Challenges and Policy Implications for Low Carbon Pathway for Kerala: An Integrated Assessment Modelling Approach

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Plan of the talk

- Objectives
- Research Framework
- Base Run
- Policy Run
- Concluding Remarks

Low carbon pathways for Kerala

- Two sides
    - Mitigation strategies
    - Abatement strategies

- Our focus - Mitigation strategies
    - It mainly involves sectors like power, transport, industries, and agriculture, which cumulatively contribute to 80 per cent of the emission in the state
    - Analysis to some extent needs to take into accounts happenings in the rest of the world
- Possible methodologies

Bottom up Energy Model

👍

Demand projections - exogenous input to model

These demands are usually projected externally for broad sectors like Agriculture, Industry, Transport, Residential and Commercial

- Sufficiently disaggregated to account for all the energy sources including characteristics of energy demand
- All existing/emerging technology choices can be captured
- Supply side attempts to meet these demands in an optimal way (least cost approach)
- Policy constraints such as environmental constraints, resource constraints, capacity constraints are captured in the model

👎

- Projected demand and overall SDP is exogenous
- Price is assumed to be unchanged in spite of changing demand
- Misses out on intra-sectoral economic impacts on the sectors

Top down Macro (CGE) Model

GDP and prices are endogenously determined

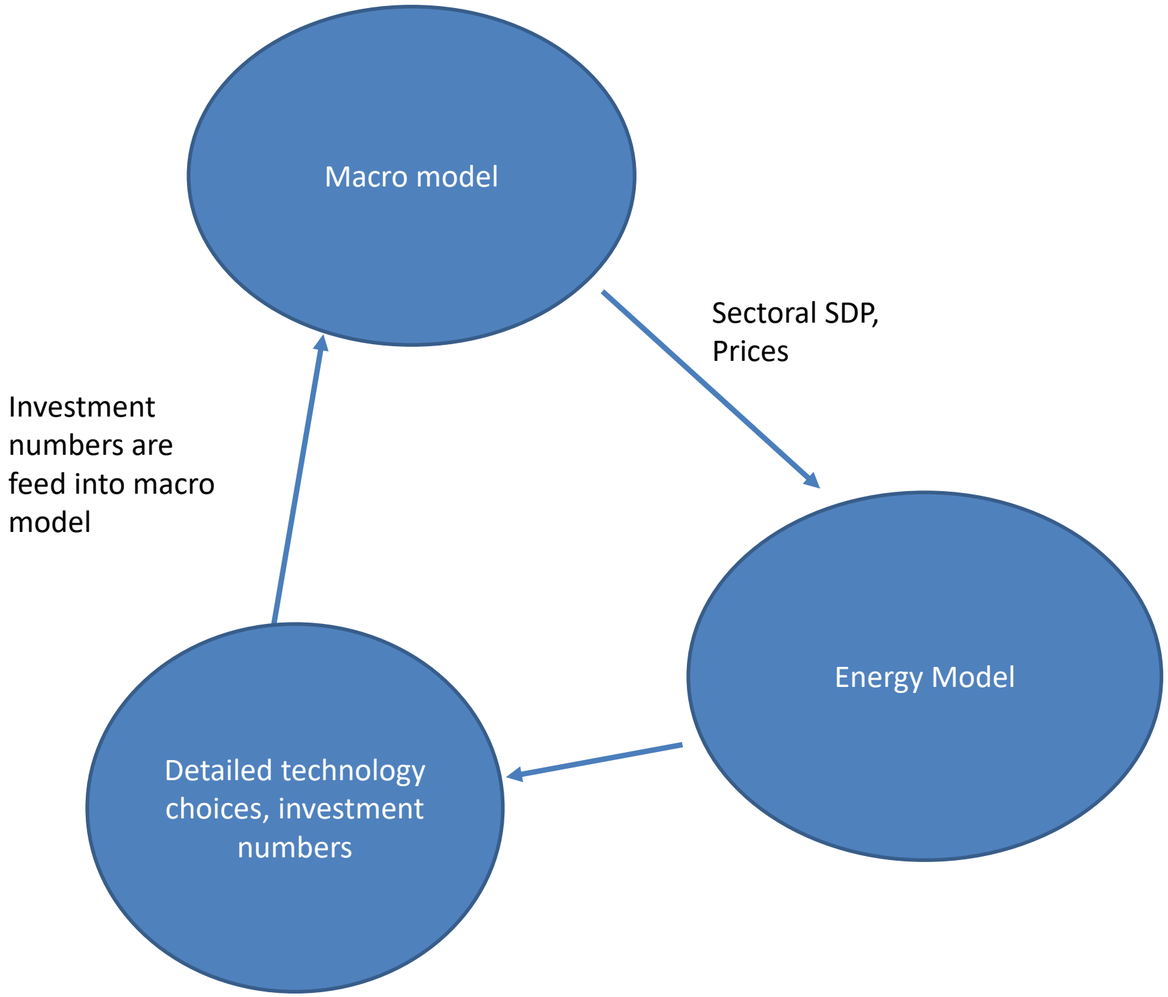
- Macro model provides consistent framework to assess sector linkages & trade-offs among different policies
- Explicitly captures cost build-up & associated price effects due to demand/supply gaps

- Data constraint does not permit incorporating all the possible technology choices
- Does not permit quantifying the energy needs in physical units

An Integrated Approach

Energy demands derived from macro model will reflect the impacts on sectors and their energy demand considering the whole network of economic interlinkages in a complete equilibrium state

Role of price is built into the system in future period depending on demand/supply situation

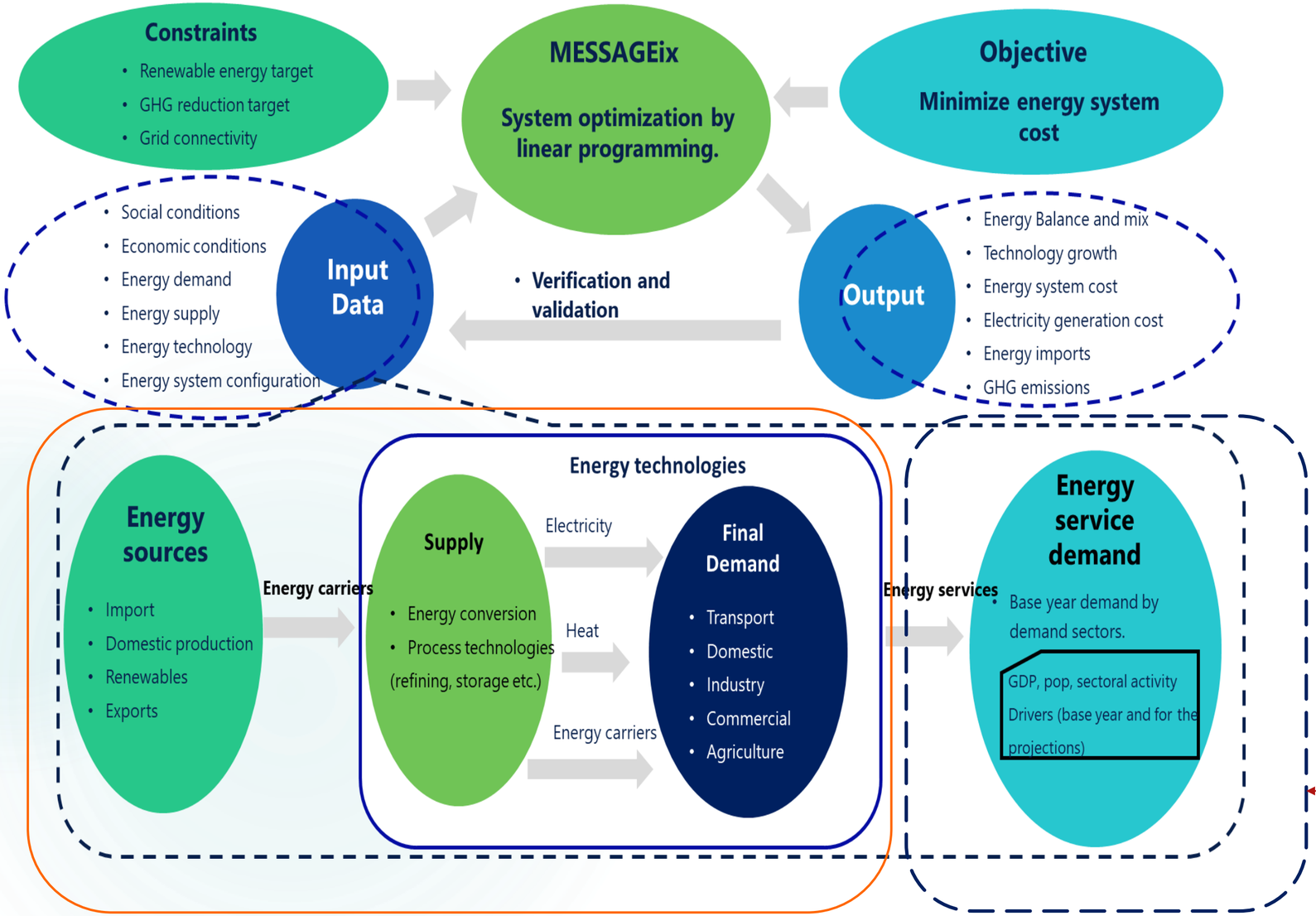


Elements of Integrated Model

- A top down multi-regional multi-sector macro (CGE model)
    - Region- Kerala, Rest of India, Rest of World (happening in rest of India matters!)
    - Patterned after GTAP power model
    - 49 sectors
    - Major sources of electricity are modelled as separate sectors

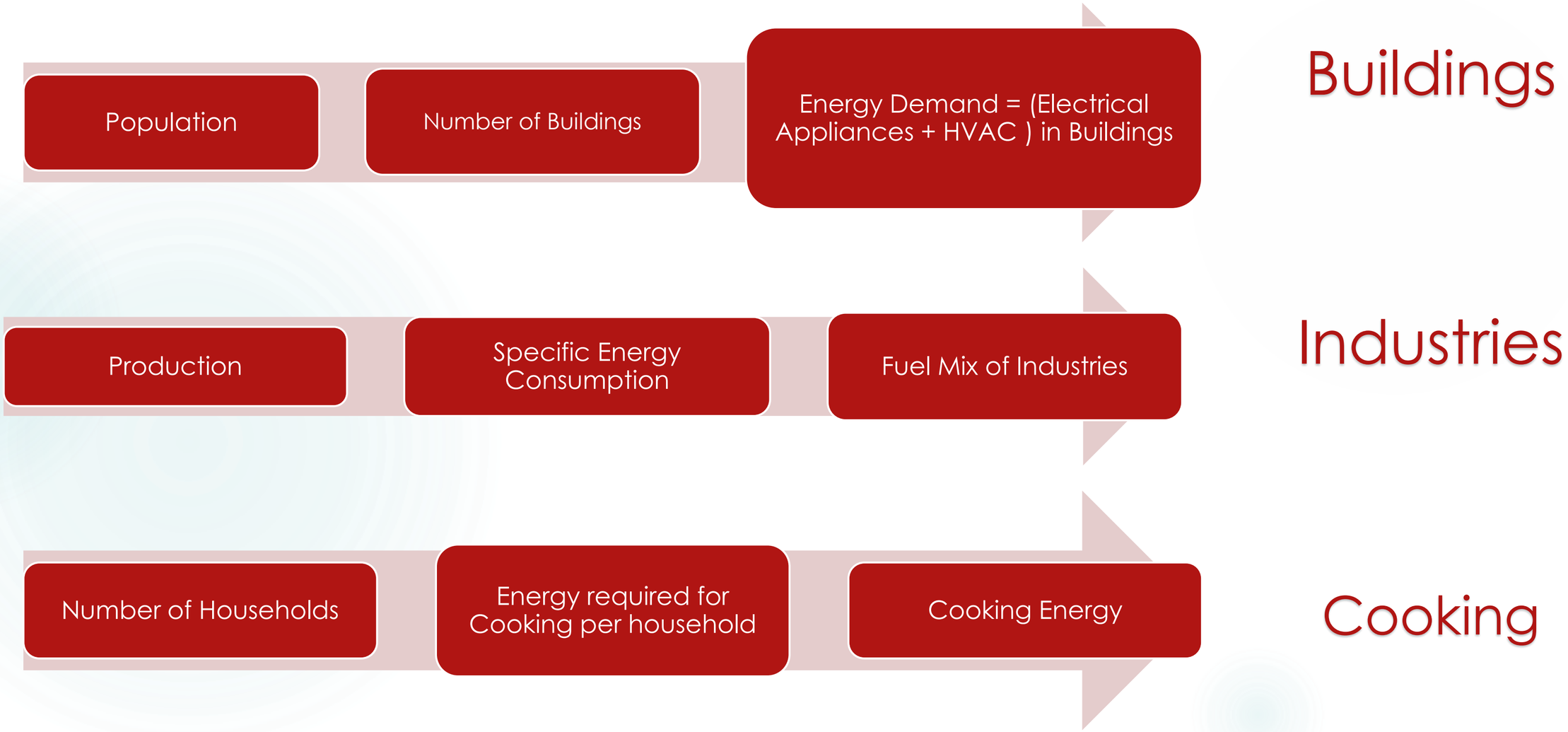
- A bottom up MESSAGEix Model
    - Model is constructed with sectors aligning to CGE sectors
    - Energy demand by broad categories- agriculture, cooking, building, industry, transport are estimated
    - Electricity capacity and energy mix are derived
    - All technologies (existing/emerging) are explored)

MESSAGEix Model structure used for India Model with IESS and GTAP link

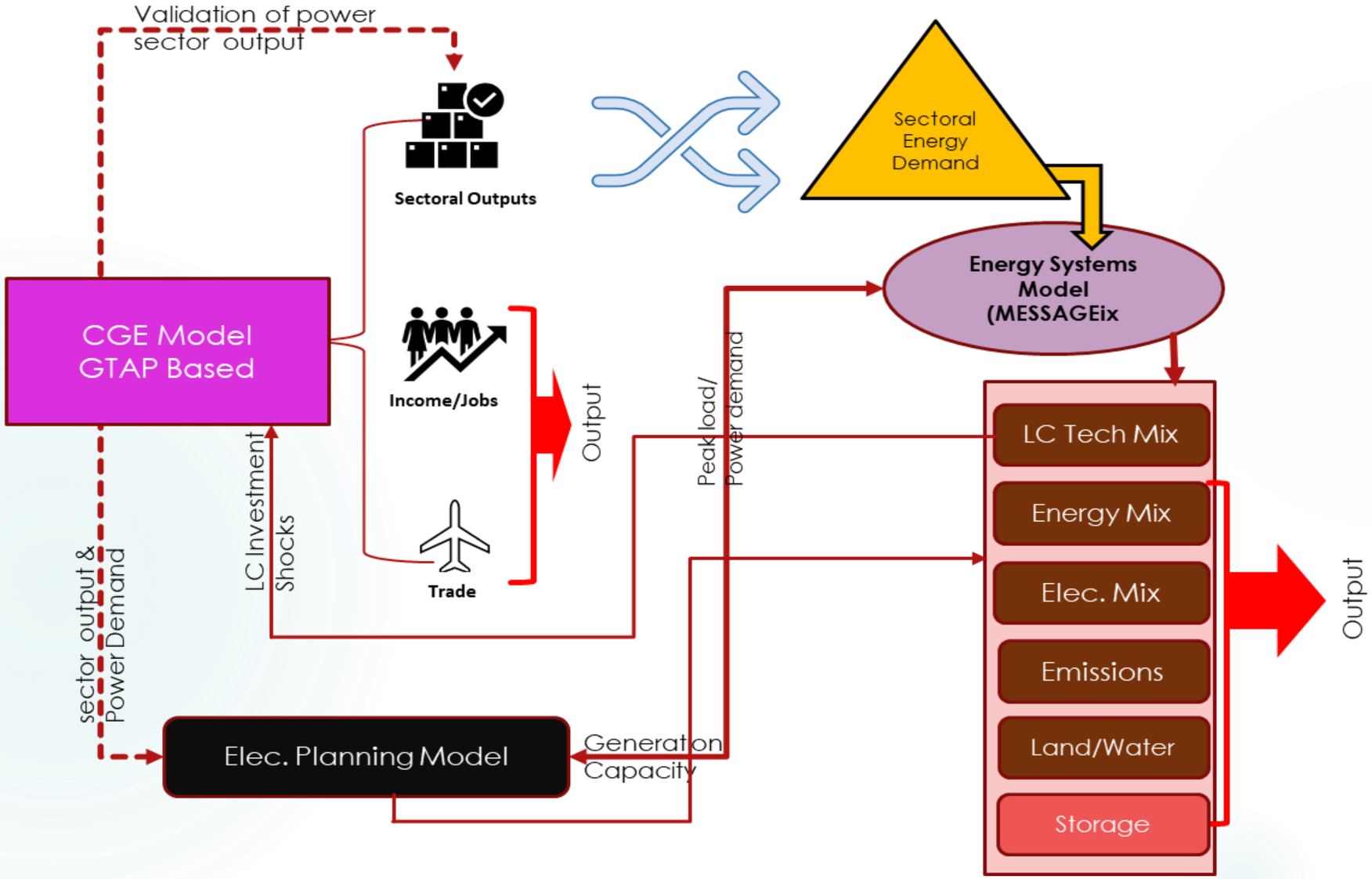


CGE Input

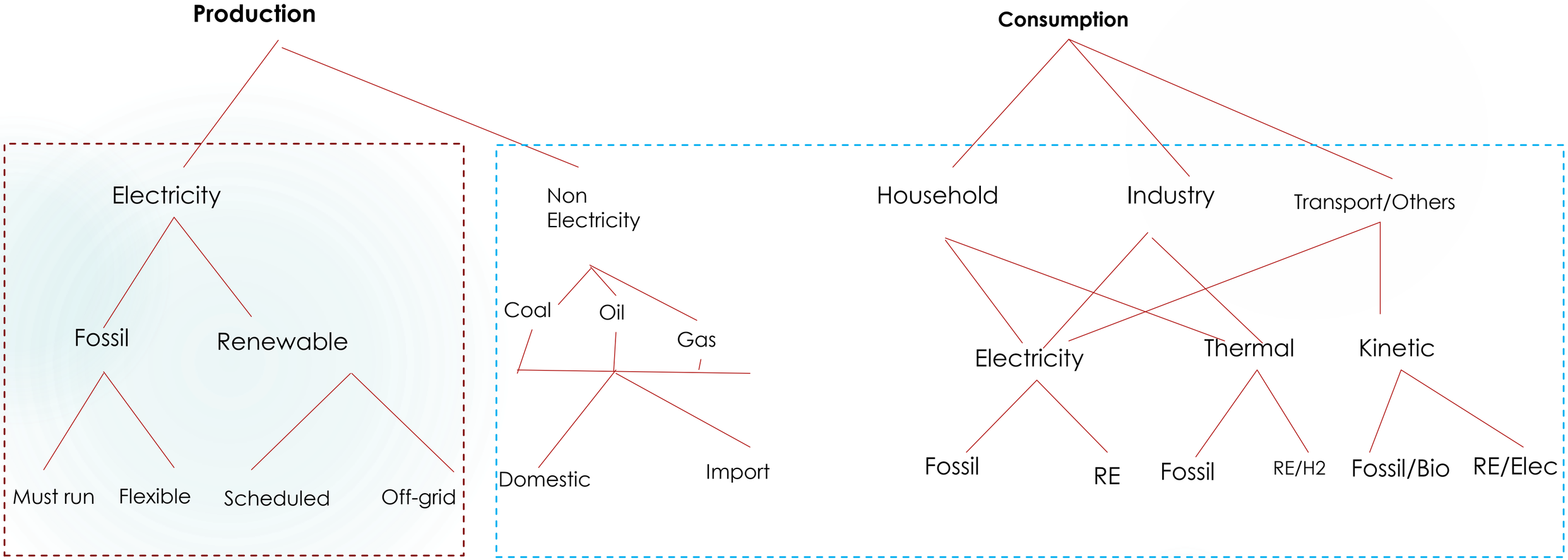
Linking approach and methodology



Integrated Model Framework



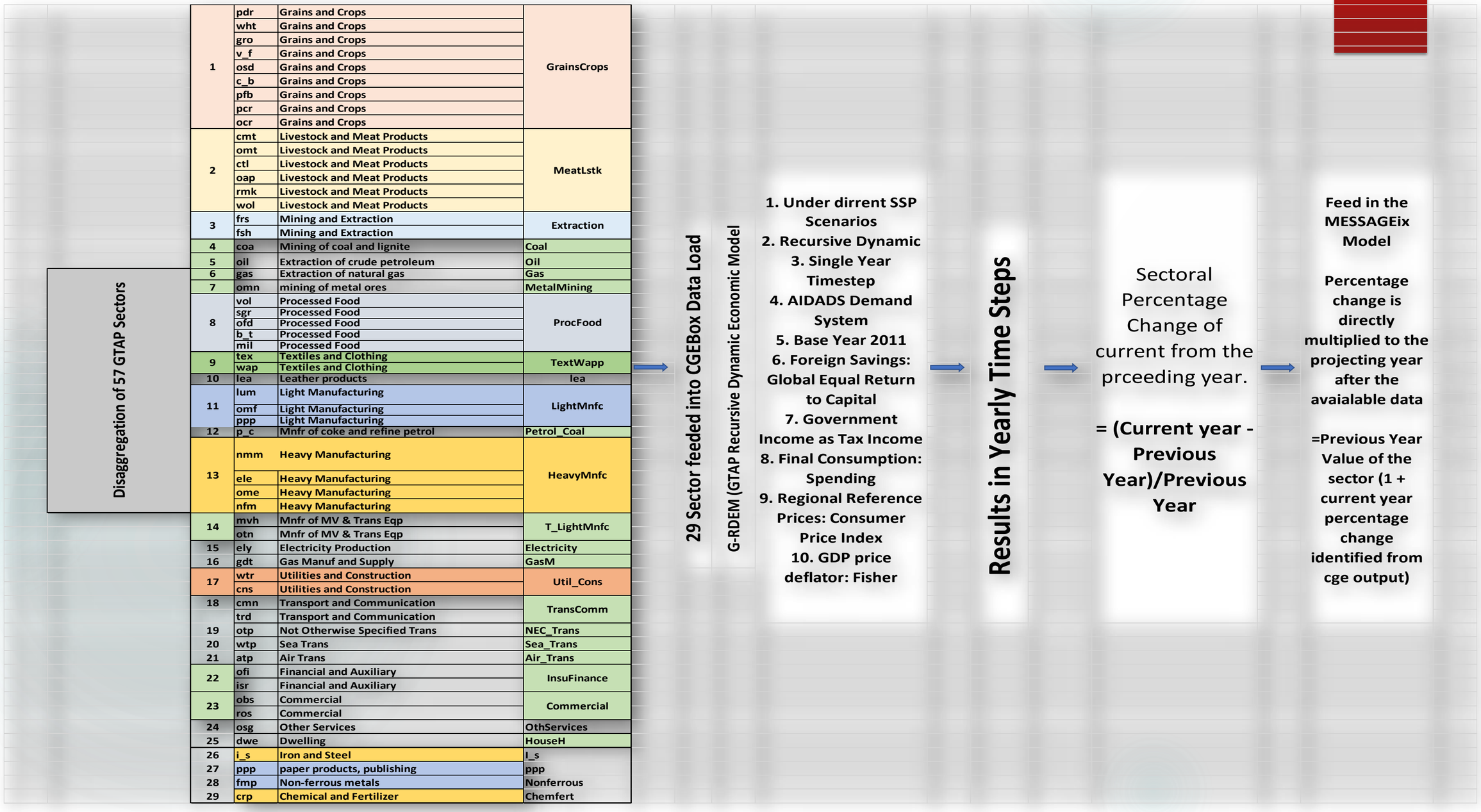
Nesting of energy production and consumption in CGE linked MESSAGEix



Sectors of CGE Model

Sl No.	Sectors	Sl. No.	Sectors
1	Paddy	26	Machinery
2	Wheat	27	Vehicles
3	Other Cereals	28	Transmission & Distribution
4	Fruits & Vegetables	29	Nuclear Electricity
5	Oil Seeds	30	Coal Electricity
6	Other Crops	31	Gas Electricity
7	Livestock	32	Wind Electricity
8	Forestry	33	Hydro Electricity
9	Fishing	34	Oil Power
10	Coal	35	Other Renewable
11	Oil	36	Solar Electricity
12	Gas	37	Water Distribution
13	Extraction	38	Construction
14	Food Beverage & Tobacco	39	Trade
15	Textiles and Garments	40	Hotels
16	Other Manufacture	41	Land Transport
17	Wood, Wood Products & Furniture	42	Water Transport
18	Paper & Paper Products, Printing & Publishing	43	Air Transport
19	Petroleum Products	44	Storage & Warehouses
20	Chemicals	45	Communications
21	Pharma	46	Financial Insurance Services
22	Non-metallic Minerals	47	Other Services
23	Ferrous Metal	48	Public Administration
24	Non-Ferrous Metal	49	Dwelling
25	Batteries, Electrical & Electronics Equipment		

Concordance Map- CGE to MESSAGEix Link



1	pdr	Grains and Crops	GrainsCrops
	wht	Grains and Crops	
	gro	Grains and Crops	
	v_f	Grains and Crops	
	osd	Grains and Crops	
	c_b	Grains and Crops	
	pfb	Grains and Crops	
	pcr	Grains and Crops	
	ocr	Grains and Crops	
2	cmt	Livestock and Meat Products	MeatLstk
	omt	Livestock and Meat Products	
	ctl	Livestock and Meat Products	
	oap	Livestock and Meat Products	
	rmk	Livestock and Meat Products	
	wol	Livestock and Meat Products	
3	frs	Mining and Extraction	Extraction
	fsh	Mining and Extraction	
4	coa	Mining of coal and lignite	Coal
5	oil	Extraction of crude petroleum	Oil
6	gas	Extraction of natural gas	Gas
7	omn	mining of metal ores	MetalMining
8	vol	Processed Food	ProcFood
	sgr	Processed Food	
	ofd	Processed Food	
	b_t	Processed Food	
	mil	Processed Food	
9	tex	Textiles and Clothing	TextWapp
	wap	Textiles and Clothing	
10	lea	Leather products	lea
11	lum	Light Manufacturing	LightMnfc
	omf	Light Manufacturing	
	ppp	Light Manufacturing	
12	p_c	Mnfr of coke and refine petrol	Petrol_Coal
13	nmm	Heavy Manufacturing	HeavyMnfc
	ele	Heavy Manufacturing	
	ome	Heavy Manufacturing	
	nfm	Heavy Manufacturing	
14	mvh	Mnfr of MV & Trans Eqp	T_LightMnfc
	otn	Mnfr of MV & Trans Eqp	
15	ely	Electricity Production	Electricity
16	gdt	Gas Manuf and Supply	GasM
17	wtr	Utilities and Construction	Util_Cons
	cns	Utilities and Construction	
18	cmn	Transport and Communication	TransComm
	trd	Transport and Communication	
19	otp	Not Otherwise Specified Trans	NEC_Trans
20	wtp	Sea Trans	Sea_Trans
21	atp	Air Trans	Air_Trans
22	ofi	Financial and Auxiliary	InsuFinance
	isr	Financial and Auxiliary	
23	obs	Commercial	Commercial
	ros	Commercial	
24	osg	Other Services	OthServices
25	dwe	Dwelling	HouseH
26	i_s	Iron and Steel	I_s
27	ppp	paper products, publishing	ppp
28	fmp	Non-ferrous metals	Nonferrous
29	crp	Chemical and Fertilizer	Chemfert

CGE Output Interpretation

Agriculture Sector

Factors from CGE

1. CGE output on “grains and crop” productivity rate.
2. The productivity rate help us determine the land use change and agricultural intensive technologies like **tractors and irrigating pumps** by increase/decrease in productivity rates.

Derived use of CGE Outputs

1. Irrigation and Land Preparation through Identification and percentage distribution between surface/ground water irrigation.
2. Land Use change is considered based on long term historical data based on national statistics

Household/Cooking

Factors from CGE

1. Direct productivity of household demand for “Electricity and Gas Supply” is obtained and applied to the base energy demand of both household and cooking.

Derived use of CGE Outputs

1. Base year energy demand from national accounts/statistics
2. Cooking activity and its productivity rates are then obtained based on weightage distribution of the fuel utilization as in its historic trends.

Commercial

Factors from CGE

1. Intermediate demand of electricity is directly obtained by deducting household demand of energy commodity from aggregate demand.

Derived use of CGE Outputs

1. Base year energy demand from national accounts/statistics
2. Identification and percentage distribution between appliance use and hot-water demand of the sector based on growth pattern of the sector.

Slide Continued……

CGE Output Interpretation

Transport (Freight and Passenger)

Factors from CGE

1. CGE provide direct intermediated growth of “Land (tranp_ nec, trp_Air and trp_Sea Transport”.

Derived use of CGE Outputs

1. Identification of Freight and Passenger distribution from historical data and current national statistics.
2. Growth parameters are identified based on sectoral demand pattern and then growth rates are directly applied.

Industry

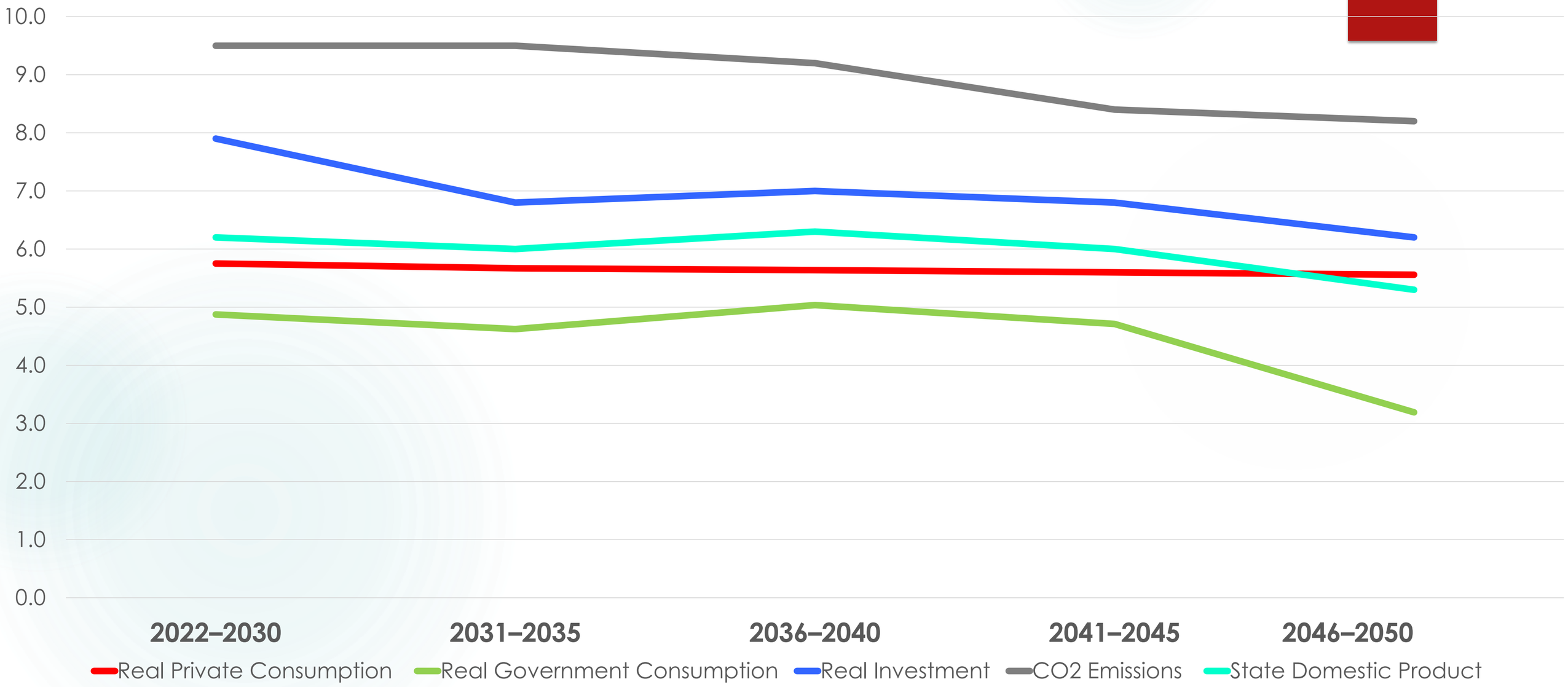
Factors from CGE

1. For identifying the growth rate of Industry sector, we take direct growth from different manufacturing and other Industries.
2. Further **mean value** of all the production growth of manufacturing and other Industries CGE output which is then directly applied to the sectoral sheet.
3. Alternatively, industry category wise output converted to industry specific energy consumption using SEC (Specific Energy Consumption)
4. CGE also provides based on sectoral disaggregation certain direct industries growth rate like heavy manufacturing and light manufacturing, etc.

Derived use of CGE Outputs

1. Base year energy demand is identified and direct mean growth rates are applied.

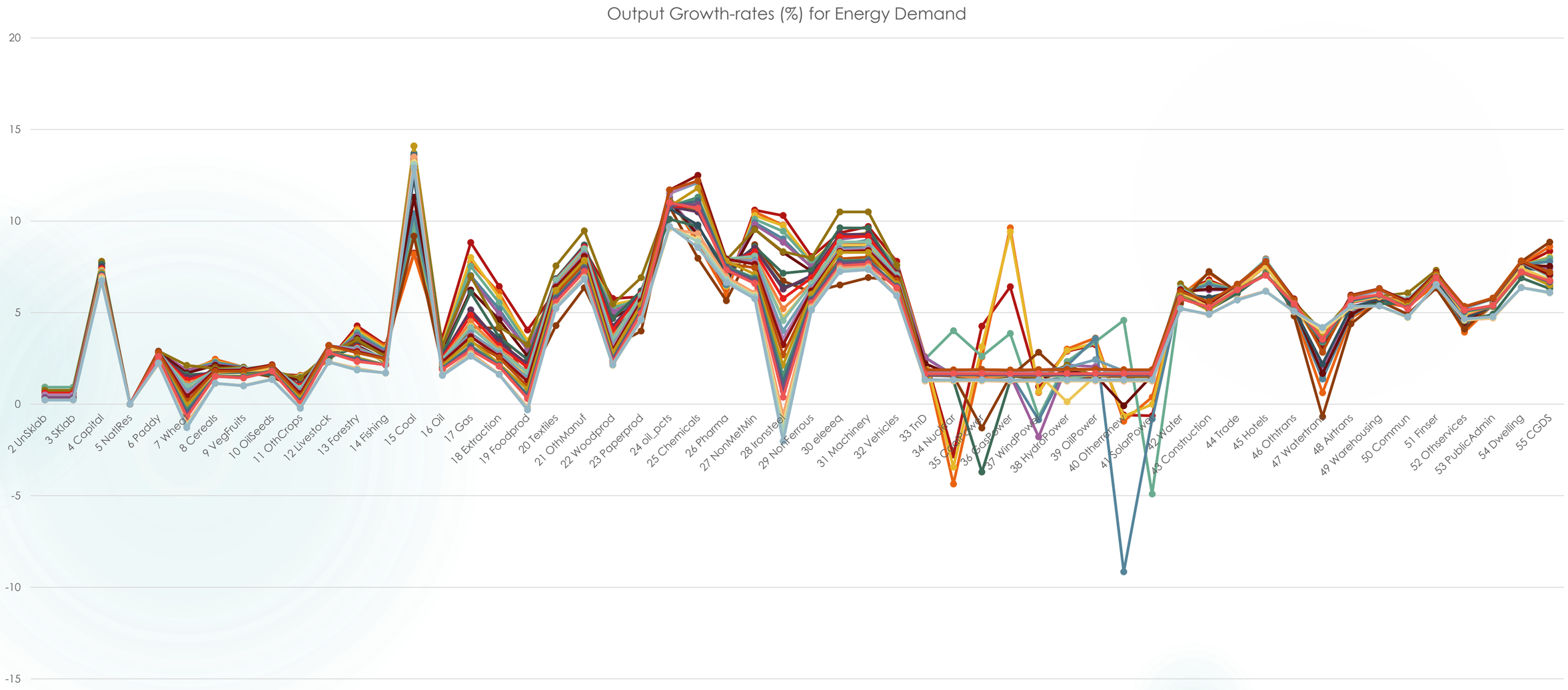
Macroeconomic Growth of Kerala in the Baseline (in percent)



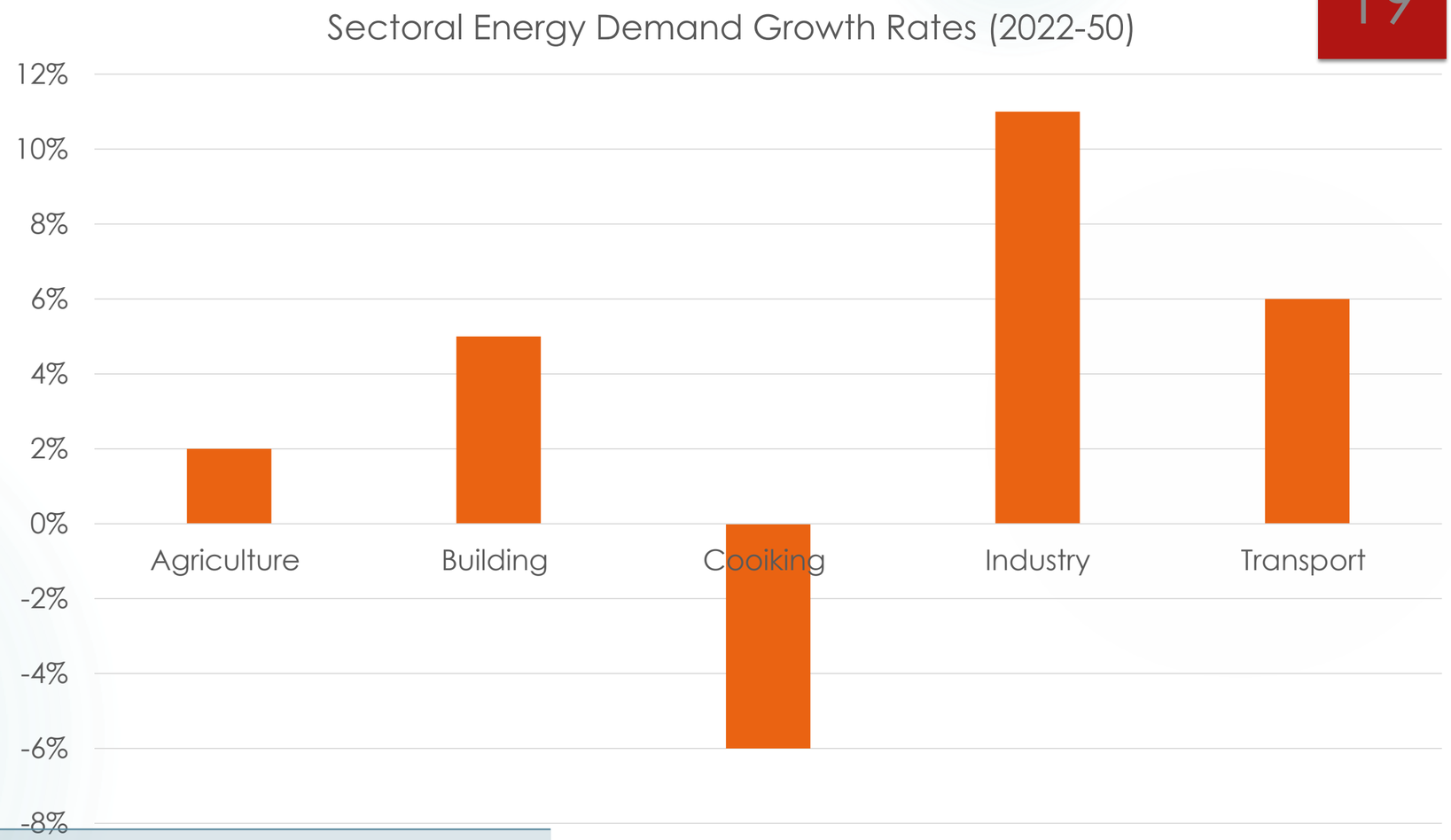
Average annual growth rates of output for major sectors in Baseline (in Percent)

Sectors	2022–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050
Other Services	4.02	4.26	4.49	4.79	4.6	3.44
Construction	6.74	6.24	5.37	5.43	5.26	5.38
Trade	6.24	6.42	6.49	6.69	6.43	6.03
Dwelling	7.55	7.51	7.18	7.47	6.9	4.39
Public Administration	5.12	5.04	4.87	5.24	4.88	2.98
Financial Insurance Services	6.8	7.09	7.37	7.56	7.43	8.36
Communications	5.17	5.41	5.53	5.61	5.24	5.31
Hotels	7.97	8.29	8.3	8.65	8.01	7.72
Land Transport	5.38	5.7	5.97	6.37	6.25	6.91
Livestock	2.65	2.71	2.65	2.87	2.68	1.78
Other manufacture	7.99	8.36	8.98	8.67	7.85	7.36
Vegetables and Fruits	2.22	2.21	2.17	2.34	2.1	1.89
Food Beverage & Tobacco	3.72	3.6	3.46	2.75	1.57	2.06
Batteries, Electrical & Electronics Equipment	8.91	9.28	9.95	9.33	8.61	8.04
Machinery	9.18	9.48	9.95	9.25	8.42	8.40
Non-Ferrous Metal	7.82	7.72	7.55	6.85	5.93	6.43

Output Growth Rates (btw 2022-2050) for Kerala Integrated Model



Energy Demand Growth Rates in Kerala (btw 2022-2050)

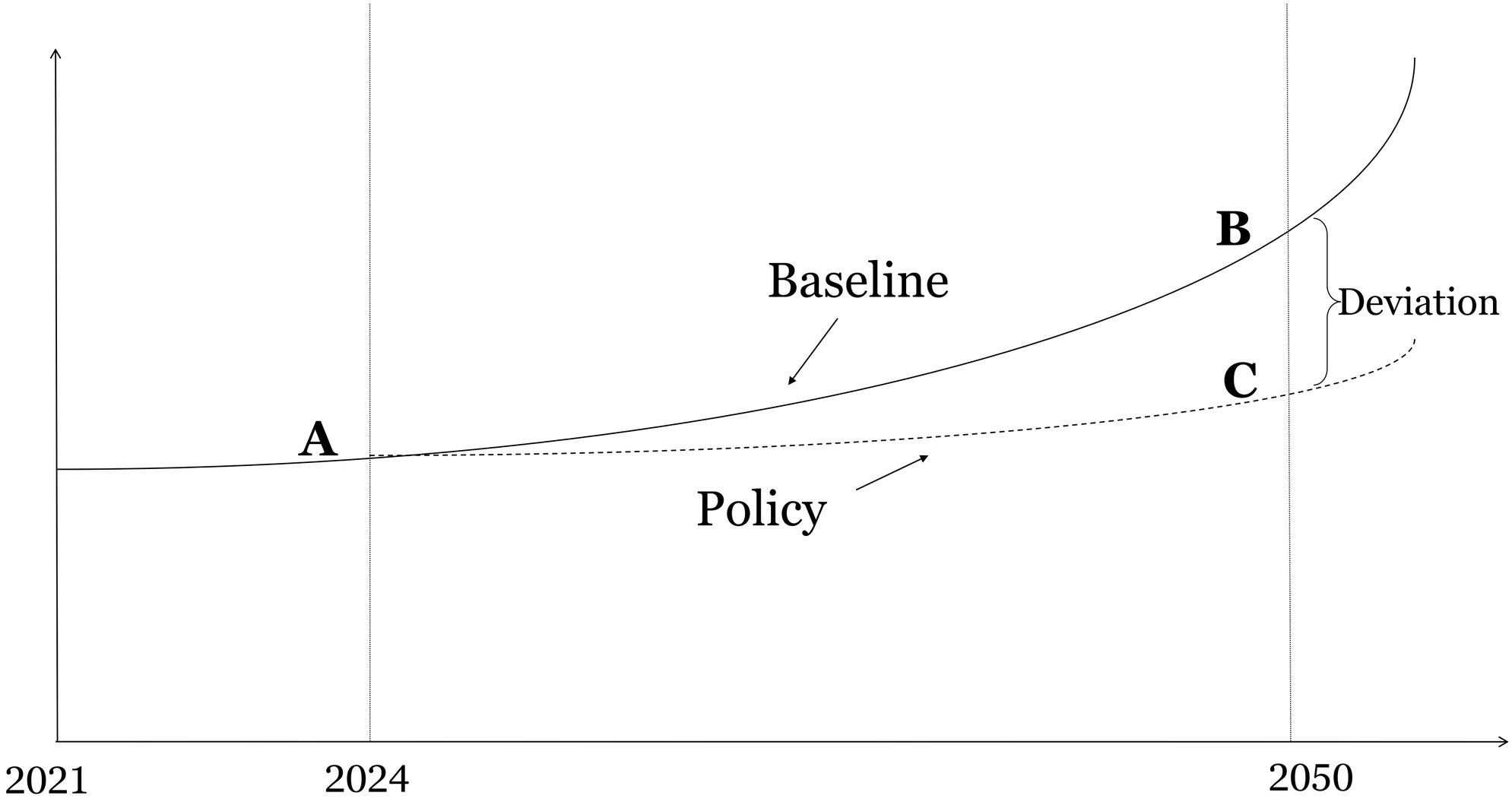


Travel Demand / Person (Pass-Km)

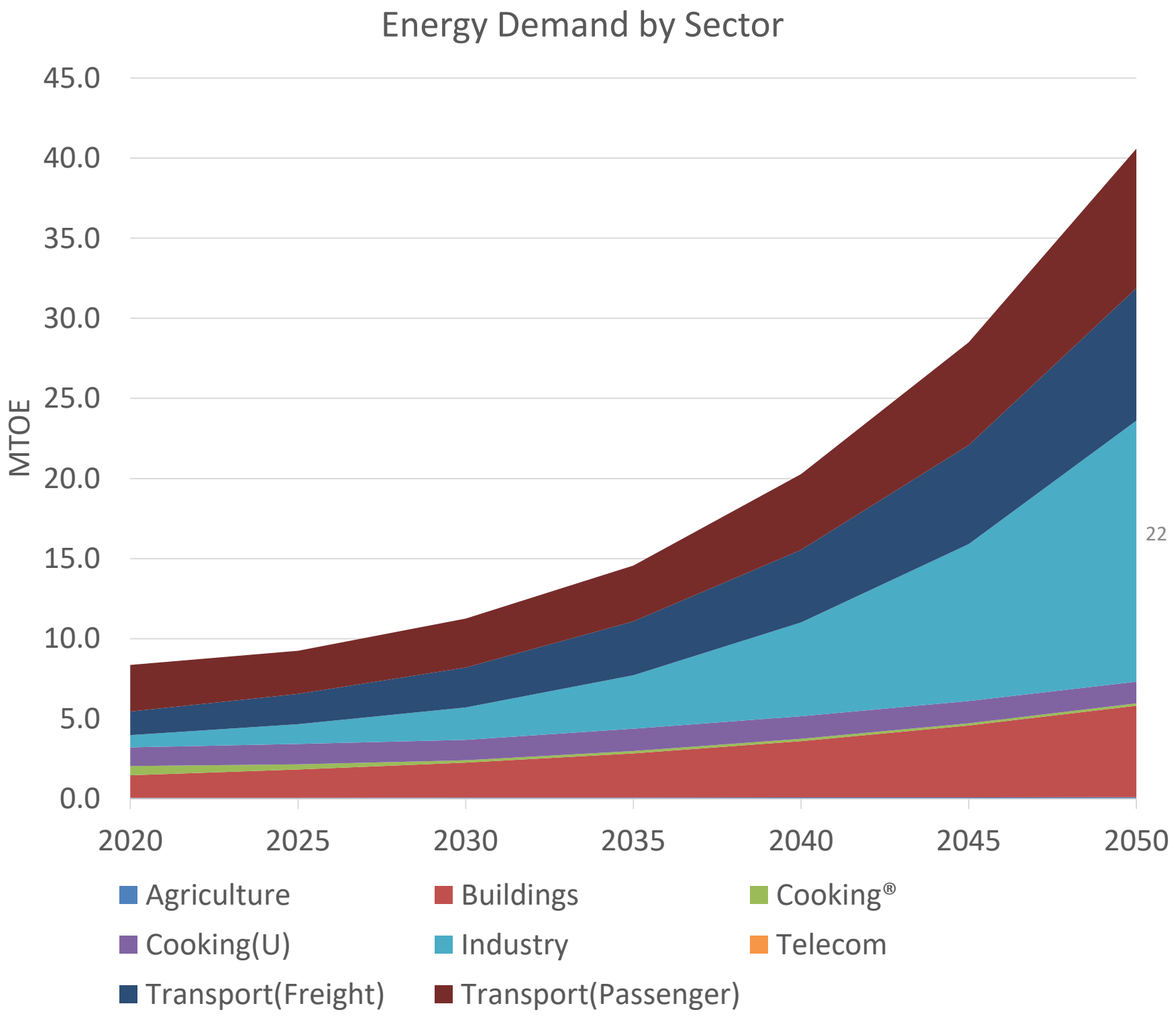
2020	2025	2030	2035	2040	2045	2050
5270	7044	9415	12585	16821	22483	30051

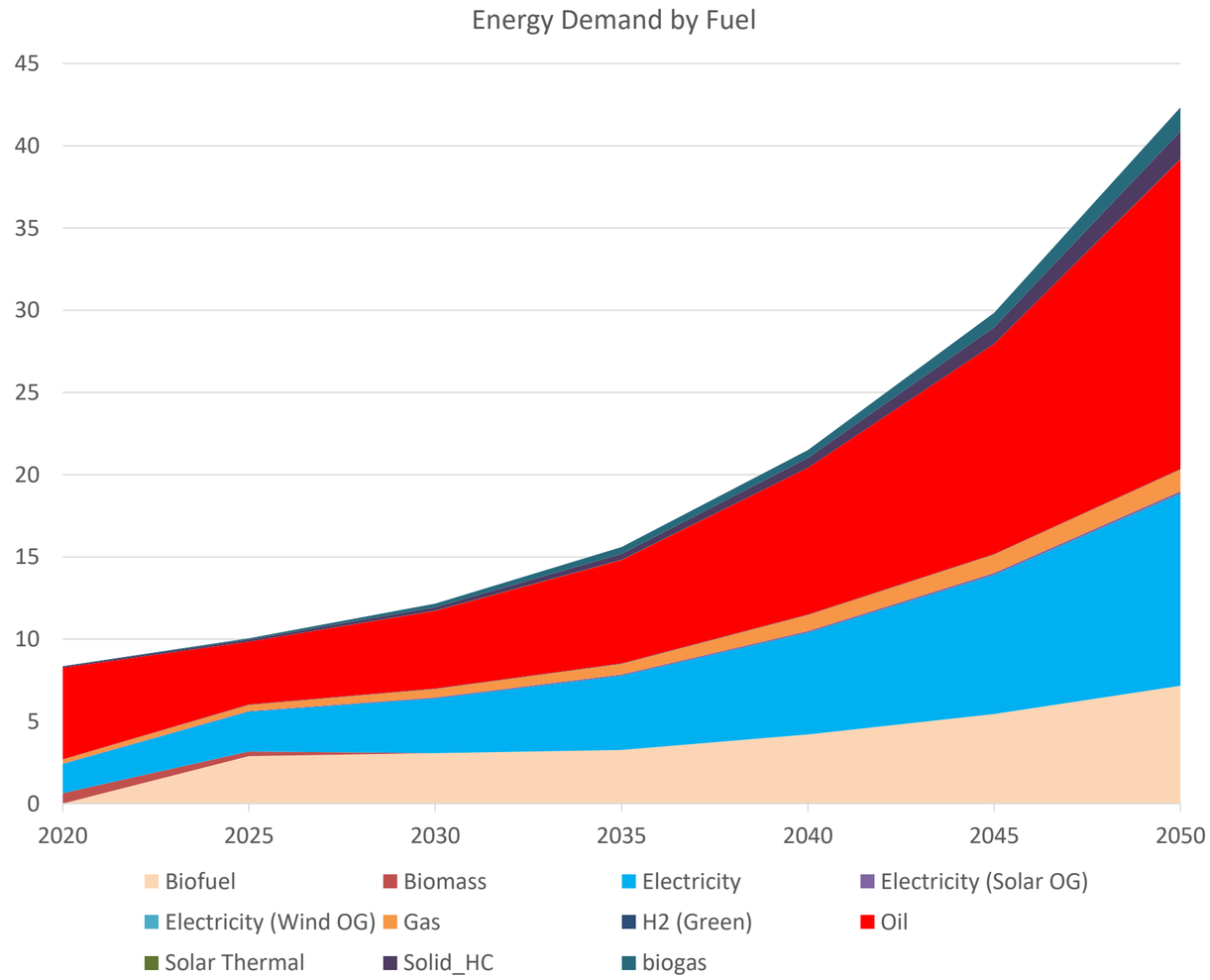
Results & Analysis

Policy Analysis with Dynamic Integrated Model

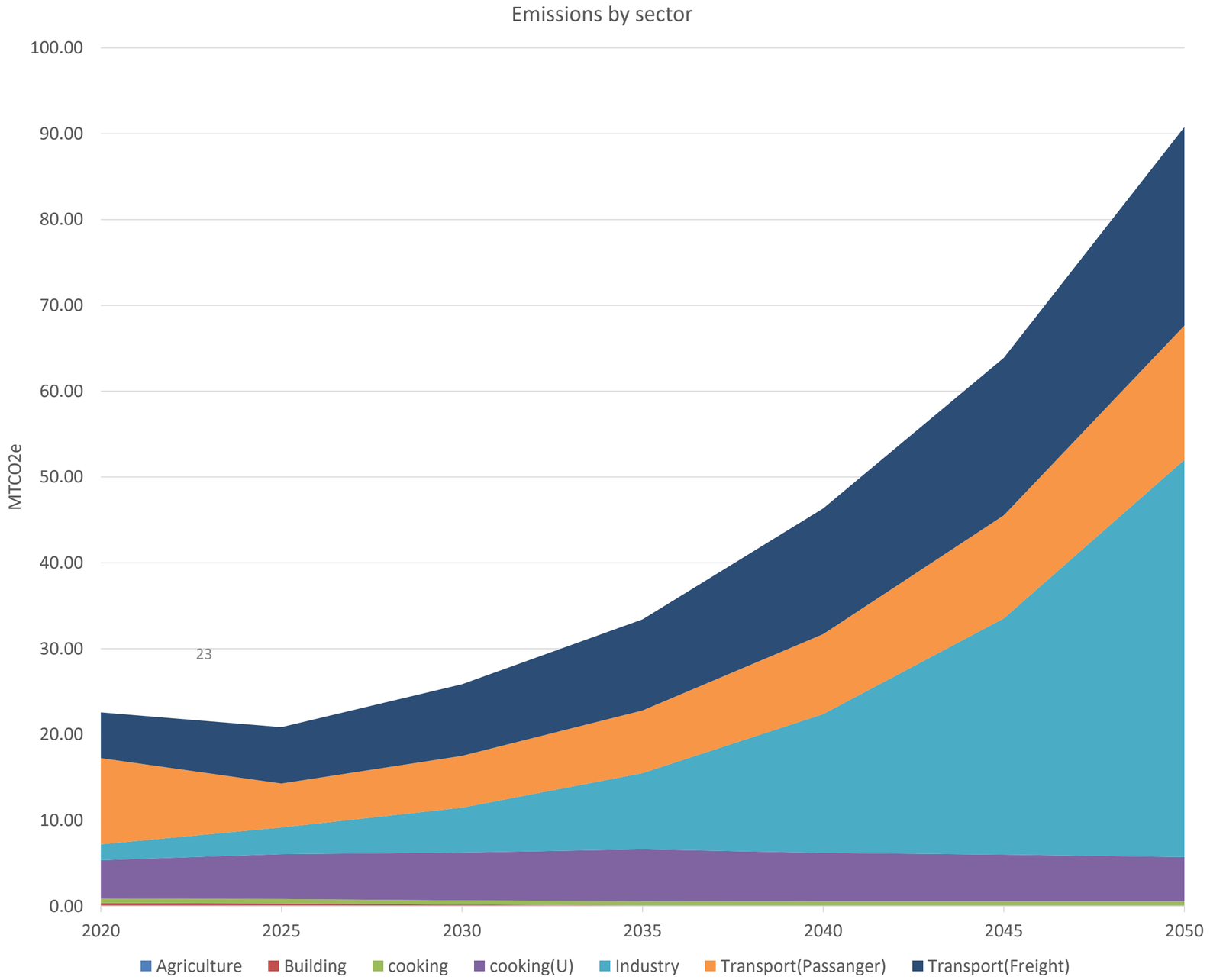


Energy Demand Projection (Baseline)

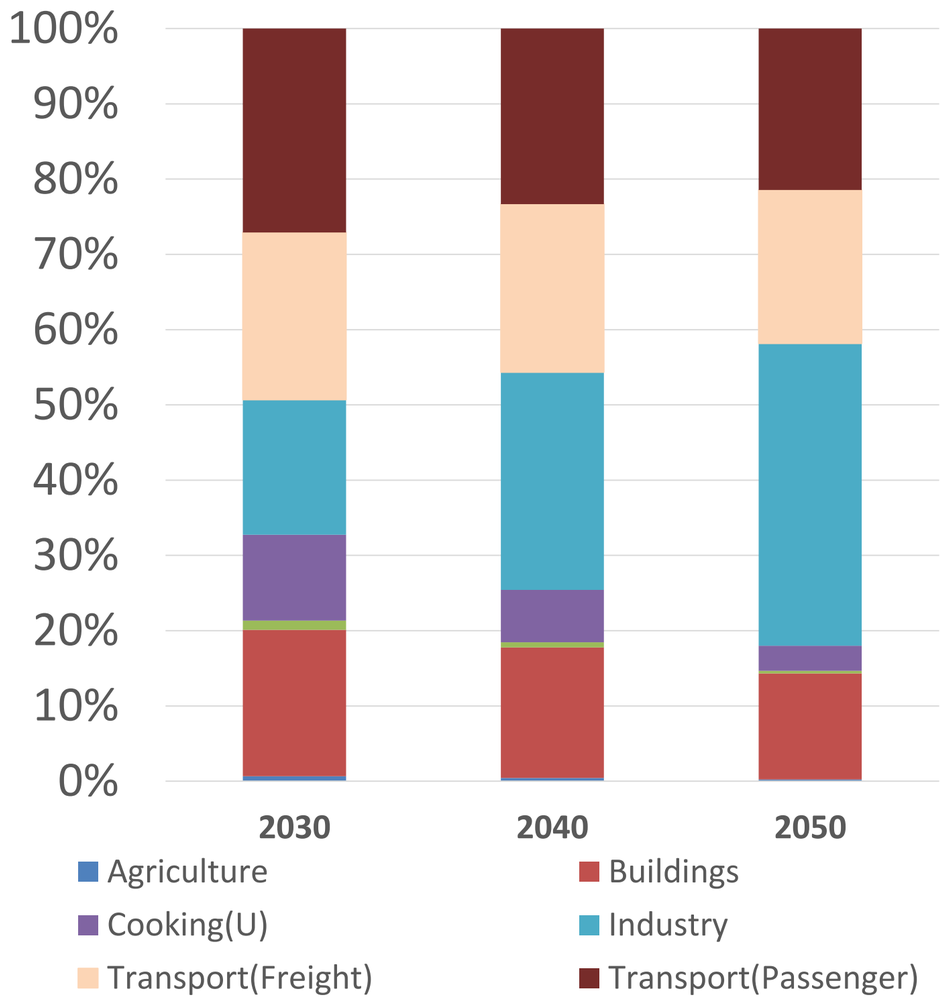




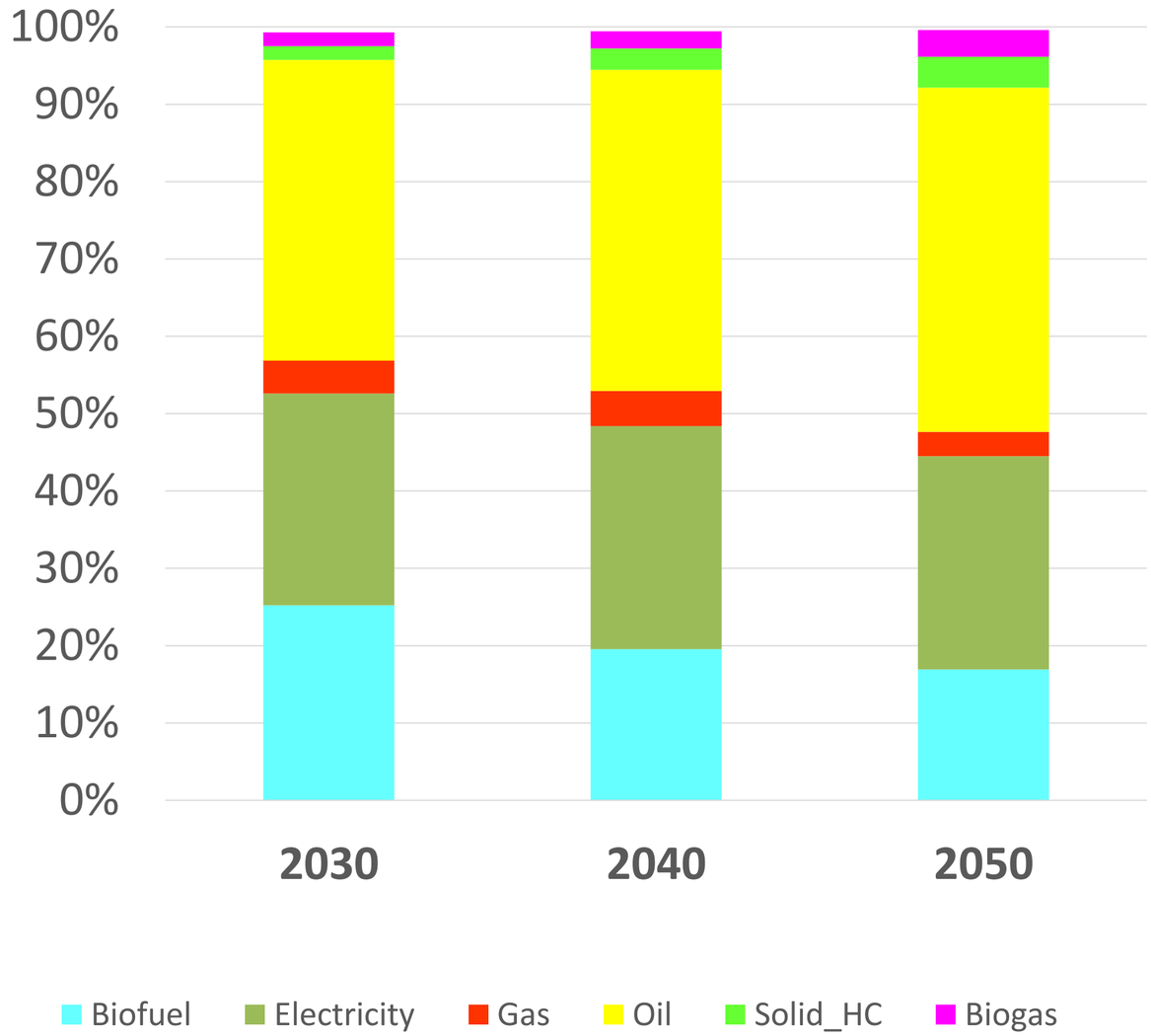
GHG Emissions Projection (Baseline)



Final Energy Demand of Kerala in the Baseline (in percent)

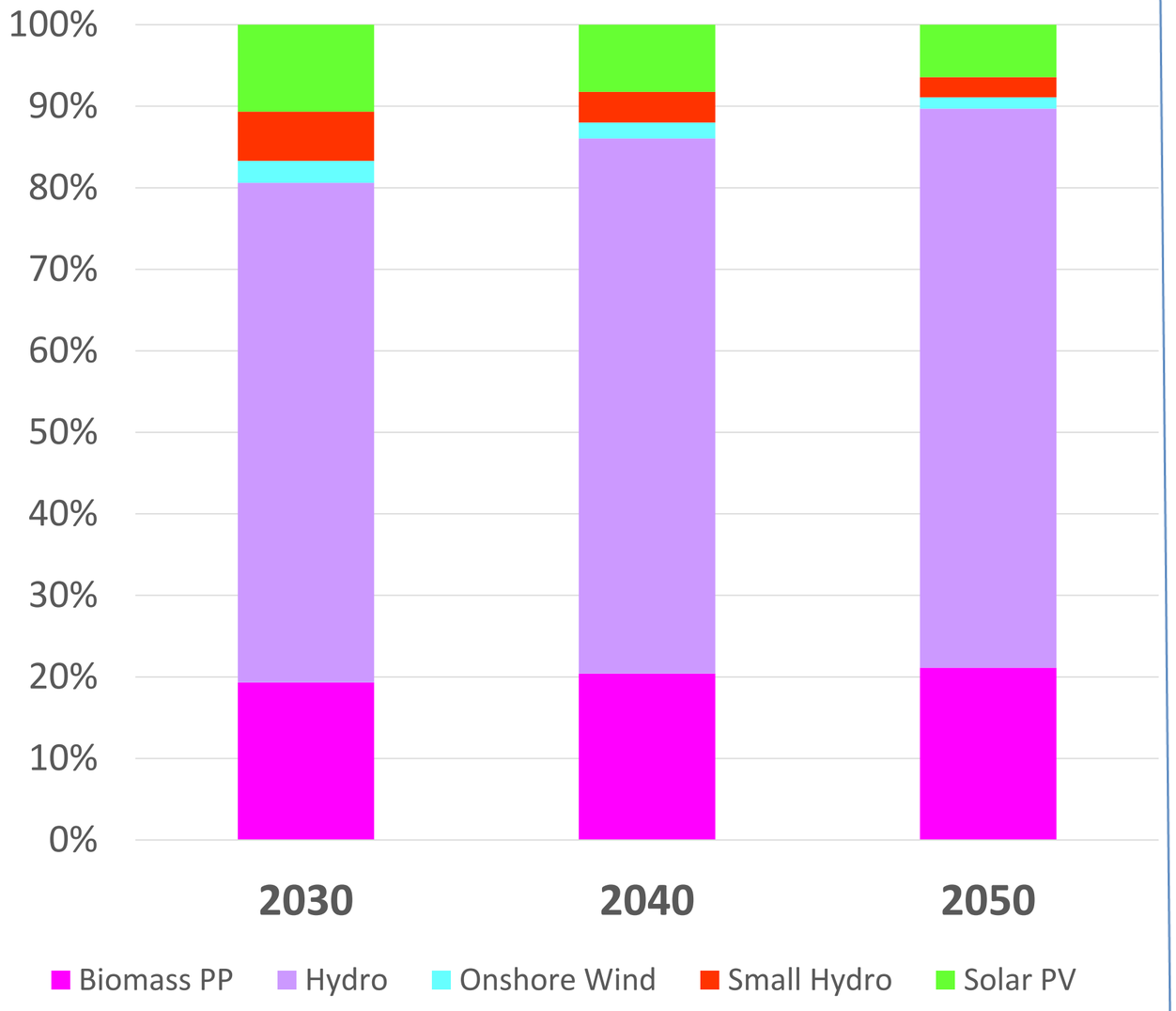


Final Energy Mix of Kerala in the Baseline (in percent)



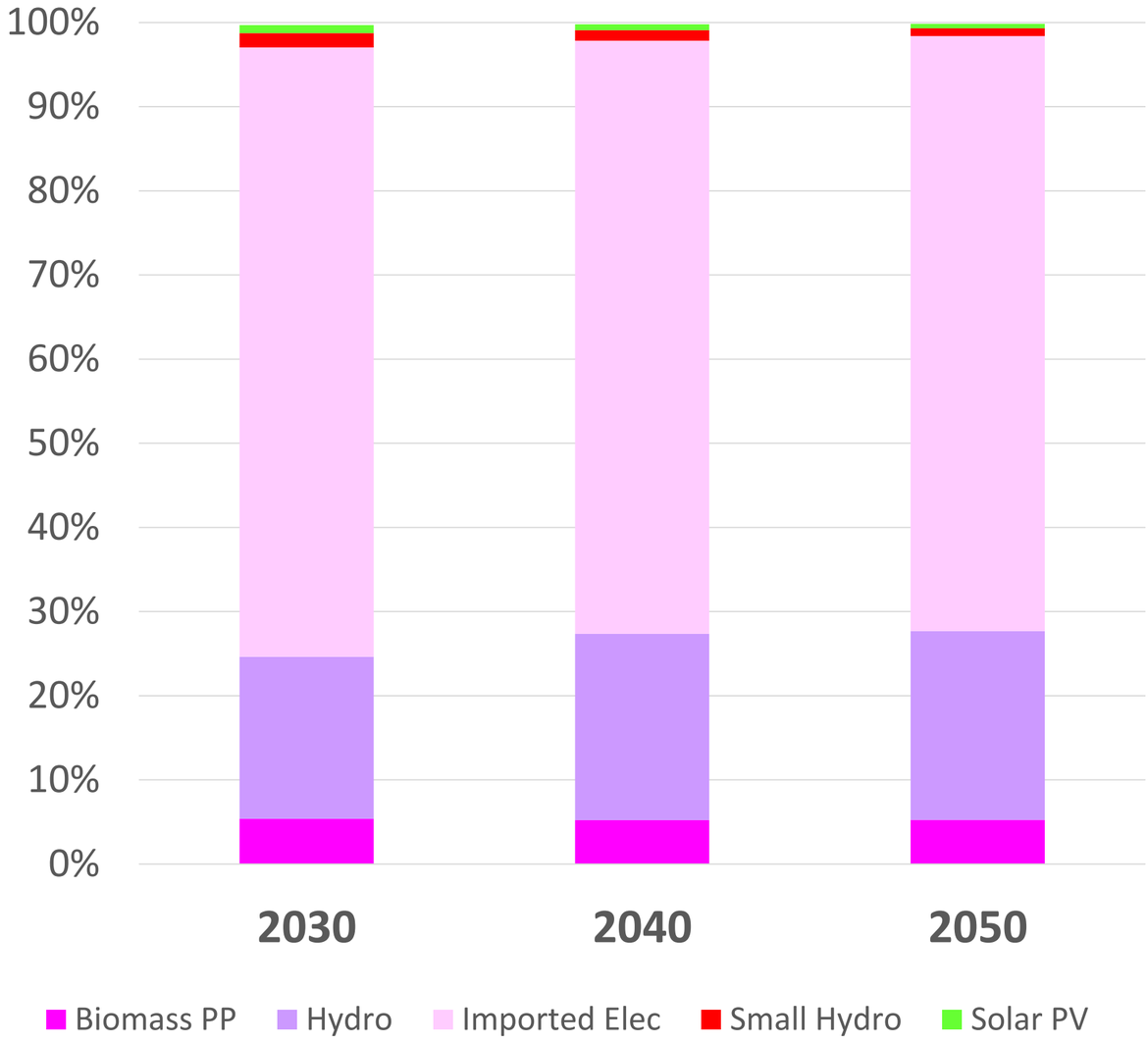
Electricity Capacity Mix of Kerala in the Baseline

(in percent)

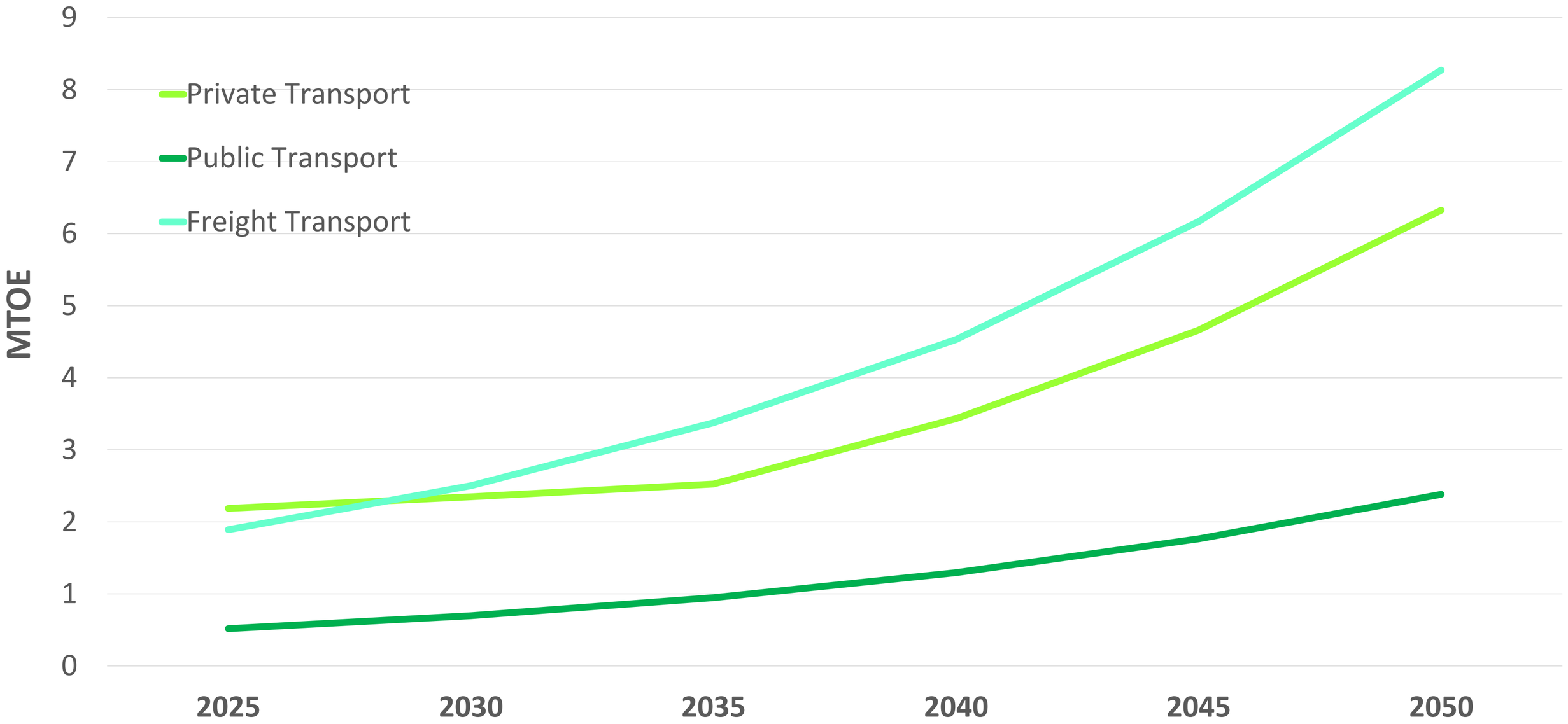


Electricity Generation in Kerala in the Baseline

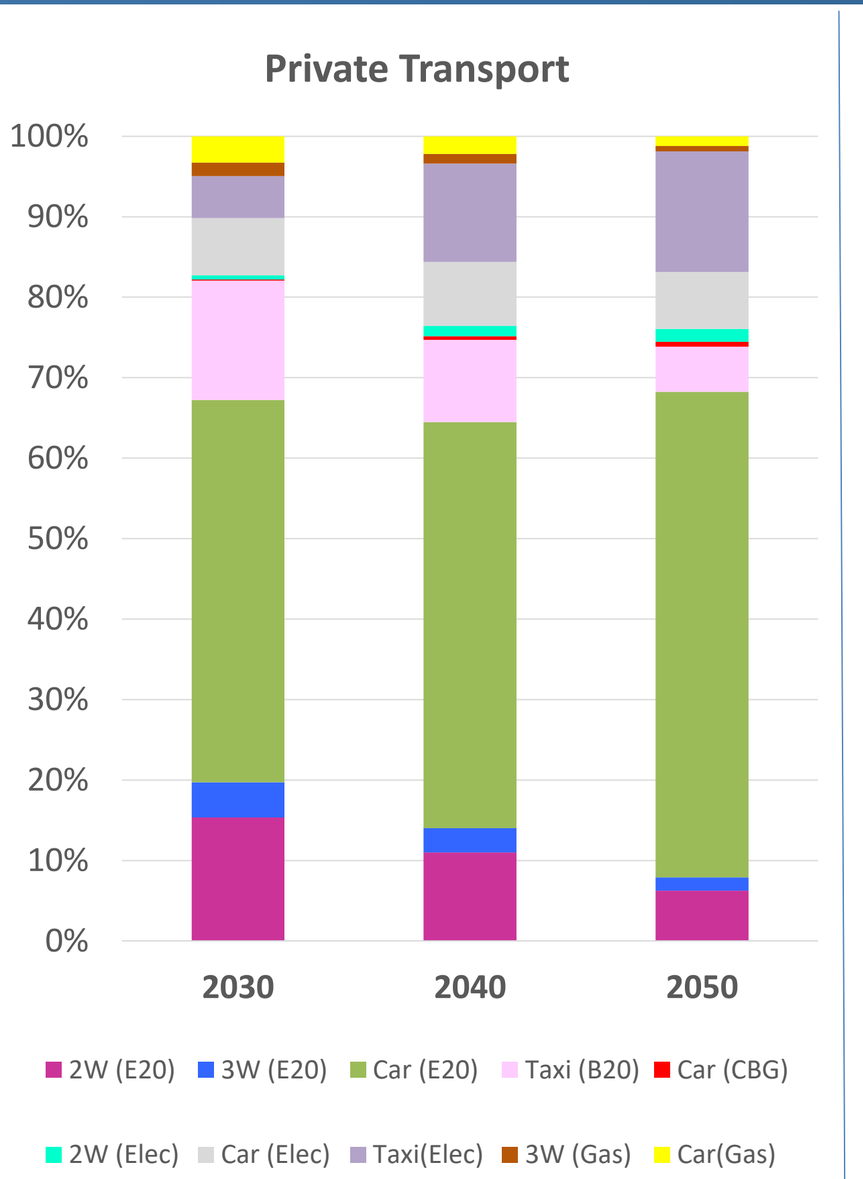
(in percent)

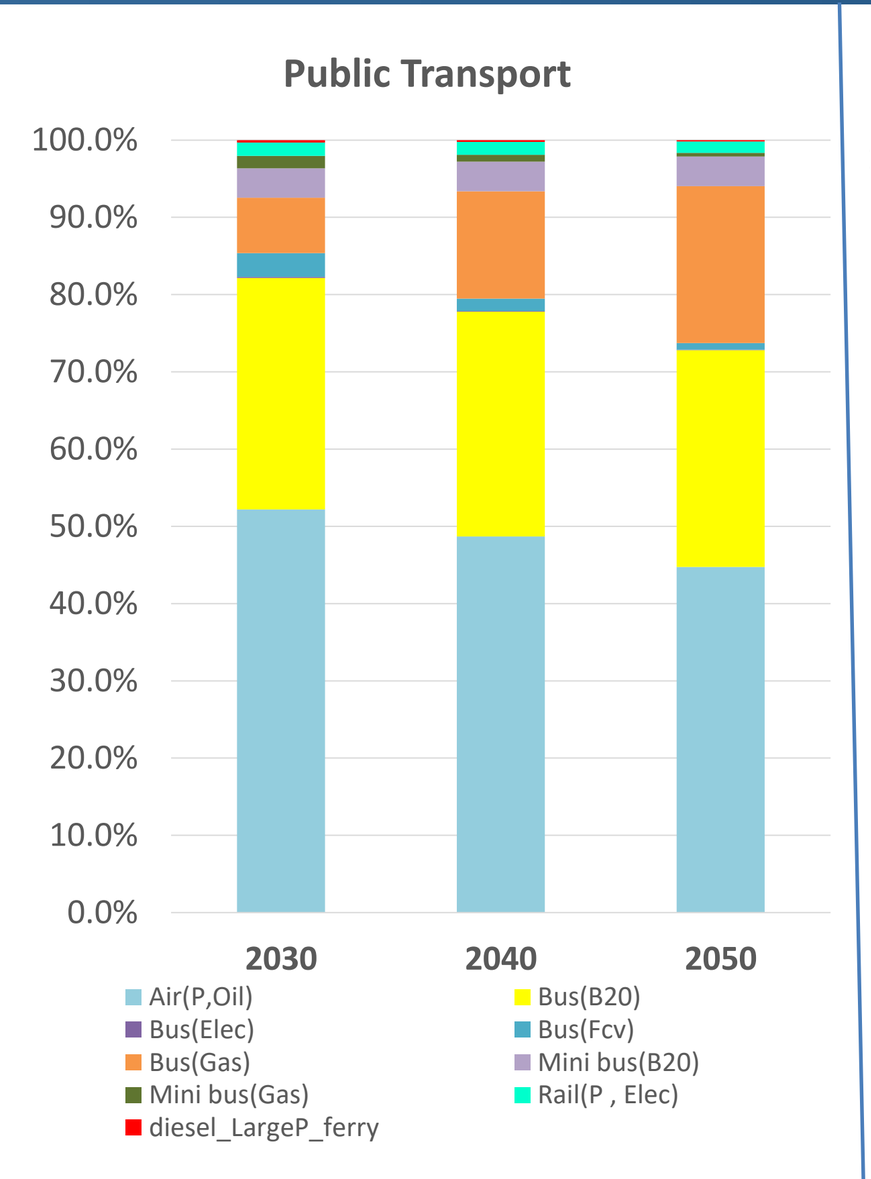


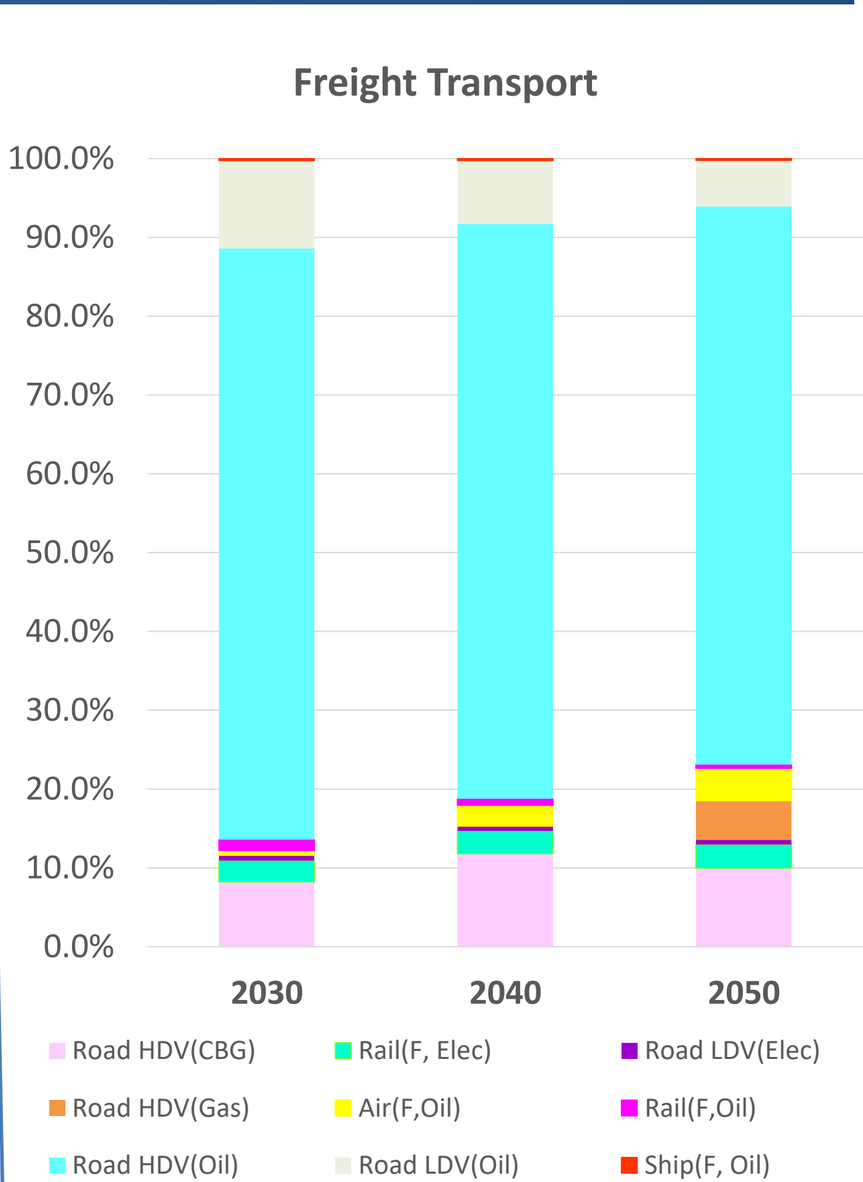
Energy Demand in Transport Sector in Kerala in the Baseline



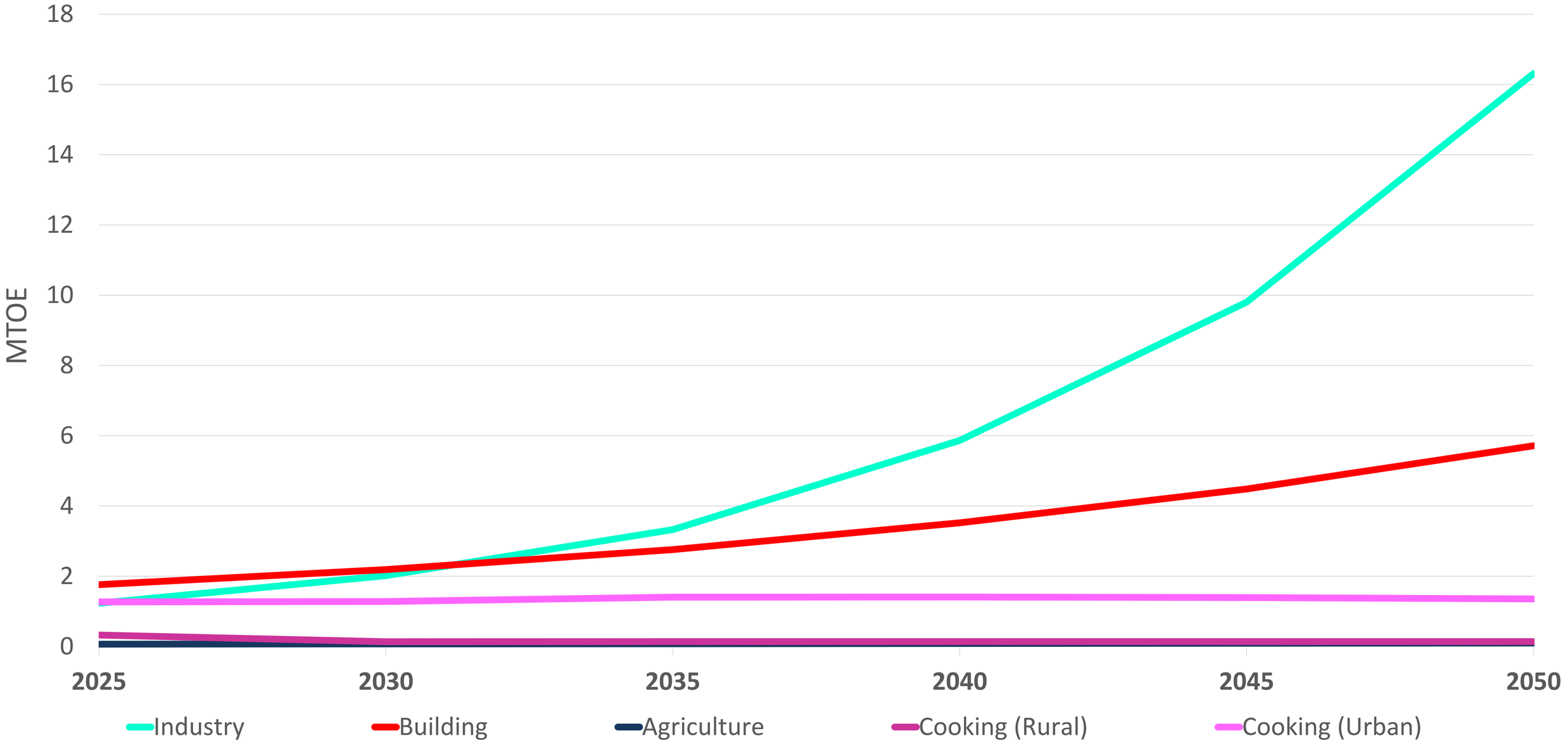
Fuel Split in Baseline



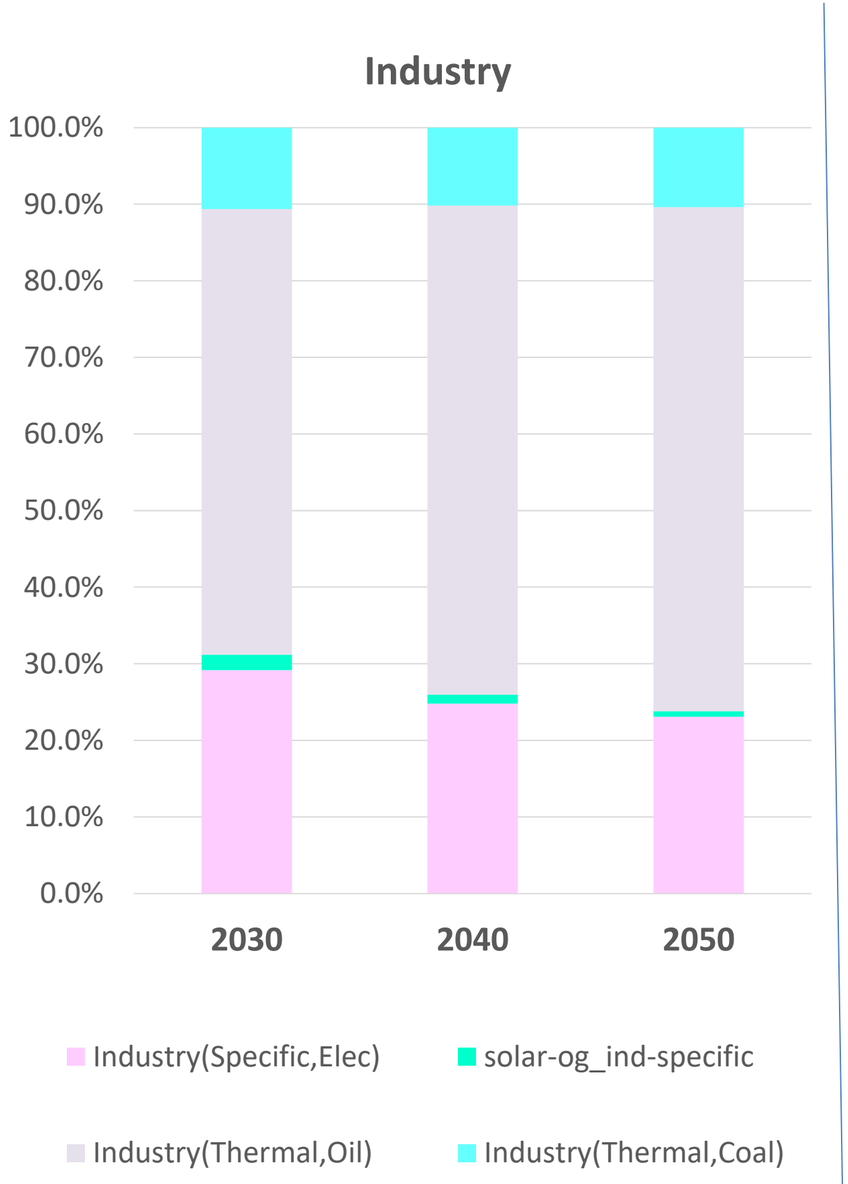


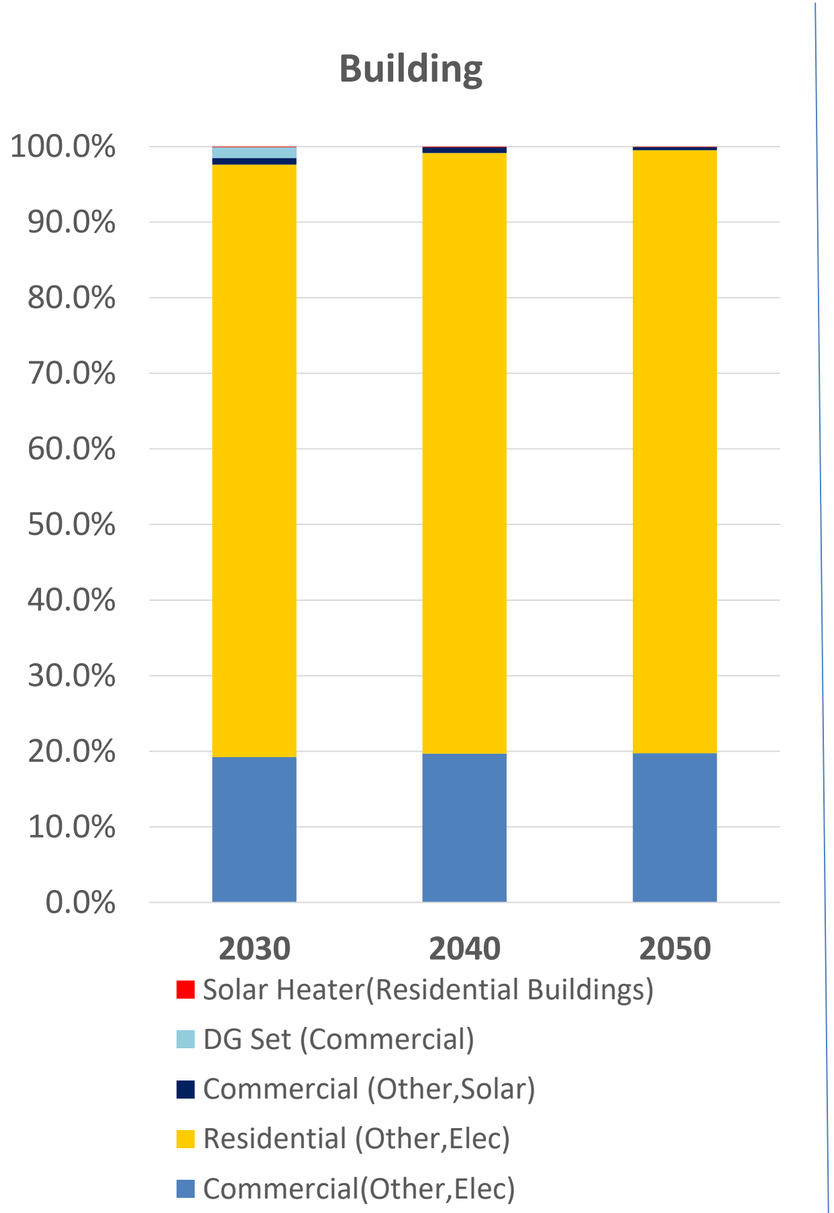


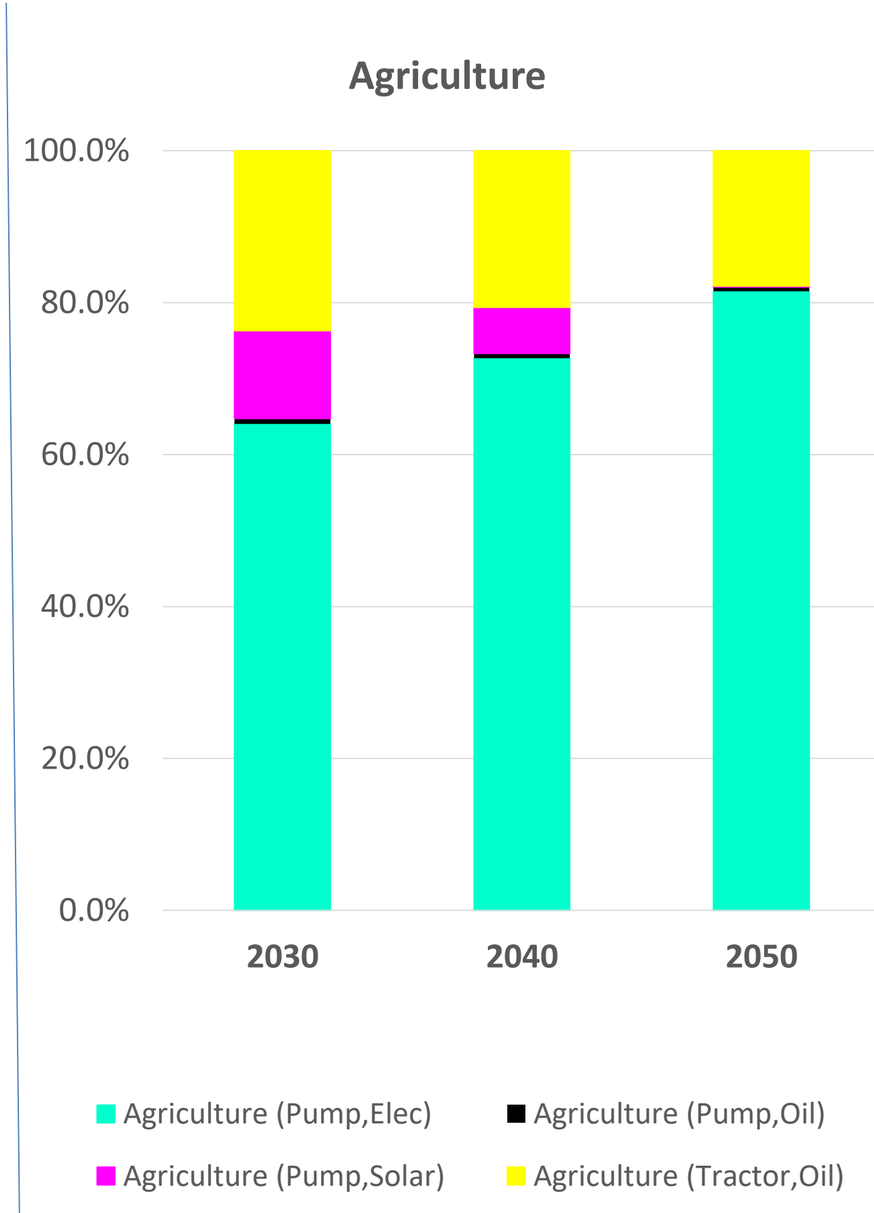
Energy Demand in Various Sectors in Kerala in the Baseline



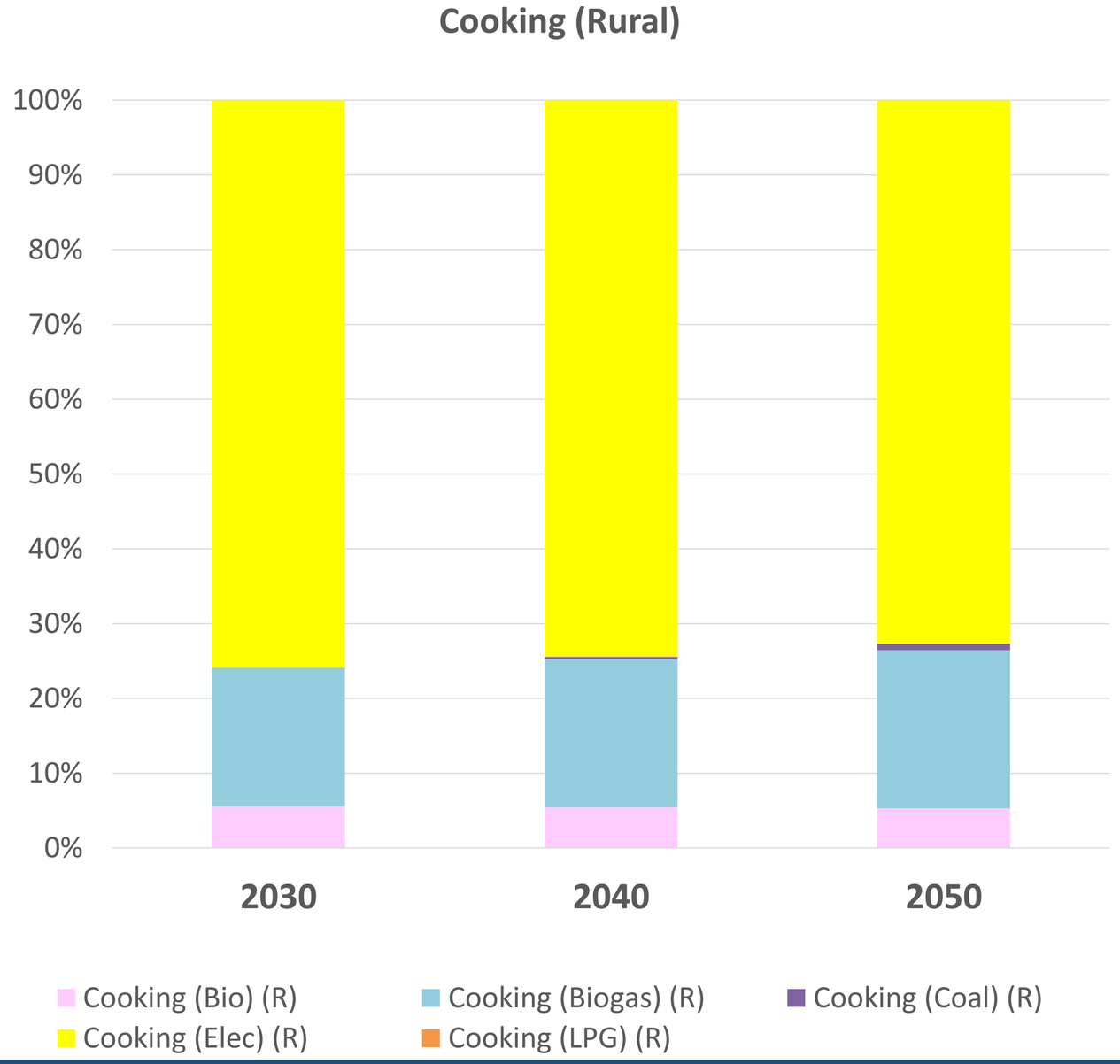
Energy Split in Baseline







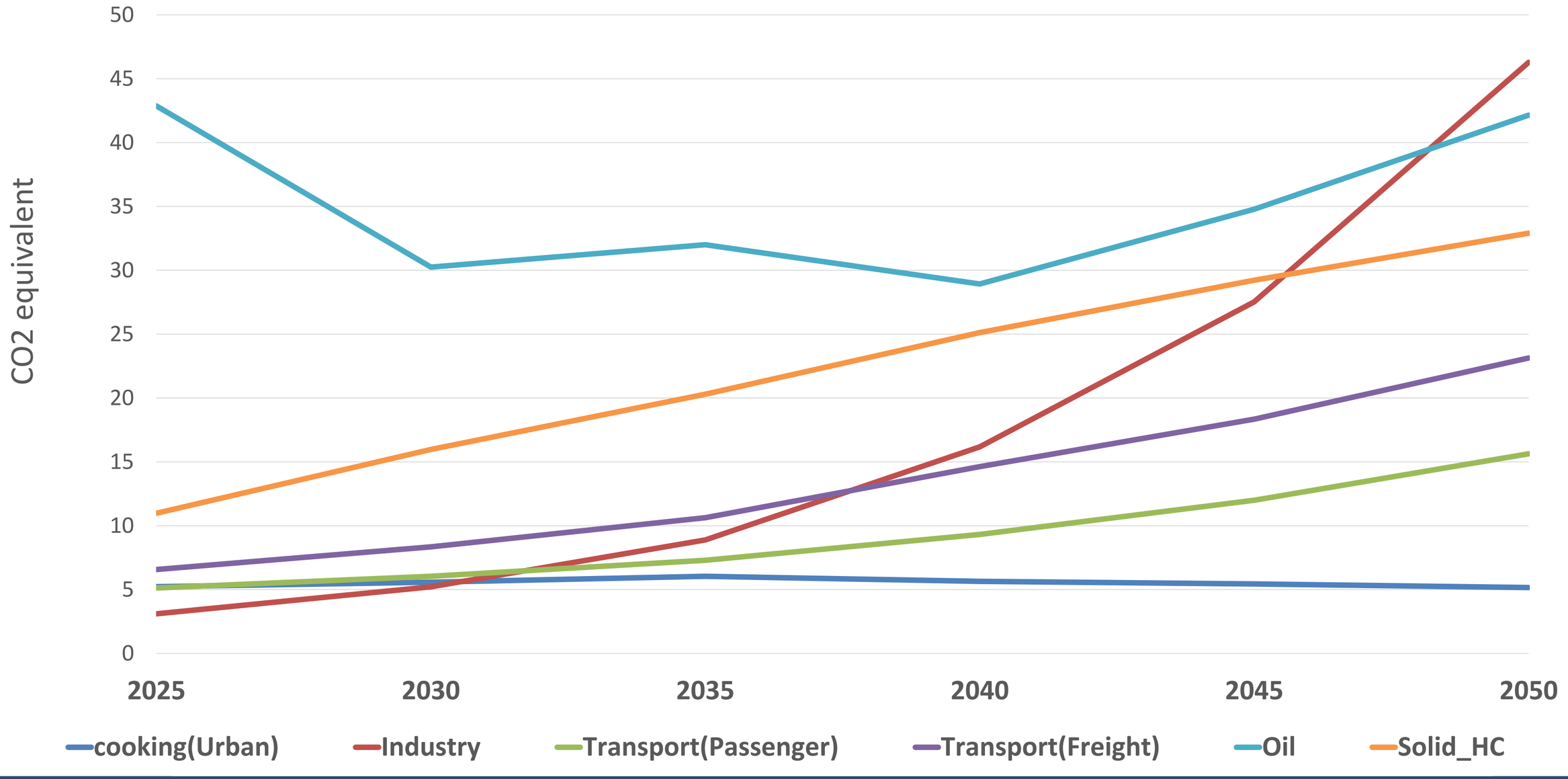
Energy Split in Baseline



Cumulative Investment in Baseline (Million USD)

Sector	2025–30	2025–50
Agriculture	241	626
Biofuel	66	154
Buildings	1131	4733
Cooking (Rural)	87	230
Cooking(U)	502	1855
Domestic (Resource)	753	5079
Electricity	1958	26152
Gas	7	38
Electricity Imports	0	0
Industry	188	3075
Transport (Freight)	11489	53638
Transport (Passenger)	31852	166834
Biogas	5	40
Green Hydrogen	22	58
TOTAL	48301 *(3.6% of cumulative SDP)*	262512 *(0.83% of cumulative SDP)*

Emissions in Baseline (CO_2 Equivalent)



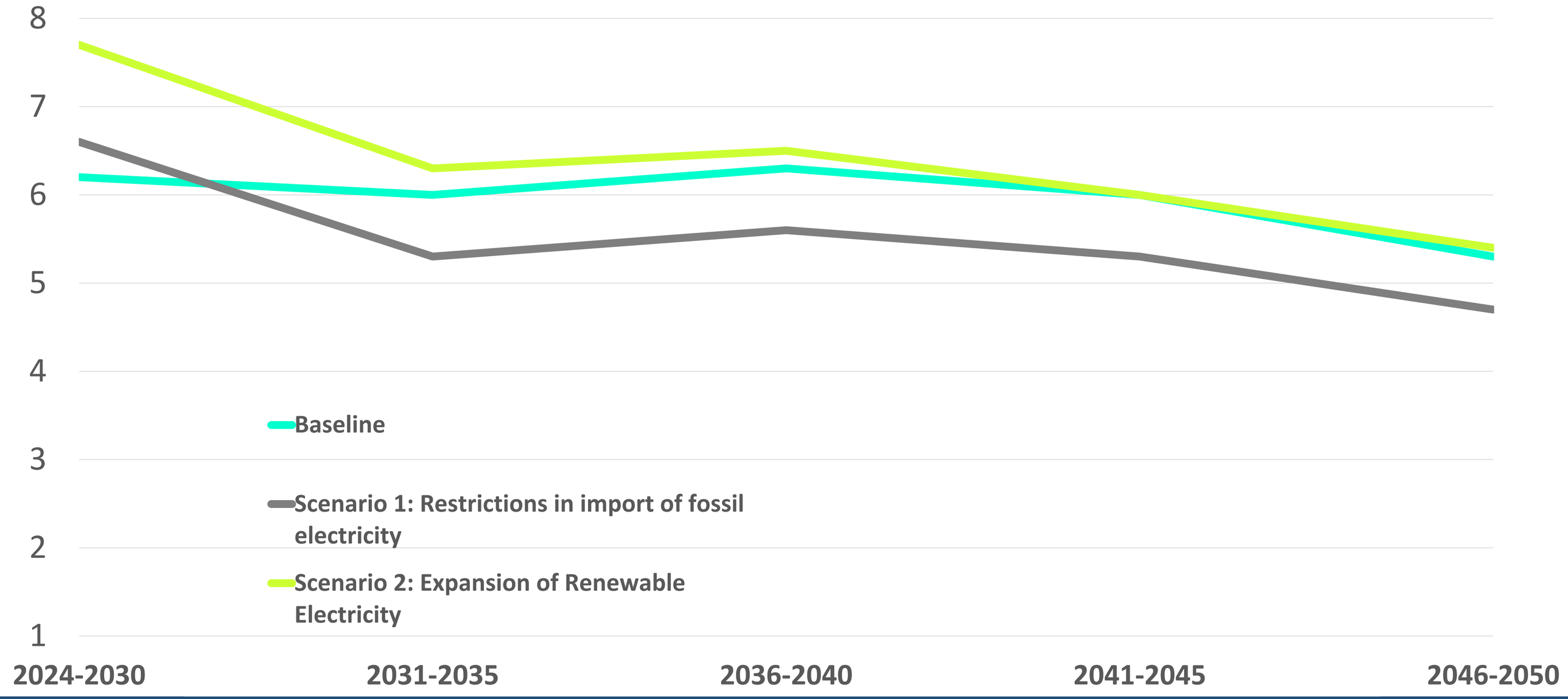
Policy Scenarios

- Scenario 1: Restriction of fossil electricity from the rest of India (Rest_F_Elec)

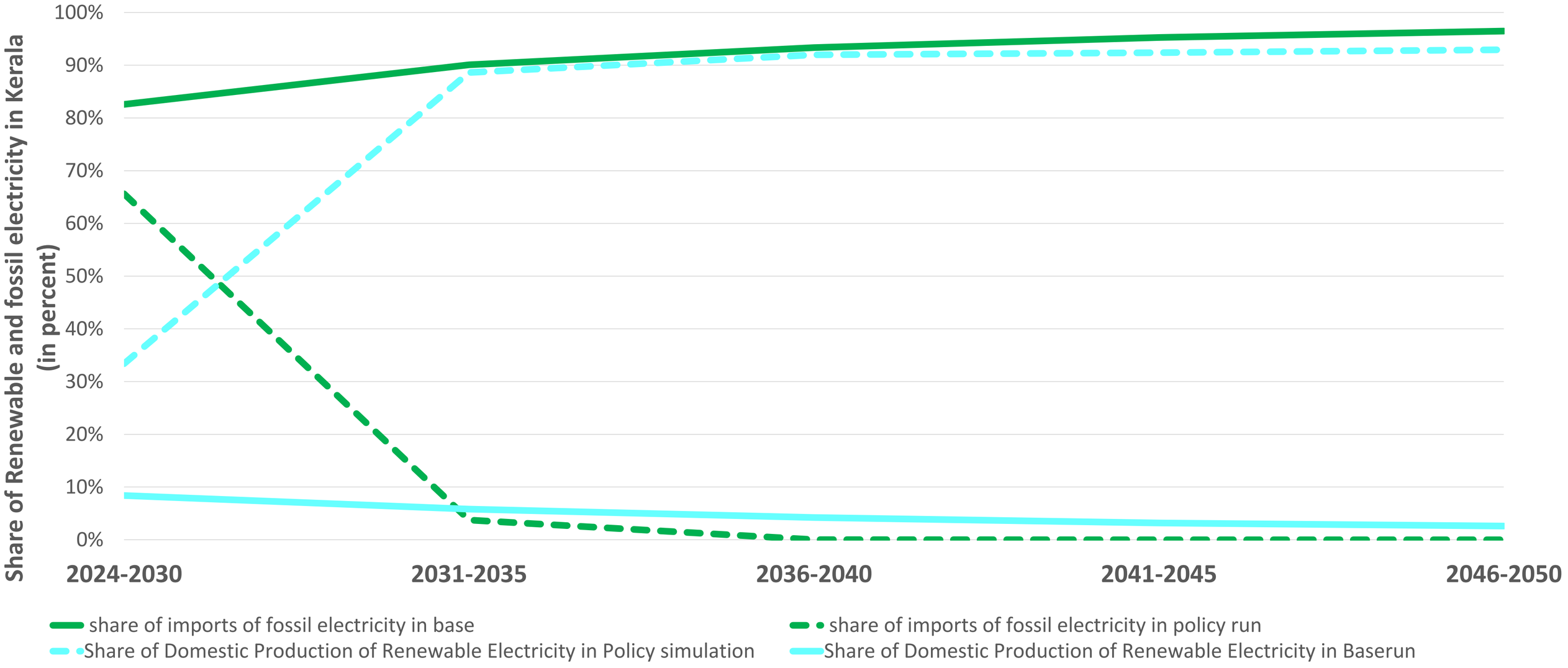
- Scenario 2: Scenario 1 + capacity augmentation of renewable electricity (Aug_R_Elec)
  - 50% of the existing potential of renewable electricity by various modes is achieved in Kerala and rest of India by the terminal year of our model run (2050)
  - Fund of investment is not a constraint.

- Scenario 3: Scenario 2 + increased energy efficiency (Incr EE)
  - Increased energy efficiency to the tune of 2.5% per annum
  - Assumed 1% total productivity growth per year in all sectors
  - This range of total factor productivity (TFP) growth has been achieved in the past in the Indian context

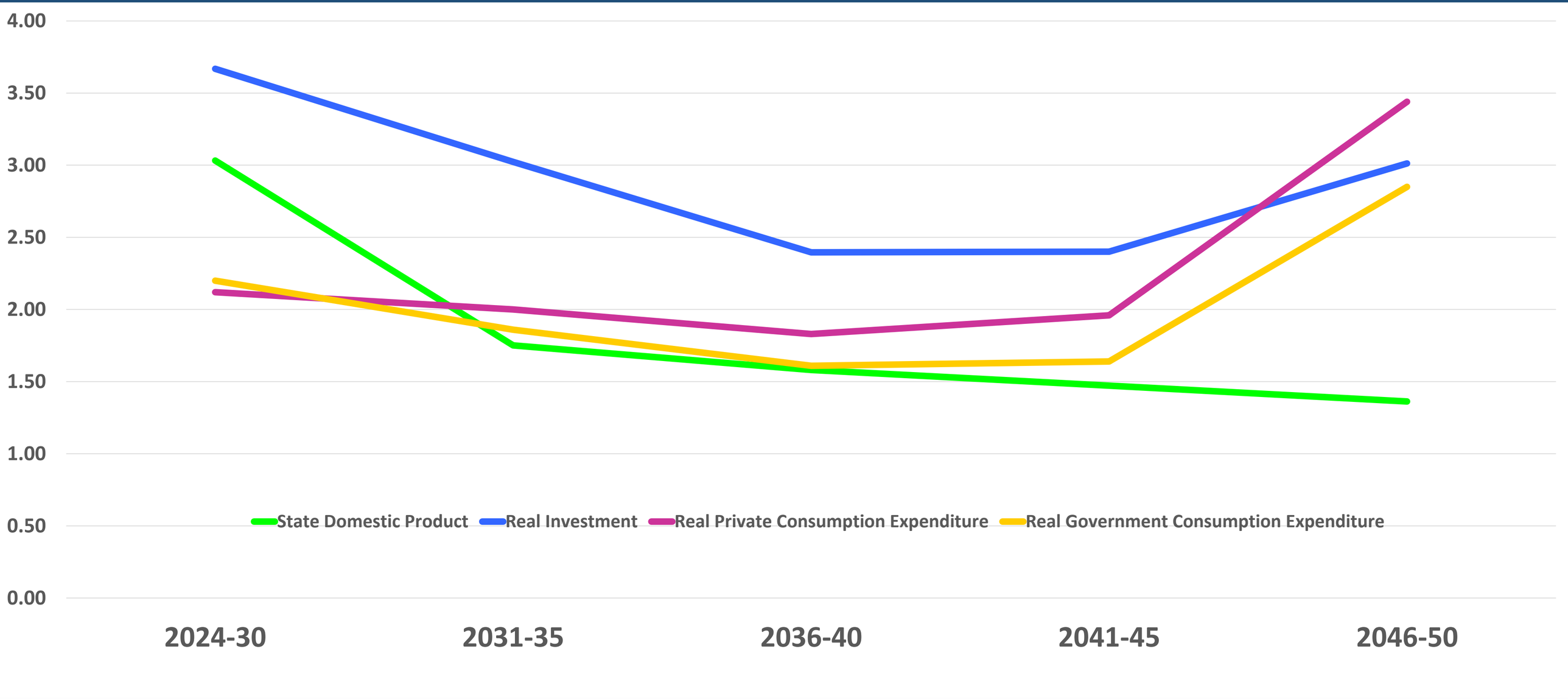
Growth of State Domestic Product of Kerala in different Scenarios (in percent)



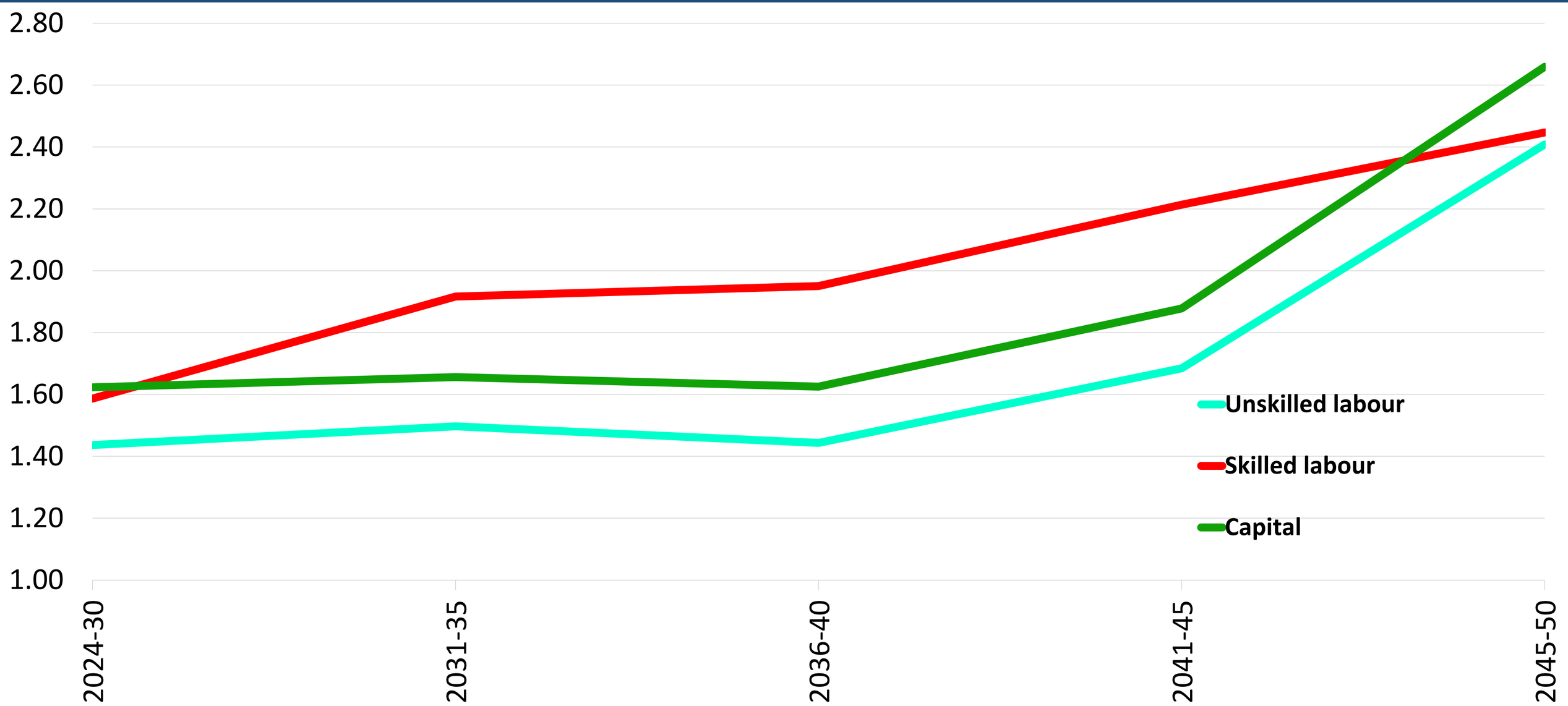
Share of Import of Fossil Electricity and Domestic Production of Renewable electricity with an increase of 50% of its existing potential in Kerala



Macro economic Growth of Kerala in Policy Scenario 3, from 2024-2050 (Percentage deviation from the Baseline)



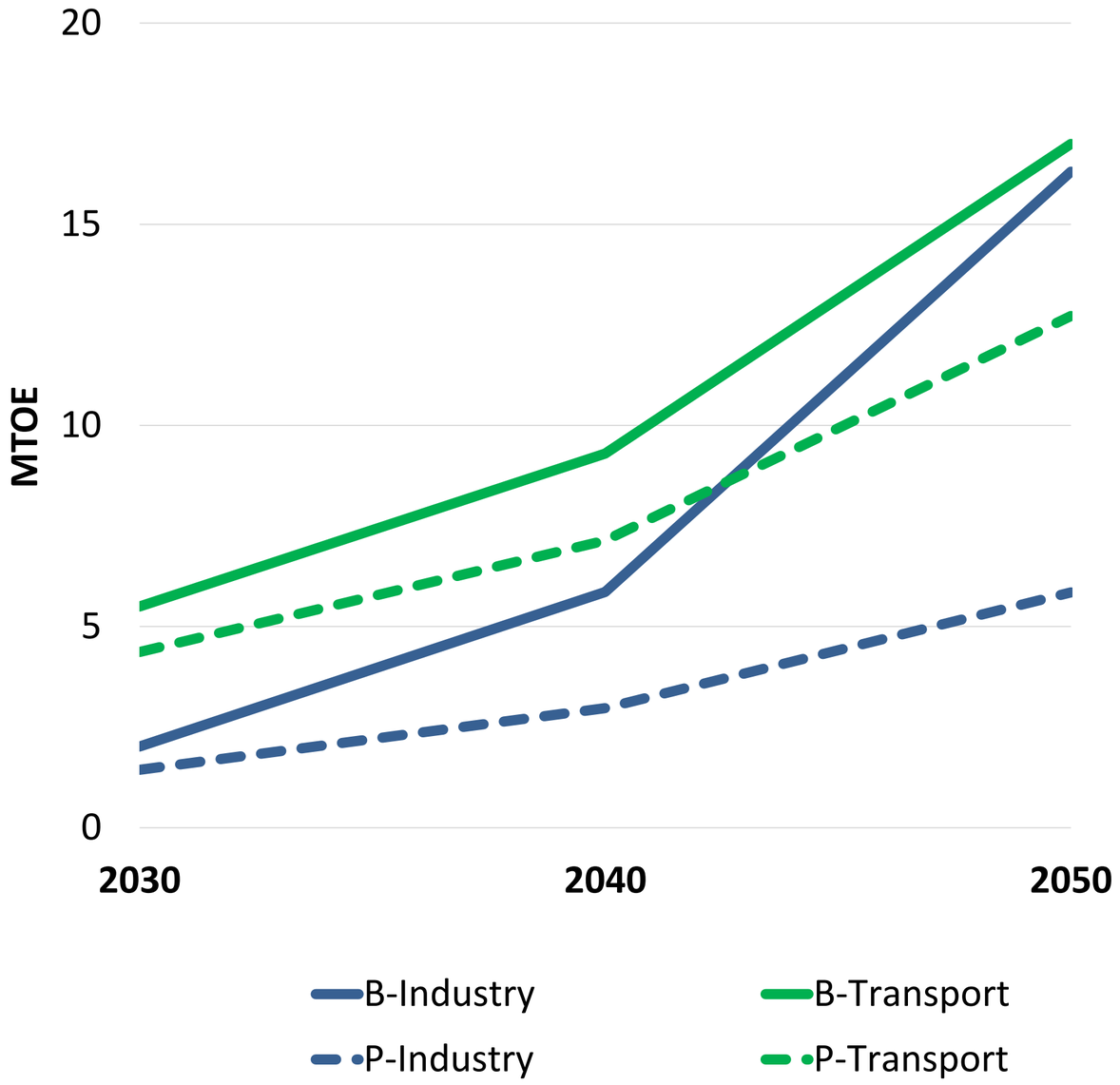
Real Returns on Factors of Production from 2024-2050 in Kerala in Policy Scenario 3, (Percentage deviation from the Baseline)



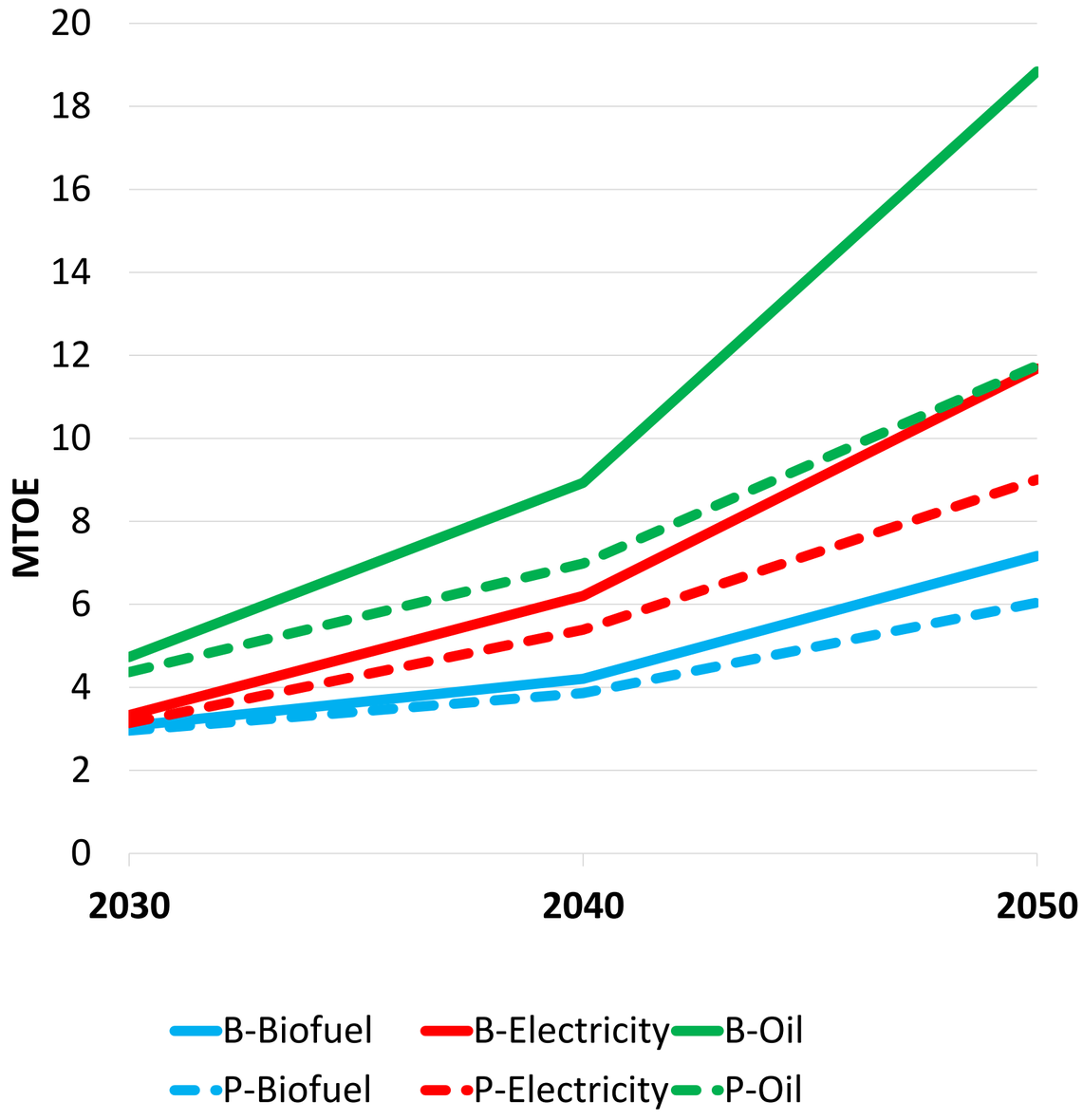
Sectoral growth of output in Kerala in Policy Scenario 3 (in Percent)

Sectors	2024–2030	2031–2035	2036–2040	2041–2045	2045–2050
Other Services	5.21	5.88	6.37	6.13	5.67
Construction	7.84	6.55	6.44	6.49	6.64
Trade	7.04	7.19	7.61	7.57	7.38
Dwelling	10.26	9.62	9.62	9.13	8.68
Public Administration	7.34	6.75	6.87	6.46	6
Financial Insurance Services	6.61	6.65	6.85	6.37	5.54
Communications	5.29	5.02	5.12	4.22	2.75
Hotels	9.79	9.1	9.27	8.71	8.17
Land Transport	5.39	5.44	5.78	5.54	5.19
Livestock	3.77	3.97	4.25	4.02	3.74
Other Manufacture	7.58	6.85	5.96	3.22	0.7
Vegetables and Fruits	2.86	2.79	2.83	2.31	1.65
Food Beverage & Tobacco	3.99	3.26	2.67	0.68	0.02
Batteries, Electrical & Electronics Equipment	7.89	7.41	6.51	3.68	0.67
Machinery	8.71	7.83	6.72	3.59	0.19
Non-Ferrous Metal	6.49	5.62	5.02	3.24	0.57
Fishing	4.02	3.56	3.67	3.39	3.09
Paddy	3.52	3.42	3.47	3.23	2.98

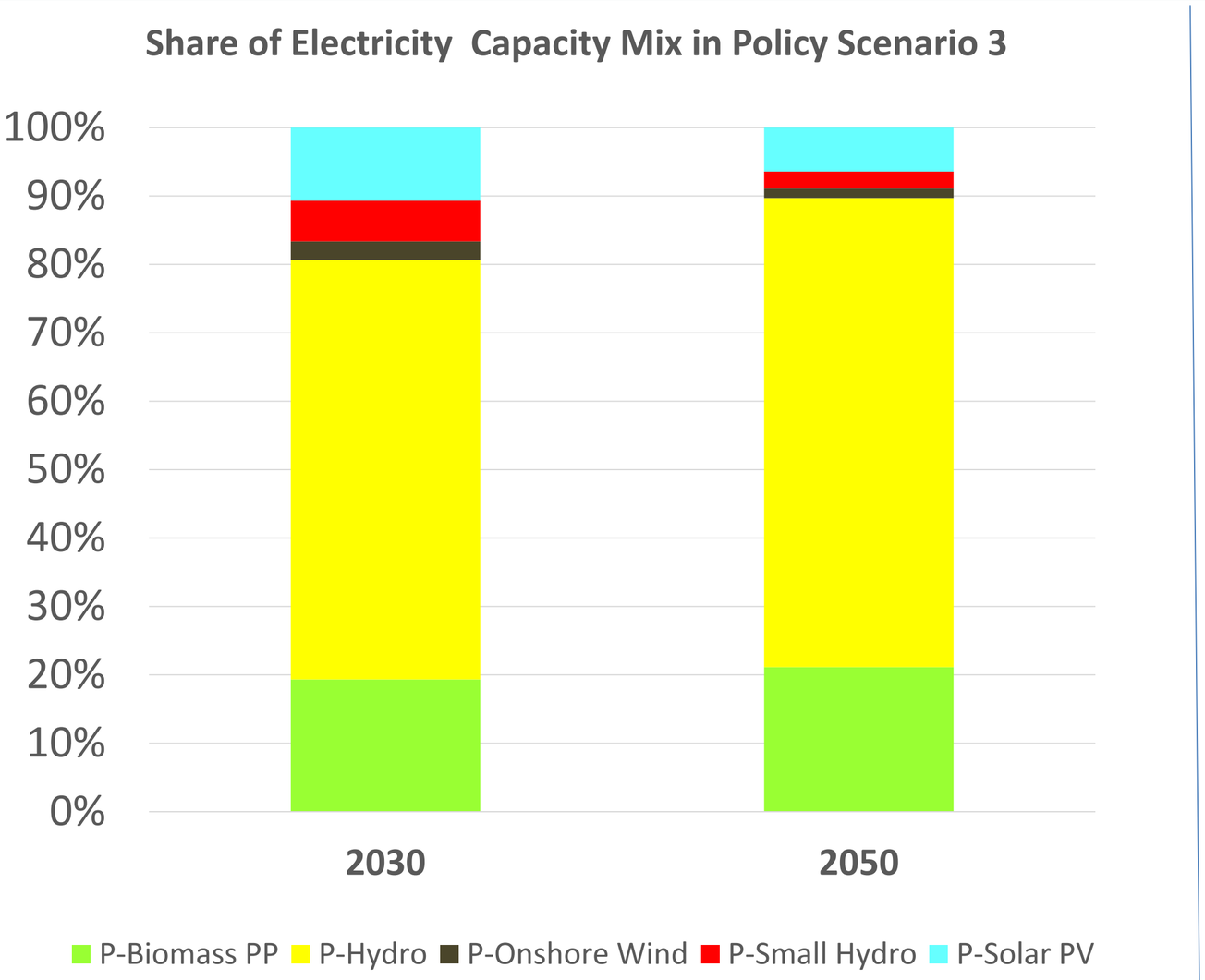
Final Energy Demand in Kerala

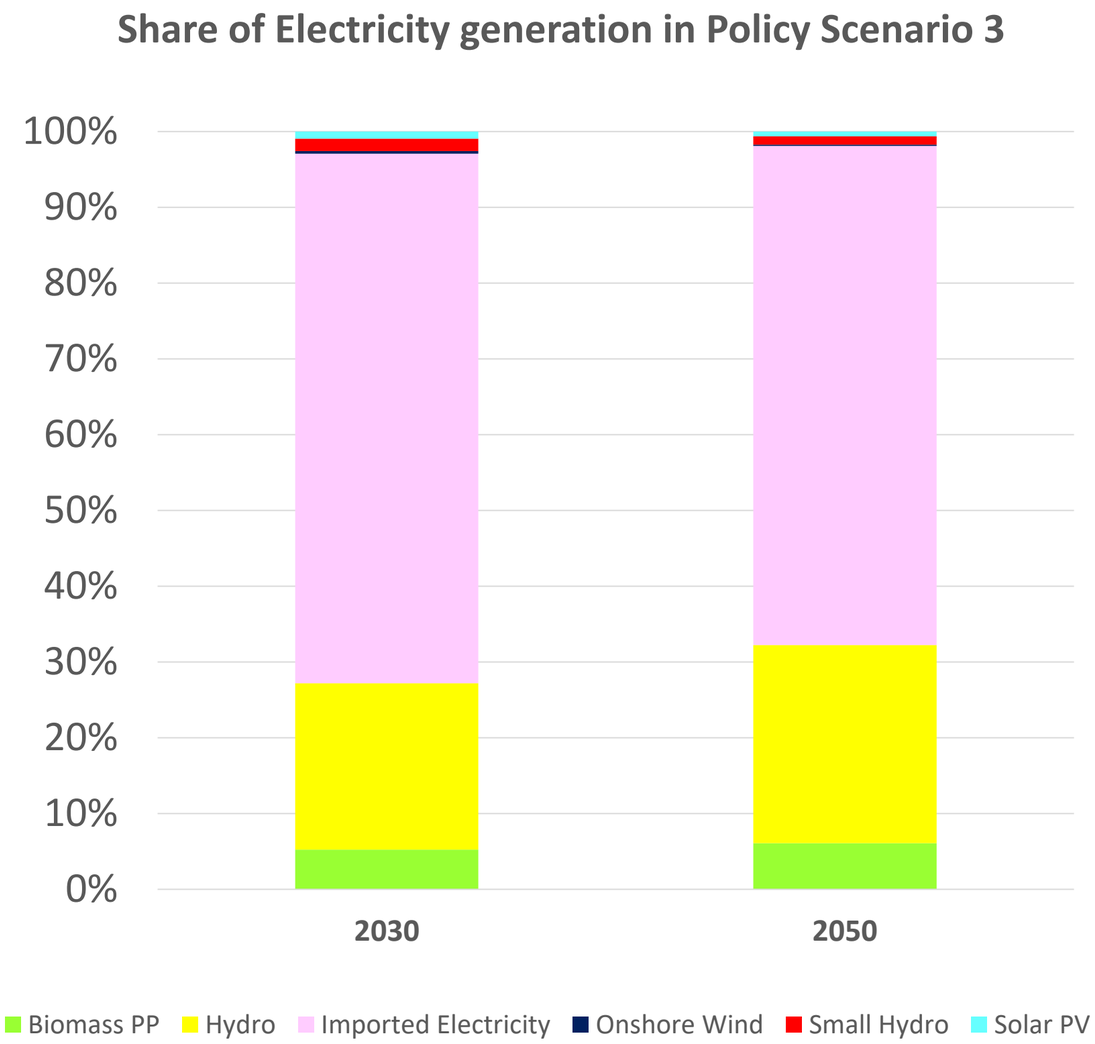


Final Fuel Mix in Kerala



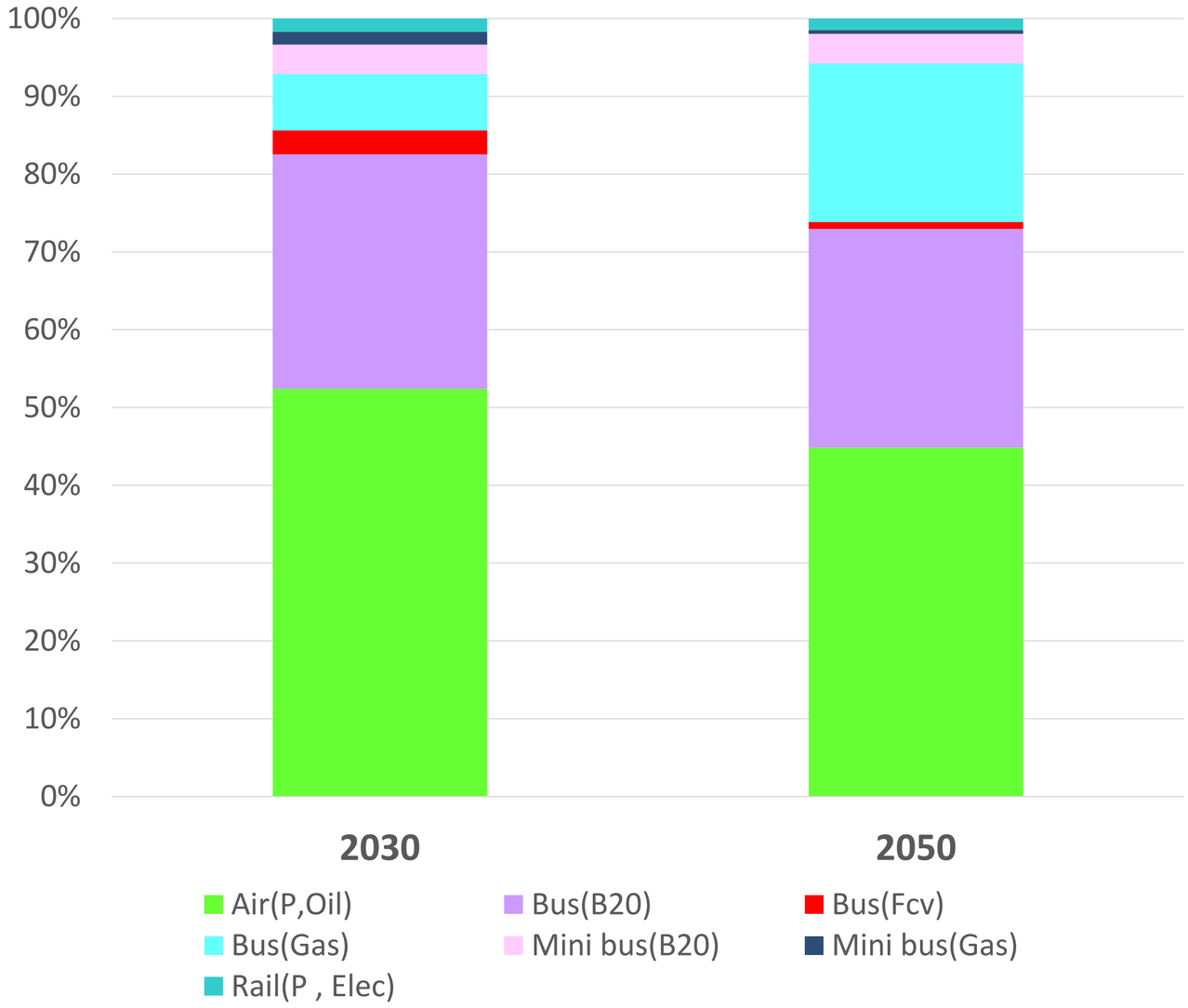
Share of Electricity Capacity Mix and Generation in Policy Scenario 3 (in Percent)



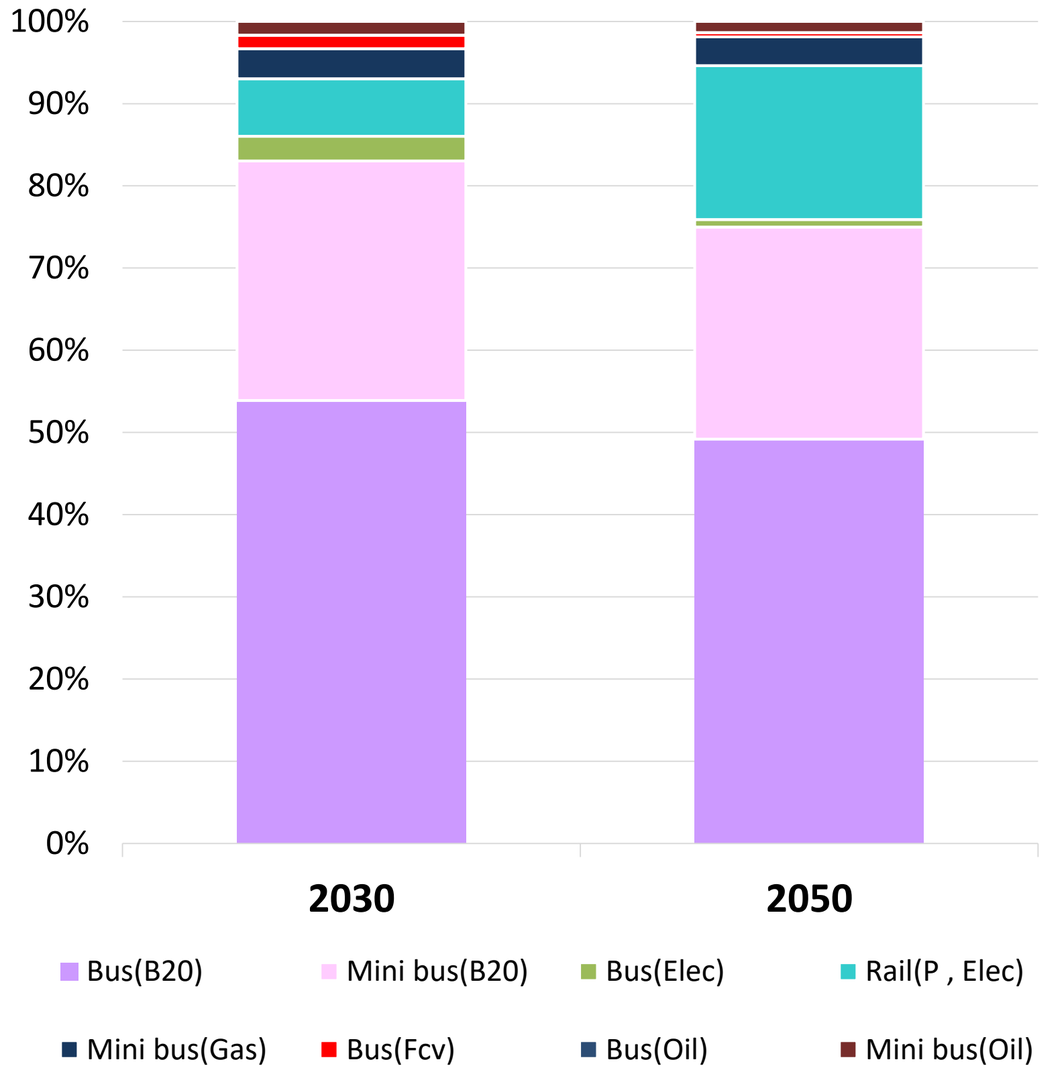


Energy/ Fuel Choices for Public Transport

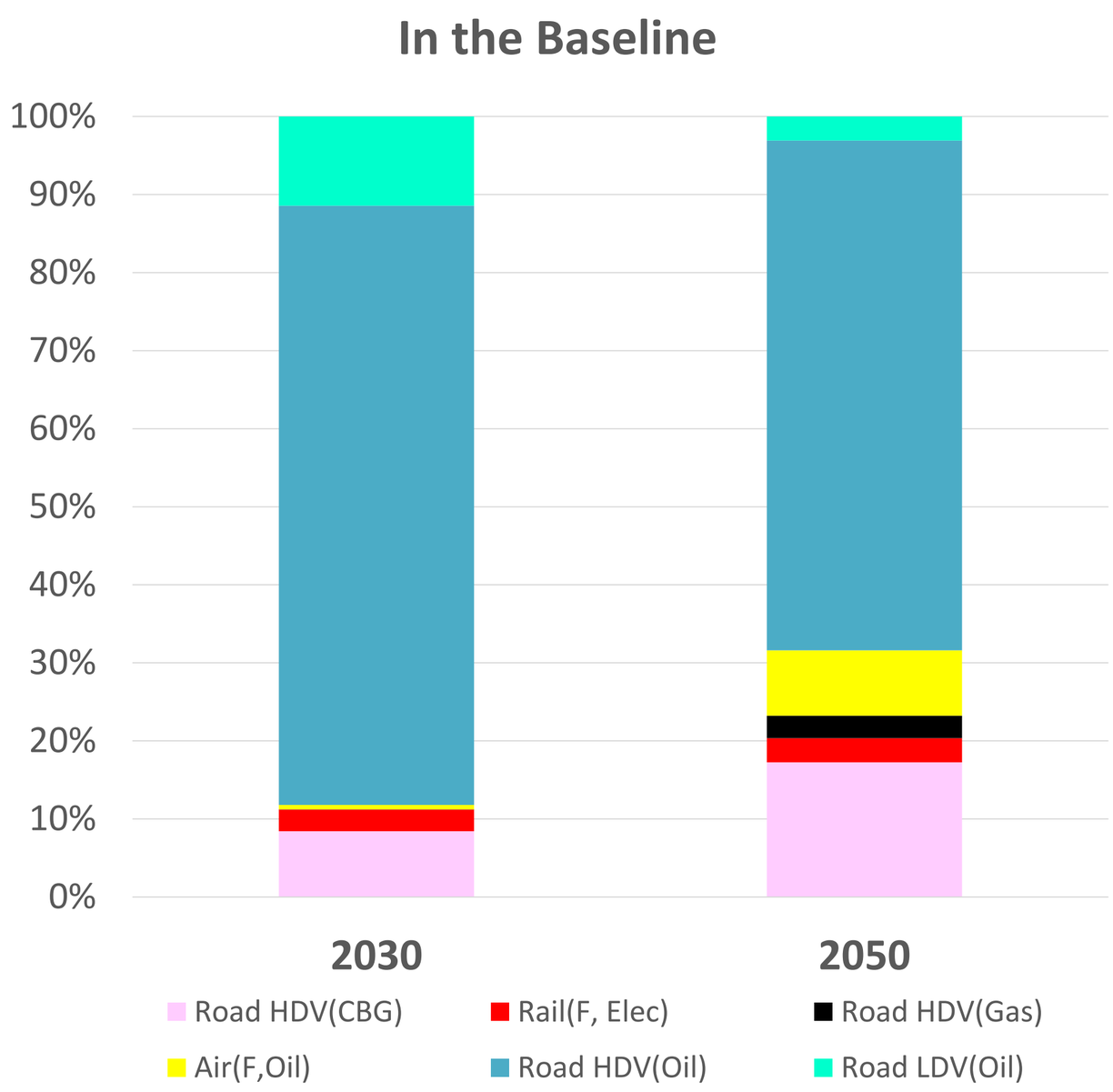
In the Baseline

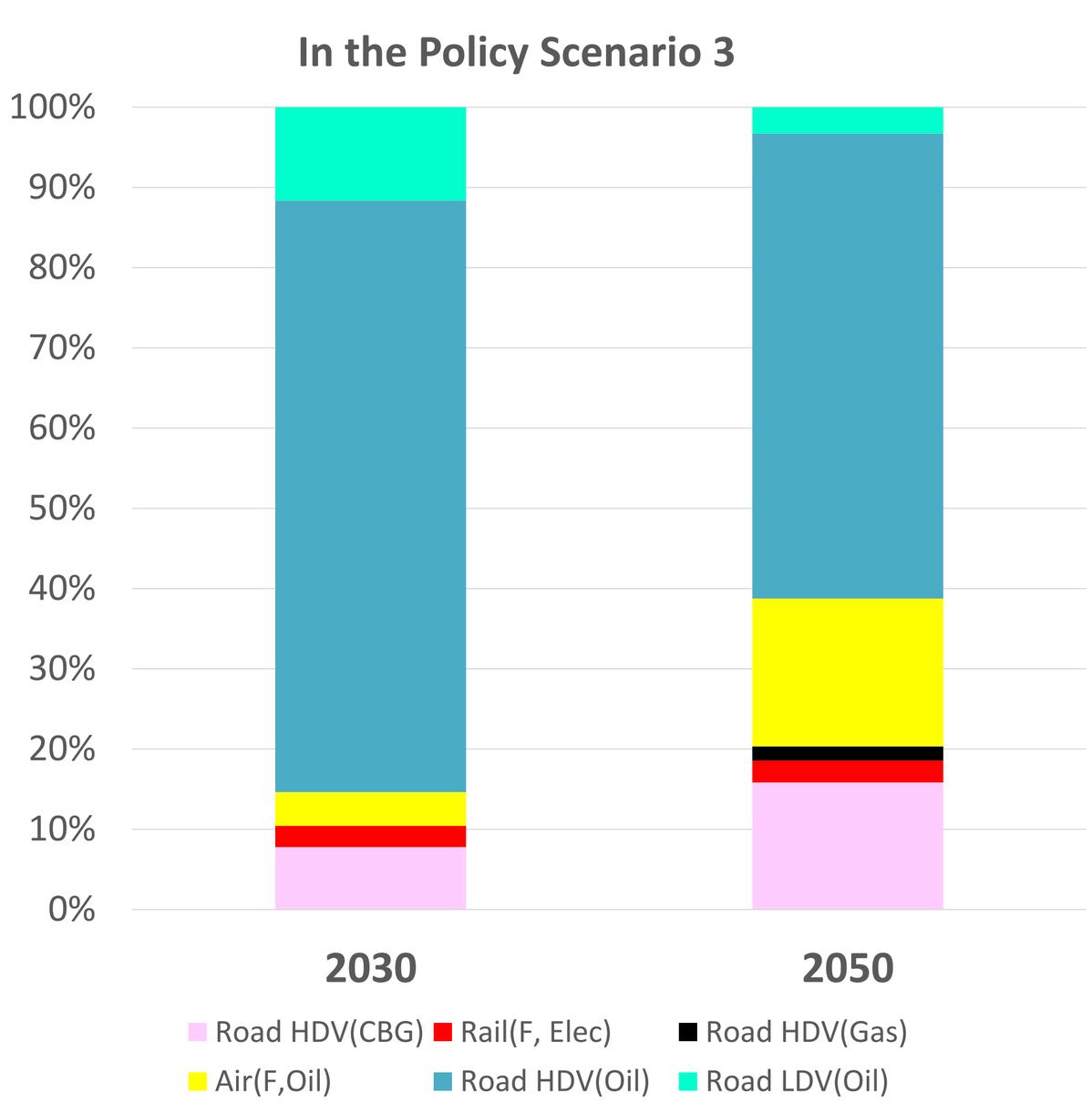


In Scenario 3

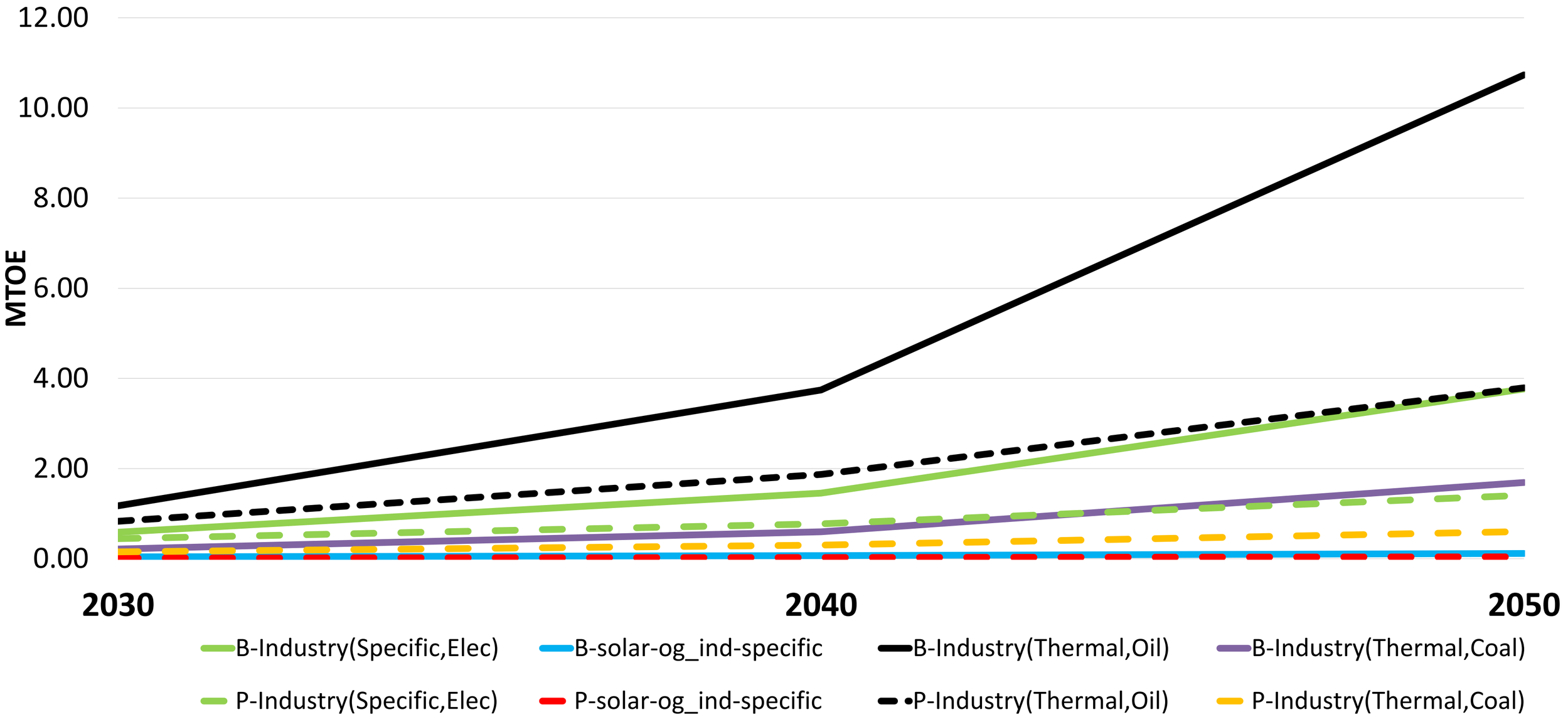


Energy/ Fuel Choices for Freight Transport

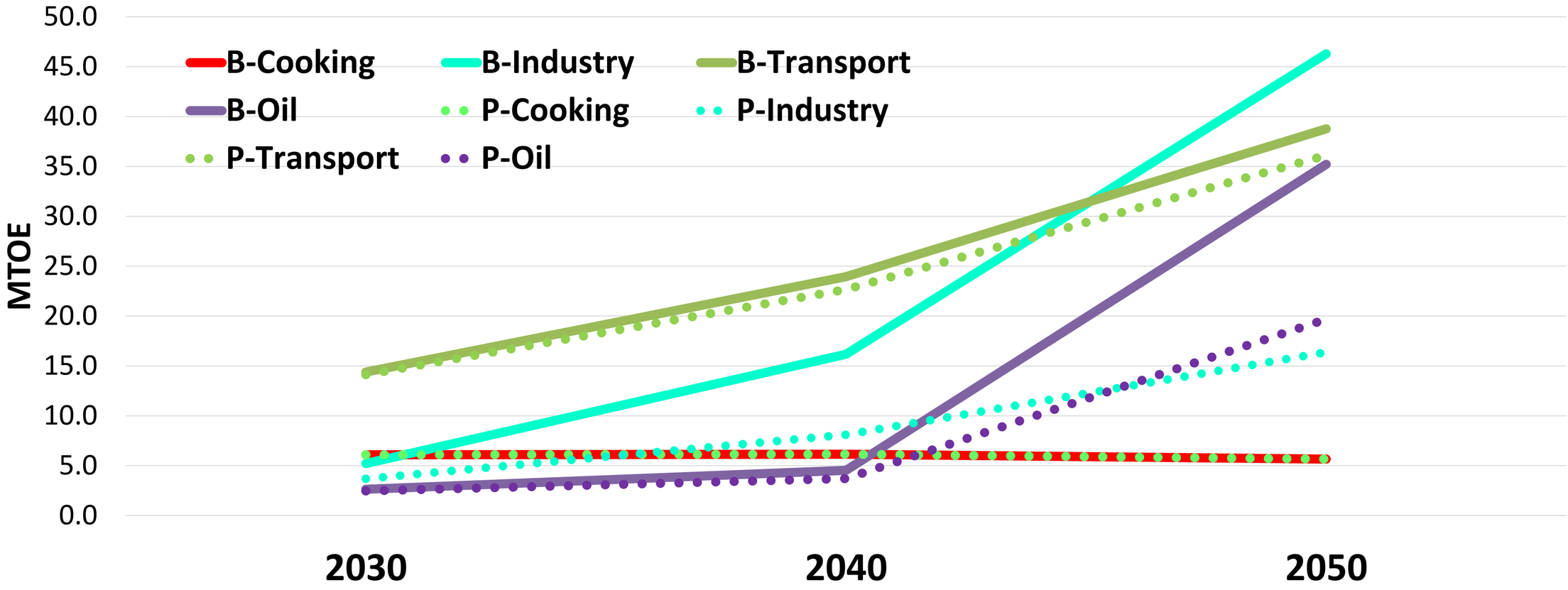




Energy/ Fuel Choices in Kerala in Policy Scenario 3 and Baseline



Emission Profile of Kerala in Policy Scenario 3 and Baseline

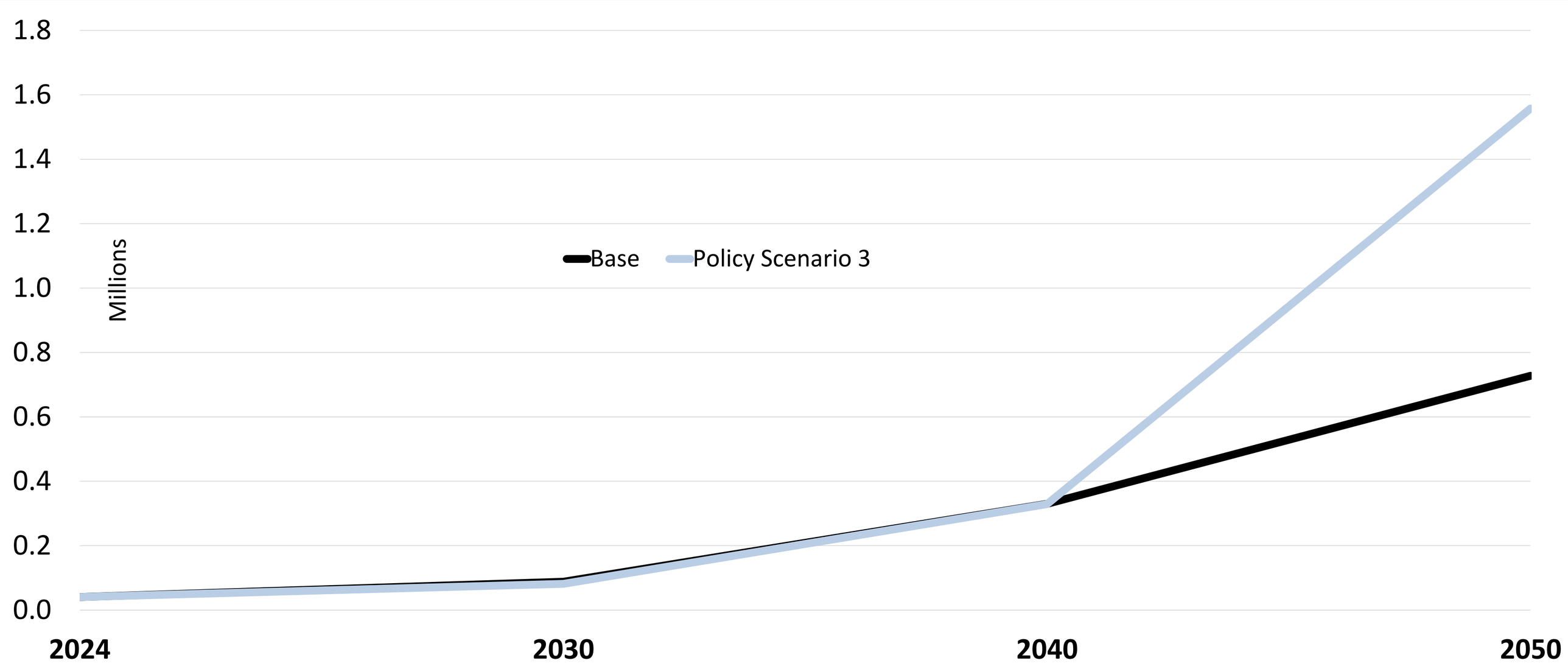


Per Capita Emission (Tons CO2e)	2030	2040	2050
Policy Scenario 3	0.72	1.15	2.18
Base Run	0.86	1.53	3.73

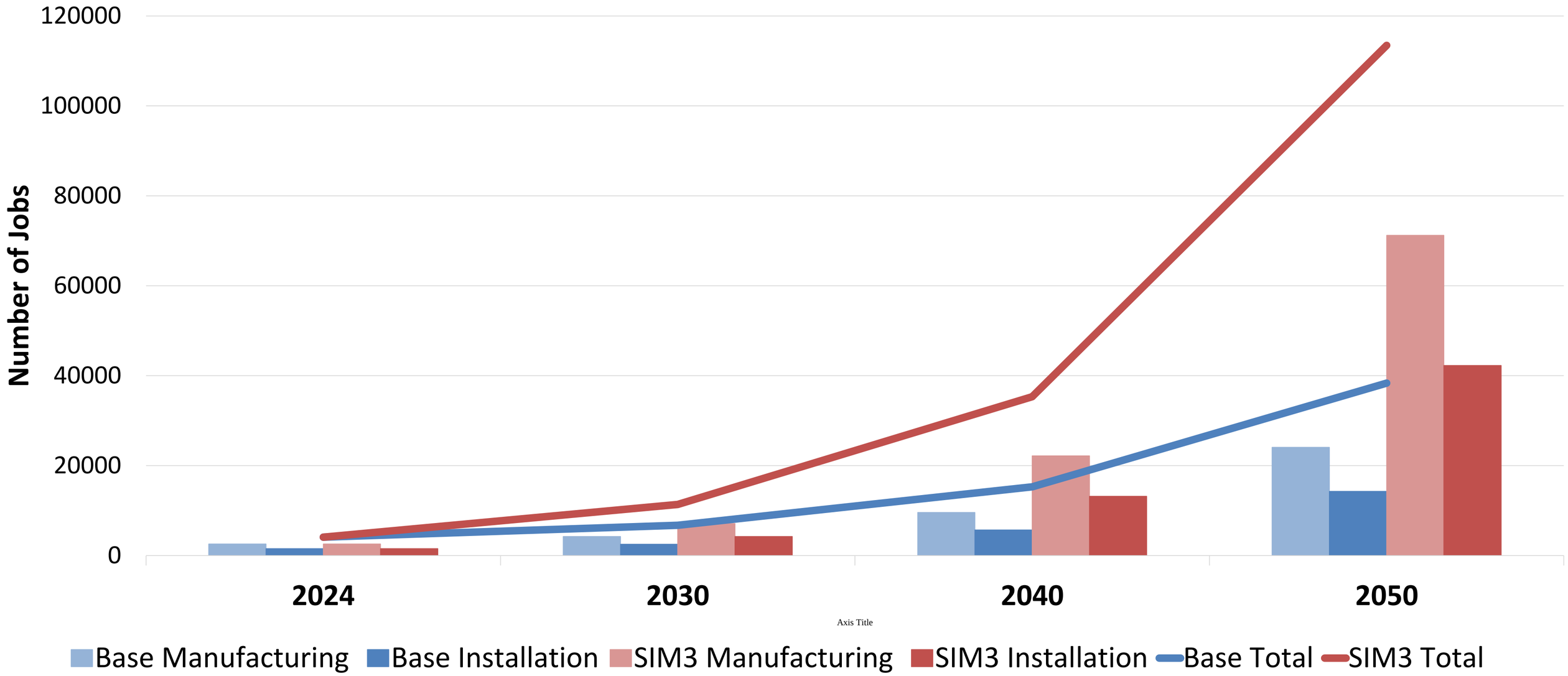
Cumulative Investment (Million USD)

Sectors	Base Run		Policy Scenario 3		Additional Investment required	
	2025-30	2025-50	2025-30	2025-50	2025-30	2025-50
Agriculture	241	626	241	626	0	0
Biofuel	66	154	63	129	-3	-25
Buildings	1131	4733	1131	4733	0	0
Cooking (Rural)	87	230	87	230	0	0
Cooking(U)	502	1855	502	1855	0	0
Domestic (Resource)	753	5079	568	3551	-185	-1528
Electricity	1958	26152	1958	26152	0	0
Gas	7	38	7	33	0	-5
Industry	188	3075	130	1223	-58	-1852
Transport (Freight)	11489	53638	11033	48842	-456	-4796
Transport (Passenger)	31852	166834	28835	143291	-3017	-23543
Biogas	5	40	5	35	0	-5
Green hydrogen	22	58	0	54	-22	-4
Total	**48301**	**262512**	**44560**	**230754**	**-3741**	**-31758**
	(3.6% of cumulative SDP)	*(0.83% of cumulative SDP)*	*(3% of cumulative SDP)*	*(0.36% of cumulative SDP)*		

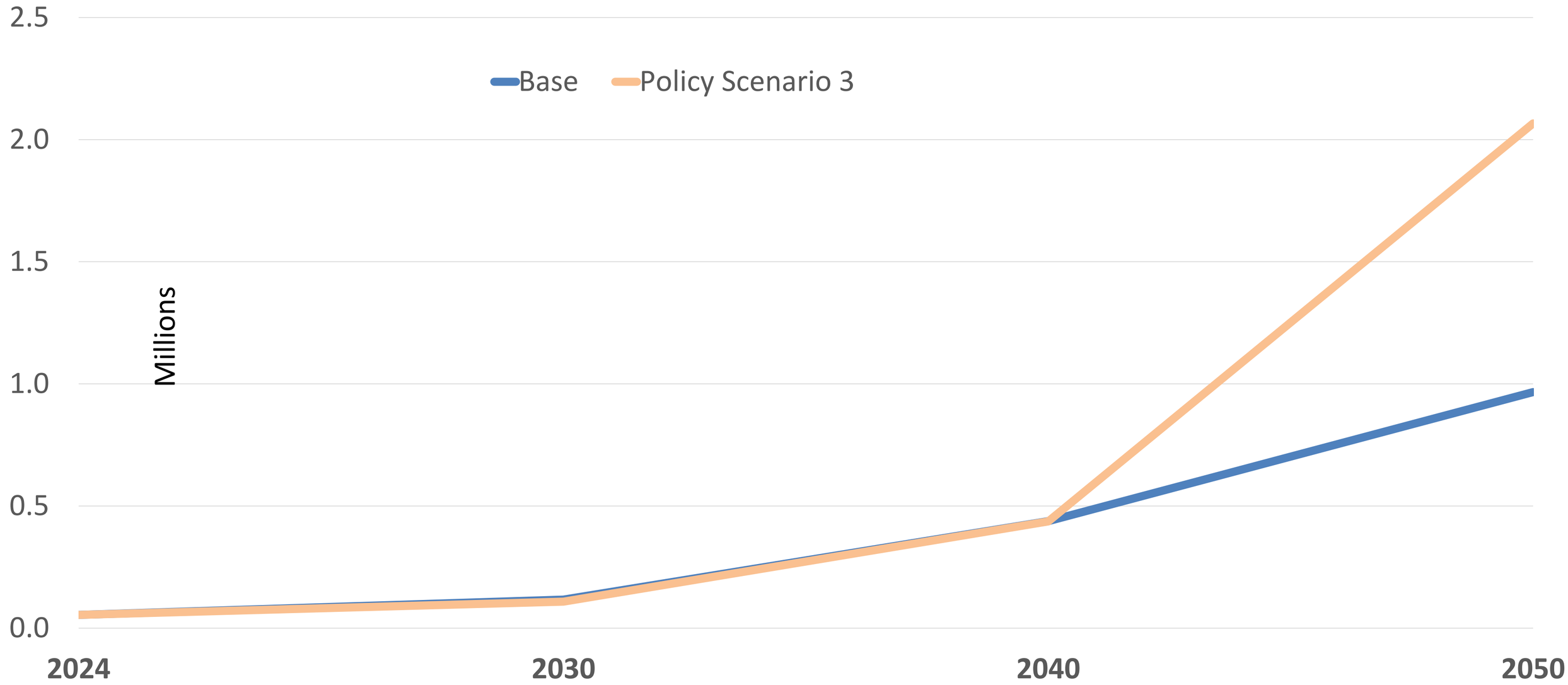
Direct Employment in Energy Sector from Operation and Maintenance in Kerala in Policy Scenario 3 and Baseline



Employment in Manufacturing and Installation of New Renewable Power Plants in Kerala



Total (Direct, Indirect and Induced Together) Employment in Energy Sector from Operation and Maintenance in Kerala



Summing Up

- Analysis of Mitigation strategies for energy transition based on Integrated modelling Approach
- Business as usual scenario indicates
    - Per capita emission will rise from 0.7 tons CO2e in 2025 to 3.73 tons CO2e in 2050
    - Imported electricity will still play an important role in BAU
    - US$ 236 billion investment will be required in the energy sector during the period 2025–2050
- Policy run indicates that restriction on import/production of fossil-based electricity, without any policy intervention specific to renewable energy capacity enhancement, will not lead to augmentation of the capacity of renewable electricity
    - Kerala's State Domestic Product (SDP) contracts as all sectors t face contraction due to reduced supply of electricity and higher price of electricity
    - A market-based approach with tax/subsidies performs better in limiting the SDP loss during the transition along with augmentation of renewable energy capacity

Summing Up

- Results improve significantly in terms of restricting emission without hampering economic growth, if the assumption on increased energy efficiency along with productivity growth is incorporated into the model for energy transition.
    - Higher energy efficiency leads to energy saving leading to lower emission and lower energy requirement
    - An energy efficiency to the tune of 2.5% concomitant with productivity growth of 1% per annum will lead to only a rise of per capita emission by 2.18 ton CO2e in 2050 versus 3.73 ton CO2e in 2050 in the base run
- It is prudent to augment capacity of renewable electricity. Depending on imported electricity may be costly
- Results show that direct employment from operation and maintenance of power plants would be significantly more than the baseline employment projection from 2040 onwards, and the policy scenario 3 (aggressive use of renewable energy, increased energy efficiency, and productivity growth) is expected to provide 0.8 million more direct employment in the energy sector in Kerala as compared to the baseline scenario.
- Investment in renewable energy not only increases employment generated from operation and maintenance, but also from manufacturing and installation of new power plants. Policy scenario 3 is expected to generate an additional 75 thousand employment in Kerala in 2050, as compared to the baseline scenario