CO_2 Emissions and Air Pollution Mitigation strategies for India's Road Transportation Sector using a Macro economic model

Presentation by
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Workshop on "Decarbonising Transport in India: DTEE + NDC-TIA"
International Transport Forum (ITF)
23 February 2021

15
IRADe Integrated Research and Action for Development

Model methodology

- The IRADe-IAM model is a multi-sectoral, inter temporal dynamic optimization model (Parikh J and Ghosh P, 2009)
  - bottom-up -includes multiple alternative technology options,
  - top-down -covers the whole economy.
- Social Accounting Matrix (SAM) for the year 2007-08 represents the economy and the inter sectoral linkages.
- The USP of the model is that it captures the changing commodity consumption patterns for different levels of per capita household expenditure using a Non-linear demand structure (Parikh et al 2016) and the structural change that comes in the economy due to growth which particularly impacts Energy and Transport demand.
- The Transport sector in the model –
  - Railways
  - Road Transport
  - Water transport
  - Air Transport
  - Auxiliary transport related activities.
- Road Transport sector services is provided by three technologies activities –
  1) conventional technology based on petroleum products
  2) Electricity based transportation
  3) Gas based transportation.
- Model outputs as drivers of Transport demand
  - Freight transport demand corresponds to the intermediate demand for transport sectors by other economic sectors in their production process
  - Public transport demand corresponds to consumption demand for road and rail transport output by the private households and government.
  - Private transportation demand corresponds to household's expenditure on energy (petroleum products) for transportation.
  - The model outputs in value terms are used as indicators and their growth rates used to project public and private passenger transport demand in PKM and freight transport demand in TKM.

Mathematical Formulation:

Model Outputs:

- Per capita total consumption expenditure $PCTC_t$
- Household consumption expenditure on Petroleum products $HCPP_t$
- Household consumption expenditure on Electricity $HCEL_t$
- Household consumption expenditure on Road transport $HCRT_t$

Estimated Shares

Share of Petroleum products expenditure by households for Transport purposes in total expenditure on Petroleum products $S^T_{pp,t}$

Share of Petrol expenditure by households for Transport purposes $S^T_{p,t}$

Share of Diesel expenditure by households for Transport purposes $S^T_{d,t}$

Share of household expenditure on Taxis $S^T_{T,t}$

Share of household expenditure on Autos(3W) $S^T_{A,t}$

Share of household expenditure on Bus $S^T_{B,t}$

For each share $S^T_{i,t}$ listed above we estimate $Ln(S^T_{i,t}) = \alpha + \beta * PCTC_t$

Estimated Expenditures

Household consumption expenditure on Petroleum products for transportation $HCPPT_t = S^T_{pp,t} * HCPP_t$

Household consumption expenditure on Petrol HCP_t, $HCP_t = S^T_{p,t} * (HCPP_t + HCRT_t)$

Household consumption expenditure on Diesel HCD_t, $HCD_t = S^T_{d,t} * (HCPP_t + HCRT_t)$

Household consumption expenditure on fuel for private cars HCC_t, $HCC_t = \lambda^{PT}_{c,t} * HCPPT_t$

Household consumption expenditure on fuel for Scooters & Bikes HCS_t, $HCS_t = \lambda^{PT}_{s,t} * HCPPT_t$

Household consumption expenditure on transportation by taxis HCT_t, $HCT_t = S^T_{T,t} * (HCPP_t + HCRT_t)$

Household consumption expenditure on transportation by Autos HCA_t, $HCA_t = S^T_{A,t} * (HCPP_t + HCRT_t)$,

Household consumption expenditure on transportation by Bus HCB_t, $HCB_t = S^T_{B,t} * (HCPP_t + HCRT_t)$

Assumption, parameters and data sources

The share of Cars ($\lambda_{c,t}^{PT}$) and 2 wheelers ($\lambda_{s,t}^{PT}$) in total household energy (petroleum products) expenditure for transport is calculated using

- Assumed vehicle Kms
- specific fuel consumption of Cars & 2W
- Projected vehicle ownership of households for Cars and 2 Ws up to 2050 based on a NCAER household survey (Parikh and Parikh (2016)).

The other shares and parameters are estimated using data from the report on" Household Consumption of Various Goods and Services In India" for the years 2004-05, 2009-10 and 2011-12 which provides the household expenditure on petrol, diesel, LPG and Kerosene for cooking purposes and transport purposes for different categories of expenditure classes.

Based on the above calculated expenditures, on road vehicles for,

cars is computed as $V_t^c = V_0^c * (1 + GR_{HCC})^t$,

2 wheelers as $V_t^s = V_0^s * (1 + GR_{HCS})^t$

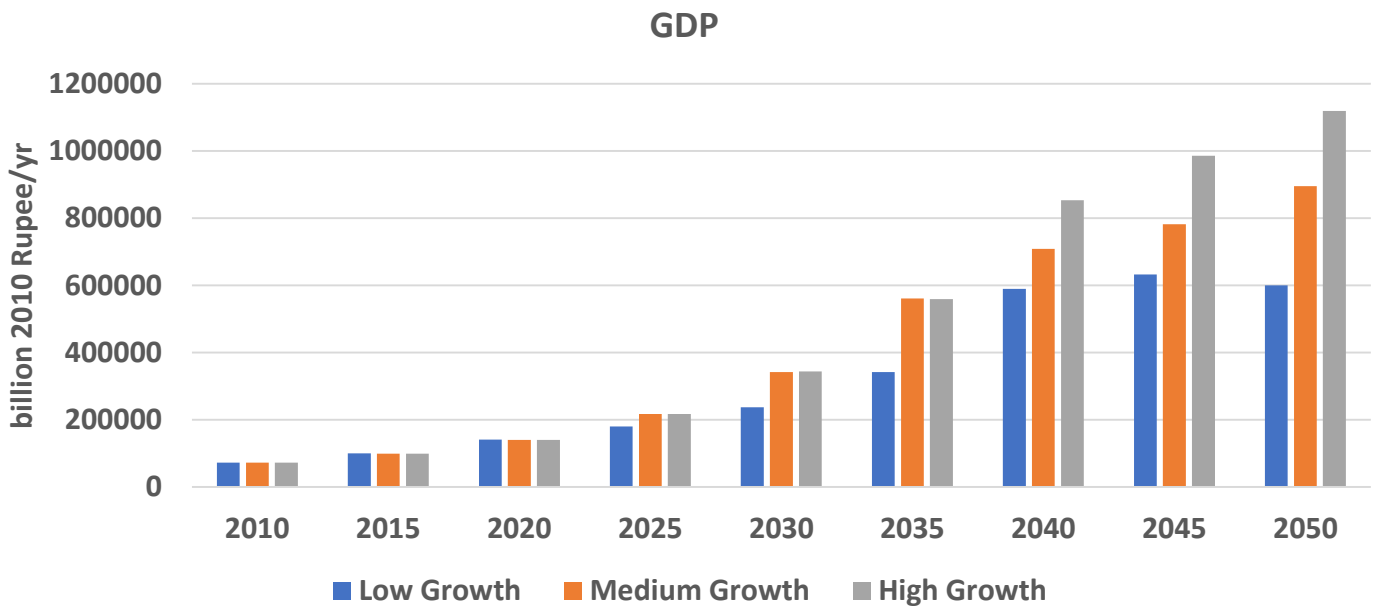
Taxis is computed as $V_t^T = V_0^T * (1 + GR_{HCT})^t$,

Autos as $V_t^A = V_0^A * (1 + GR_{HCA})^t$

and for buses is computed as $V_t^B = V_0^B * (1 + GR_{HCB})^t$

		Passenger	
	Vehicle in Use in 2007-08	Productivity	occupancy
2W	29.24	10001	1.2
3W	0.85	31400	2
LDV	4.99	11251	2.37
Taxis	0.48	11251	2.37
Bus	0.43	88135	33.75
		Freight	
	Vehicle in Use in 2007-08	Productivity	tonnage
LMV	0.75	25500	1.93
Trucks & lorries	2.61	45000	5
HMV	0.35	45000	6

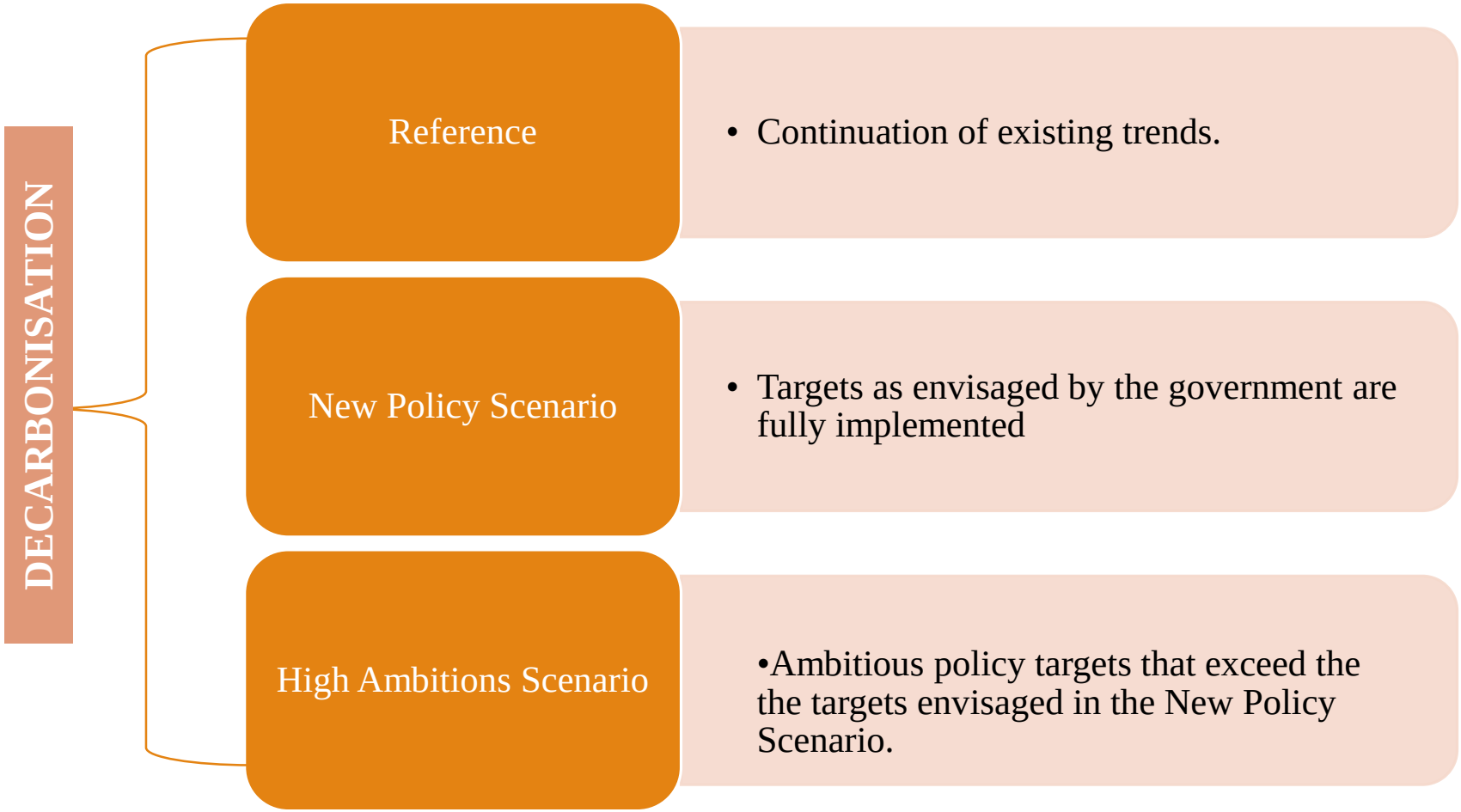
Socio-economic Assumptions



million	2010	2015	2020	2025	2030	2035	2040	2045	2050
Population	1231	1309	1383	1452	1513	1565	1605	1637	1659

- **GDP growth scenarios were based on based on NITI Aayog's assumptions od Low economic Growth (5.8%), Medium Economic Growth (6.7%) and High Economic Growth (7.3%) from 2011-2047.**
- **IRADe model was used to simulate GDP scenario with CAGR close to the NITI Aayog's assumed growth rates.**
- **Population for India up to 2050, which is a exogenous input to the model was assumed from the UN Medium variant projection**

Common Set of Scenarios Modelled across teams



CMP Targets

Targets for Strategy #1: Decarbonising Road and Railway Transport Sectors through Electrification

Targets	New Policy Scenario			High Ambitions Scenario		
	2020	2030	2050	2020	2030	2050
% share of total battery electric vehicles in new two-wheeler sales	10%	30%	30%	15%	50%	80%
% share of total battery electric vehicles in new car sales	2%	3%	5%	5%	20%	30%
% share of total battery electric vehicles in new vehicle sales for buses	2%	10%	20%	5%	20%	40%
% share of electric traction vs. diesel traction in total passenger movement by rail	60%	70%	80%	80%	90%	100%
% share of electric traction vs. diesel traction in total freight movement by rail	70%	80%	100%	90%	100%	100%

Targets for Strategy #2: Increased Use of Alternative Fuels for Transport

Key Elements of Strategies	Targets	New Policy Scenario			High Ambitions Scenario		
		2020	2030	2050	2020	2030	2050
Increased bio-ethanol blending in petrol	% share of bio-ethanol blending in petrol	4%	10%	10%	7%	20%	20%
Increased bio-diesel blending in diesel	% share of bio-diesel blending in diesel respectively	0.1%	5%	5%	1.5%	5%	5%

Targets for Strategy #3: Modal Shifts

Key Elements of Strategies	Targets	New Policy Scenario			High Ambitions Scenario		
		2020	2030	2050	2020	2030	2050
Increased share of public transport for passenger movement	% share of public transport vehicles (buses and three-wheelers) vis-à-vis personalised vehicles in road based passenger movement	75%	80%	85%	90%	90%	95%
Increased share of railways	% share of rail transport vis-à-vis road transport in total passenger movement	15%	15%	15%	20%	20%	20%

Targets for Strategy #4: Increased Fuel Efficiency for Vehicle Categories

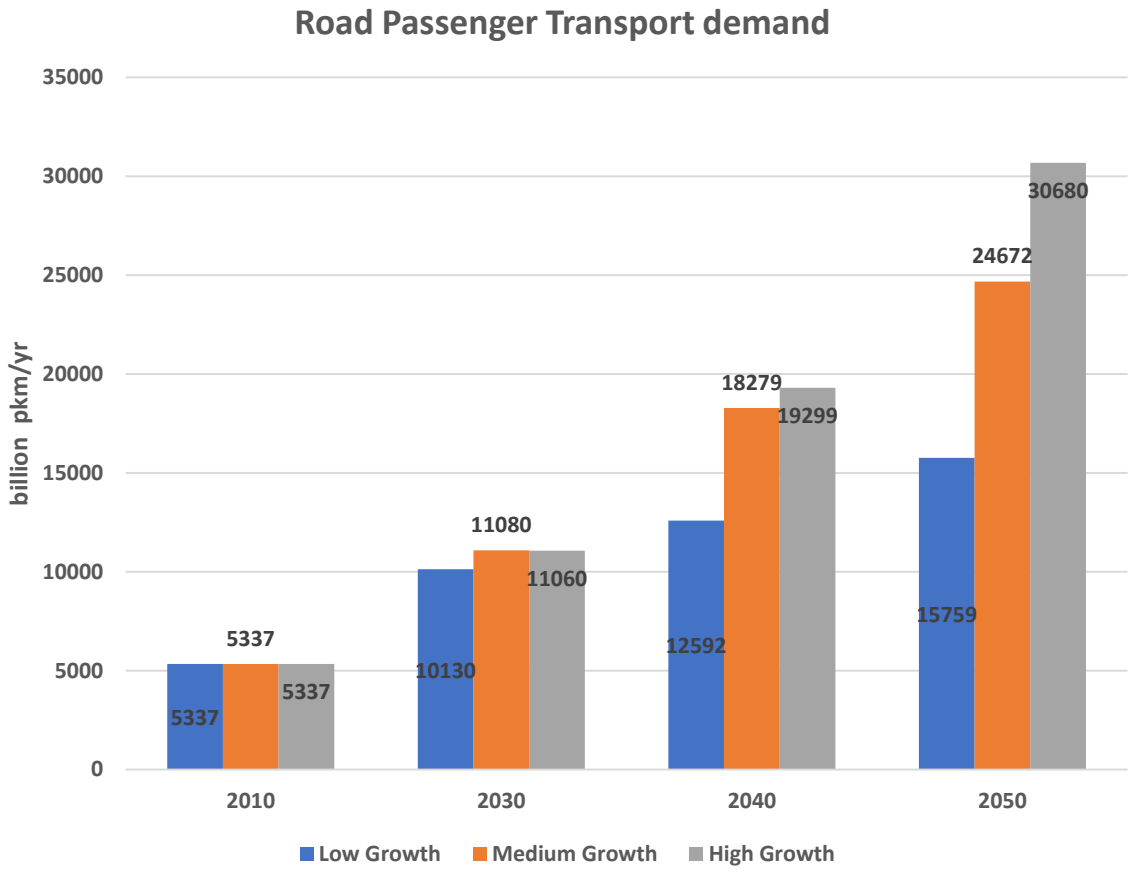
Targets	New Policy Scenario			High Ambitions Scenario		
	2020	2030	2050	2020	2030	2050
4 Wheelers (Passenger cars of all size classes)	Increase in fuel efficiency by 25% from 2017-18 levels till 2021-22, 15% increase in fuel efficiency from 2021-22 onwards till 2030, then constant at 2030 levels			Increase in fuel efficiency by 30% from 2017-18 levels till 2021-22, 20% increase in fuel efficiency from 2021-22 onwards till 2030, then constant at 2030 levels		
Buses and Trucks	Increase in fuel efficiency by 25% from 2019-20 onwards till 2030; then constant at 2030 levels			Increase in fuel efficiency by 30% from 2019-20 onwards till 2030; then constant at 2030 levels		
Passenger rail	Improvement in Specific Energy Consumption (SEC), 4.8% in passenger segment from 2013-14 levels			Improvement in SEC of 8% in passenger segment from 2013-14 levels		
Freight rail	Improvement in SEC of 13.2% in freight segment from 2013-14 levels			Improvement in SEC of 20% in freight segment from 2013-14 levels		

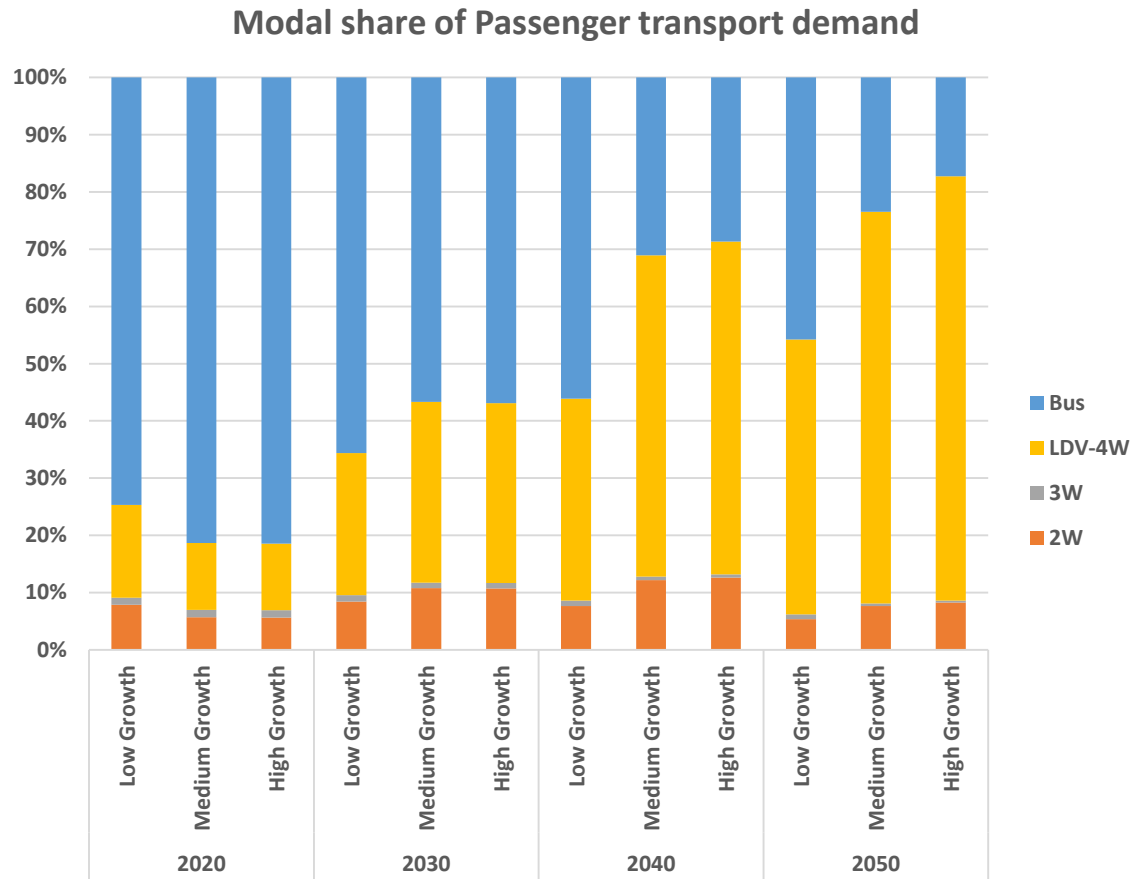
Targets for Strategy #5: Moderating Motorised Transport Demand

New Policy Scenario		High Ambitions Scenario	
2030	**2050**	**2030**	**2050**
10% reduction in demand for motorized transport	15% reduction in demand for motorized transport by 2050	15% reduction in demand for motorized transport	20% reduction in demand for motorized transport

Reference scenario and projections

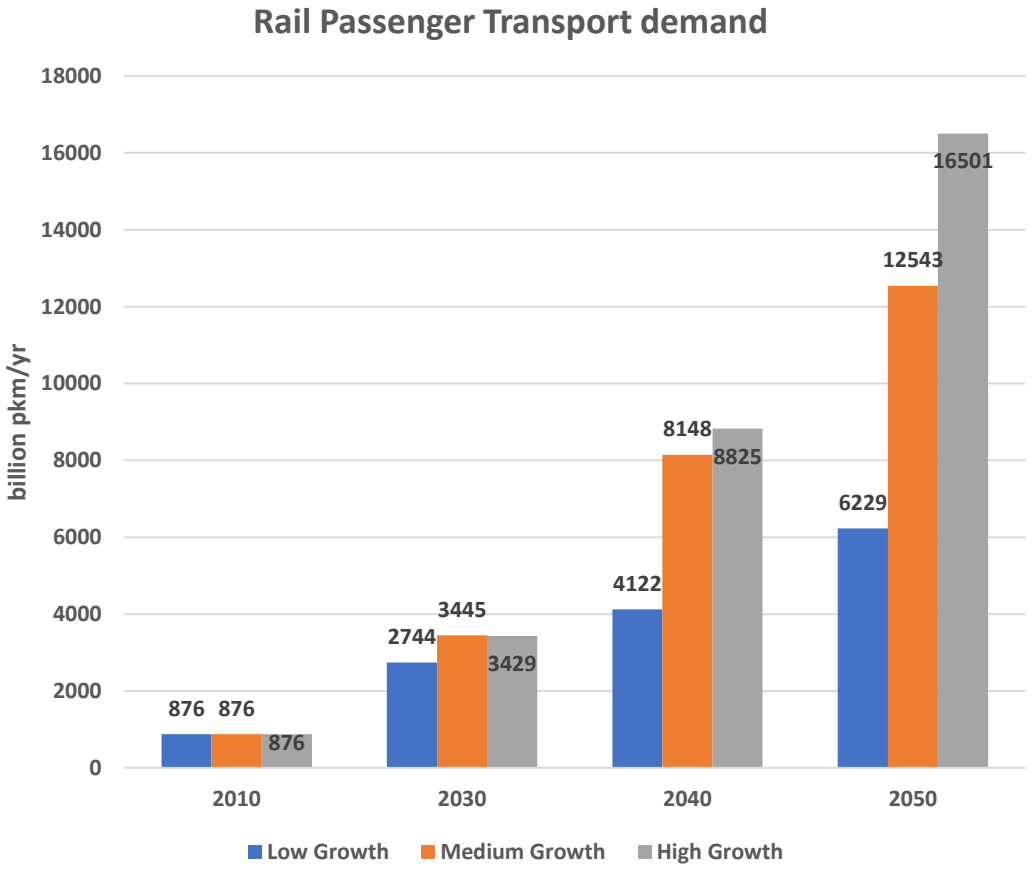
Road Passenger Transport Demand

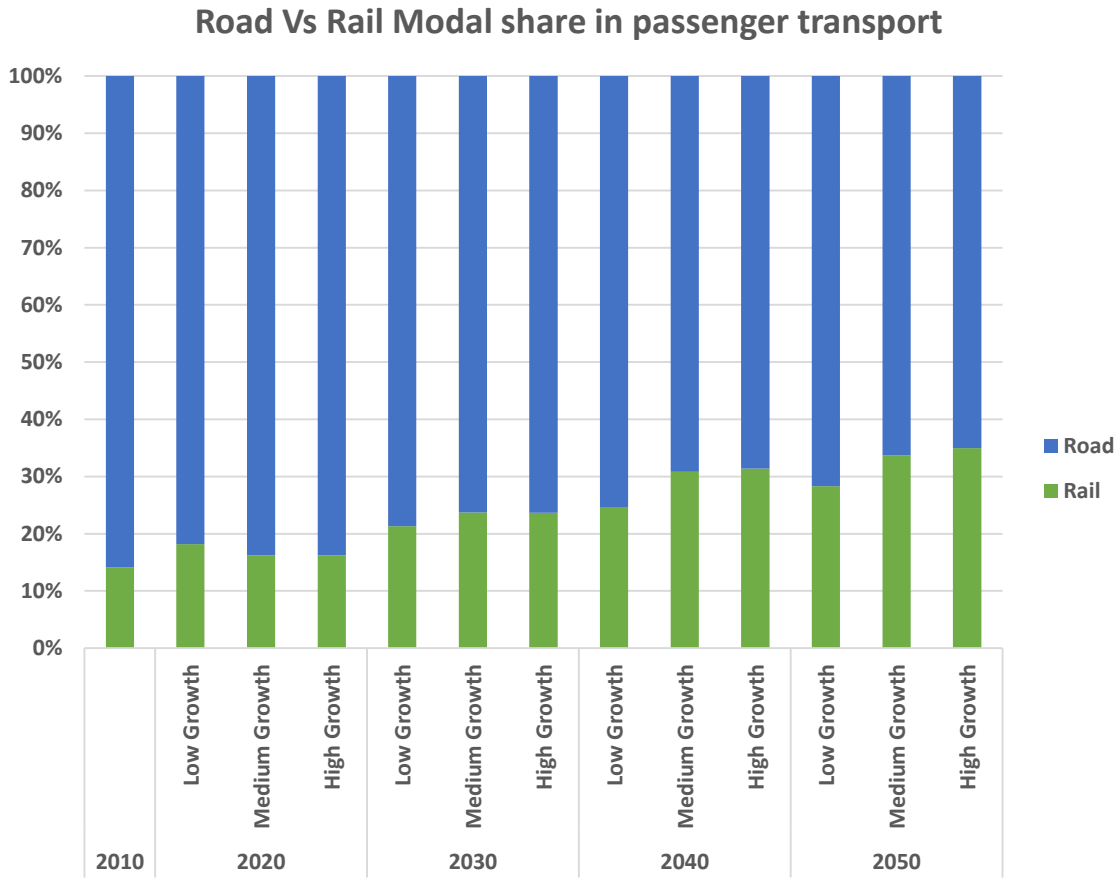




- **Demand increases by 3.3% in Low growth scenario and 3.7% in medium and high growth scenario from 2010 to 2030**
- **Demand increases by 2.23%, 4.08% and 5.23% for Low, medium and high growth scenarios From 2030-2050.**
- **The share of bus decreases over time and with economic growth**
- **The share of private cars increases over time with economic growth.**

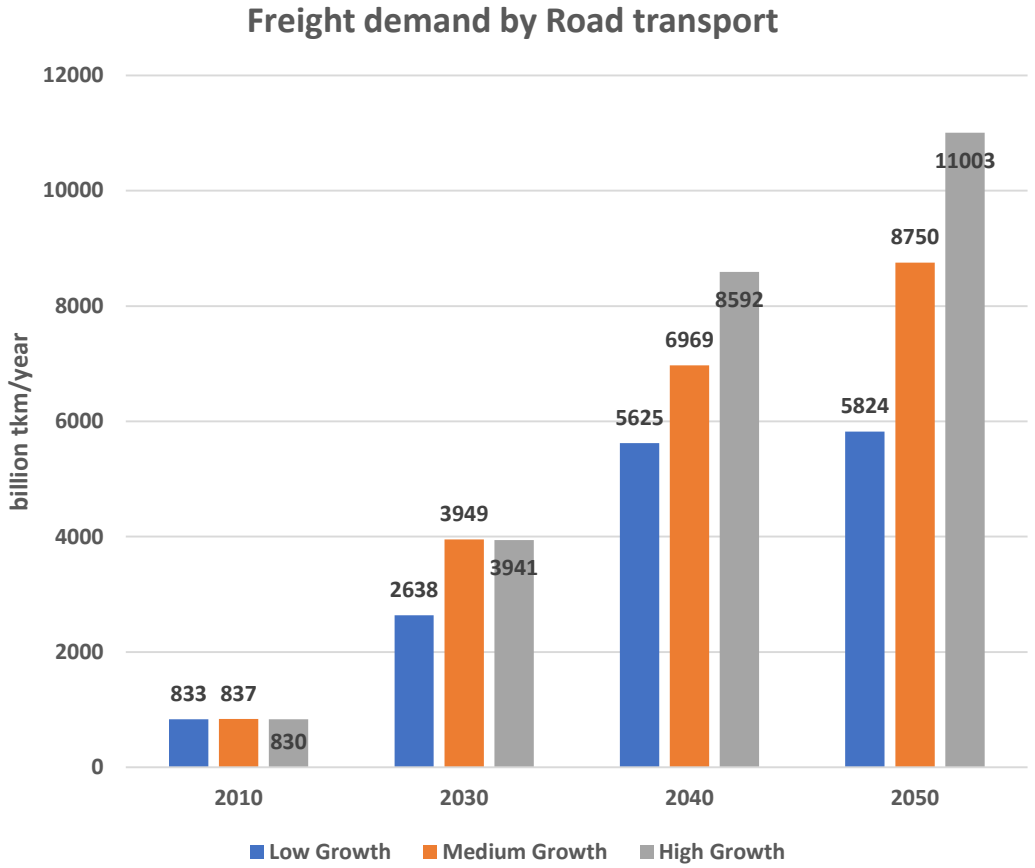
Rail Passenger Transport demand

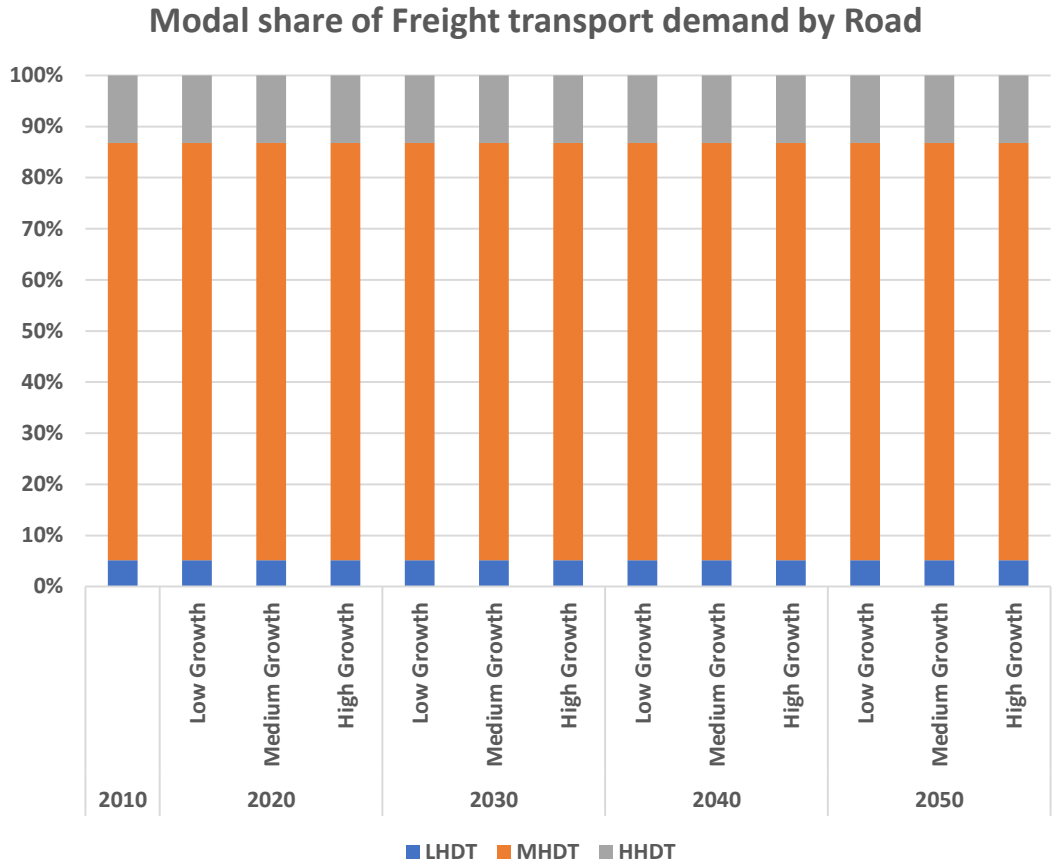




- **Demand increases by 5.88%, 7.09% and 7.06% for Low, medium and high growth scenarios from 2010 to 2030**
- **Demand increases by 4.18%, 6.67% and 8.17% for Low, medium and high growth scenarios From 2030-2050.**
- **The share of rail is projected to increase over time and with economic growth**

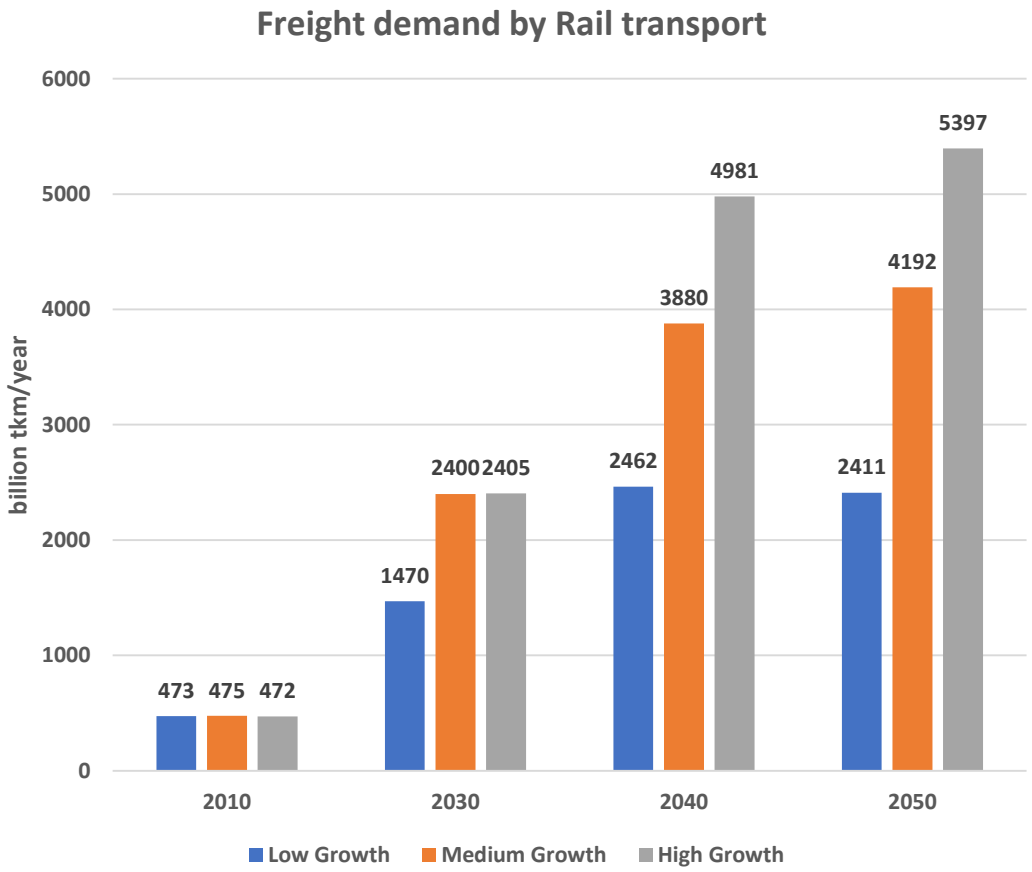
Road Freight Transport Demand

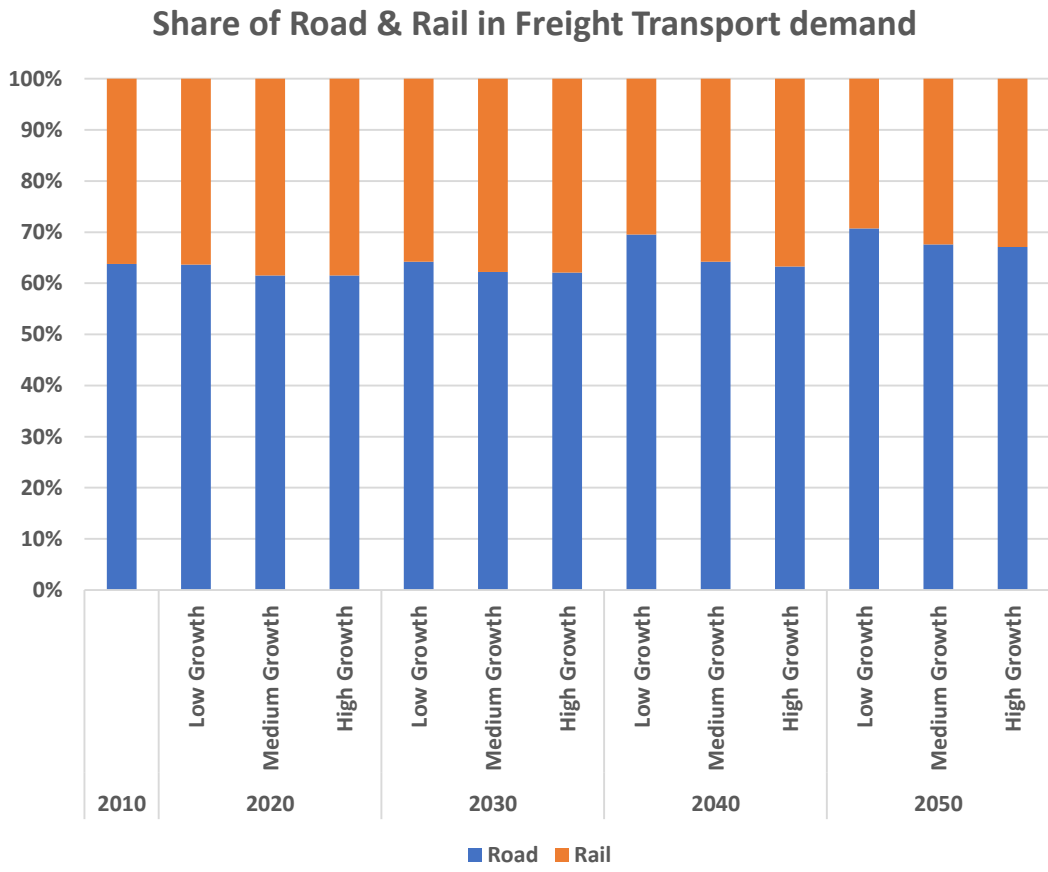




- **Demand increases by 5.94%, 7.09% and 7.06% for Low, medium and high growth scenarios from 2010 to 2030**
- **Demand increases by 4.04%, 4.06% and 5.27% for Low, medium and high growth scenarios From 2030-2050.**
- **MHDT has the most dominant share in freight through road and is projected to continue to be so**

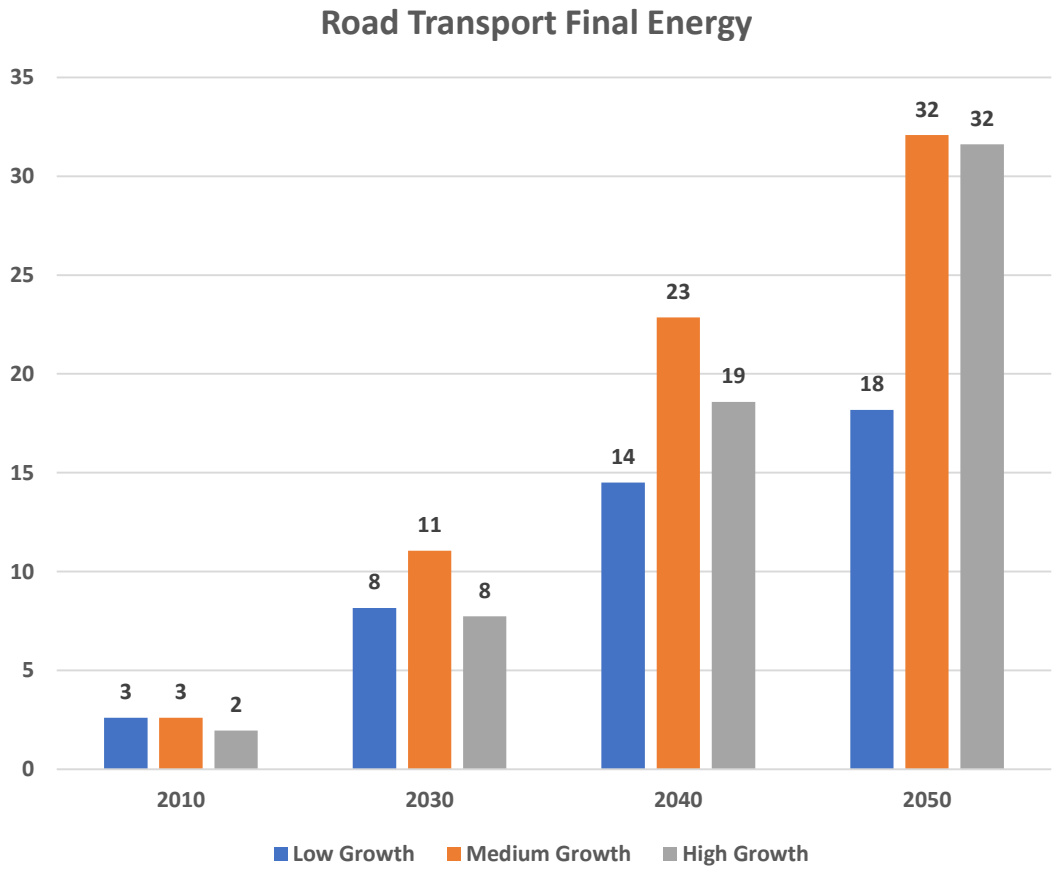
Rail Freight Transport Demand

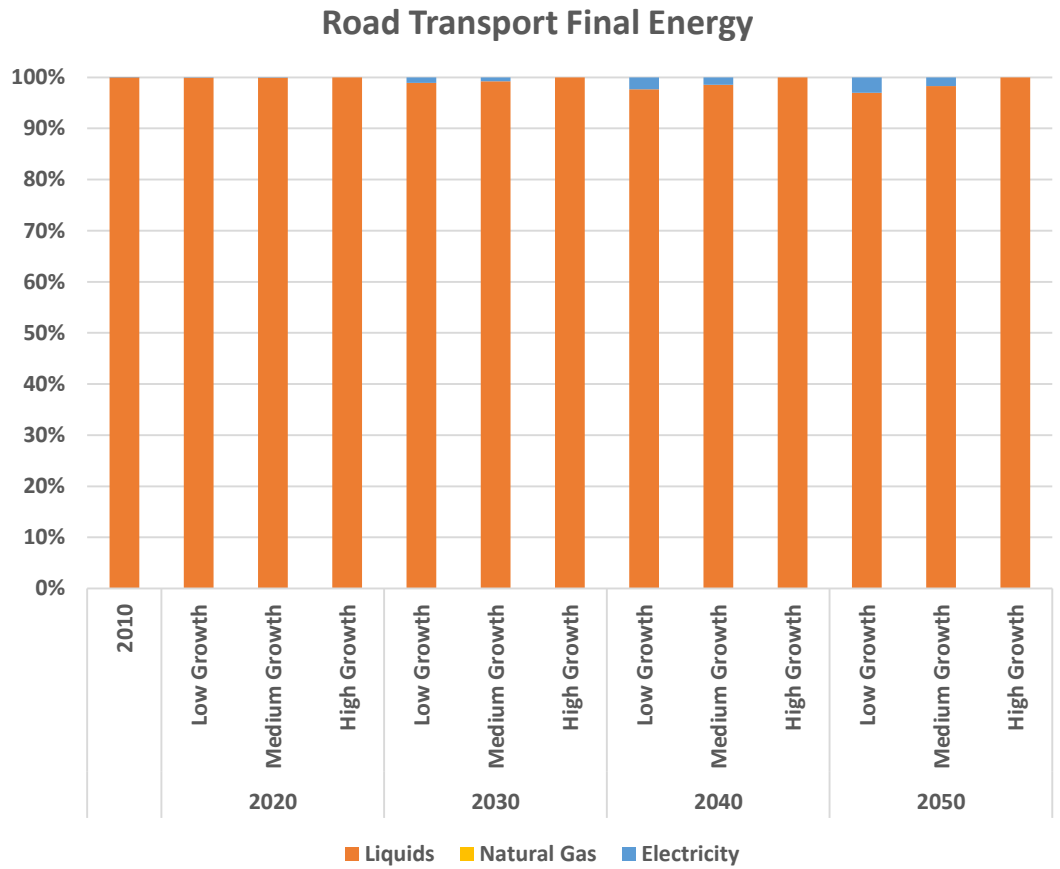




- **Demand increases by 5.84%, 8.44% and 8.49% for Low, medium and high growth scenarios from 2010 to 2030**
- **Demand increases by 2.51%, 2.83% and 4.12% for Low, medium and high growth scenarios From 2030-2050.**
- **Projected share of rail and road in freight is stable under all scenario from 62-65%.**

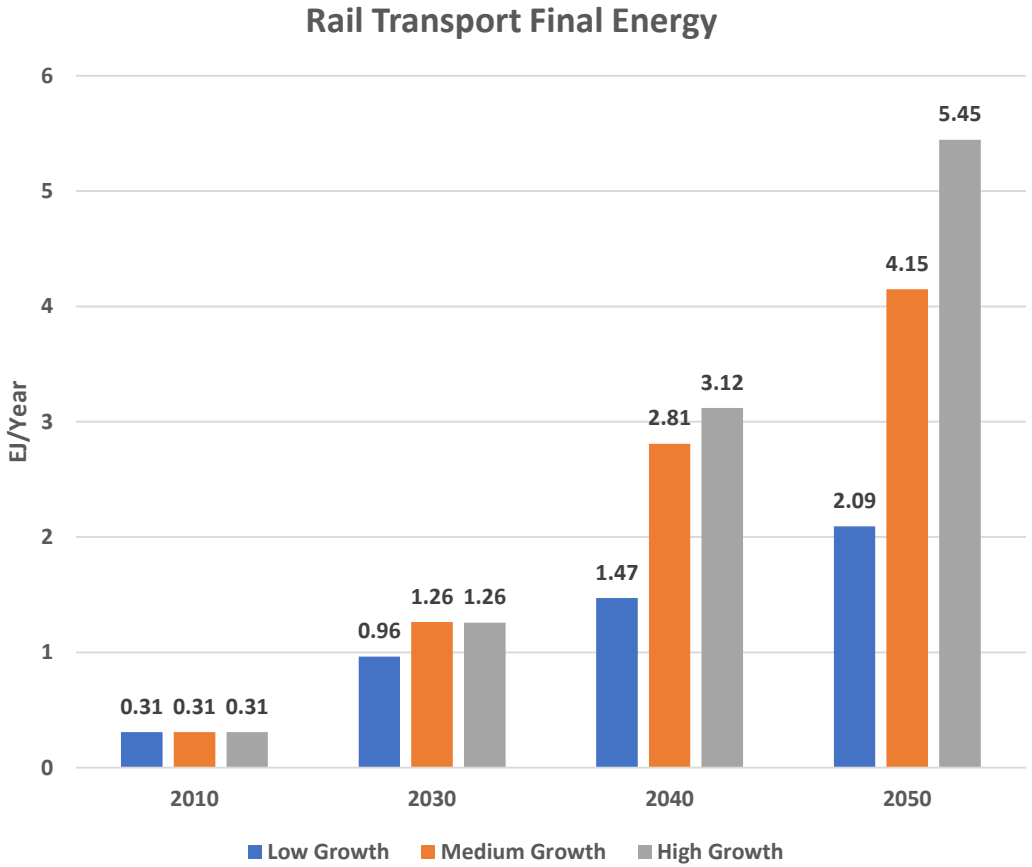
Final Energy consumption-Road

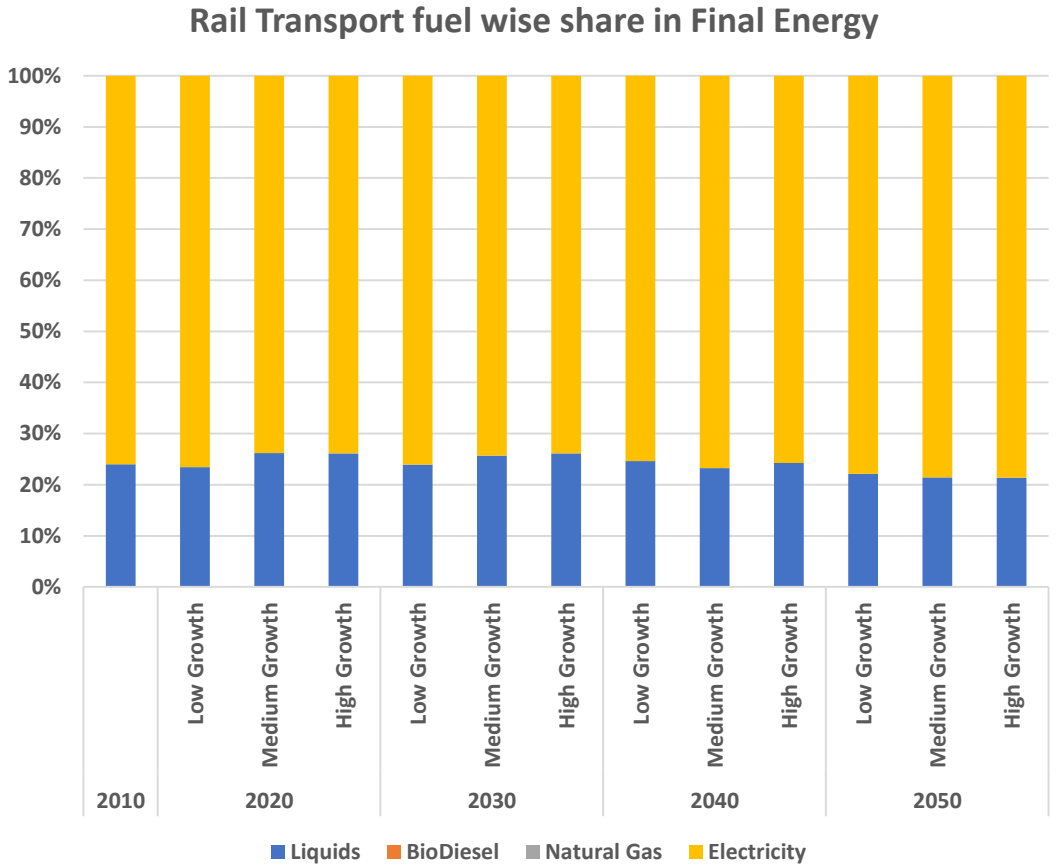




- **Demand increases by 5.87%, 7.48% and 7.11% for Low, medium and high growth scenarios from 2010 to 2030**
- **Demand increases by 4.08%, 5.47% and 7.29% for Low, medium and high growth scenarios From 2030-2050.**
- **Road Transport sector is completely dominated by Petroleum products in the reference scenarios.**

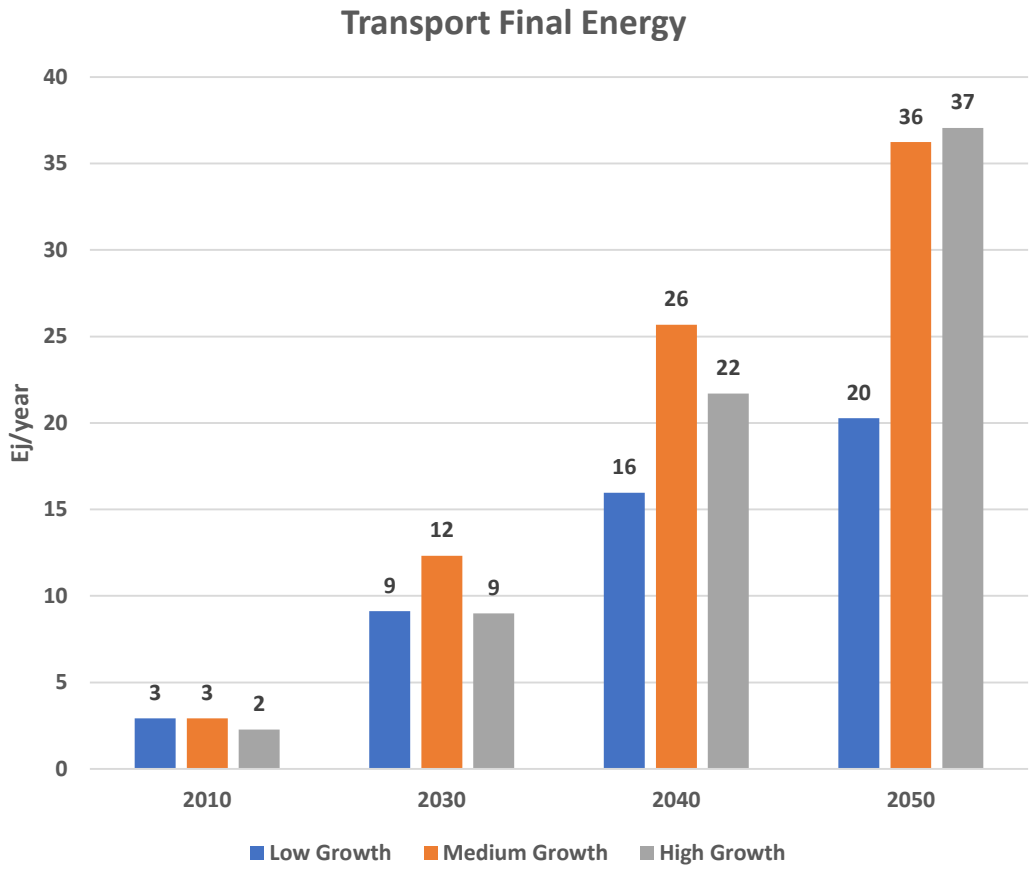
Final Energy consumption-Rail

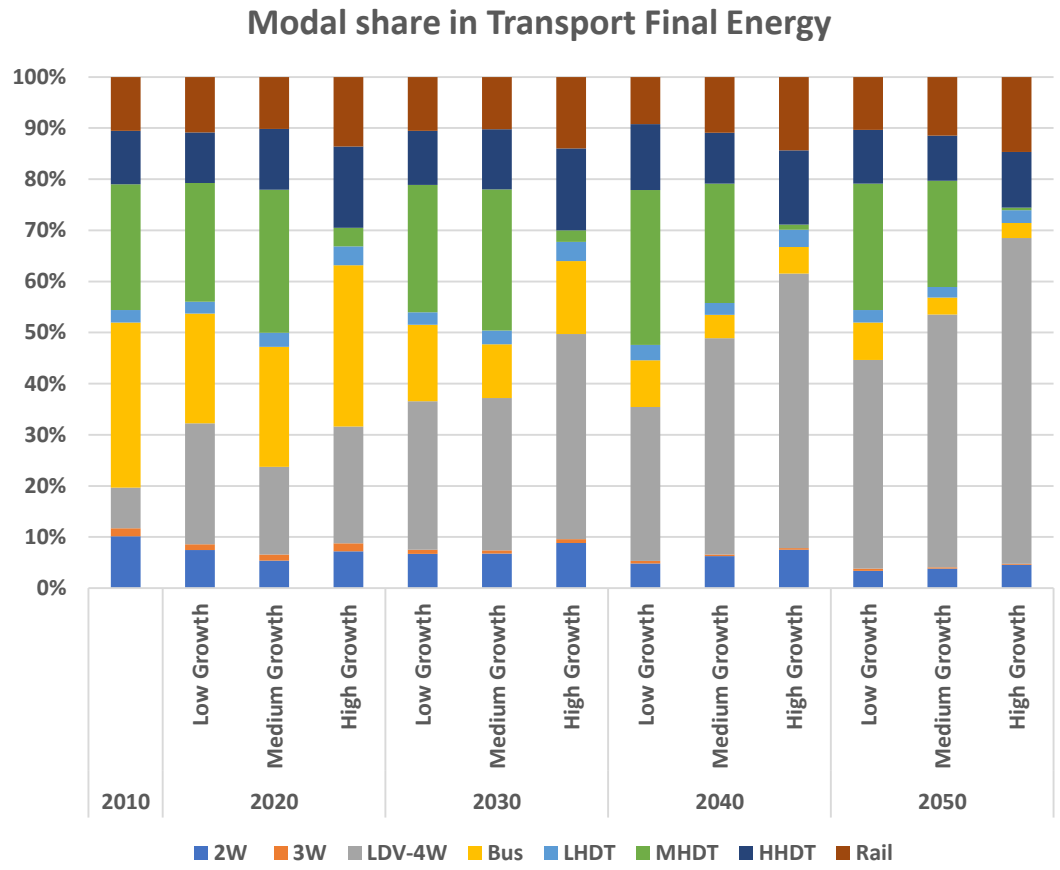




- Demand increases by 5.87%, 7.32% and 7.30% for Low, medium and high growth scenarios from 2010 to 2030
- Demand increases by 3.96%, 6.13% and 7.60% for Low, medium and high growth scenarios From 2030-2050.
- Rail Transport sector is dominated by electricity due to past and ongoing electrification program.
- However some share of diesel based traction is assumed in the reference scenario

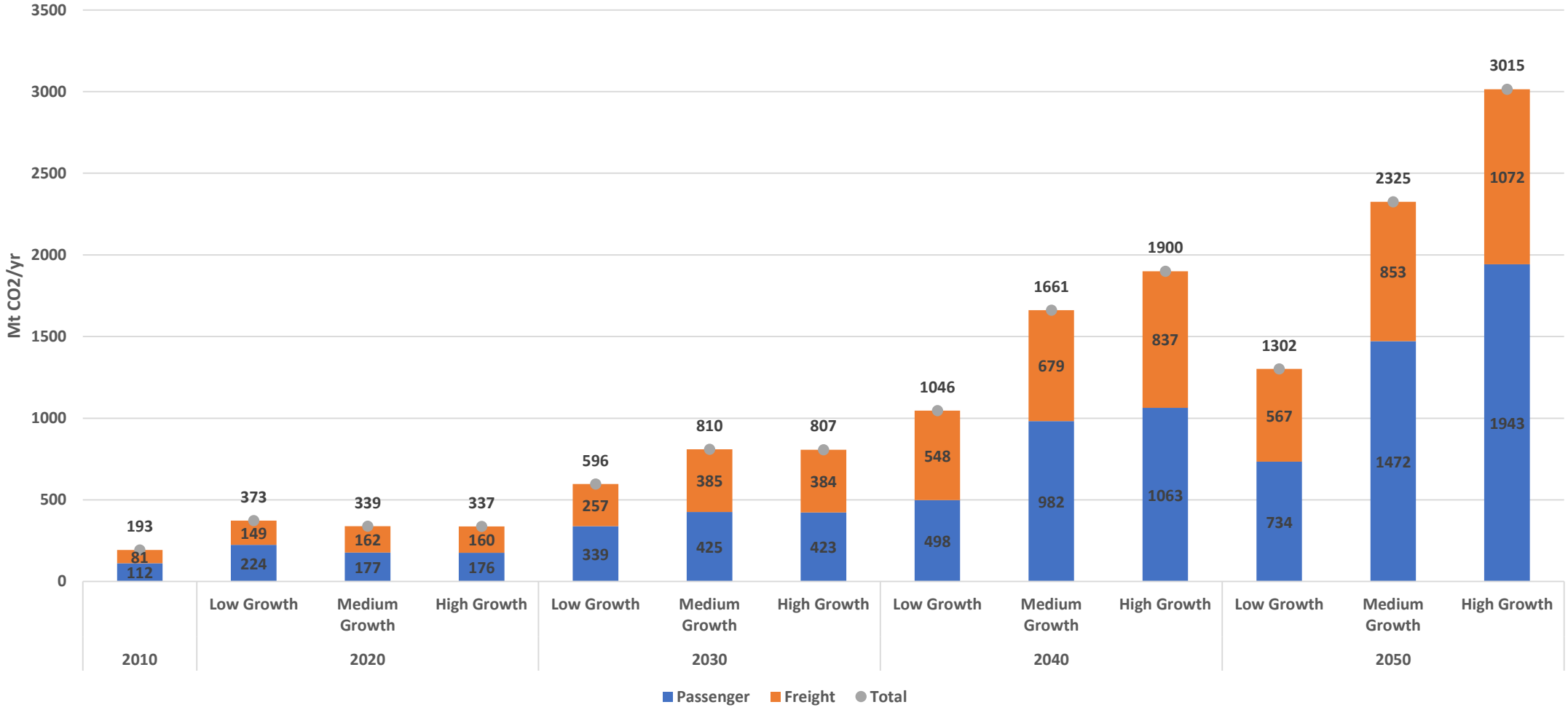
Final Energy consumption





- **Demand increases by 5.87%, 7.46% and 7.14% for Low, medium and high growth scenarios from 2010 to 2030**
- **Demand increases by 4.07%, 5.54% and 7.33% for Low, medium and high growth scenarios From 2030-2050.**
- **Share of 2W and busses in final energy consumption decrease over time.**
- **Share of Cars, HHDT and rail increase with economic growth.**

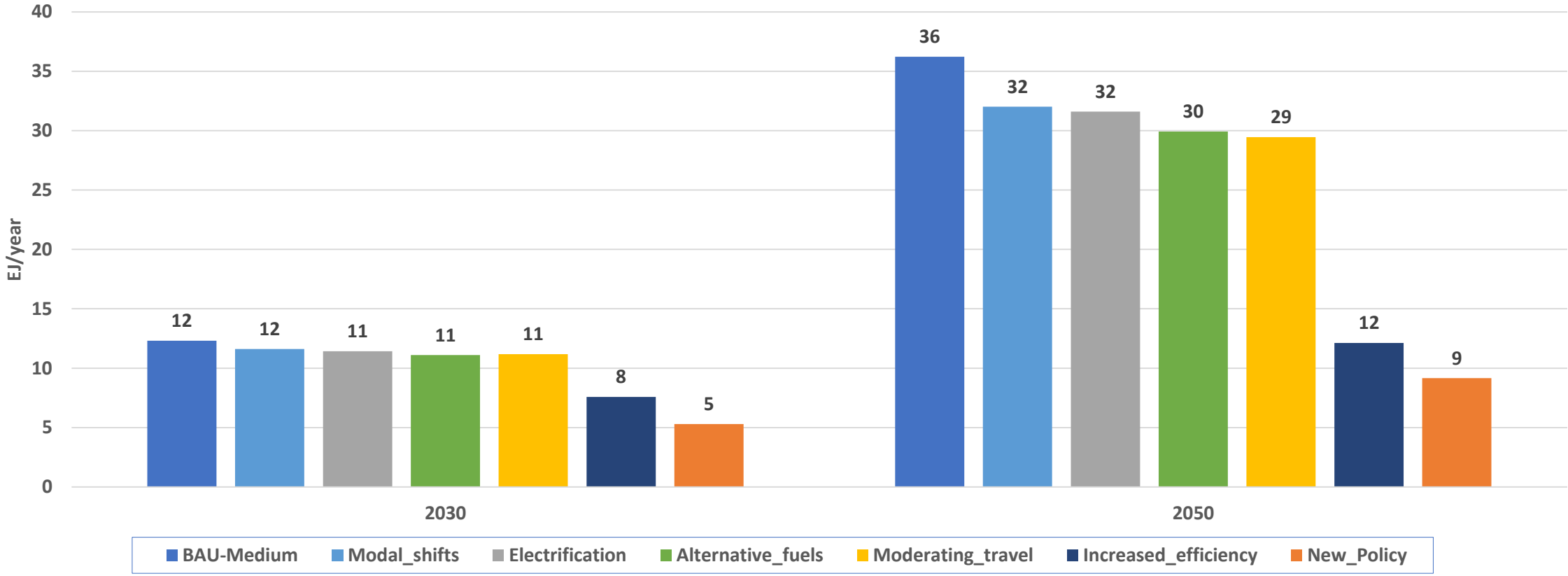
CO_2 emissions from Road



Emissions increase with economic growth with contributions from passenger transport increasing due to the increasing trend of use of private vehicles

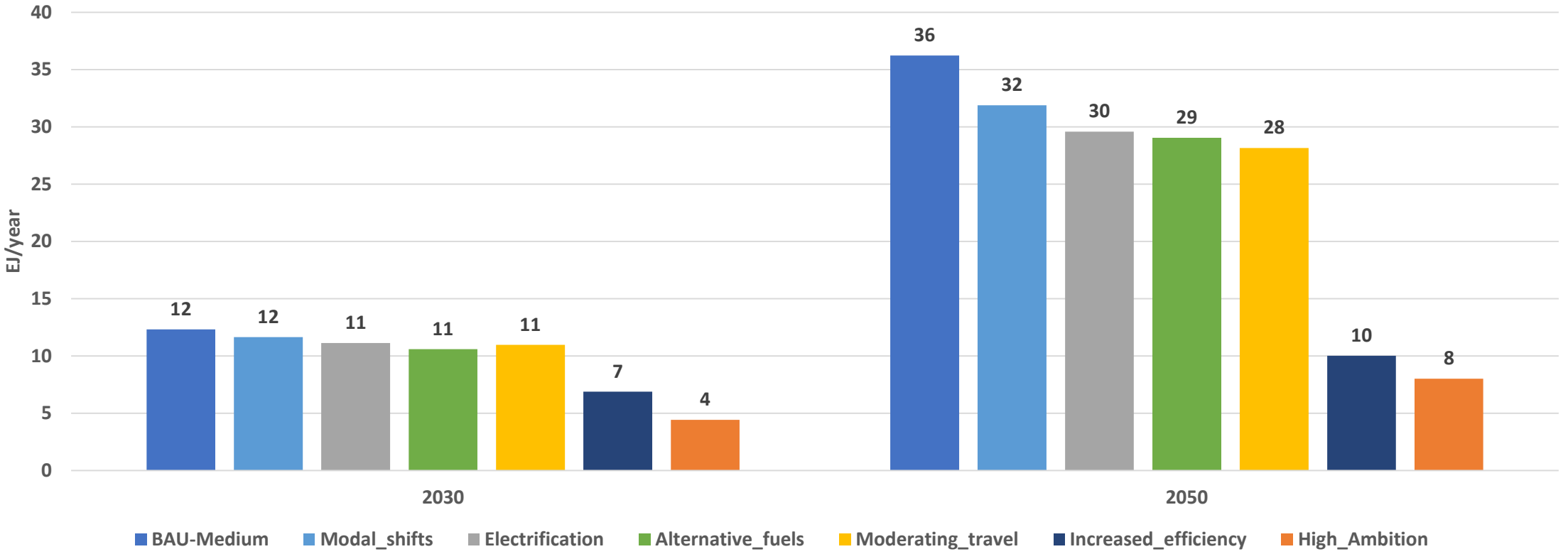
Impacts of Low carbon strategies

Transportation Final Energy under New Policy



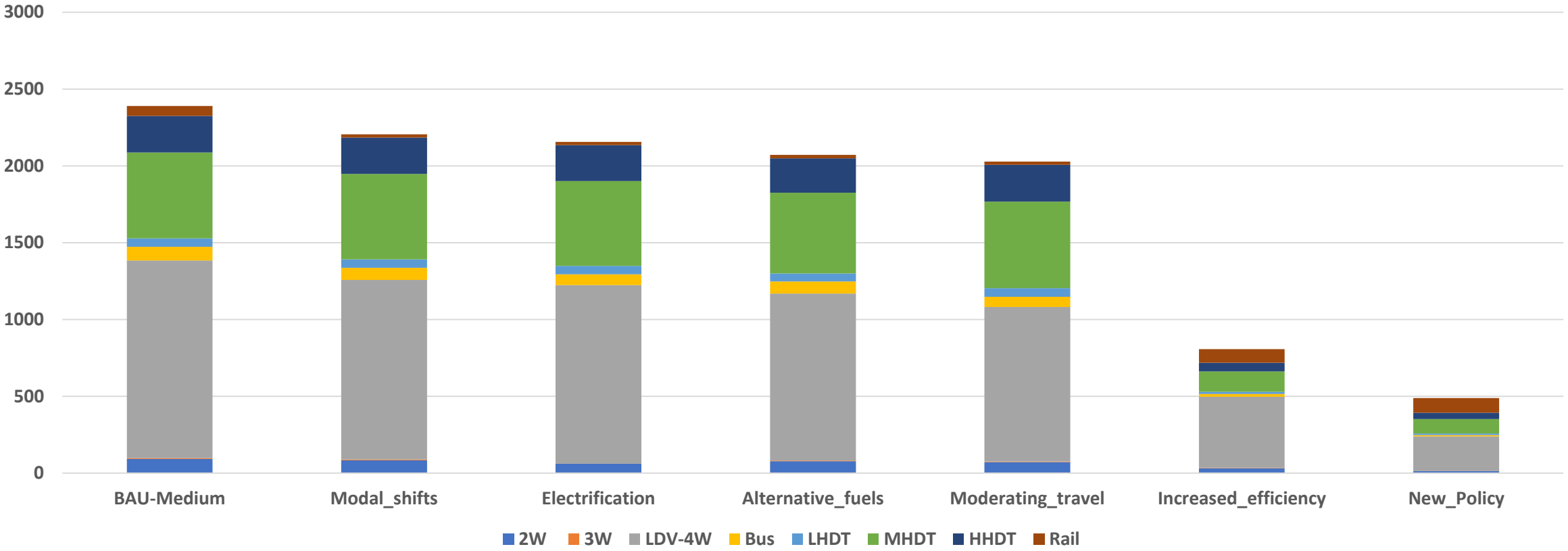
- In 2050, New policy reduces final energy by 75% with maximum reduction of 67% coming from increased efficiency
- Moderating travel reduces by 19%, Alternative fuel by 17%, electrification by 13% and modal shift by 12%

Transportation Final Energy under High Ambition



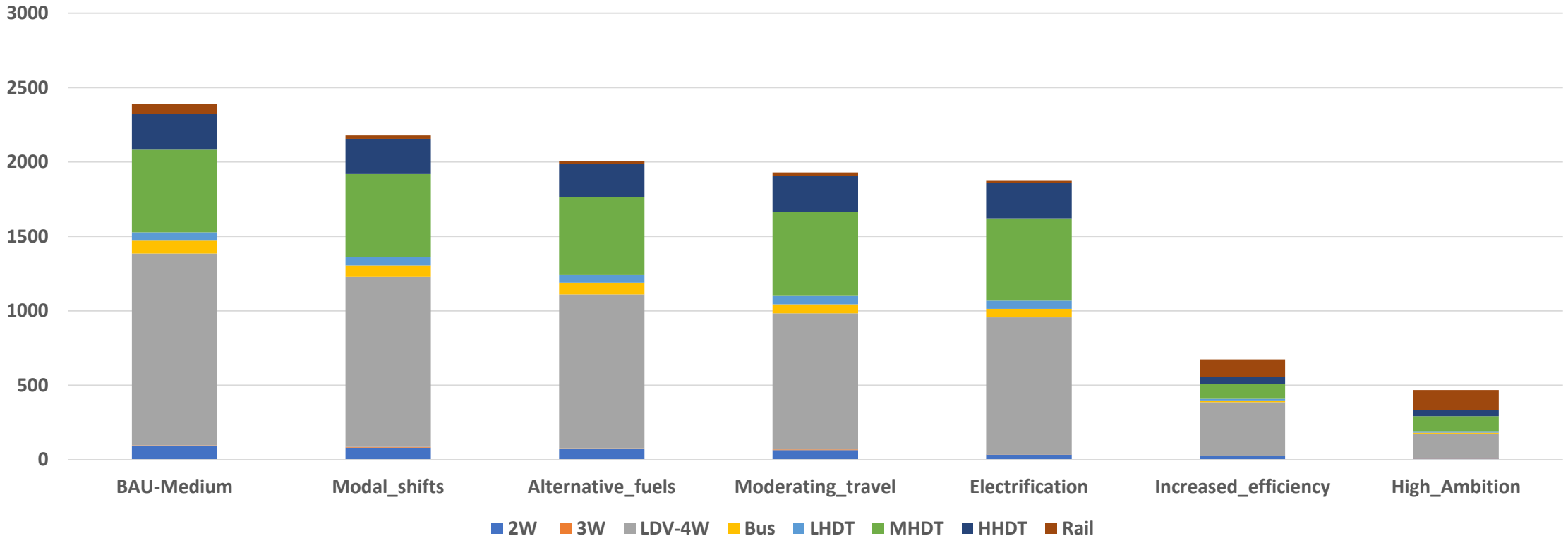
- **In 2050, New policy reduces final energy by 78% with maximum reduction of 72% coming from increased efficiency**
- **Moderating travel reduces by 22%, Alternative fuel by 20%, electrification by 18% and modal shift by 12%**
- **The reference scenario does not consider improvements in efficiency and hence the increase efficiency shows highest reduction.**

CO_2 mitigation under New Policy in 2050



2050	BAU-Medium	Modal shifts	Electrification	Alternative fuels	Moderating travel	Increased efficiency	New_Policy
CO2 emissions (MT)	2389	2206	2156	2071	2028	807	489
% reduction		8%	10%	13%	15%	66%	80%

CO_2 mitigation under High Ambition in 2050



2050	BAU-Medium	Modal shifts	Alternative fuels	Moderating travel	Electrification	Increased efficiency	High Ambition
CO2 emissions(MT)	2389	2177	2007	1929	1877	673	467
% reduction		9%	16%	19%	21%	72%	80%

Conclusions and recommendations

- **As a policy, increased efficiency seems to be the most effective for transport sector, however if consider that significant efficiency measures are already in place, others seem important strategies to consider**
- **Modal shift and Alternative Fuels seem to be the 2 very relevant strategies for decarbonisation in the transport sector**
- **Modal shifts is cost efficient but may be more difficult to implement and require larger public sector investments and infrastructural requirements, while fuel efficiency is seen as being relatively easier to implement however with higher cost to the economy.**
- **The impact of electrification is observed to be significant only in the long run (by 2050). It has a very significant impact under the high ambition scenario targets compared to New policy targets**