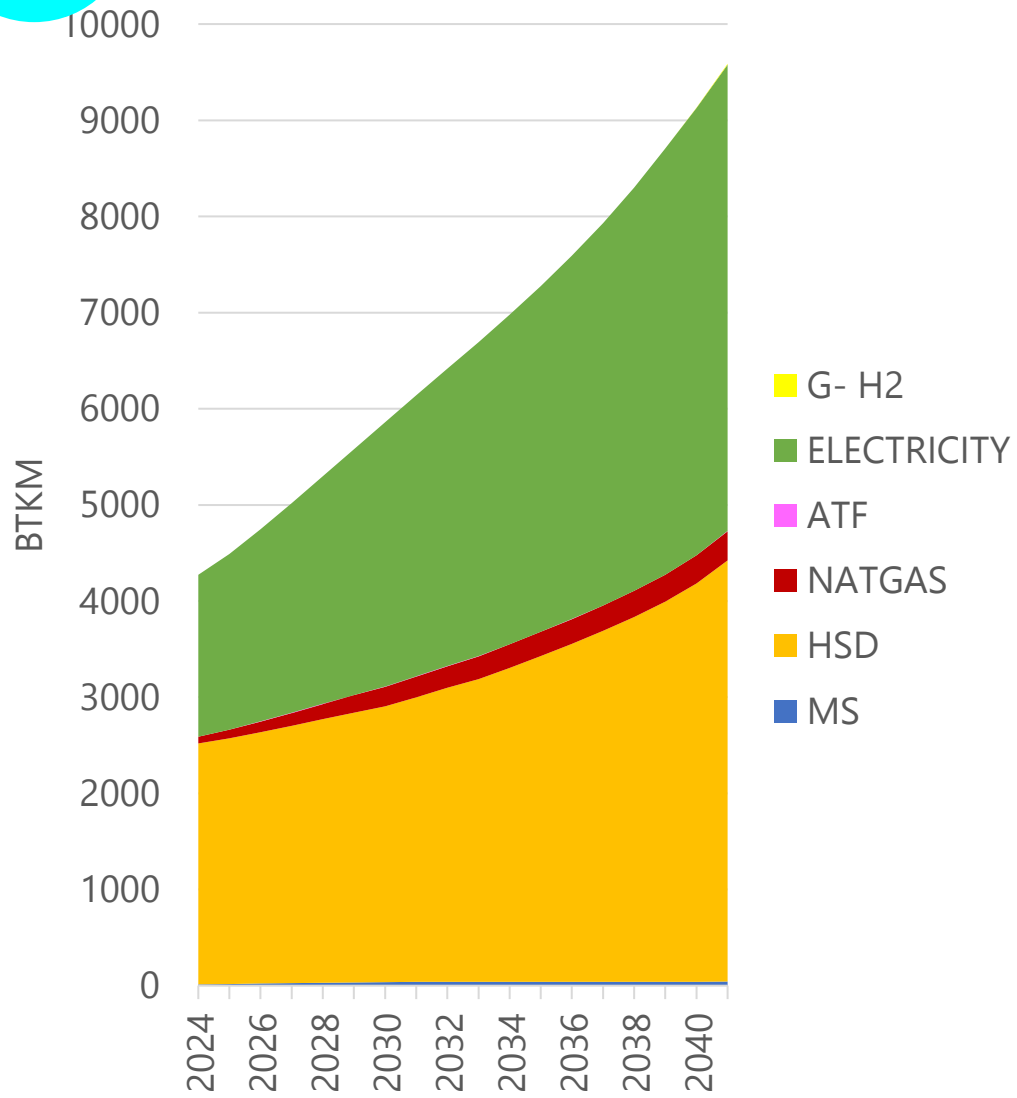


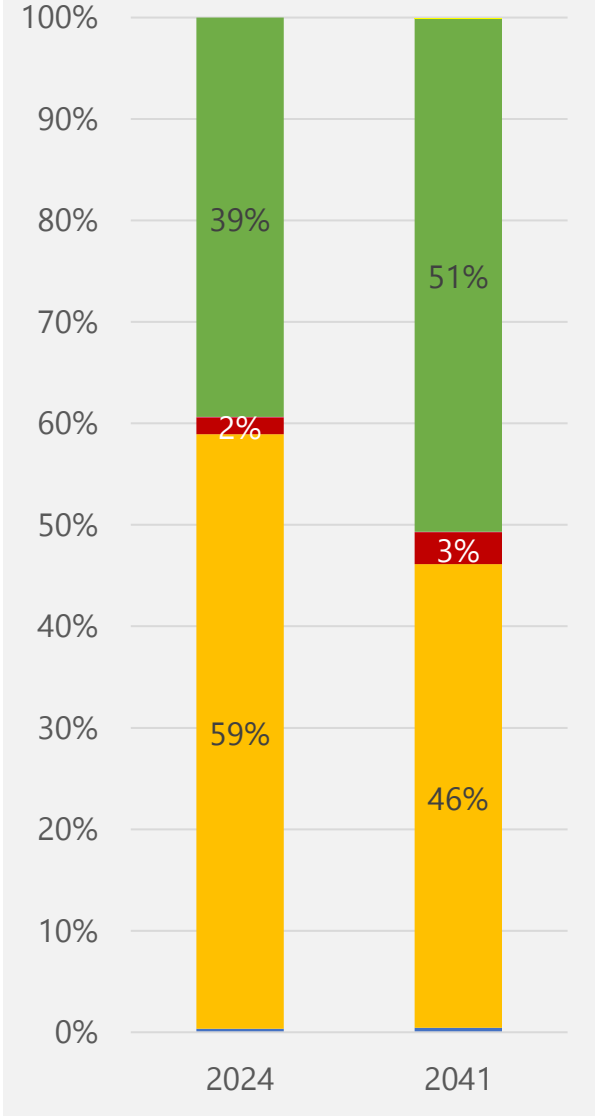


- Water and International Freight is excluded in this analysis since it has been expressed in MT instead of BTKM due to lack of data
- Rail includes Dedicated Freight Corridor (DFC), whose demand grows at higher growth rate in comparison to freight on regular rail.
- Share of DFC BTKM in total RAIL BTKM is assumed to go from 4% to 35% between FY24-FY41; suggesting a prominent role played by DFC
- Road however continues to dominate the Modal share only marginally reducing (61% to 59%)
- Overall, the BTKMs more than doubles in the model period

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

Freight: Intermediate outputs (BTKMs served by Fuel)

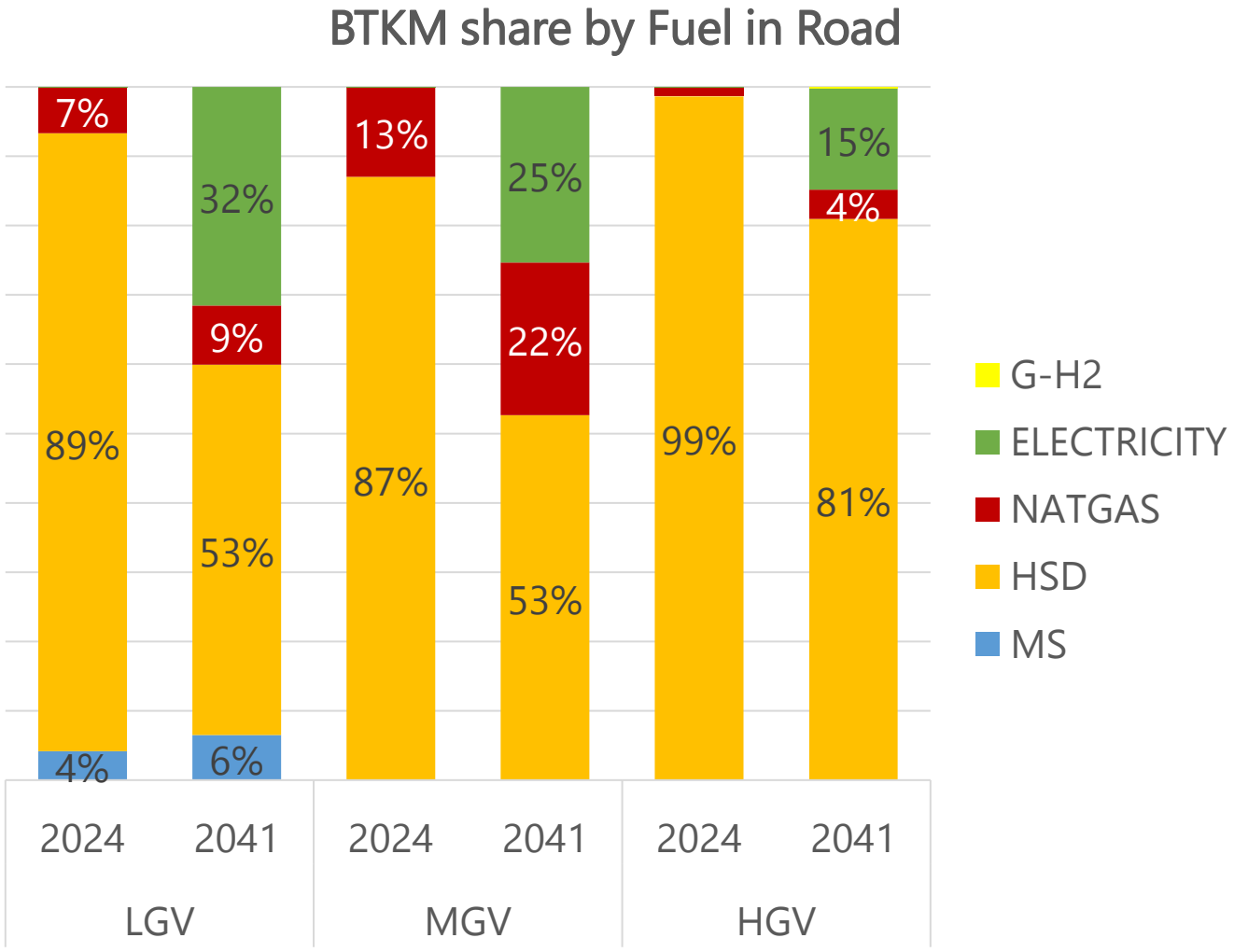




- Freight is already highly electrified because of RAIL (which forms 39% of modal share in FY41)
- By the end of the model period ~51% of the demand is served by Electricity-based modes
- Diesel dependence reduces from 59% to 46%
- The push for CNG vehicles also leads to a small increase in its share in energy demand from 2% to 3%

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

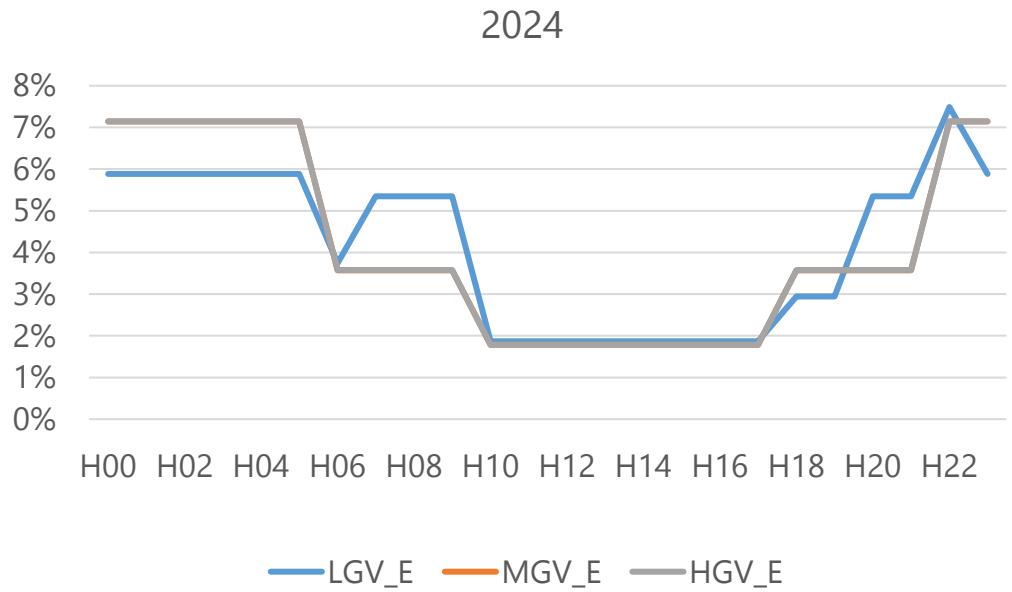
Freight: Intermediate outputs (Road BTKMs served by Fuel)

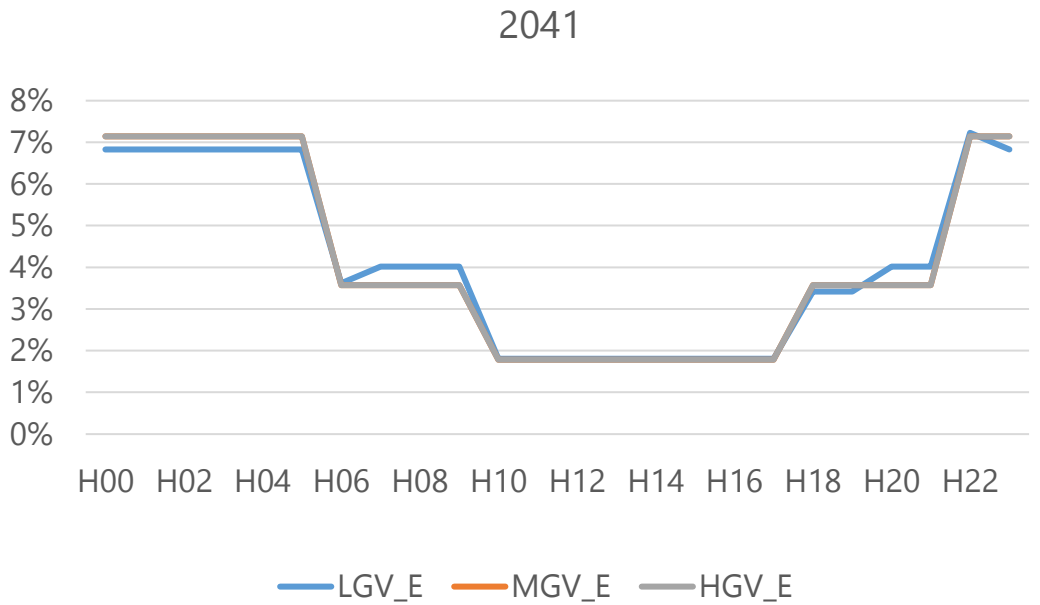


- LGV is the most electrified segment in freight among the Road segments at 32% in FY41, followed by MGV and MGV
- Following the VAHAN registration data, in LGV segment CNG and MS act as choices of transition from HSD to Electricity
- Whereas it is CNG alone in MGV and HGV

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

Freight: Charging profile assumptions



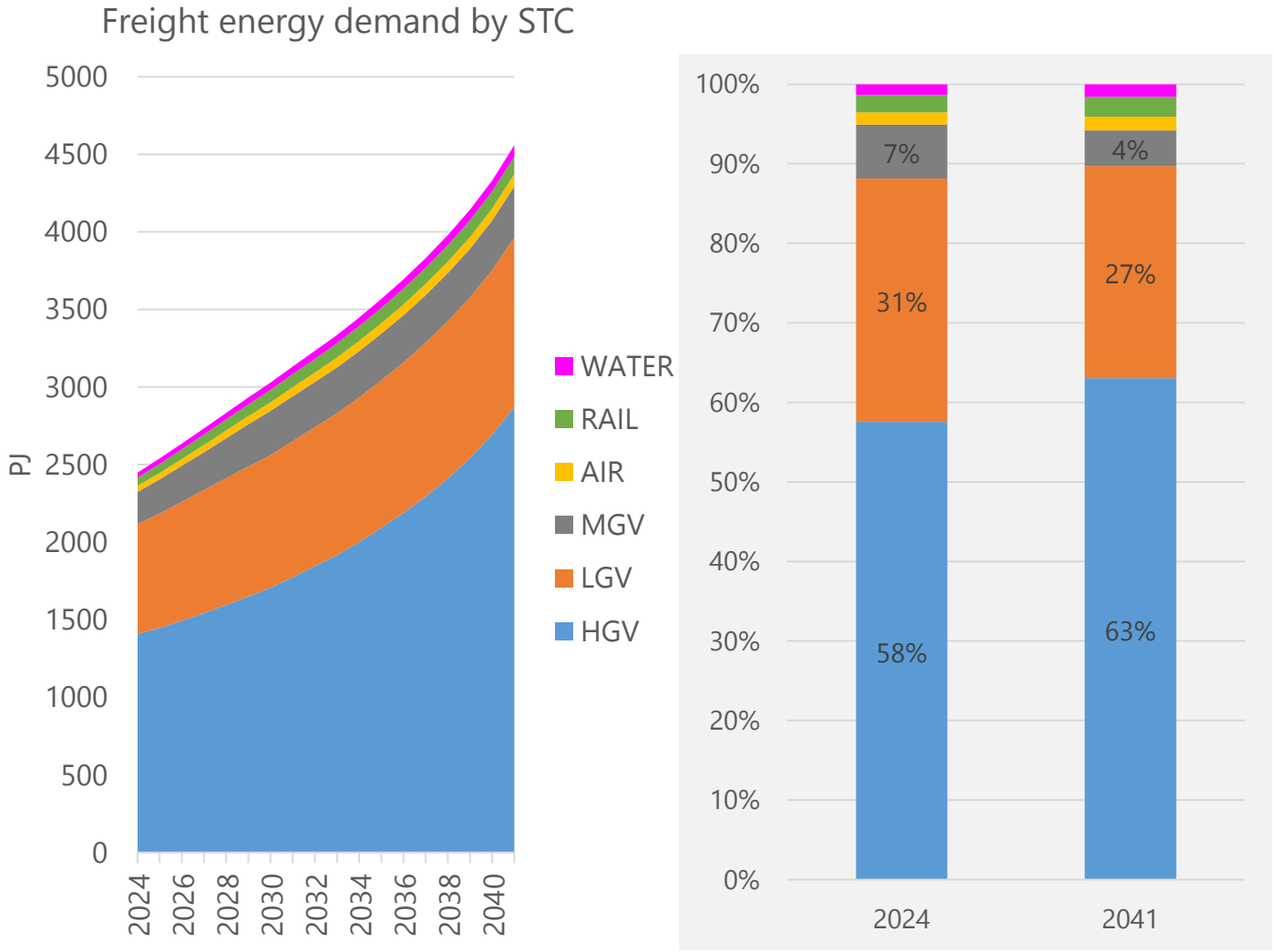


- LGV is the only segment assumed to have home-charging and public-charging options. Hence two profiles are considered.
- Home:Public ratio is allowed to change over the years to account for more progress in public charging networks
- LGV home charging share = FY24 → FY41: 40% → 10%
- Aggregate profiles are then applied
- Rail: while profile is considered 'flat', load is allocated to states based on Train-Kilometers. That is, Train-kilometers at Zonal level is translated to States based on the ratio of occurrence of the State of Division offices
- For example, 'Northeast Frontier' Zone has three Divisional heads in Assam and one each in Bihar and West Bengal. Hence the Train-kms for this Zone is allocated to Assam:Bihar:WB in the ratio of 3:1:1

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

Freight Model Results and Insights

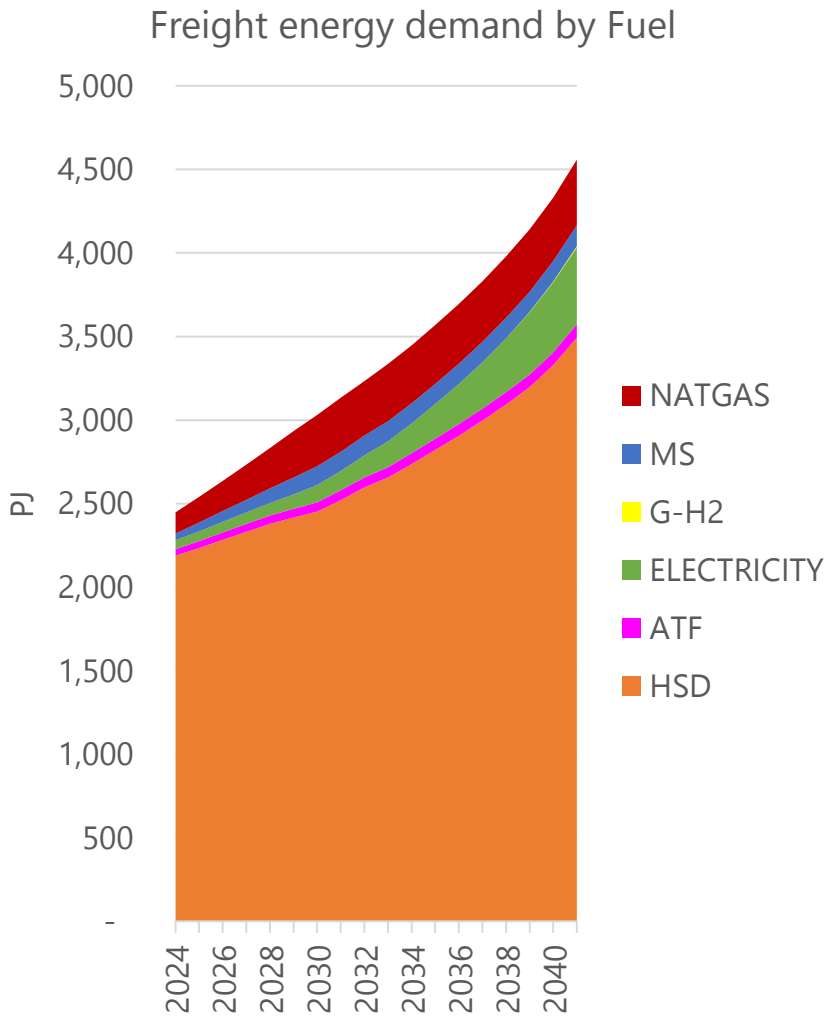
Freight: Main outputs (Energy demand by STC)

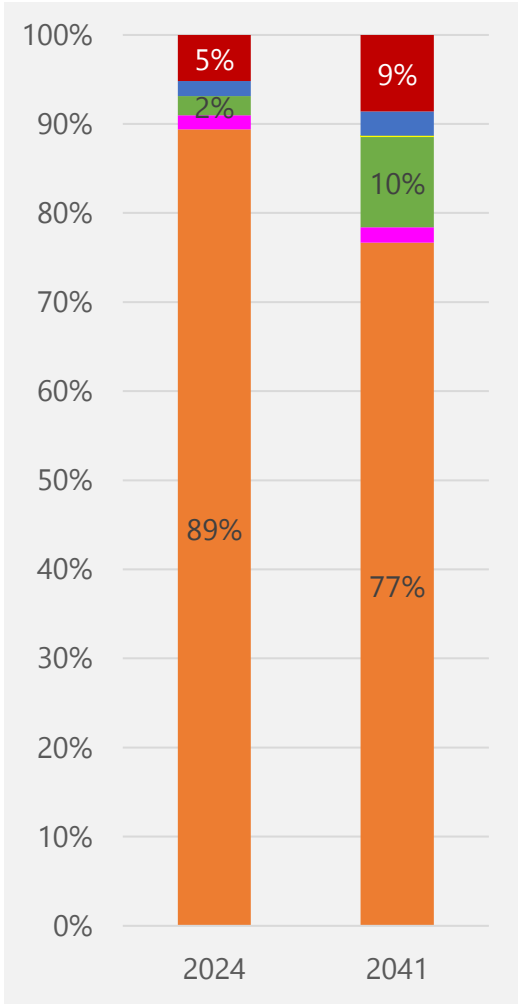


- Unlike Passenger, the Freight energy demand does not peak, due to slower electrification
- Goes from 2449 PJ in FY24 to 4558 PJ in FY41 with a modest 3.7% growth
- Road continues to dominate the freight sector, the share in total freight energy going down from 95% in FY24, and 94% in FY41
- HGV forms the largest share in total freight energy and increases, going from 58% in FY24 to 63% in FY41;
- This is due to the difficulty in electrification of heavier segments owing to various reasons including lack of charging infra, heavier battery sizes, reduced load-carrying capacity, longer distances etc

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

Freight: Main outputs (Energy demand by Fuel)

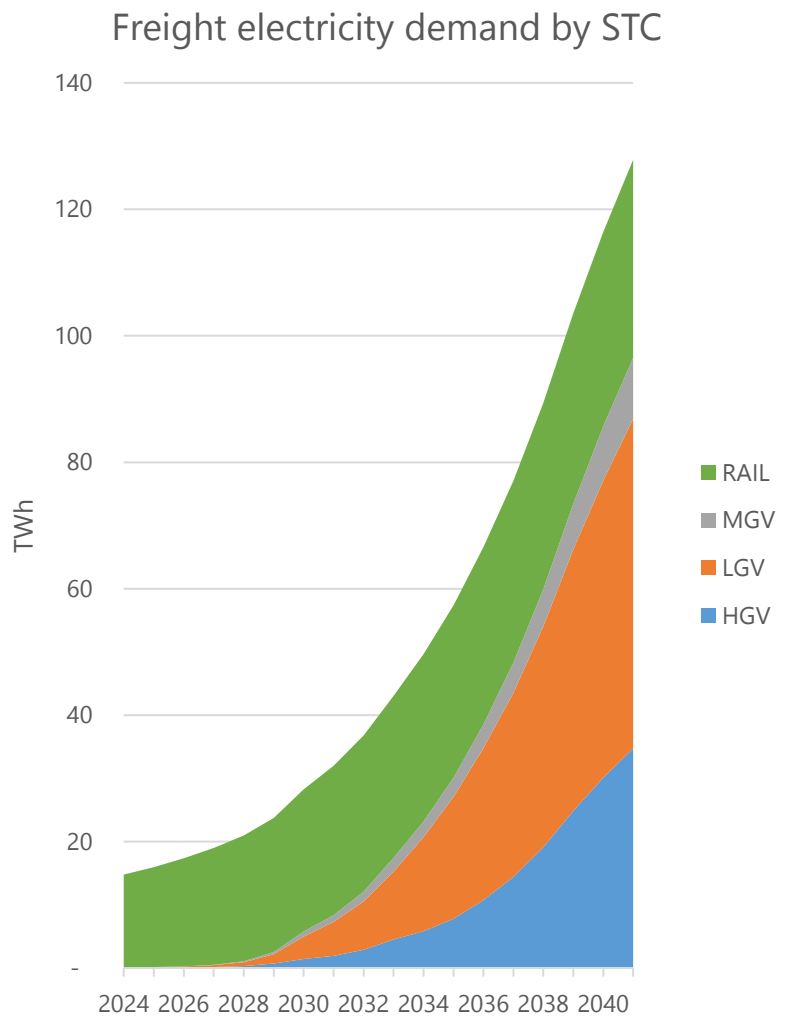


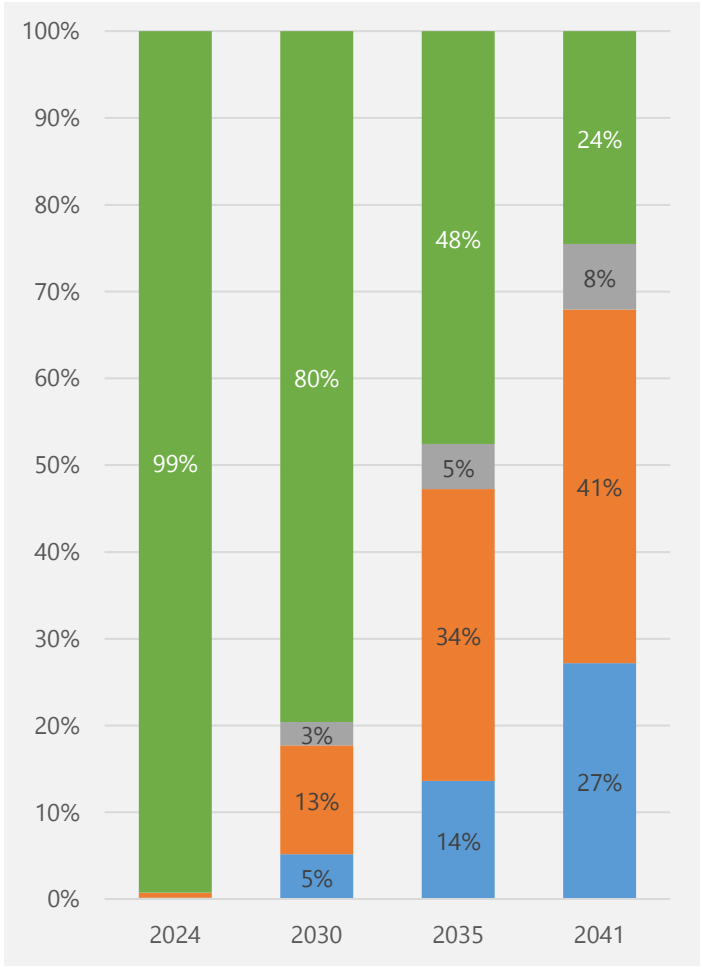


- While HSD dominance in Freight continues, its share reduces from 89% in FY21 to 77% in FY41
- Even with modest electrification of road, the electricity demand increases mostly due to Rail, and its share in the energy demand goes from 2% to 10% in FY41
- The push for CNG vehicles also leads to a small increase in its share in energy demand from 5% to 9%

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

Freight: Main outputs (Electricity demand)

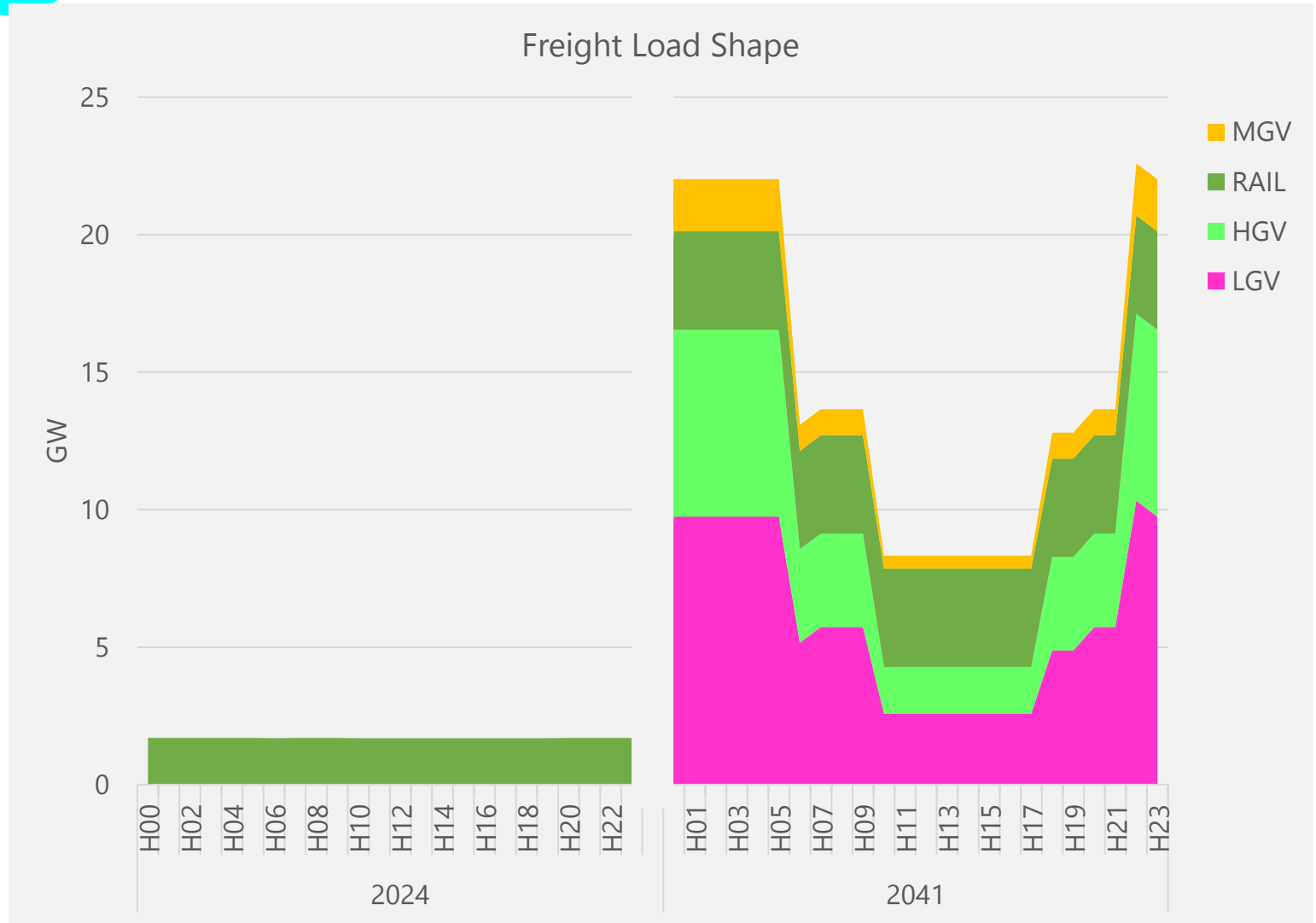




- Freight electricity demand grows at about the same rate ~13.5% CAGR as Passenger,
- However, the Road share in Freight electricity reaches 76%
- Freight EV Electricity Demand i.e LGV, MGV, HGV combined grows at 49% CAGR, with HGV growing at a 54% CAGR; fastest among all segments in passenger and freight
- LGV electricity demand is always above that of HGV throughout the model period despite LGV electricity demand growing at a lower growth rate than HGV Electricity demand

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

Freight: Main outputs (Electricity Load)



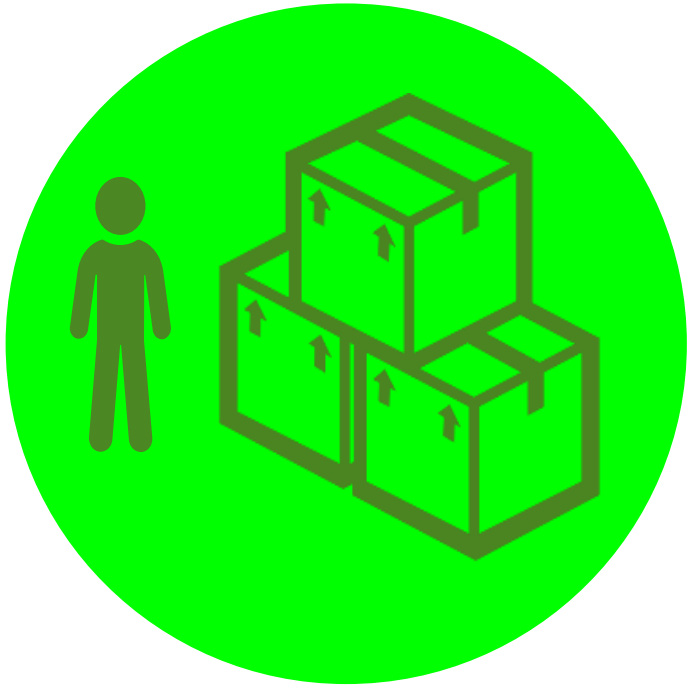
- Peak load in FY41 for freight is ~22GW
- Peak in FY41 occurs at night hours (H22)
- H00-05, & H23 are also loaded comparable to the Peak
- LGV contributes significantly (~45%) to the Peak load
- Loading is assumed to not change by seasons (months)

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

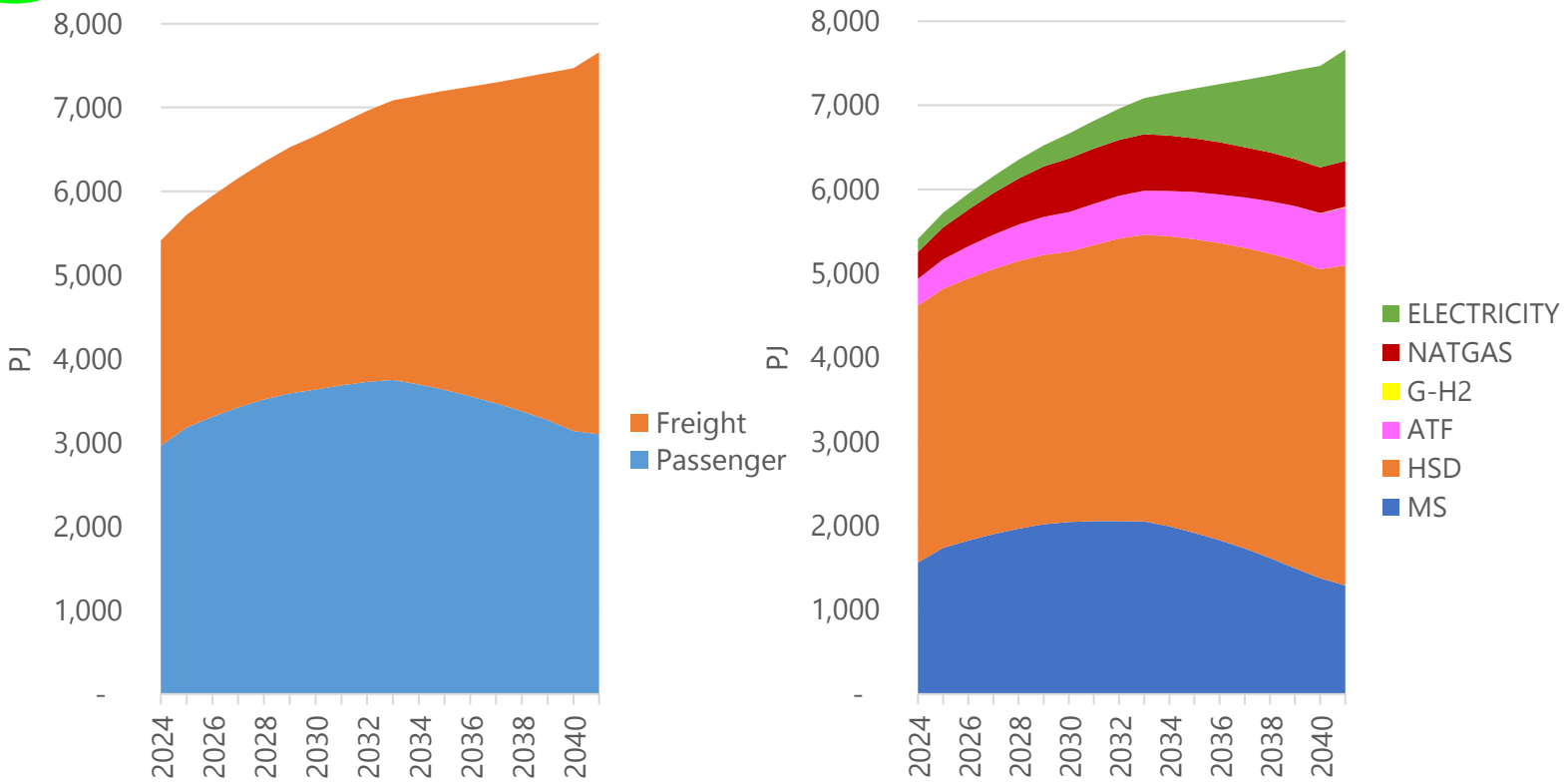
Freight: Insights

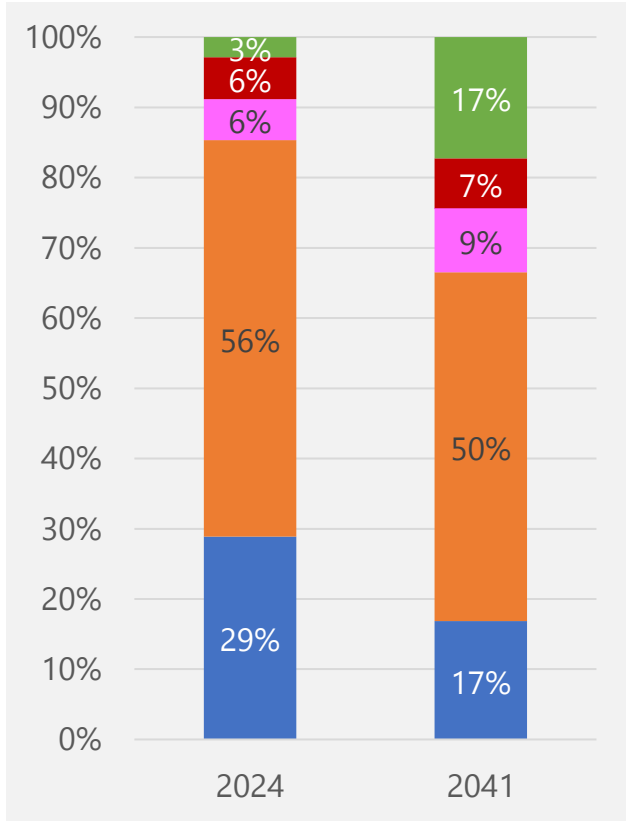
- Continued prevalence of HSD in Freight: While only 46% of the BTKM in FY41 comes from Diesel driven locomotives, HSD forms 77% of the energy demand
- This is despite over half of the BTKMs shifting to Electricity, primarily driven by Rail
- These results suggest that there is a need for greater policy focus on managing HGV growth by increasing the share of Rail in Freight

Combined Transport Results and Scenarios



Total Transport Energy Demand - 1

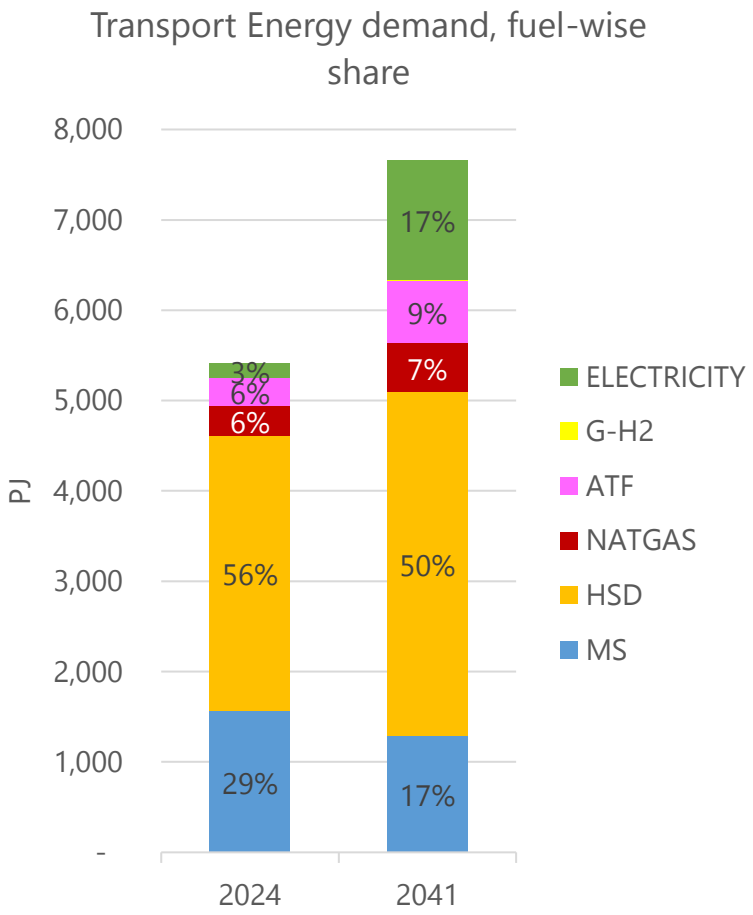


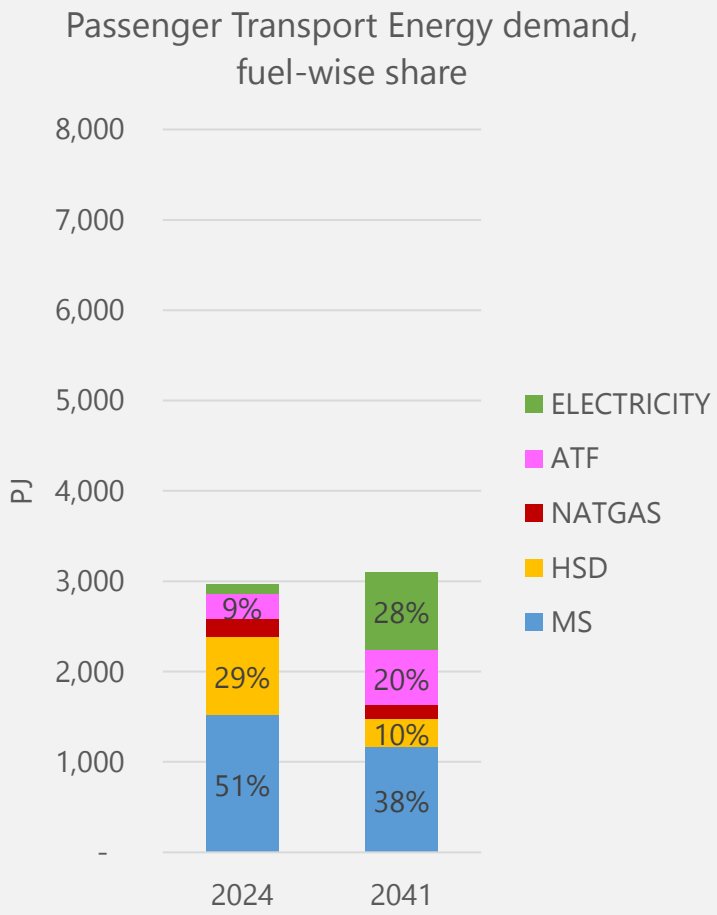


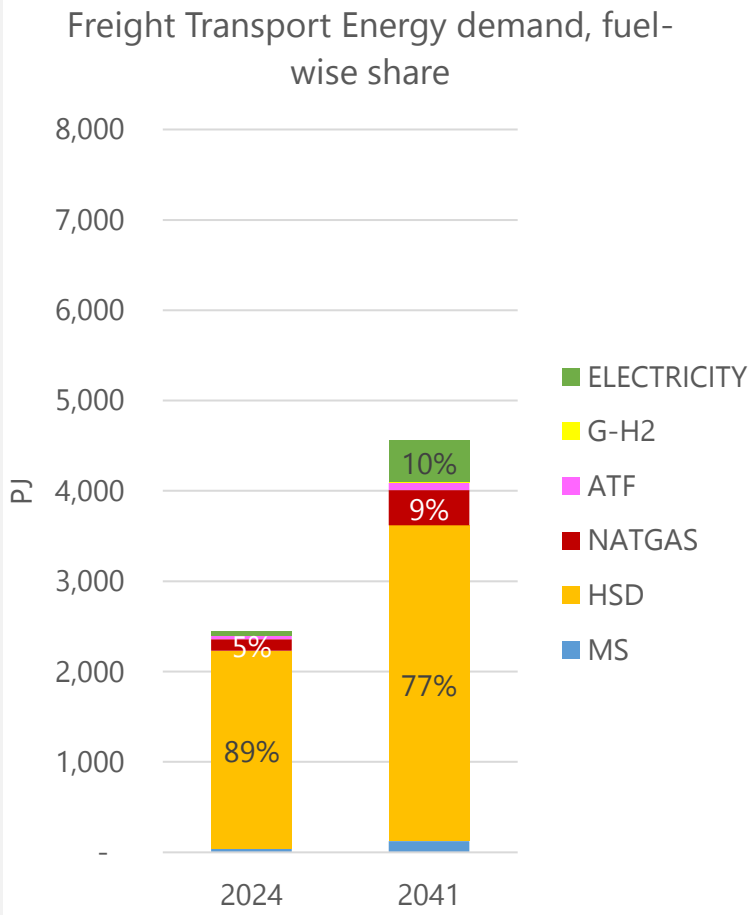
- While total transport energy demand grows, the fossil fuel energy demand in overall transport peaks around FY33
- Further, MS and HSD share in the total demand fall; however despite this HSD still forms half of the energy demand in FY41
- Electricity forms 17% of total Transport energy demand in FY41

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

Total Transport Energy Demand - 2

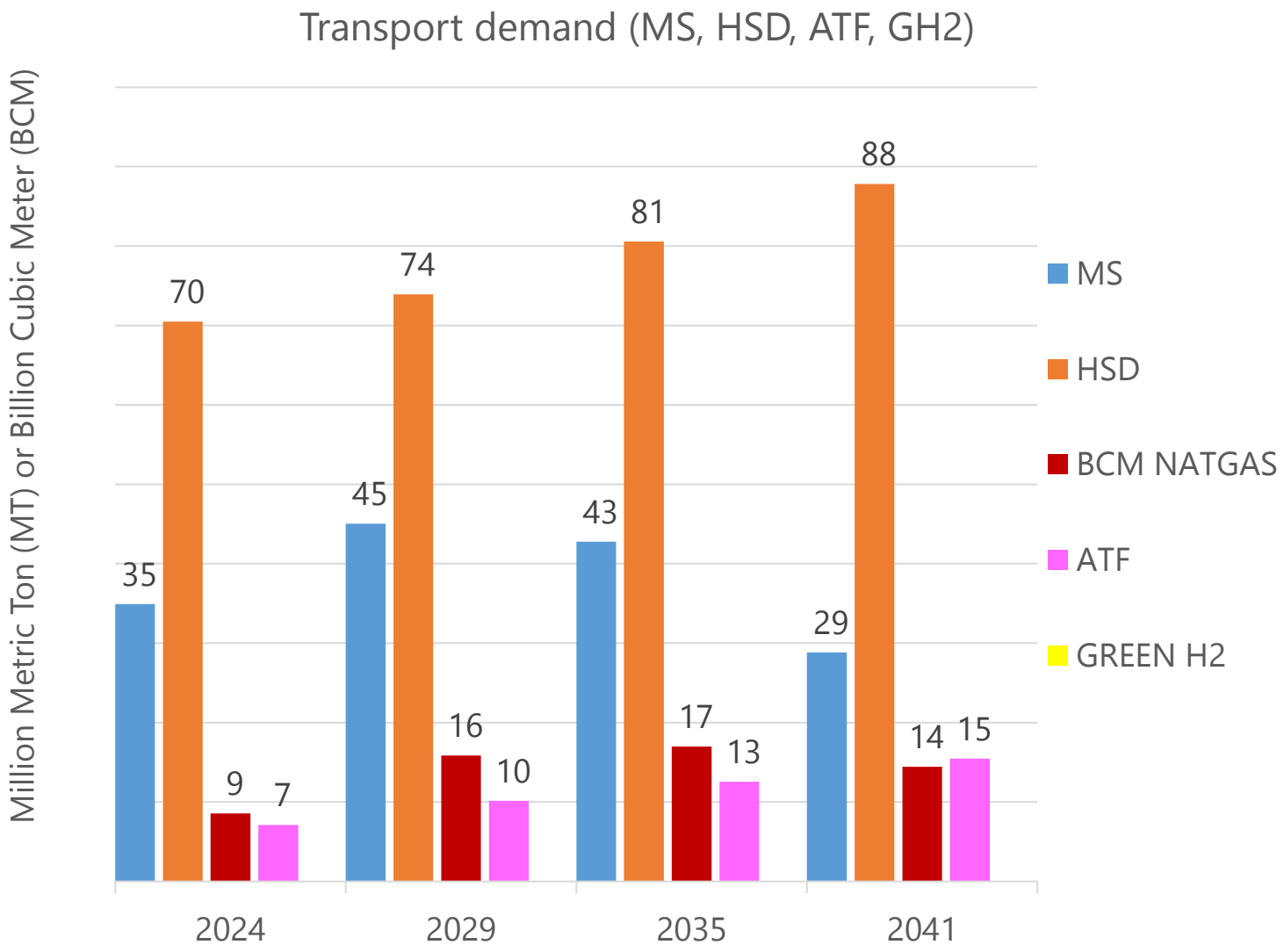






2024 refers to FY23-24, 2041 refers to FY40-41 etc

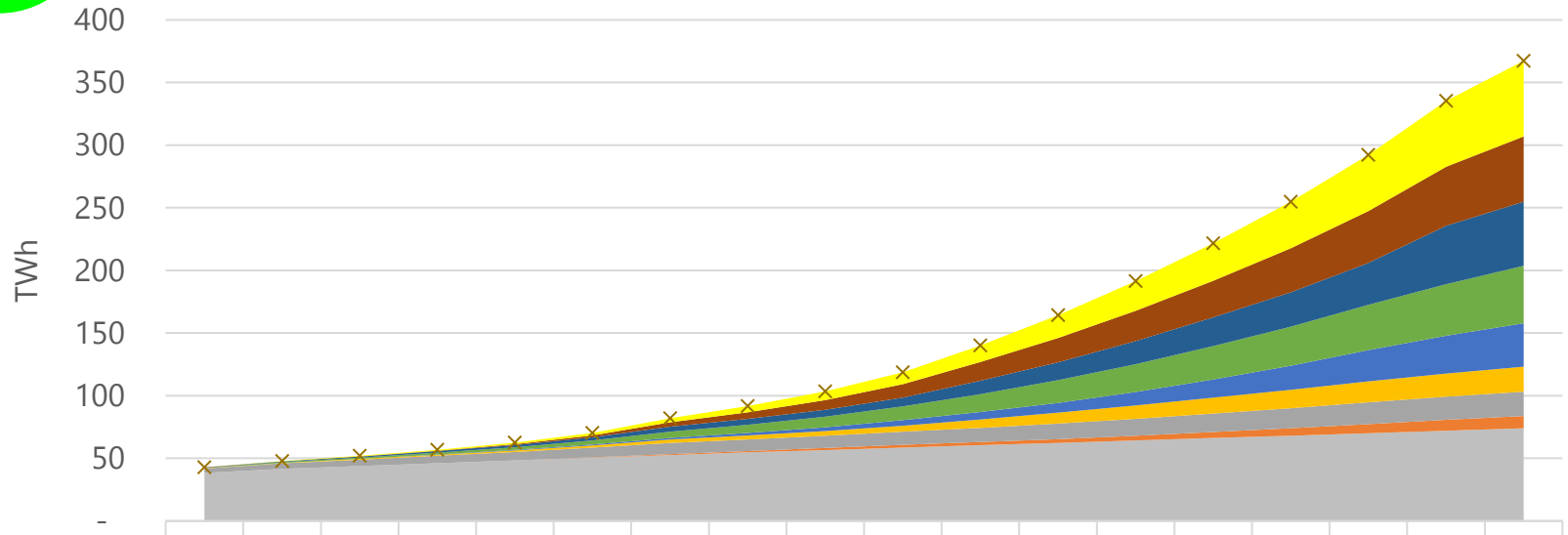
Transport energy demand by Fuels



- Overall, HSD shows a small growth of 1% CAGR
- Green H2 demand goes from 0MT between FY24-35 to 0.06MT in FY41 (not seen in the figure)
- Among the Petroleum products, ATF shows the highest growth of 5% CAGR, mostly driven by the Passenger segment
- While MS peaks in FY32, NATGAS peaks in FY33

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

Transport Electricity demand

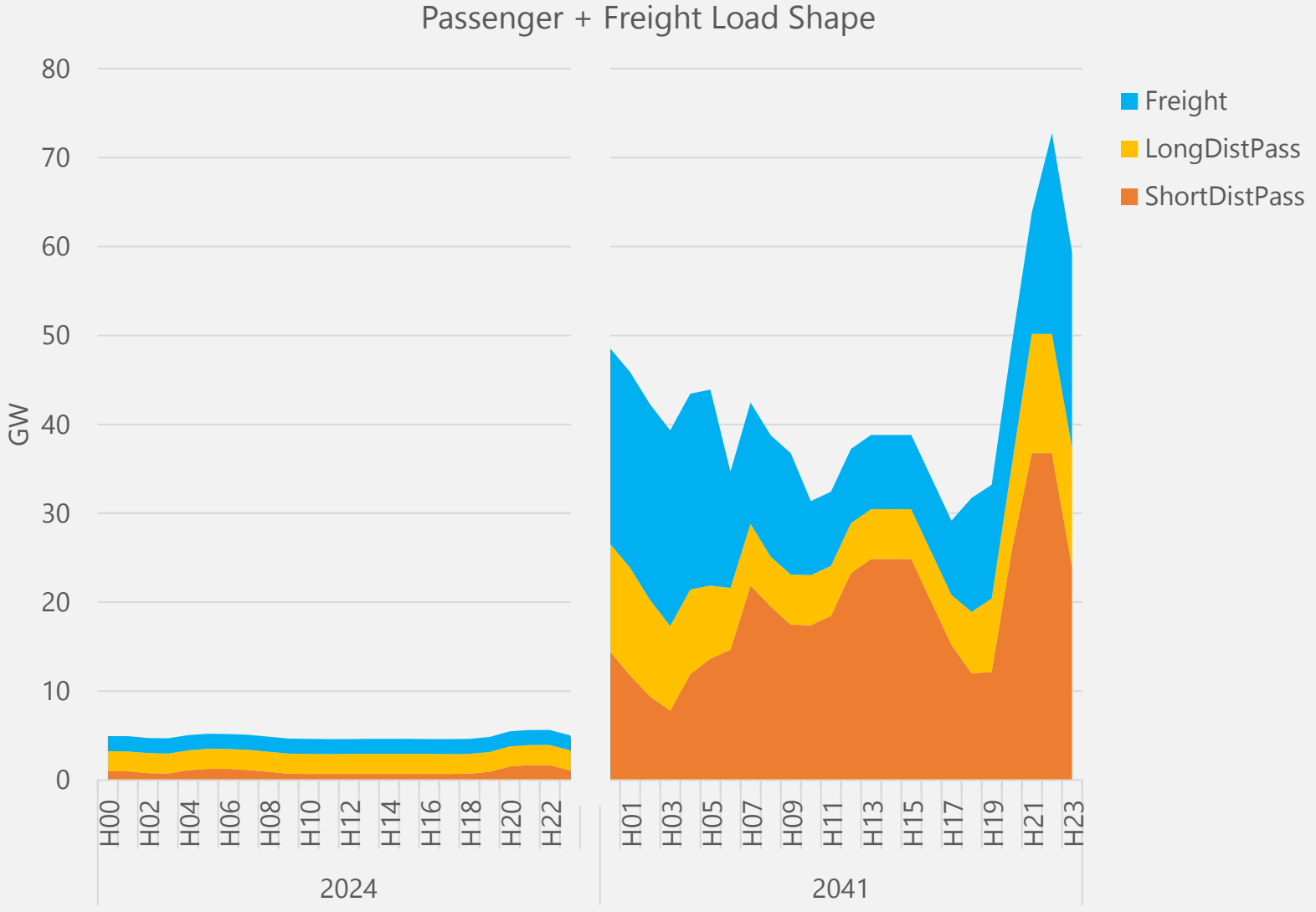


	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041
4W	0	0	0	1	1	2	3	5	7	9	13	18	24	30	37	45	53	60
LGV	0	0	0	0	1	1	4	5	8	11	15	19	24	29	35	41	47	52
BUS	0	0	1	1	2	3	4	5	5	7	11	14	19	23	28	34	47	51
2W	0	1	1	1	2	3	5	7	9	11	14	18	22	27	31	36	41	46
HGV	0	0	0	0	0	1	1	2	3	5	6	8	11	14	19	25	30	35
IPT4W	0	0	1	1	1	2	3	3	4	5	7	9	11	13	15	17	18	20
IPT3W	4	4	5	6	7	8	9	9	10	10	11	12	14	15	16	17	19	20
MGV	0	0	0	0	0	0	1	1	2	2	2	3	4	5	6	7	9	10
RAIL	38	42	44	46	48	51	53	55	57	59	61	62	64	66	68	70	72	74
Total	43	48	52	57	62	70	82	92	103	119	140	164	192	222	255	292	335	367

- Electricity demand grows the fastest among all energy carriers at ~14% CAGR from ~43BUs to 367BU i.e a 8.6 folds growth in 17 years
- By the end of the model period, 4W individually and 4W+IPT4W form the largest segment among the Road segments
- Moreover, 4W+IPT4W overtakes Rail in FY41
- Total share of transport electricity in total electricity demand (all sectors combined) goes from 2% in FY24 to ~9.5% in FY41

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

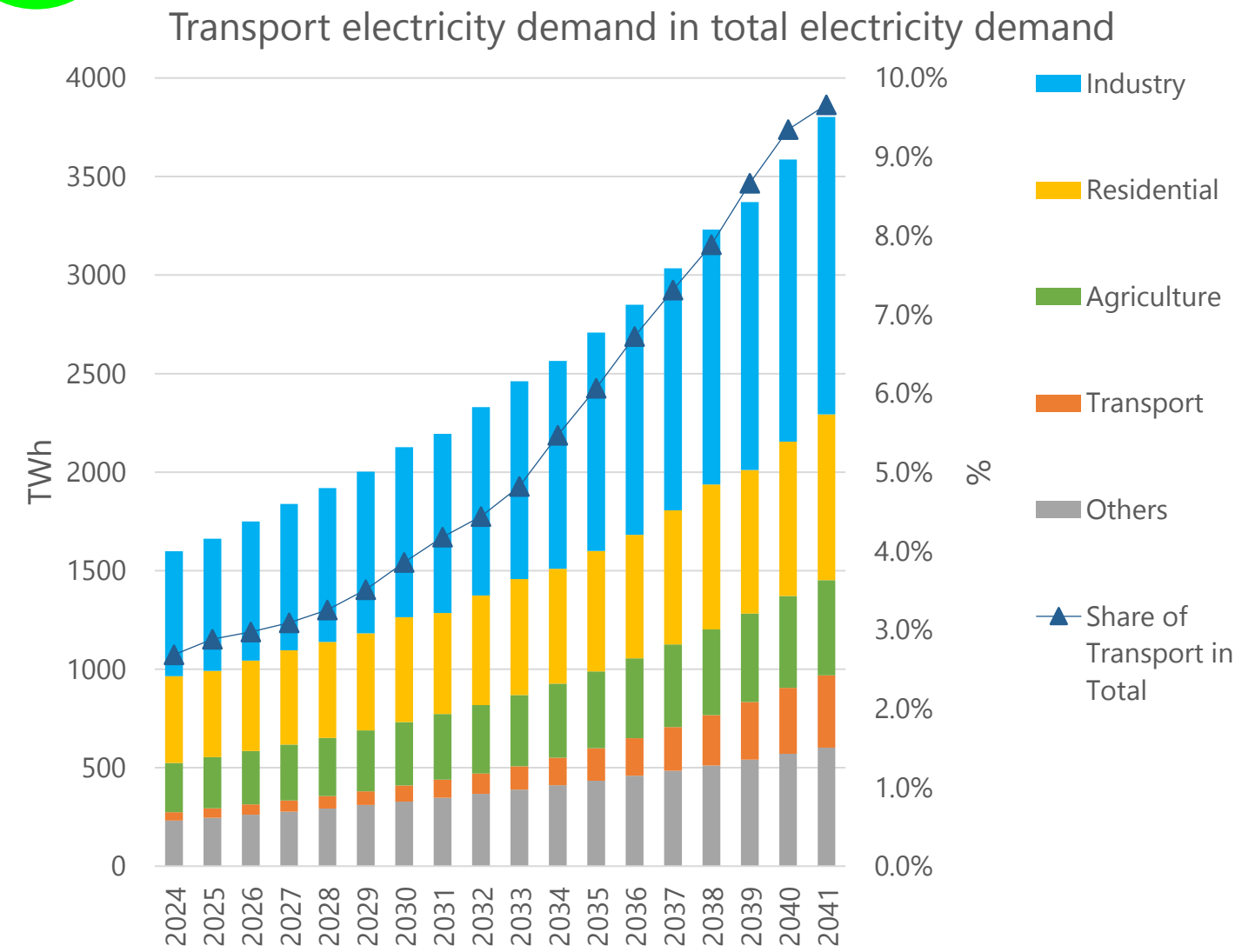
Total Transport Electricity Load



- Peak load in FY41 for transport is ~73GW
- Peak in FY41 occurs at night hours (H22)
- H00-05, & H23 are also loaded comparable to the Peak, this is driven mostly by the freight segment
- Passenger contributes ~70% to the Peak load
- Loading is assumed to not change by seasons (months)

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

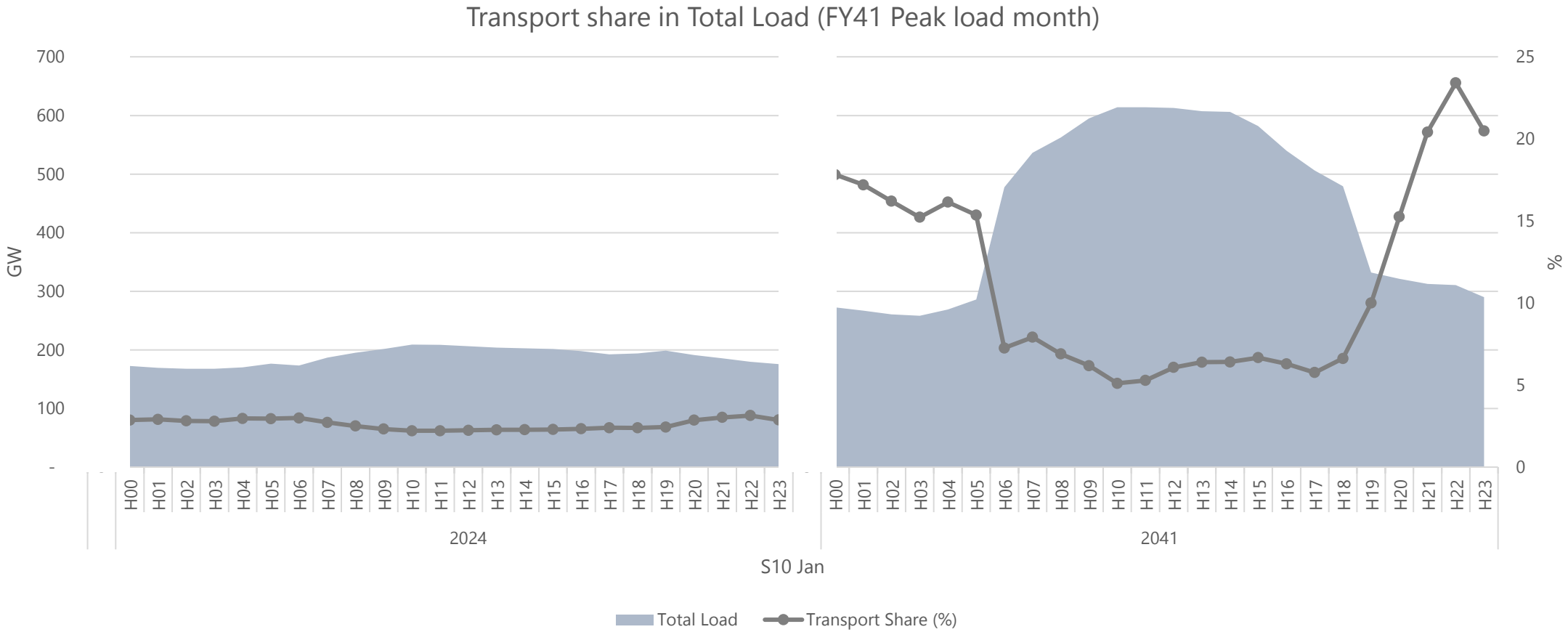
Insight 1: While a significant load and energy, Transport electricity demand forms a relatively small share in total electricity demand



- While in standalone terms, the electricity demand from transport is significant (~370 BU in FY41)
- Its share in total sector-wide electricity demand does not touch even 10% in the model period

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

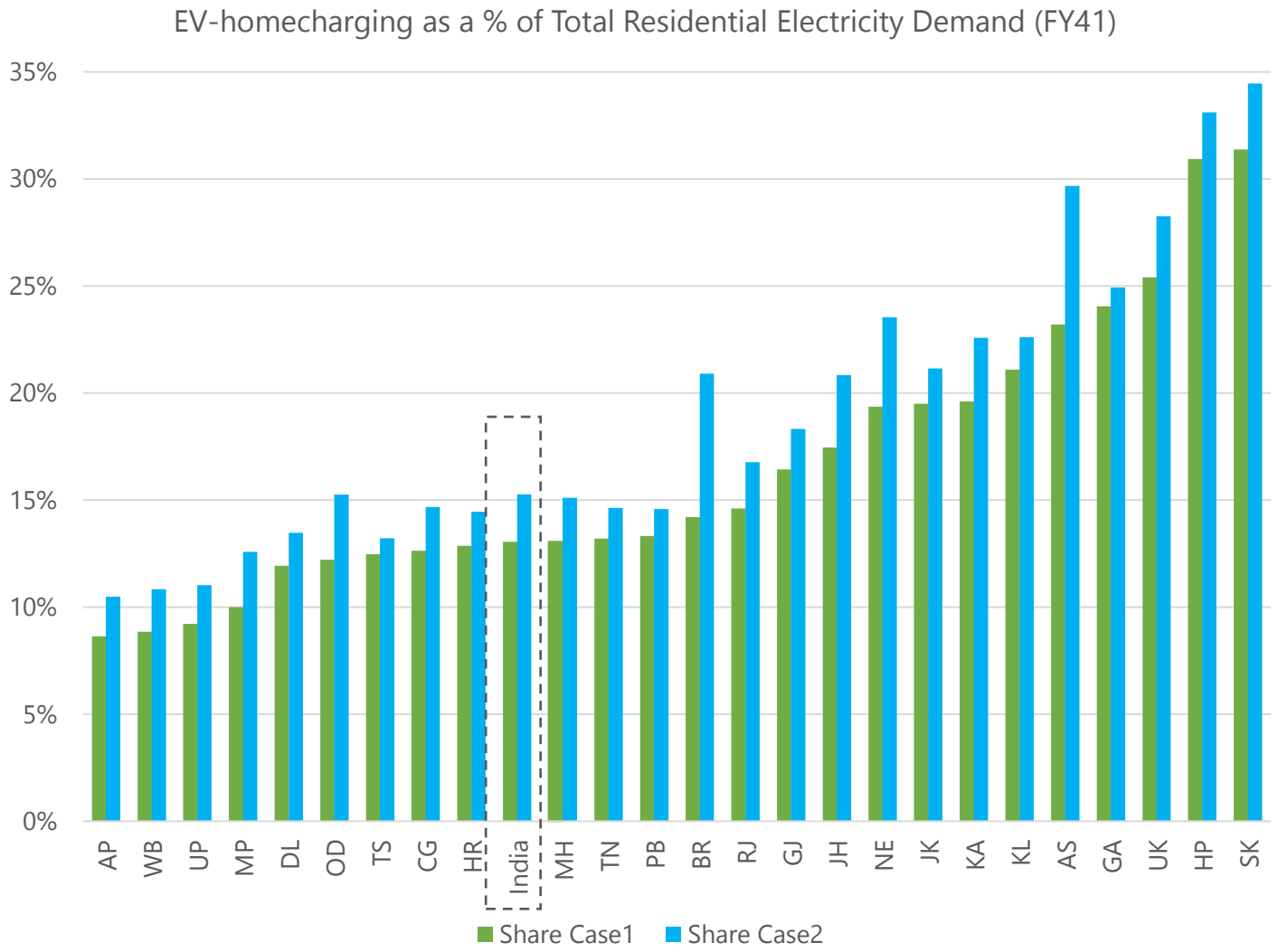
Insight 2 : Contribution of Transport in non-solar hours load



- The contribution of Transport in solar hours range between 5-8%
- In the non-solar hours transport load range between 13-20% of the total load

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

Insight 3: Despite rapid growth, EV home-charging will be a relatively small part of residential electricity demand in most states



Indicative cases considered for home-charging:

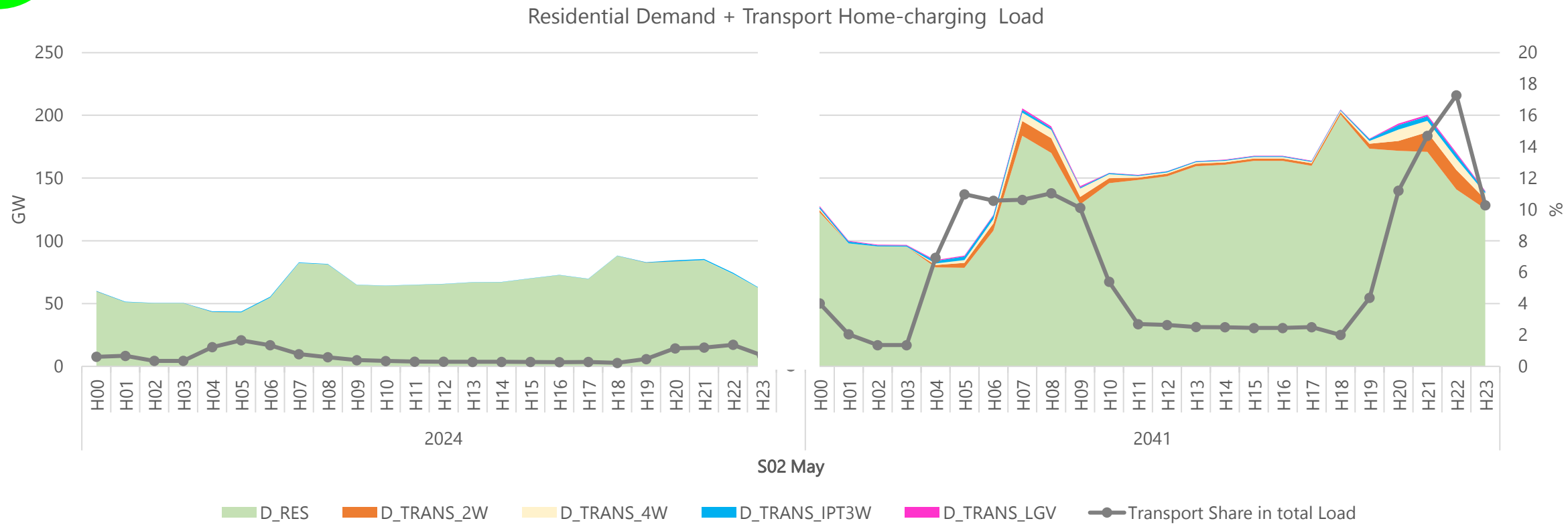
Case 1: 100% of 2W, 4W and 50% of IPT3W are home charged (100% of IPT4W public charged) and only 20% of LGV are home-charged

Case 2: 100% of 2W, 4W, IPT3W are home charged (100% IPT4W public charged) and 50% of LGV are home-charged

EV Home-charging share = α /(α+ β)

Where,
α – Estimated home-charging demand through bottom-up transport model
β – Estimated residential demand in bottom-up residential model

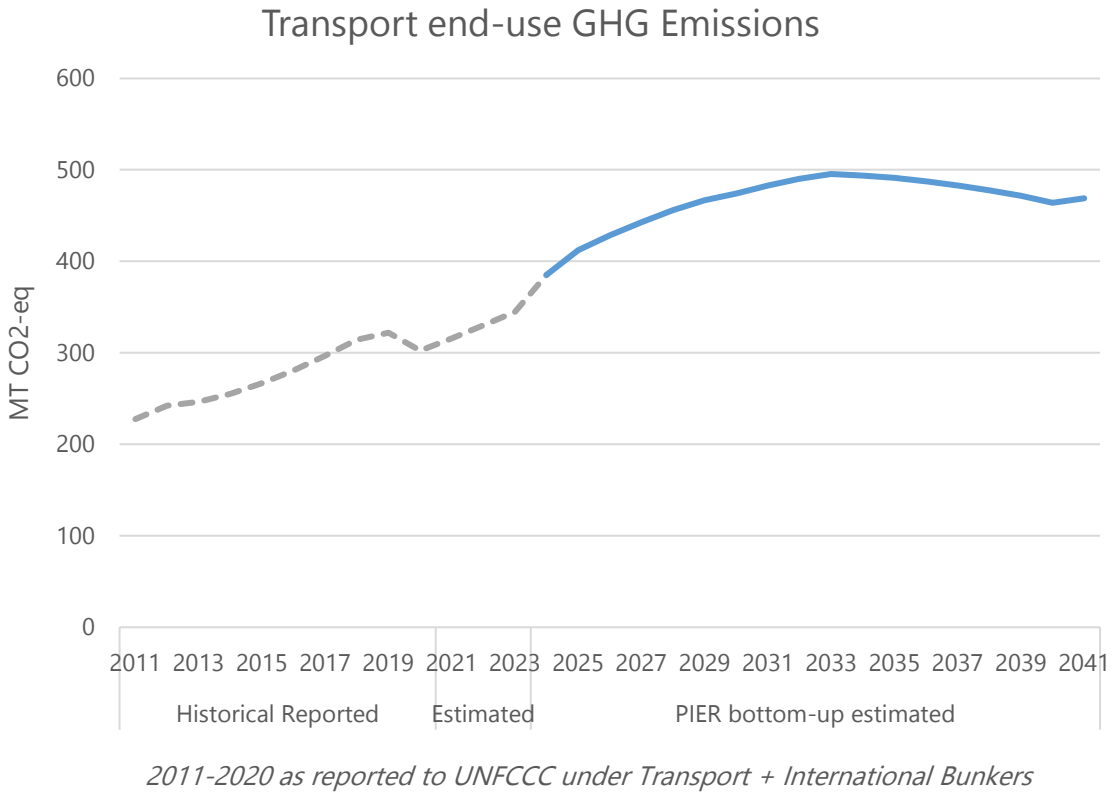
Insight 4 : Despite rapid growth, EV home-charging will be a relatively small part of residential load and peak load



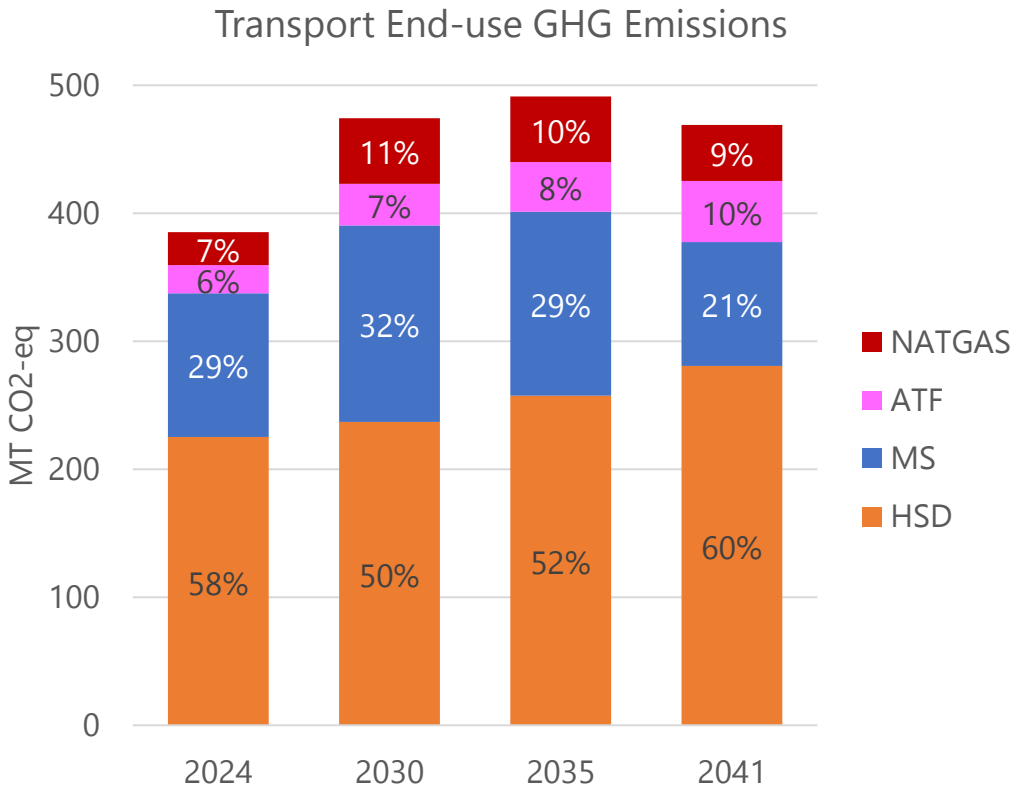
- EV home-charging load forms as low as 2% of the Total Residential+EV homecharging Load in H02 and as high as 20% in H22 (considering S02 May when Residential Peaks)
- In fact, EV home-charging has almost no impact on the Residential peak in FY41 (i.e S02 May H18)
- Load concerns of EV-home charging in the overall residential demand is relevant mostly in early and late hours of the day

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

Insight 5 : Transport End-use GHG emission is at a turning point



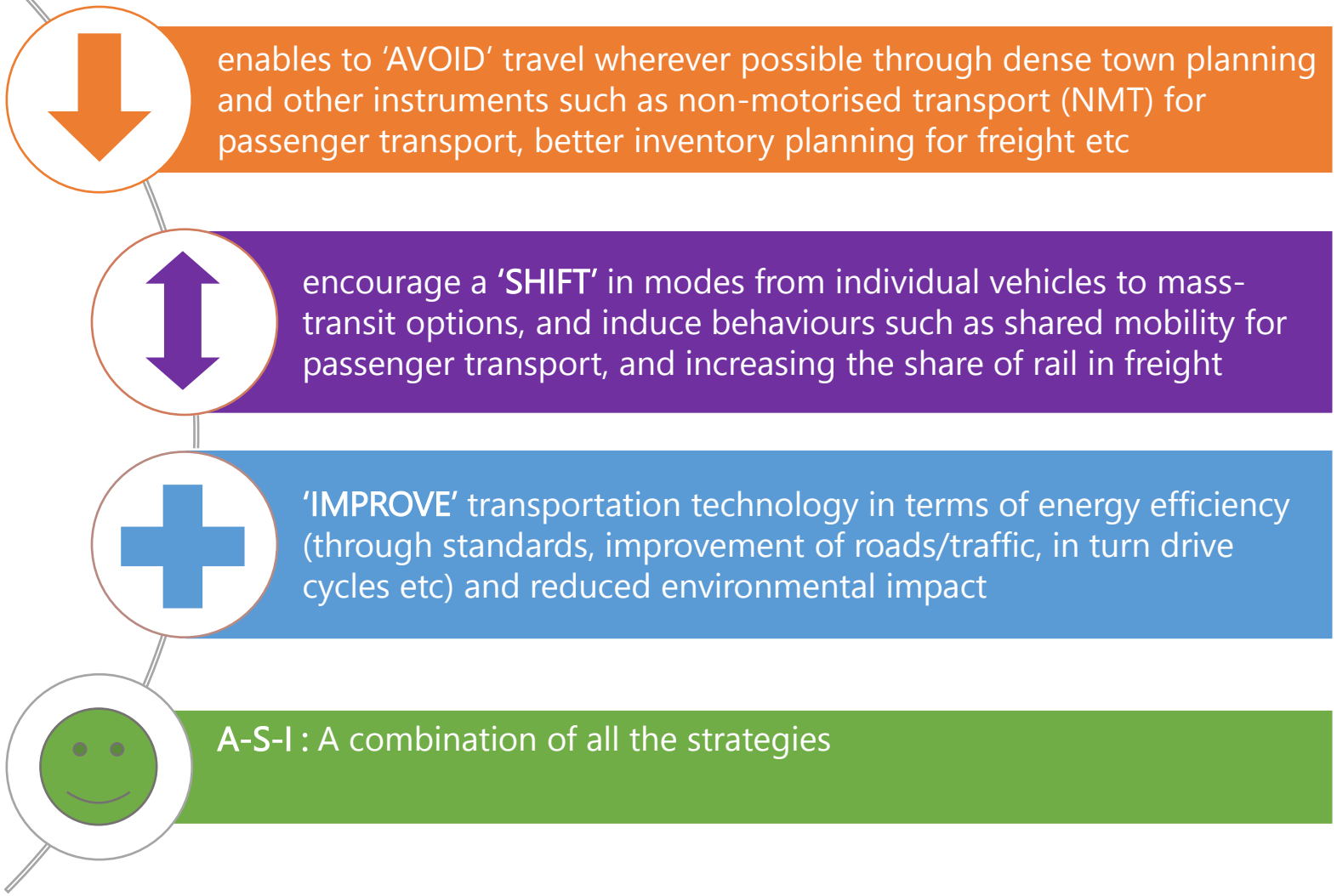
2011-2020 as reported to UNFCCC under Transport + International Bunkers



- Non-electricity transport GHG emissions is set to peak in the beginning of the next decade (~2033)
- Total GHG emissions from the transport sector will thus be determined by the supply mix of electricity

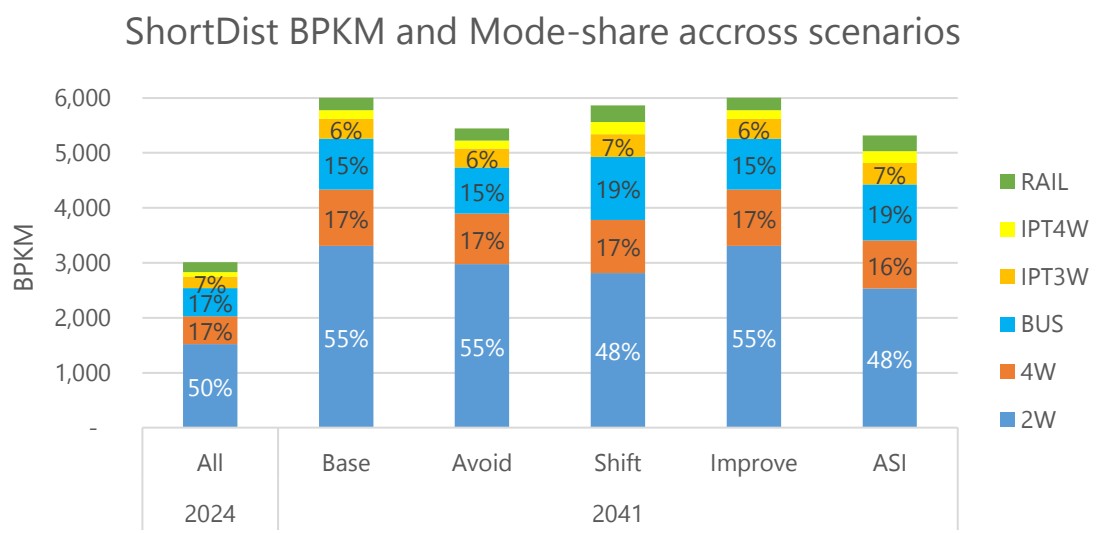
2024 refers to FY23-24, 2041 refers to FY40-41 etc

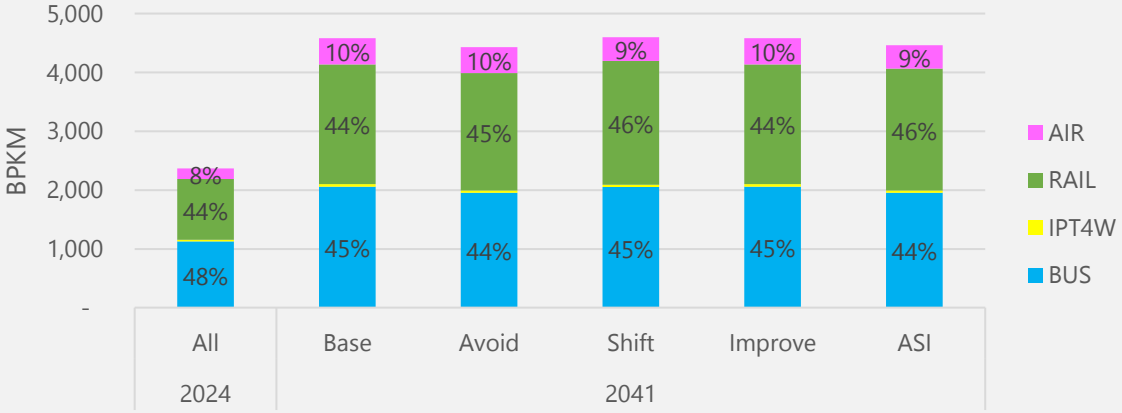
Scenarios: Avoid, Shift, Improve, ASI



- ASI is a common framework in transportation studies/theories and policy strategies
- These storylines were tested as scenarios through the input levers
- These scenarios enable to pin-point which strategy may have the highest returns in terms of energy
- Following scenarios modelled only for D_TRANS - these are apart from the three scenarios (REF, Vikasit and Vichalit) modelled across demand sectors

Pass Inputs: Avoid, Shift, Avoid+Shift, Improve



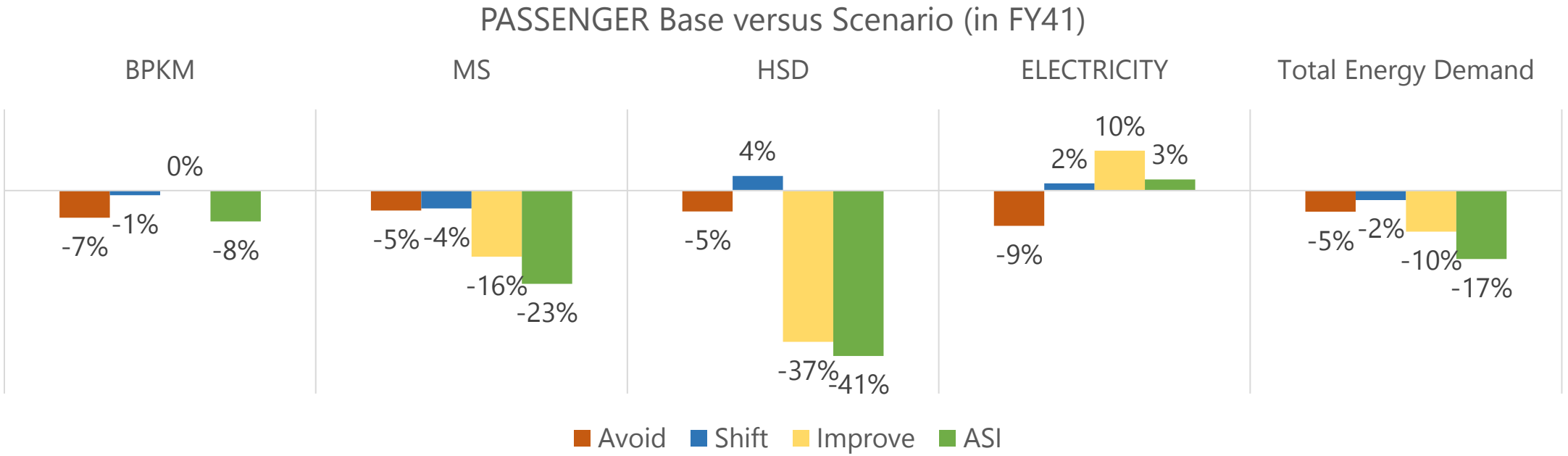


Improve scenario

	EV Sales penetration (%)						EV Stock penetration (%)					
	2030		2035		2041		2030		2035		2041	
	Base	Improve	Base	Improve	Base	Improve	Base	Improve	Base	Improve	Base	Improve
2W	65%	80%	90%	96%	100%	100%	12%	14%	37%	42%	70%	75%
IPT3W	68%	81%	84%	93%	97%	99%	53%	58%	68%	76%	88%	95%
IPT4W	45%	70%	80%	92%	97%	100%	17%	23%	46%	58%	85%	94%
4W	30%	45%	68%	81%	95%	97%	5%	7%	22%	28%	54%	61%
BUS	35%	50%	72%	82%	95%	97%	13%	17%	38%	47%	79%	87%
TOTAL	**60%**	**75%**	**87%**	**94%**	**99%**	**100%**	**12%**	**14%**	**35%**	**40%**	**69%**	**74%**

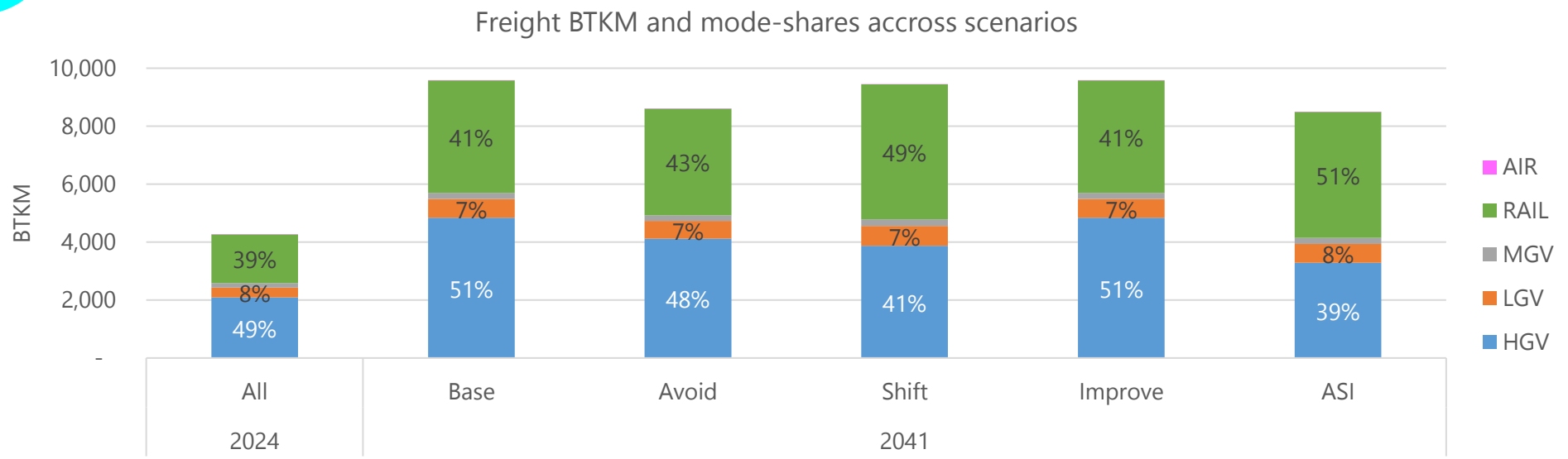
+ ICE improvements are accelerated a bit versus Base

Pass: Scenario Insight



- An Improve strategy alone leads to greater gains in energy savings when compared to Avoid and Shift.
- While overall energy reduces in Shift, there is an increase in HSD as well as Electricity because of increased usage of Buses
- Avoid and Shift no doubt have equity, air-quality, congestion etc related co-benefits, but have lesser impact on energy

Freight Inputs: Avoid, Shift, Avoid+Shift, Improve

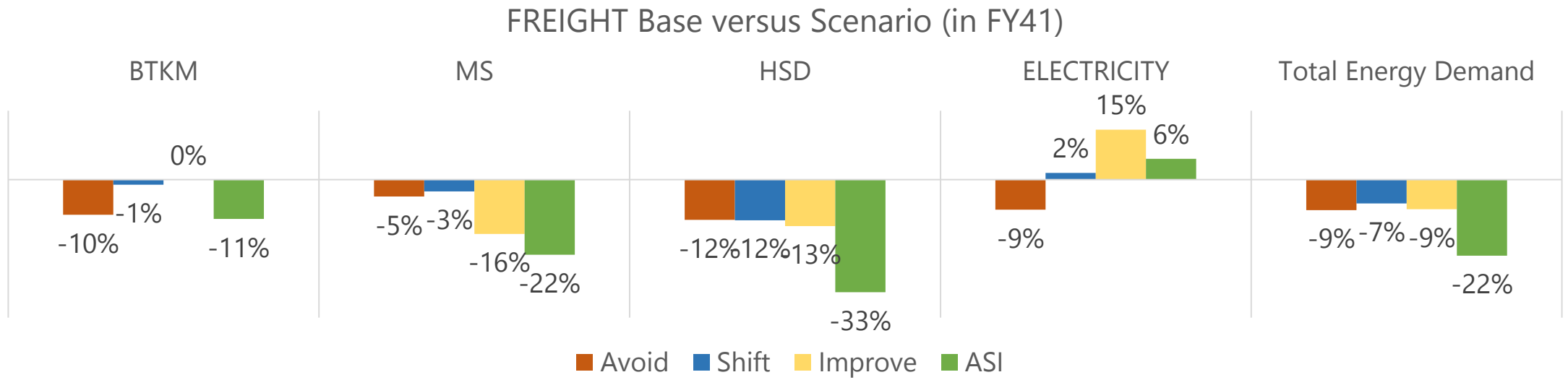


Improve scenario

	EV Sales penetration (%)						EV Stock penetration (%)					
	2030		2035		2041		2030		2035		2041	
	Base	Improve	Base	Improve	Base	Improve	Base	Improve	Base	Improve	Base	Improve
LGV	15%	20%	28%	33%	40%	47%	3%	4%	15%	19%	32%	38%
IMGV	10%	15%	21%	28%	34%	40%	3%	4%	10%	13%	25%	32%
HGV	5%	10%	11%	19%	21%	28%	1%	2%	5%	9%	15%	22%
TOTAL	**12%**	**17%**	**24%**	**30%**	**36%**	**42%**	**3%**	**4%**	**12%**	**16%**	**27%**	**33%**
	H2 Sales Penetrations (%)						H2 Stock Penetrations (%)					
HGV	0%	0%	0.01%	0.01%	1%	2%	0%	0%	0.001%	0.001%	0.16%	0.29%

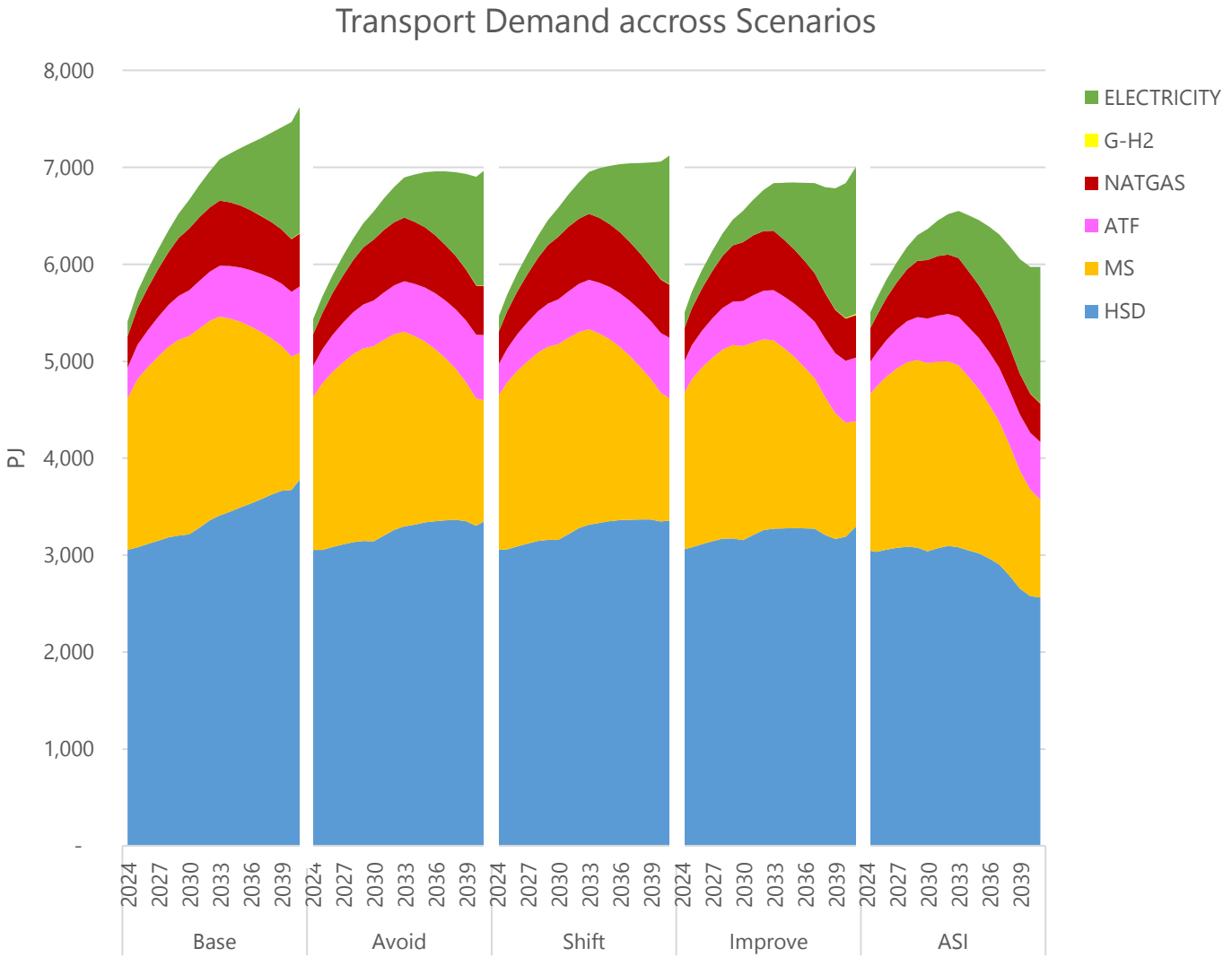
+ ICE improvements are accelerated a bit versus Base

Freight: Scenario Insight



- An Improve strategy alone leads to comparable gains in energy savings when compared to Avoid and Shift
- The greatest energy benefit comes from reducing the freight activity (Avoid) or a greater shift to Rail than Base, because road freight electrification does not offer too much gains in this time period

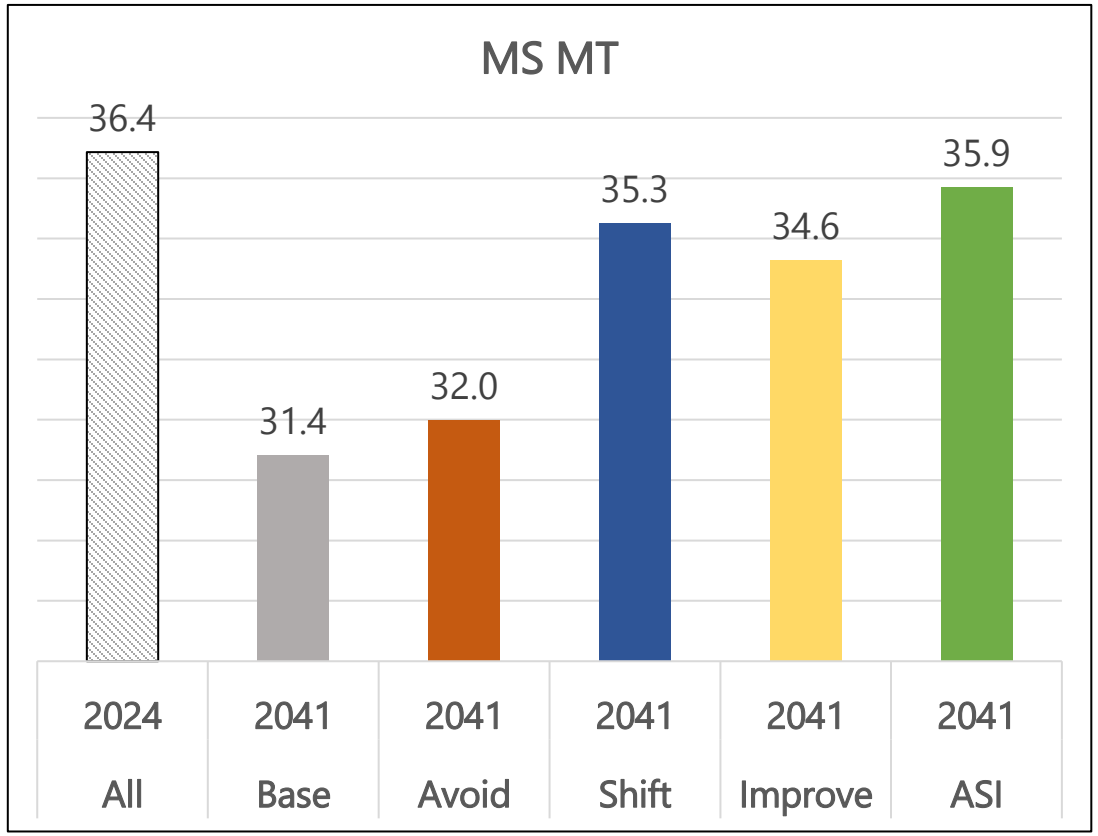
Insight: Only combined strategies yield to peaking of Transport Energy demand

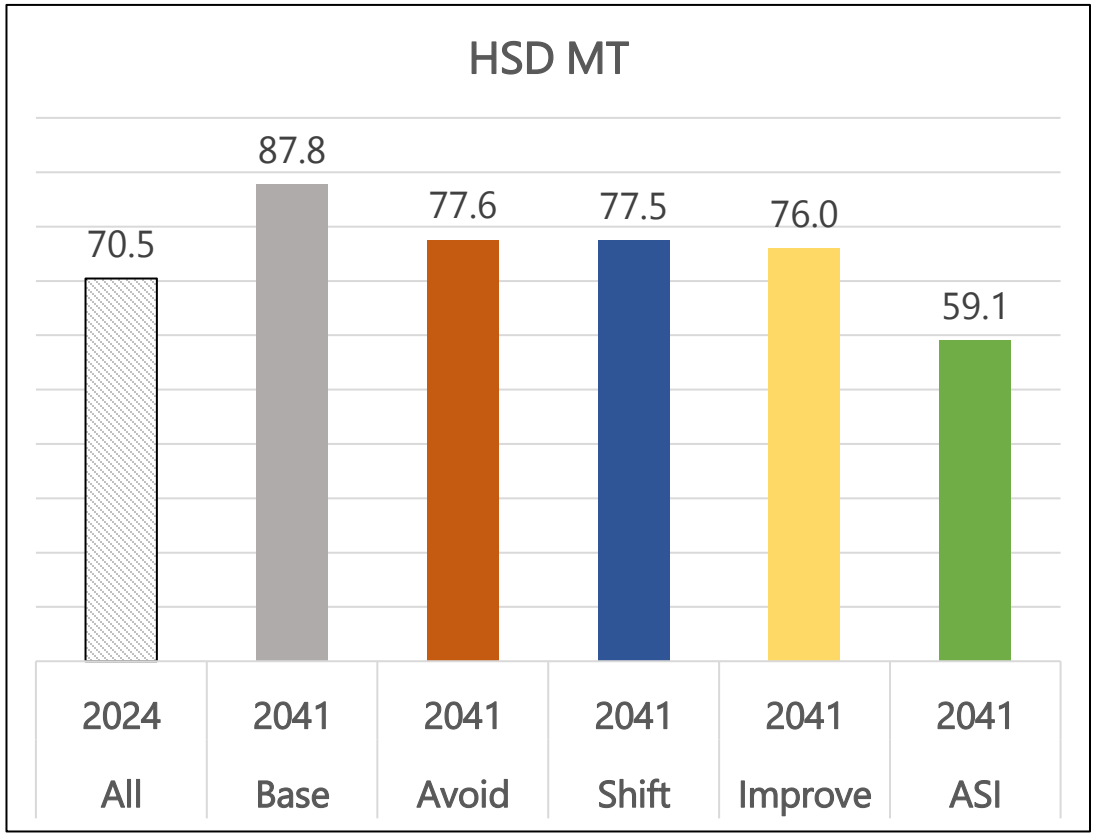


- It is clear from the scenarios that all strategies lead to a peaking of MS demand for transport with peak years ranging between FY2030 to FY2032
- It is noteworthy however that in a combined Avoid-Shift-Improve strategy, the HSD demand also peaks

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

Fuel demand across scenarios (MS, HSD)

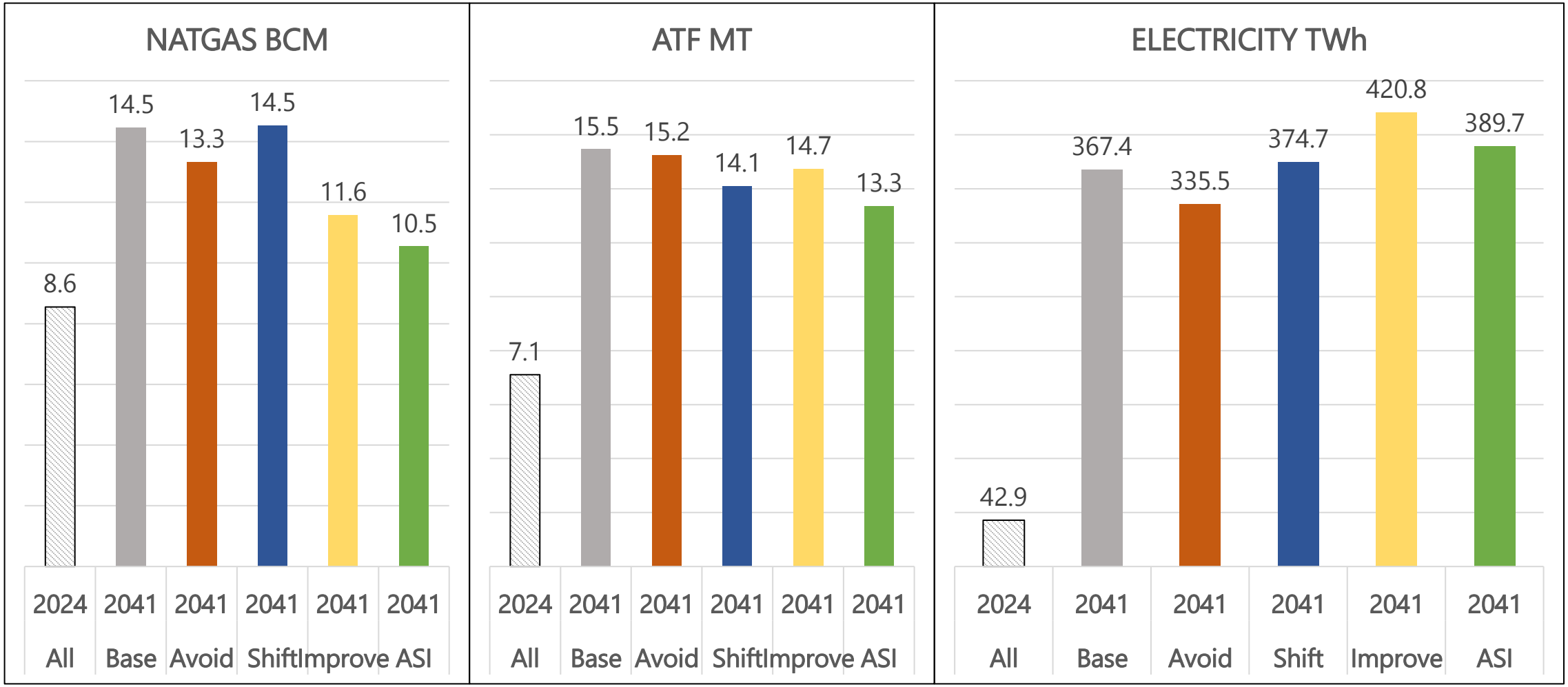




- In ASI Scenario, even HSD demand falls by FY41

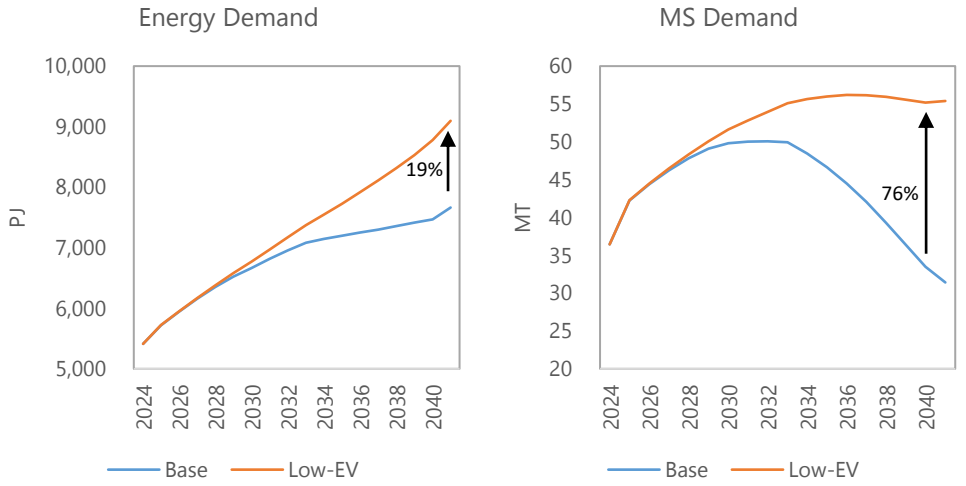
2024 refers to FY23-24, 2041 refers to FY40-41 etc

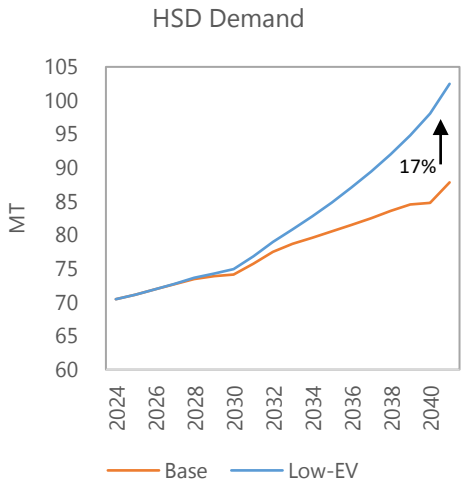
Fuel demand across scenarios (NATGAS, ATF, ELECTRICITY)

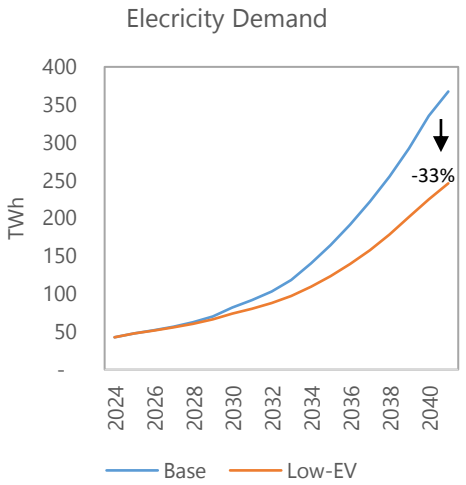


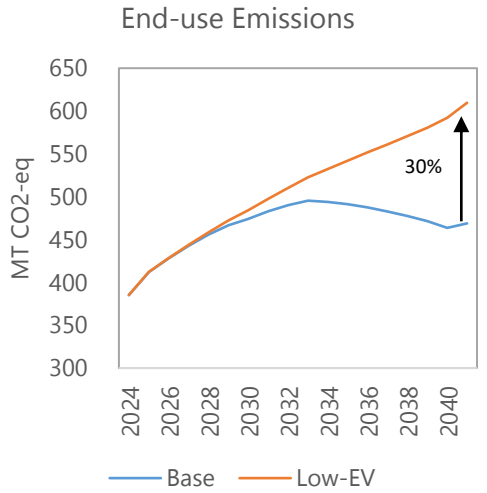
2024 refers to FY23-24, 2041 refers to FY40-41 etc

Sensitivity: 'Low EV'









- Low-EV sensitivity run can be considered a 'What-if' scenario where EV penetration is much lower than the Base
- Instead of ~68%, the stock penetration in FY41 is considered as ~39% for this run
- Passenger energy demand does not peak as in the Base
- Electricity demand in FY41 is 111 TWh lesser i.e 30% lesser than in Base
- In FY41, 24 MT more MS and 15 MT more HSD would be required in comparison to Base
- Effectively across years Low-EV scenario would add 786 MT CO2-eq of GHG emissions

Note: Y-axes truncated to highlight differences

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

Conclusions

Model findings

- Large growth in vehicle ownership and use
- No commensurate increase in energy demand
- Quantification of the role of electrification of transport on overall energy, electricity load and petrol demand
- Large diversity across states but the trends hold

Useful policy insights

- Focussed decarbonisation efforts through electrification, modal shifts, behaviour-change required
- Need relatively higher focus on sustainable aviation fuels in the passenger segment
- Ethanol blending of petrol can be a stop-gap arrangement; there are greater benefits in pursuing electrification instead
- Need for greater policy focus on managing HGV growth by increasing the share of Rail in Freight
- Need for utilities to better understand charging behavior and thus plan for power procurement and network infrastructure accordingly

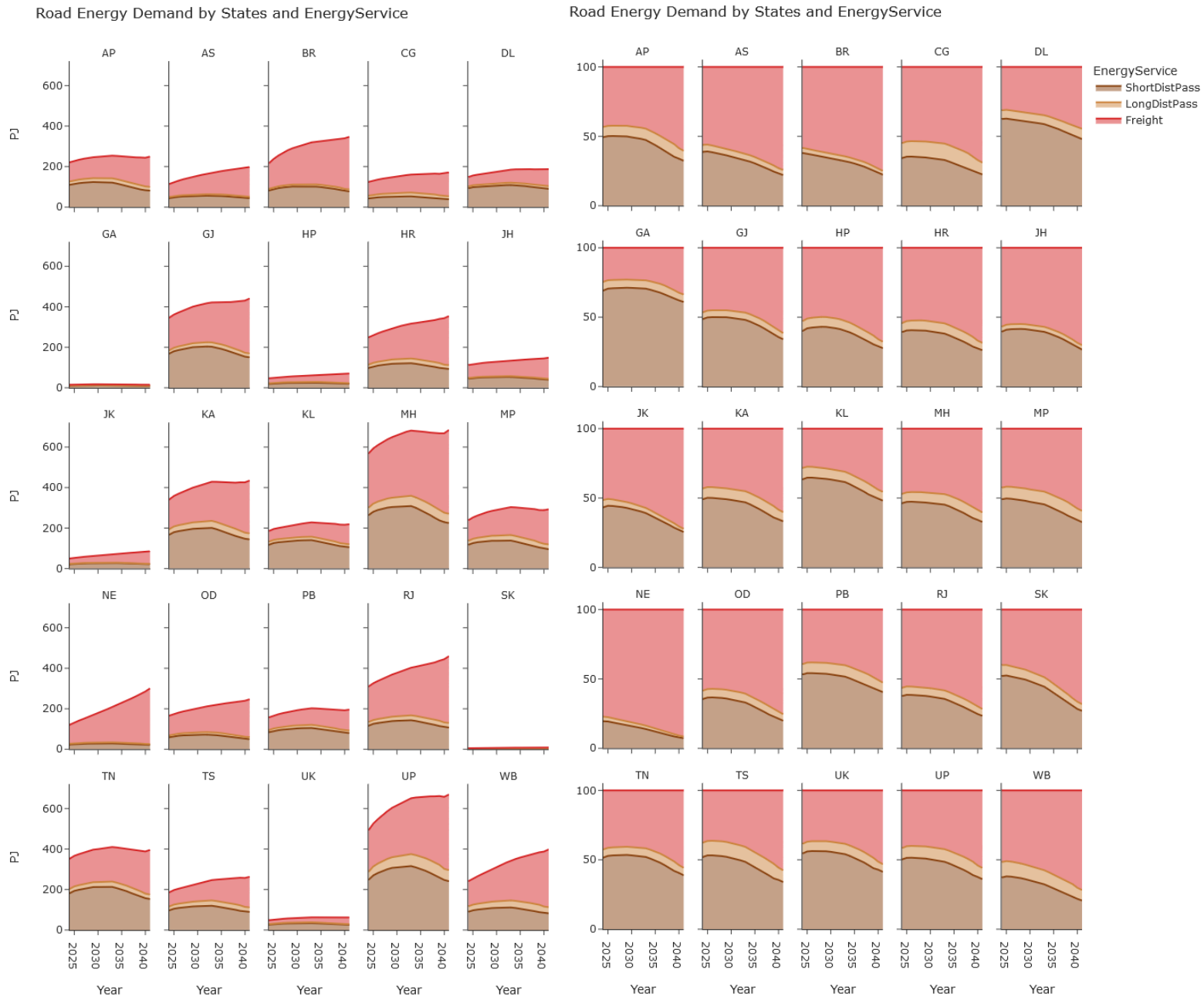
Download PIER 2.0 from:
https://doi.org/10.5281/zenodo.14603083

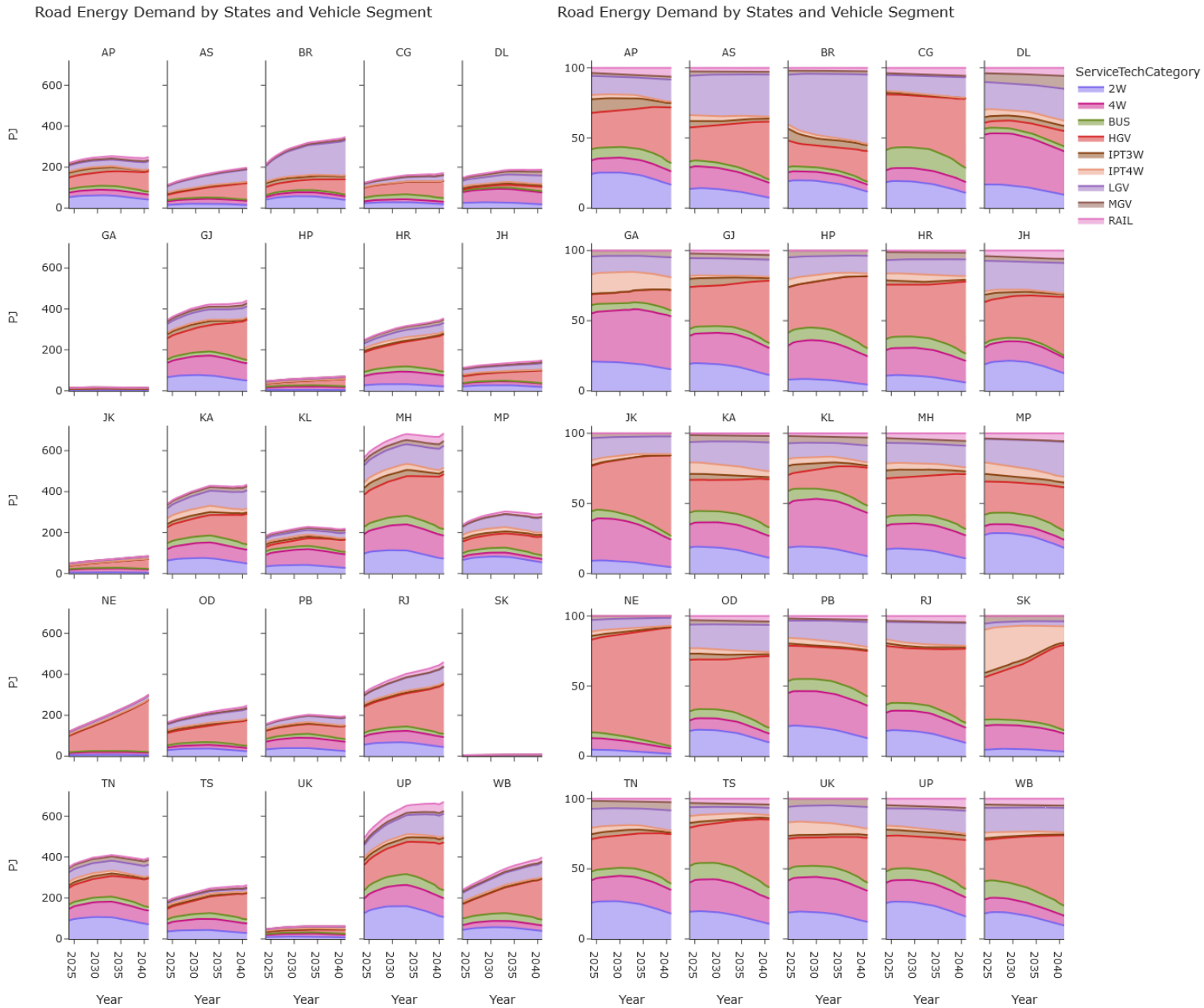
Suggested Citation:

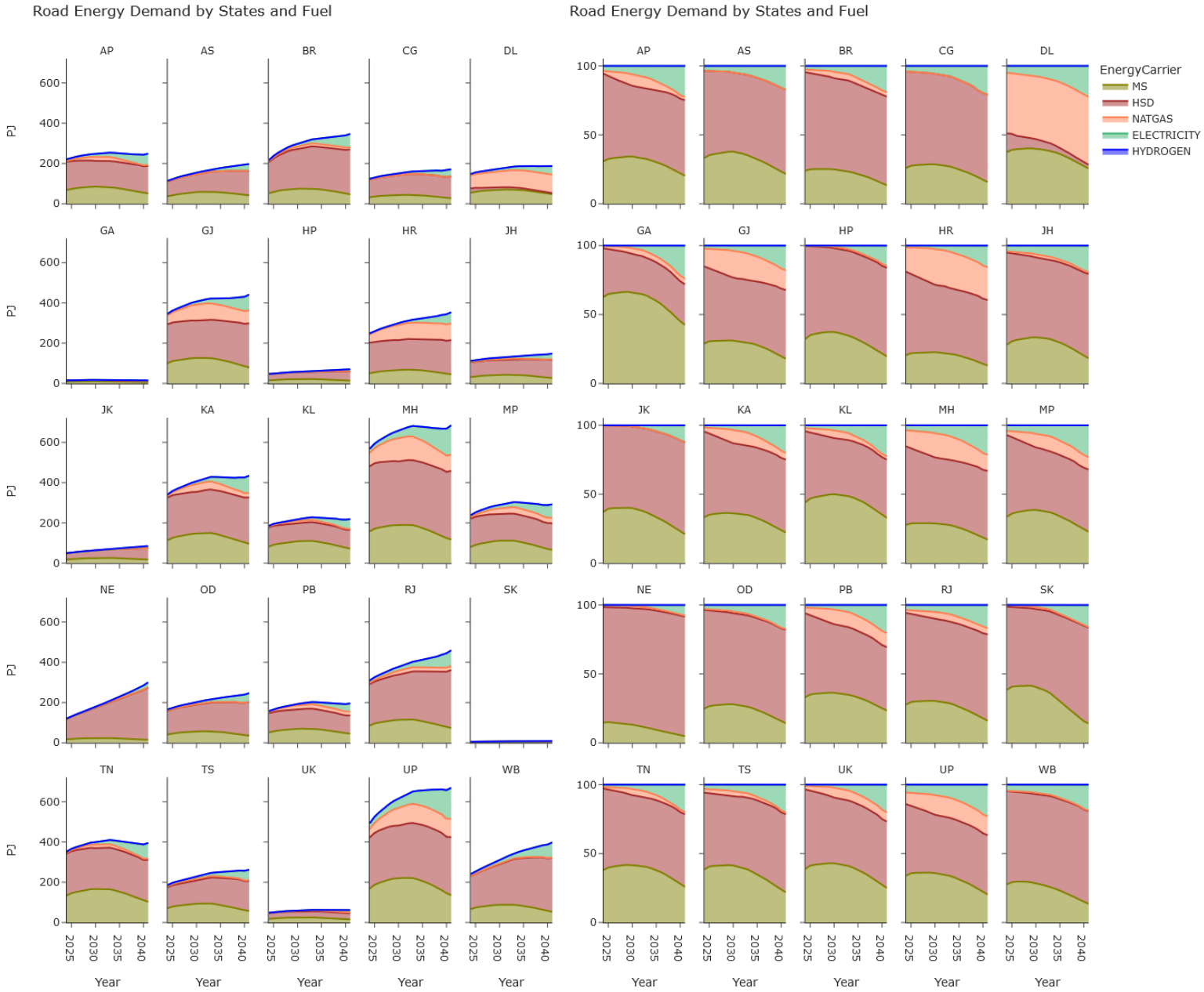
Prayas (Energy Group). (2025). PIER: Detailed demand-side energy modelling of Residential, Transport, Industry sectors for India from FY2023-24 to FY2040-41 (2.0 Demand Model). https://doi.org/10.5281/zenodo.14603083

Contact:

energy.model@prayaspune.org


Road Energy Demand by States and EnergyService
Road Energy Demand by States and EnergyService
AP
AS
BR
CG
DL
GA
GJ
HP
HR
JH
JK
KA
KL
MH
MP
NE
OD
PB
RJ
SK
TN
TS
UK
UP
WB
PJ
Year
EnergyService
ShortDistPass
LongDistPass
Freight


Road Energy Demand by States and Vehicle Segment
Road Energy Demand by States and Vehicle Segment
AP
AS
BR
CG
DL
GA
GJ
HP
HR
JH
JK
KA
KL
MH
MP
NE
OD
PB
RJ
SK
TN
TS
UK
UP
WB
PJ
Year
2025
2030
2035
2040
ServiceTechCategory
2W
4W
BUS
HGV
IPT3W
IPT4W
LGV
MGV
RAIL


Road Energy Demand by States and Fuel
Road Energy Demand by States and Fuel
AP
AS
BR
CG
DL
GA
GJ
HP
HR
JH
JK
KA
KL
MH
MP
NE
OD
PB
RJ
SK
TN
TS
UK
UP
WB
PJ
Year
EnergyCarrier
MS
HSD
NATGAS
ELECTRICITY
HYDROGEN

Icon credits

- electric by Kosong Tujuh from Noun Project (CC BY 3.0)
- fuel dispenser by Wuppdidu from Noun Project (CC BY 3.0)
- Scooter by Bakunetsu Kaito from Noun Project (CC BY 3.0)
- Human by Adrien Coquet from Noun Project (CC BY 3.0)
- Bus by Rainbow Designs from Noun Project (CC BY 3.0)
- Taxi by Sierra Pennala from Noun Project (CC BY 3.0)
- Car by Langtik from Noun Project (CC BY 3.0)
- Rickshaw by Phạm Thanh Lộc from Noun Project (CC BY 3.0)
- Train by Lee Mette from Noun Project (CC BY 3.0)
- Airplane by Darrin Loeliger from Noun Project (CC BY 3.0)
- Medium truck by Peter van Driel from Noun Project (CC BY 3.0)
- semi truck by Blaise Sewell from Noun Project (CC BY 3.0)
- Truck by ABDUL LATIF from Noun Project (CC BY 3.0)
- ship goods by LUTFI GANI AL ACHMAD from Noun Project (CC BY 3.0)
- boxes by b farias from Noun Project (CC BY 3.0)