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

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Challenges and Policy Implications for Low-Carbon Pathway for Kerala: An Integrated Assessment Modelling Approach[1]

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Abstract

As India has embarked on the journey of fulfilling its net-zero emissions target by 2070, the states of India are steering up too to meet the target. The per capita emissions for Kerala are lower than the national average. The energy sector is the main contributor to GHG emissions in Kerala. A major share of 76 percent of electricity power is purchased from other states. When other states undergo an energy transition, the availability of imported electricity may be a challenge for Kerala. Hence, the State needs to harness its own potential for renewable energy sources and incorporate improved technologies leading to energy efficiencies in all sectors. Accordingly, this paper has undertaken integrated modelling (an approach with the primary objective of quantifying the gains and losses of low-carbon transitions and their financial implications). The integrated modelling approach involves soft linking of the macroeconomic top-down CGE model and bottom-up (Messageix) energy model. The integrated model is a recursive dynamic model with multiple periods of time. In this paper, we have undertaken a policy scenario in which (i) the imports of fossil-based electricity from other states of India are restricted to Kerala, (ii) 50 percent of the existing potential of renewable electricity by various modes is achieved in Kerala and the rest of India, and (iii) energy efficiency in all energy sectors is increased to the tune of 2.5 percent per annum along with 1 percent total productivity growth per annum in all sectors of the Kerala and India economies. Our results show that the reduced import of fossil fuel electricity without any policy intervention to strengthen the renewable energy sector would hamper growth. On the other hand, investment in renewable energy to facilitate a complete energy transition with self-reliance on energy for the state would expand the economy, increase the returns to the factors of production, and increase employment. The key message that comes out from our simulation is that the energy transition towards renewable energy will not take place without complementarity support polices towards this sector. Our observation is that energy transition may be a win–win situation in the sense that growth and employment creation may be positive with suitable policy intervention. It must be mentioned that the paper

[1] This paper is the product of the research staffs of NCAER/CDS/TCE. The findings, interpretations and conclusion expressed herein do not necessarily represent the views of the Governing Body or Management of NCAER, CDS, and TCS.

focused only on the energy sector. The developed model may be used in the future to focus on the economic implications of other policies, such as carbon sequestration.

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1 Introduction

Kerala, with a coastline of approximately 590 kilometres, is a densely populated state and is very vulnerable to the effects of climate change. It has experienced extreme events such as heavy rainfall, floods, landslides and droughts in the last few years. Agricultural and fishery production are affected by these extreme events, in addition to public health and nutritional consequences. During the 2018 flood, 1,259 out of 1,664 villages spread across its 14 districts were affected, displacing 1.4 million people, and 433 lives were lost between 22 May and 29 August 2018.

The gross state value added at constant prices in Kerala experienced a negative growth rate from 2020–21 due to the COVID-19-induced economic slowdown (Pohit et al, 2023). From 2021–22, the economy recovered, and the growth rate reached 12.09% from 2019–20 (as per quick estimates). The share of the primary sector in gross state value added at constant prices in Kerala was approximately 9%, the share of the secondary sector was 27%, and that of the tertiary sector was 64% from 2021–22. However, agriculture, livestock, forestry and fishing accounted for 23% of the workforce in Kerala in 2020–21.

Per capita emissions are low for Kerala (0.09 tCO_2e per capita) compared to the national average (2.24 tCO_2e per capita). The energy sector is the major contributor to emissions in Kerala (81% in 2018 excluding AFOLU[2]). Within the energy sector, transport had the highest share of emissions (52 percent), followed by industries (19 percent) and the residential sector (18 percent) in 2018. One of the reasons for the lower emissions in Kerala than in India is the lower share of the total emissions in the power generation sector than in other states. This is mainly because of two reasons. First, Kerala meets a large part of its energy demand by purchasing power from other states. That is, 66% of the total power purchased by KSEB was purchased at delivery points, i.e., not generated within the state. Second, the major sources of power generation in Kerala are hydro (85%) in Kerala, followed by small hydro (8.5%), solar (4.5%) and wind (1.2%). A lower reliance on thermal power also contributes to lower emissions from the power sector.

Given that the Government of India declared India to be a net-zero emitter by the 2070s, all states are now gearing towards achieving that goal by adopting a low-carbon pathway for their economic growth. Kerala is no exception to this trend. In this endeavour, Kerala, like any other state, faces several challenges and policy dilemmas. A summary of the review of energy sector policies is given in the next section.

1.2 Policy Dilemma

Environmental concern is recognized as a serious issue by the state government of Kerala and is an agenda for development planning in the state. The major energy and environmental policy initiatives in recent years are discussed in Kerala Perspective Plan 2030 (a part of Kerala Economic Review 2015), Kerala Economic Review 2022, the State Action Plan on Climate Change (SAPCC) developed in 2014, and the revised Kerala State Action Plan on Climate Change (SAPCC) 2.0 (Pohit et al., 2023). Along with the central government, the state government has taken several initiatives to increase power generation from renewable energy sources and to improve energy efficiency in energy-intensive sectors. Mitigation strategies are designed to reduce emissions from power generation, transport, industry, building, and agriculture and to increase the reliance on renewable energy sources in those sectors. Apart from these initiatives, there is increasing awareness and emphasis on adaptation strategies to reduce the harmful effects of extreme events in sectors such as agriculture, livestock, coastal fisheries, dairy development, and forest and water resources. Apart from these, to promote electric vehicles in Kerala, the State Government announced special electric vehicle subsidies and incentives to promote the usage of e-vehicles in Kerala. For the abatement of air pollution, the Pollution Control Board has established ambient air quality monitoring stations in the state along with other initiatives.

Mitigation strategies in Kerala involve sectors such as power, transport, industry, agriculture, and buildings, which cumulatively contribute 80% of the emissions in the state.

[2] Agriculture, Forestry and Other Land Use

This paper focuses on mitigation strategies and emphasizes improving energy efficiency and productivity growth to facilitate energy transition through demand and supply-side management of energy sectors, conforming to the net-zero target for emissions by 2070. The implementation of the above policies has short- and long-term costs and benefits. Understandably, the implementation of these changes has a large financial burden. Therefore, sequencing the changes is necessary considering the cost and benefits of alternative pathways. This has been the principal objective of this paper, which uses a methodology, namely, an ***integrated modelling approach***, commonly adopted in other countries to quantify the gains and losses of low-carbon transition and the financial implications thereof.

It is also important to analyse the issues in a modelling framework that determine prices in the system and the interplay between energy and economic systems that are embossed in the framework. This is possible only if price is endogenously determined in the model through the sectoral demand/supply equation. In that case, economic equilibrium (where demand and supply in the economy meet) would result in the determination of price and output in the economy. In an economic model, demand and supply equations for all sectors of the economy, including the energy sector, are explicitly built, and hence, price and output are endogenously determined. Typically, the supply function depends on labour, capital, other intermediate inputs and their prices. On the other hand, the demand function is derived from the preferences of agents, income and prices.

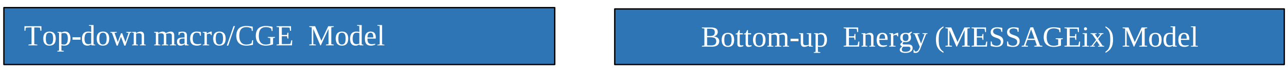
As Kerala is a small state of India, the Kerala economy is impacted by economic forces occurring in the rest of India or the world. Therefore, the economic framework needs to take this into account by employing a multiregional modelling tool. These issues are discussed in detail in the next section.

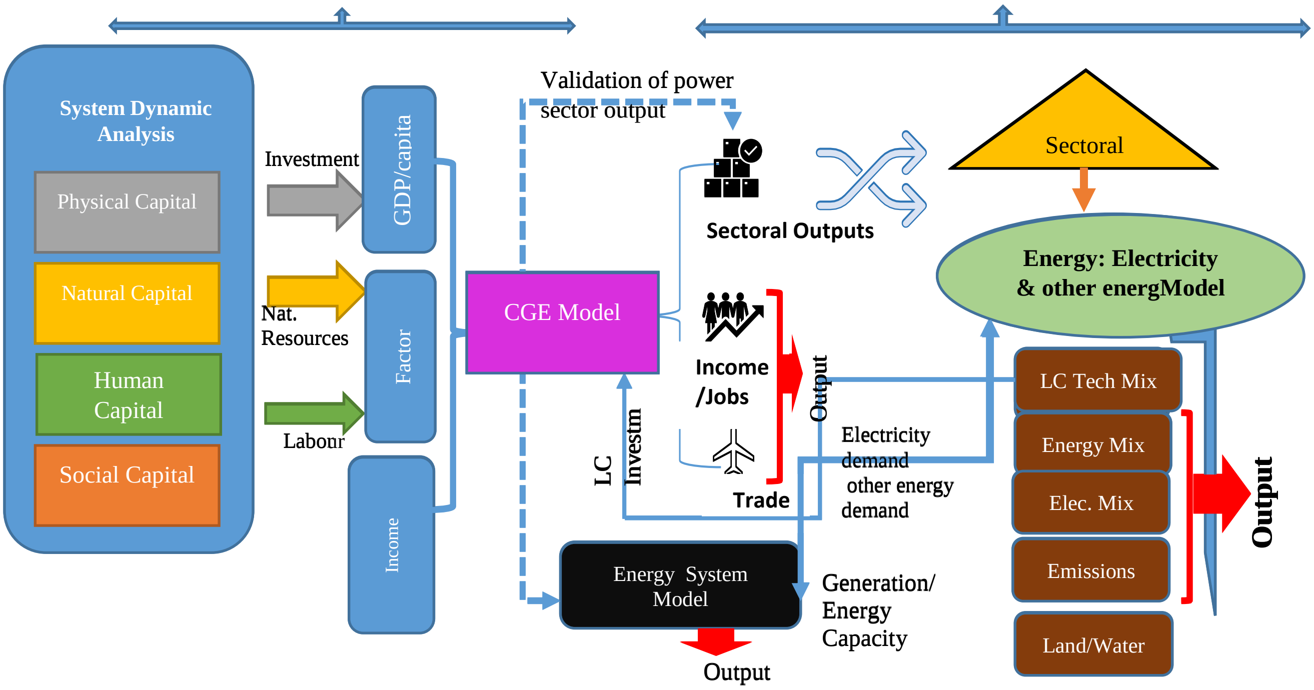
The remainder of this paper is organized as follows. Section 2 discusses our economic modelling tools that were used for this exercise. Section 3 provides an overview of Kerala's economy with the key structure for the base year of our model, namely, 2021. Section 4 describes the mechanism for policy analysis with the model. Section 5 provides the long-term path of Kerala's economy for the baseline or BAU scenario, along with our results for the various policy simulations that we undertook using the integrated model. Section 6 focuses on the employment implications of adopting a low-carbon pathway. Finally, Section 7 provides concluding remarks.

2 Integrated Model Approach

Figure 1 provides a pictorial representation of our integrated modelling structure. As this figure indicates, the modelling structure incorporates two models—a top-down computable general equilibrium (CGE)-type macro model, which provides baseline/policy forecasts of prices and outputs (sectoral GDP), the results of which are then fed into a bottom-up energy (MESSAGEix) model, which provides the best technology options among all the possible available technology bundles, given that the available resources are used in the least cost way. The bottom-up energy model also provides us with the investment amounts that are necessary to achieve these technology choices. These are then fed into the macro (CGE) model to validate whether the growth path diverges. This process of two-way feedback continues until the differences in GDP between successive rounds converge.

Figure 1 Structure of the Integrated Model





2.1 Framework of the Integrated Model (NCAER CGE Model – MESSAGEix)

As noted earlier, two separate soft-linked models are used for deriving the results. This is possible only if the models are constructed by aligning the sectoral classification of the two models, as shown in the concordance map in Table 1.

The top-down macro (CGE) model divides an economy into multiple sectors and defines the economic relationship between these sectors with the help of demand and supply equations. Based on these relationships, the model generates long-term projections for an economy for the BAU and policy scenarios considering the equilibrium state of the economy. In an equilibrium model, the growth or decline of the state of the economy is reflected in the growth and decline of other sectors linked to the economy. There are several outputs that can be generated from a CGE model, but the paper focuses on one major outcome of such model simulations, which is the growth rate of the sector. The growth rates determine the value added in a sector, which, with the help of an energy multiplier, can help determine the growth of energy demand in an individual sector.

Using the concordance map shown in Table 1, we obtained the outputs of the sectors that we aggregated/disaggregated based on our requirements. The sectoral outputs are obtained in the form of quantity changes in intermediate demand, sectoral aggregate demand and household demand to be prioritized based on our requirements. The obtained results are aligned to the required disaggregated sectors. The next two sections provide an overview of the two models, top-down and bottom-up, the details of which are given in Annex A1 and Annex A2, respectively.

Table 1 Concordance map between the NCAER CGE and MESSAGEix sectors

S.No.	Sectors (NCAER)	MESSAGEix	S.No.	Sectors (NCAER)	MESSAGEix
1	Paddy	Agri pumping /Agri transport	22	Coal	Power energy supply
2	Wheat		23	Gas	Power energy supply
3	Other Cereals		24	Extraction	Not applicable
4	Fruits & Vegetables		25	Food Beverage & Tobacco	Industry thermal
5	Oil Seeds		26	Textiles and Garments	
6	Other Crops		27	Other Manufacture	
7	Oil	Power energy supply	28	Wood, Wood Products & Furniture	
8	Nuclear Electricity	Nuclear electricity	29	Paper & Paper Products, Printing & Publishing	
9	Coal Electricity	Coal electricity	30	Petroleum Products	
10	Gas Electricity	Gas electricity	31	Chemicals	

11	Wind Electricity	Wind electricity (onshore// offshore)	32	Pharmaceutical	
12	Hydro Electricity	Hydro electricity	33	Nonmetallic Minerals	
13	Oil Power	Oil power	34	Ferrous Metal	
14	Solar Electricity	Solar electricity (all forms)	35	Non-Ferrous Metal	
15	Other Renewable	other renewable	36	Batteries, Electrical & Electronics Equipment	Commercial others
16	Land Transport	p_transport_road_OMNIBUS	37	Machinery	
		f_transport_road	38	Vehicles	
		p_transport_road_BUS	39	Transmission & Distribution	
		p_transport_road_TAXI	40	Water Distribution	
		p_transport_road_CAR	41	Construction	
		p_transport_road_2 W	42	Trade	
		p_transport_road_3 W	43	Hotels	
		f_transport_rail	44	Storage & Warehouses	
		p_transport_rail	45	Communications	
17	Water Transport	f_transport_IWT	46	Financial Insurance Services	
		p_transport_ferry	47	Other Services	
18	Air Transport	f_transport_air	48	Public Administration	
		p_transport_air	49	Dwelling	Residential others
19	Livestock	Not applicable			
20	Forestry				
21	Fishing				

Note: p stands for passengers, f for freight, IWT for inland water transport, 2 W for two wheelers, and 3 W for three wheelers.

2.2 Key Features of the Top-Down CGE Model

The model recognizes 49 industries that produce 49 goods and services. Of the 49 industries, three produce primary fuels (coal, oil and gas), one produces refined oil (petroleum products), and nine generate electricity. The petroleum products industry produces gasoline. The eight generation industries are defined according to a primary source of fuel: electricity-nuclear includes nuclear-operated power plants using turbines that generate electricity; electricity-gas includes all plants using turbines, cogeneration, and combined cycle technologies driven by burning gas; electricity-hydro covers hydro generation; electricity-solar covers generation from photovoltaic systems; electricity-wind covers renewable wind generation; electricity-coal produces electricity by burning coal; electricity-oil produces electricity from oil sources; and other renewables also produce small amounts of electricity from other renewables. There is one electricity distributor. In the model economy, there are 14 industries, with all the major energy-intensive industries modelled separately.

The model further recognizes three types of transport. Land transport moves goods or people by roads/rails using motor vehicles, rails and trucks; air transport moves passengers and freight via air; and water transport refers to people and goods moving by boats or ships over seas and rivers.

Our model is patterned after GTAP-power. It is a multiregional model in which the region is Kerala, the rest of India and the rest of the world. We assume that the regions trade among themselves in commodities/services. However, we assume that electricity trade only occurs between Kerala and the rest of India.

2.3 Key Features of the Bottom-up Energy Model

The bottom-up MESSAGEix requires demand projections as an exogenous input to the model. Based on these projected demands, the supply side in the MESSAGEix model attempts to meet these demands in an optimal way. Optimization in MESSAGEix is constrained to least cost optimization, which means that the optimization occurs for a least cost system expansion plan to meet the future demands in and around all the other policy constraints, such as environmental constraints, resource constraints, and capacity constraints. Hence, the supply side of the information is highly relevant because it primarily covers most of the policy aspects. To make the model more robust in terms of linking the energy model to an economy based on economic performance, the energy demand that should be used in the MESSAGEix model as an input should be derived from a macro (CGE) model. The detailed structure of the model is given in Annex A2.

2.4 Dynamics

The model is multiperiod in nature, where the unit of the period is one year. It is a recursively dynamic (RD) model and is solved as a sequence of static single-year CGE models, after updating sectoral capital stocks, available labour supply each year and other plausible policy shocks over the year. The logic for using a recursive dynamic model is that the Indian government has a set policy target for short-, medium- and long-term low-carbon pathways. To some extent, the RD version of the model can simulate these changes. The sectoral capital stocks are exogenously given at the beginning of a particular period. Between two periods, there will be additions to capital stocks in each sector because of the investment undertaken in that sector in the previous period. More precisely, the sectoral capital stocks for any year t are determined by adding the investments by destination sectors, net of depreciation in year t-1 to the sectoral capital stocks at the beginning of year t-1. Overall, we assume that the rate of investment is market determined and governed by the profitability of the investment.

The labor supply is updated each year by adding new entrants to the labor force, which is governed by population growth. Apart from the above variables, the dynamic version of the model requires assumptions regarding changes in foreign prices for future years, sectoral productivity growth of endowments, technology and preferences (tastes). These may be shocked depending on the choices of policy interventions.

3 Key Features of the Kerala Economy

Table 2 reports the main components of the state domestic product (SDP) from the income and expenditure side of the state Kerala for the base year of our model, namely, 2021. On the income side, the share of labour is 48.2 percent (skilled and unskilled labour together), whereas the share of capital is 33.7 percent. The combined share of natural resources (agricultural land and oil and gas reserves) and capital is 34.8%.

On the expenditure side, the largest component is household consumption, with an SDP share of 60.9%. Investments account for 32.5 percent of the SDP, and government spending accounts for 12.9 percent. Exports as a share of SDP are 18.9 percent, while imports are 25.2 percent. This implies a trade balance deficit of US$ 6.4 billion.

Table 2 SDP components from the expenditure and income side, 2021 (US $ million)

Expenditure components	Value (US$)	Share (%)	Income component	Value (US$)	Share (%)
Household Consumption	63161	60.9	Land	9220	8.9
Investment	33677	32.5	Unskilled Labour	24884	24.0
Government Consumption	13402	12.9	Skilled Labour	25096	24.2
Exports	19604	18.9	Capital	34949	33.7
Imports	26104	25.2	Natural Resources	1136	1.1
			Indirect Taxes	8455	8.1
SDP	**103741**	**100.0**	**SDP**	**103740**	**100.0**

Table 3 reports for 32 aggregated industries, their value-added composition and their share in overall added of Kerala’s economy, indicating the size of each industry.

Table 3 Composition of value added for 31 aggregated sectors, 2021

Sl No	Industry	Composition of value added						Value added by industry	
		Land	*Unskilled Labour*	*Skilled Labour*	*Capital*	*Natural Resources*	*Total*	*Share in value added*	*Rank*
1	Agriculture and Livestock	44%	38%	0%	18%	0%	100%	7.1%	4
2	Forestry	0%	49%	0%	41%	9%	100%	0.6%	24
3	Fishing	0%	42%	0%	26%	32%	100%	0.4%	27
4	Extraction Industries	0%	18%	3%	55%	24%	100%	0.0%	32
5	Food Beverage & Tobacco	0.0%	47.0%	8.0%	44.0%	0.0%	100%	1.6%	12
6	Textiles and Garments	0.0%	47.0%	8.0%	44.0%	0.0%	100%	0.6%	21

7	Other Manufacture	0.0%	49.0%	9.0%	42.0%	0.0%	100%	1.8%	11
8	Wood, Wood Products & Furniture	0.0%	59.0%	10.0%	31.0%	0.0%	100%	0.3%	28
9	Paper & Paper Products, Printing & Publishing	0.0%	51.0%	9.0%	40.0%	0.0%	100%	0.5%	25
10	Petroleum Products	0.0%	9.0%	1.0%	90.0%	0.0%	100%	0.2%	31
11	Chemicals	0.0%	25.0%	4.0%	70.0%	0.0%	100%	0.8%	20
12	Pharma	0.0%	17.0%	3.0%	79.0%	0.0%	100%	0.4%	26
13	Nonmetallic Minerals	0.0%	27.0%	5.0%	68.0%	0.0%	100%	0.6%	22
14	Ferrous Metal	0.0%	24.0%	4.0%	72.0%	0.0%	100%	0.6%	23
15	Non-Ferrous Metal	0.0%	43.0%	7.0%	50.0%	0.0%	100%	1.2%	16
16	Batteries, Electrical & Electronics Equipment	0.0%	39.0%	7.0%	54.0%	0.0%	100%	1.5%	13
17	Machinery	0.0%	43.0%	8.0%	49.0%	0.0%	100%	1.3%	14
18	Vehicles	0.0%	47.0%	8.0%	44.0%	0.0%	100%	0.8%	18
19	Electricity	0.0%	21.4%	55.9%	22.8%	0.0%	100%	1.3%	15
20	Water Distribution	0.0%	13.0%	30.0%	58.0%	0.0%	100%	1.0%	17
21	Construction	0.0%	55.0%	26.0%	19.0%	0.0%	100%	13.9%	2
22	Trade	0.0%	20.0%	15.0%	64.0%	0.0%	100%	10.3%	3
23	Hotels	0.0%	27.0%	20.0%	53.0%	0.0%	100%	2.8%	9
24	Land Transport	0.0%	57.0%	11.0%	33.0%	0.0%	100%	2.4%	10
25	Water Transport	0.0%	52.0%	10.0%	38.0%	0.0%	100%	0.3%	29
26	Air Transport	0.0%	47.0%	9.0%	44.0%	0.0%	100%	0.3%	30
27	Storage & Warehouses	0.0%	40.0%	8.0%	52.0%	0.0%	100%	0.8%	19
28	Communications	0.0%	45.0%	9.0%	46.0%	0.0%	100%	3.9%	8
29	Financial Insurance Services	0.0%	6.0%	24.0%	70.0%	0.0%	100%	5.7%	7
30	Other Services	0.0%	11.0%	64.0%	25.0%	0.0%	100%	25.5%	1
31	Public Administration	0.0%	11.0%	62.0%	26.0%	0.0%	100%	5.7%	6
32	Dwelling	0.0%	2.0%	11.0%	87.0%	0.0%	100%	5.8%	5

Table 3 shows the status of the Kerala economy, which is grouped approximately 32 industries. More than 73 percent of the value added is contributed by the top 10 ranking industries, namely, other services (25.5 percent), construction (13.9 percent), trade (10.3 percent), agriculture and livestock (7.1 percent), dwelling (5.8 percent), public administration (5.7 percent), financial insurance services (5.7 percent), communications (3.9 percent), hotels (2.8 percent) and other transport services, including land transport (2.4 percent). In terms of the contribution of the main sectors to total value added, services contributed 63.6%, manufacturing contributed 12.2%, agriculture and allied contributed 8%, utilities contributed 2.3% and construction contributed 13.9%.

Generation of Electricity

Table 4 shows the contribution of each fuel to electricity generation, imports and consumption in Kerala in 2021. It is interesting to note that 56% of the total electricity consumption in Kerala is imported from other states. Only 44% of the total consumption of electricity is produced within the state. Of the total electricity generation in Kerala, hydroelectricity contributes 85% (large and small hydropower plants together). Renewable sources comprising wind, solar and bio power generate 15% of the electricity generated within the state.

Table 4 Generation, import and consumption of electricity in Kerala by fuel source, 2021

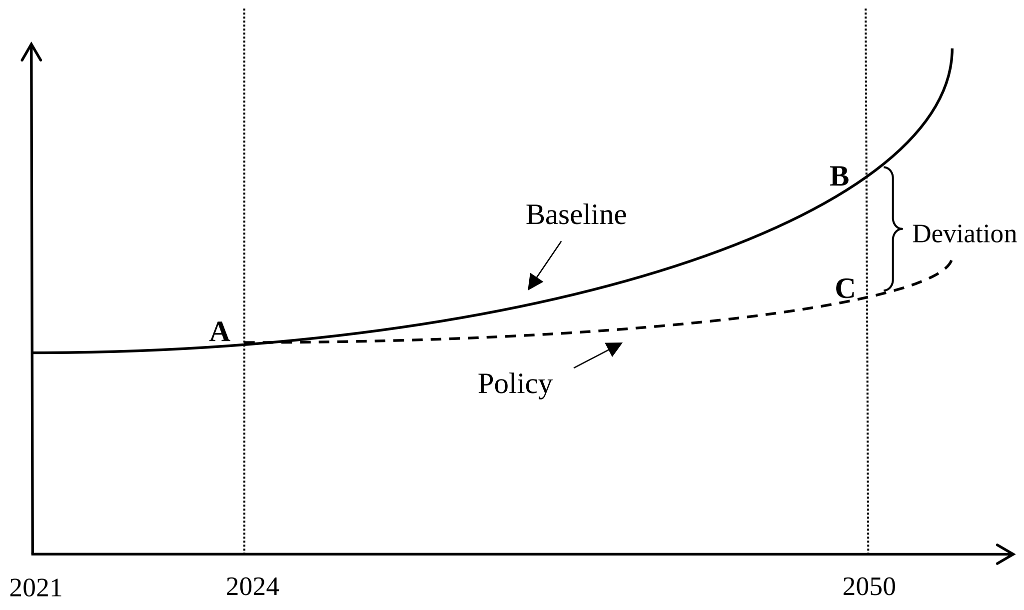
<table>
<tr><th></th><th>Generation</th><th colspan="2">Net of import</th><th colspan="2">State own consumption</th></tr>
<tr><td>Amount (MU)</td><td>10932.1</td><td colspan="2">14059.4</td><td colspan="2">24991.5</td></tr>
<tr><td>Share (%)</td><td>43.7%</td><td colspan="2">56.3%</td><td colspan="2">100%</td></tr>
<tr><th colspan="6">Share in generation</th></tr>
<tr><th>Wind</th><th>Hydro</th><th>Small-Hydro</th><th>Oil & Gas</th><th>Solar</th><th>Bio Power</th></tr>
<tr><td>1.2%</td><td>85.2%</td><td>8.5%</td><td>0%</td><td>4.5%</td><td>0.44%</td></tr>
</table>

Policy Analysis with a Dynamic Model

The model is a versatile and flexible comprehensive analytical framework that explicitly traces each variable through time at annual intervals. As illustrated in Figure 2, policy analysis with a *dynamic* CGE model requires two simulations.[3] The first simulation is the *baseline* forecast or business-as-usual simulation. This simulation models the growth of the economy over time in the absence of policy change. The second simulation is the *policy* simulation. In this case, a second forecast is generated that incorporates all the exogenous features of the baseline forecast plus policy-related shocks reflecting the details of the policy under consideration. The impacts of a policy are typically reported through percentage deviations away from the baseline forecast. In this paper, we identified three plausible scenarios and developed a macroeconomic model to capture the effect of policy interventions on the overall macroeconomy, energy sector, sector-specific effects, investment requirements and implications for emissions.

[3] For a more complete discussion see Dixon and Rimmer (2002).

Figure 2 Policy Analysis with a Dynamic Model



4 Baseline Simulation

The baseline simulation is the control projection against which policy scenarios are compared

To accommodate the extraneous information supplied to the model, numerous naturally endogenous variables in the model are made exogenous.[4] To allow the naturally endogenous variables to be exogenously determined, an equal number of naturally exogenous variables are made endogenous. For example, real SDP is a naturally endogenous variable in the model, while the economy-wide technology variable is naturally exogenous. To accommodate the exogenous settings of real
SDP, the economy-wide technology variable is set endogenously and allowed to adjust to accommodate changes in real SDP.

4.1 Macroeconomic Results

Table 5 shows baseline projections for key macroeconomic variables. We report the results for the income and expenditure-side components of the SDP and for other variables, such as the SDP deflator and consumer price index. The first five columns of Table 5 show the annual average growth rates over the period spanning from 2022 to 2050. The last column reports the annual average growth rates over the entire forecast period. The first five columns imply rapid growth in the Indian economy with a slight slowing towards the end of the simulation period. The results show that 6% of the annual growth in real SDP is likely to be sustained for 38 years. This means that the Kerala economy in 2050 will be approximately 5 times larger than that in 2022.

[4] We use the term exogenous to mean user-determined. The term endogenous means model-determined. In each simulation, every variable is classified as either exogenous or endogenous, with the number of endogenous variables equal to the number of equations in the model. A feature of the Indian model and all other models solved using the GEMPACK software is that users are allowed to choose which variables are exogenous and which are endogenous, provided that the choice is economically sensible.

Table 5 Macroeconomic results for 2022 – 2050 (percent)

Selected Variables	**2022–2030**	**2031–2035**	**2036–2040**	**2041–2045**	**2046–2050**	**2022–2050**
A. Income Components of SDP (Growth Rate)						
1 Real SDP	6.2	6.0	6.3	6.0	5.3	6.0
2 Demand for Capital	7.7	7.5	7.2	7.1	6.9	7.3
3 Demand for Skilled Labour	0.1	-0.3	-0.3	-0.3	-0.3	-0.2
4 Demand for Unskilled Labour	0.1	-0.3	-0.3	-0.3	-0.3	-0.2
5 Demand for Natural Resource	0.0	0	0	0	0	0.0
6 Multifactor Productivity	1.0	1.0	1.0	0.9	0.8	0.9
7 Real Wage for Unskilled Labour (CPI deflated)	5.9	5.7	5.8	5.3	4.8	5.6
8 Real Wage for Skilled Labour (CPI deflated)	5.5	5.5	5.7	5.1	4.0	5.2
B. Expenditure Components of SDP (Growth Rate)						
9 Real Private Consumption (Growth Rate)	4.8	4.7	4.9	4.5	3.0	4.4
10 Real Government Consumption	4.5	4.5	4.9	4.6	3.1	4.3
11 Real Investment	7.9	6.8	7.0	6.8	6.2	7.1
C. Other Macro Indicators (Growth Rate)						
12 SDP Deflator	8.2	7.5	7.7	7.8	5.5	7.5
13 Population	0.4	0.1	0.1	0.1	0.1	0.2
14 Consumer Price Index (CPI)	8.2	7.8	8.2	8.5	7.3	8.1
D. Other Variables (Growth Rate)						
16 CO_2 Emissions	9.5	9.5	9.2	8.4	8.2	9.0
E. Other Variables at the End of the Year	**2030**		**2040**		**2050**	
17. Emission per Person (Tonne CO_2e)	0.86		1.53		3.73	
18. Elec. Consumption per Person (KWh)	1055		1951		3772	

The forecast data imposed on the SDP suggest that the average annual growth in the real SDP over the period 2022–2050 is 6.01 percentage points per annum (Row 1, Table 5). The demand for unskilled labour (Row 3, Table 4.1-1) is set to increase at an average annual growth rate of -0.18%, which is much lower than the real SDP. The demand for skilled labour (Row 4, Table 5) is also likely to grow at an annual growth rate of -0.18 percent, on average. The natural resource supply is forecasted to remain unchanged throughout the simulation period. The growth in capital is tied down by the high growth in investment. The demand for capital (Row 2, Table 4.1-1) is set to grow at 7.34 percentage points per annum. With the SDP, L and K determined, the multifactor productivity (Row 6, Table 5) is projected to increase by approximately 0.93 percentage points per annum.

The average growth in the real wage rate for unskilled labor (Row 7, Table 5) is estimated to be 5.6 percent per year across the entire period, while the same for skilled labor (Row 8, Table 5) is estimated to be 5.2 percent for the entire period. This is allowed for, in part, by growth in productivity, which in our modelling is biased towards capital.

Table 6 shows the projected growth rates in the production of major sectors, which are selected on the basis of their contribution to the value added, and together, they contribute 87% of the value added of the state.

Table 6 Average annual growth rates of output for major sectors* in the baseline (%)

Sl. No.	Industry	2022–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2050
1	Other Services	4.02	4.26	4.49	4.79	4.6	3.44	4.27
2	Construction	6.74	6.24	5.37	5.43	5.26	5.38	5.74
3	Trade	6.24	6.42	6.49	6.69	6.43	6.03	6.38
4	Dwelling	7.55	7.51	7.18	7.47	6.9	4.39	6.83
5	Public Administration	5.12	5.04	4.87	5.24	4.88	2.98	4.69
6	Financial Insurance Services	6.8	7.09	7.37	7.56	7.43	8.36	7.44
7	Communications	5.17	5.41	5.53	5.61	5.24	5.31	5.38
8	Hotels	7.97	8.29	8.3	8.65	8.01	7.72	8.16
9	Land Transport	5.38	5.7	5.97	6.37	6.25	6.91	6.10
10	Livestock	2.65	2.71	2.65	2.87	2.68	1.78	2.56
11	Other manufacture	7.99	8.36	8.98	8.67	7.85	7.36	8.20
12	Vegetables and Fruits	2.22	2.21	2.17	2.34	2.1	1.89	2.16
13	Food Beverage & Tobacco	3.72	3.6	3.46	2.75	1.57	2.06	2.86
14	Batteries, Electrical & Electronics Equipment	8.91	9.28	9.95	9.33	8.61	8.04	9.02
15	Machinery	9.18	9.48	9.95	9.25	8.42	8.4	9.11
16	Non-Ferrous Metal	7.82	7.72	7.55	6.85	5.93	6.43	7.05

Note: *For sectors whose share of the total value is more than 1%. These sectors together contribute 87% of the total value for the State. Public administration, though a major growth sector, is not included in the table.

As Table 7 shows, the major industries in Kerala that import goods from the Rest of India are coal electricity (39%), construction (22.9%), and chemicals (13.9%). The imports of these industries are also growing at a very fast rate, with average annual growth between 2021 and 2050 being 23.4%, 14% and 19%, respectively. Other major importing sectors are public administration, financial insurance services, communications, transmission and distribution, other services, wood, wood products and furniture and pharma. The top 10 exporting industries from Kerala to the rest of India are construction, hotels, transmission and distribution, land transport, financial insurance services, vegetables and fruits, other crops, fishing, communications and other manufacturing. Among these sectors, construction has the greatest share of exports. The fastest growth in exports occurs in sectors such as financial insurance services (20.5%), hotels (20.2%), and other manufacturing sectors (20.1%).

Table 7 Major exporting and importing sectors in Kerala

Top 10 importing sectors from other states of India to Kerala in 2021				Top 10 exporting sectors in Kerala (to other states of India) in 2021			
Sector no	**Importing sector**	**Share in total import**	**Average annual growth between 2021-2050**	**Sector no**	**Exporting sector**	**Share in total export**	**Average annual growth between 2021-2050**
30	Coal Electricity	39.0	23.4	9	Fishing	2.0	13.5
38	Construction	22.9	14.0	38	Construction	59.5	13.5
20	Chemicals	13.9	19.0		Land Transport	4.2	10.6
46	Financial Insurance Services	4.4	11.5	41	Financial Insurance Services	3.8	20.5
45	Communications	3.8	12.3	45	Communications	1.9	15.1
47	Other Services	1.1	12.7	4	Other Crops	2.3	3.7
17	Wood, Wood Products & Furniture	1.0	15.5	40	Hotels	7.5	20.2
				46	Vegetables and Fruits	2.9	4.7
21	Pharma	0.9	11.1	16	Other Manufacture	1.5	20.1

4.2 Results from the Bottom-up Energy Model

As noted earlier, our macro model is being run in conjunction with a bottom-up energy model. The bottom-up model results provide us with the decomposition of the energy mix/emissions at a more granular level, which we report here.

4.2.1 *Energy Demand and Sources*

The main sources of energy demand in Kerala are transport, industry, buildings, cooking demand in urban areas and agriculture. As shown in Figure 3, the share of energy demand in industry will increase substantially to 40% from 2025 to 2050. The energy demand for cooking in urban areas will decrease from 11% in 2030 to 3% in 2050, and that for the building sector will decrease from 19% in 2030 to 14% in 2050. The model also explored the share of energy demand in telecom in Kerala, which reached zero percent.

The share of imported oil increases to 44 percent in 2050, and that of biofuels in the energy mix declines from 25 percent in 2030 to 17 percent in 2050 in the baseline scenario (Figure 4). The share of electricity hovers approximately 28%, that of gas hovers approximately 4%, that of biogas hovers 2%, and that of solid hydrocarbons hovers approximately 3% from 2030 to 2050. The model also explored the presence of biomass, off-grid solar and wind electricity, solar thermal electricity, and green hydrogen in Kerala but did not show a significant presence in the base run.

Figure 3 Final Energy Demand

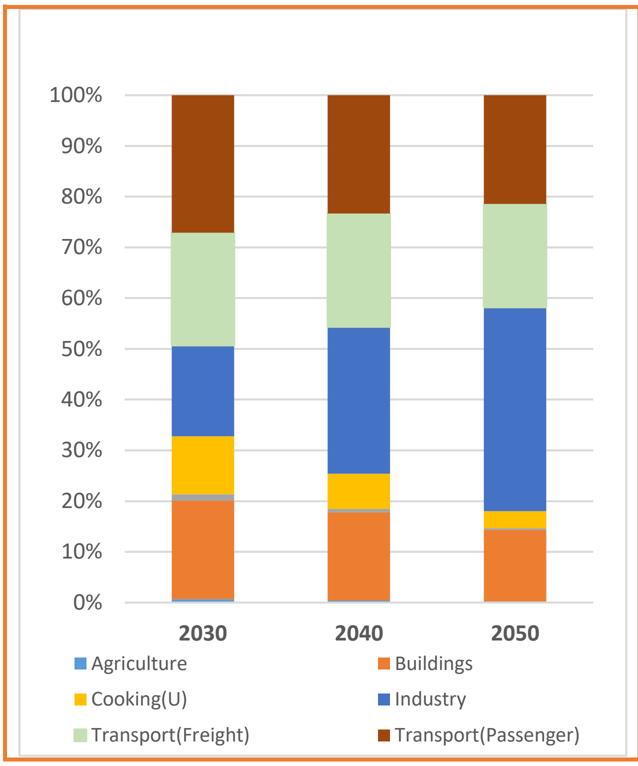
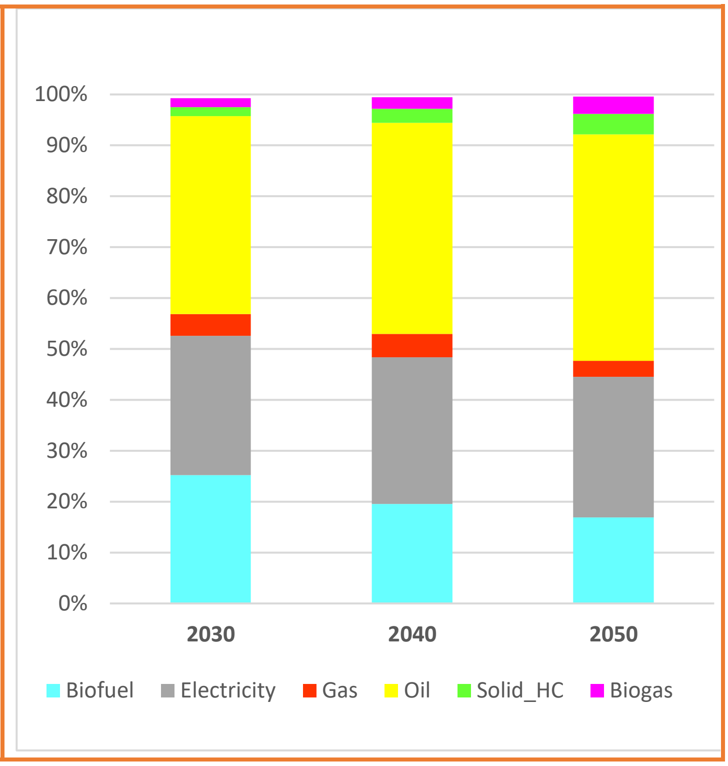


Figure 4 Final Energy Mix



4.2.2 *Electricity Capacity and Generation Mix*

Figures 5 and 6 show the electricity capacity mix and generation mix for Kerala for the years 2030–2050. The hydroelectricity capacity is expected to increase from 2.1 GW in 2025 to 13 GW in 2050 under the baseline scenario. The amount of biomass polypropylene (Biomass PP) is expected to increase from 0.3 GW in 2025 to 4 GW in 2050. The solar PV capacity remains almost unchanged at approximately 1 GW, and the small hydro capacity increases very marginally from 0.3 GW in 2030 to 0.5 GW in 2050. The onshore wind capacity will increase slightly from 0.1 GW in 2025 to 0.3 GW in 2050. Our model explored the emergence of technologies such as gas, nuclear, offshore-wind, oil, solar CSP, solid hydrocarbon, and solar PV storage-based electricity capacity. However, we find that these factors do not play any role in BAU.

The major share of electricity is imported from other states, and hydroelectricity is generated from ample water reservoirs in Kerala. The amount of electricity imported from other states of India will increase from 31 Twh in 2025 to 213 Twh in 2050, and the amount of hydroelectricity will increase from 11 Twh to 67 Twh in 2050. The amount of biomass polypropylene (PP) will increase from 1 Twh in 2025 to 16 Twh in 2050.

Figure 5 Electricity Capacity Mix

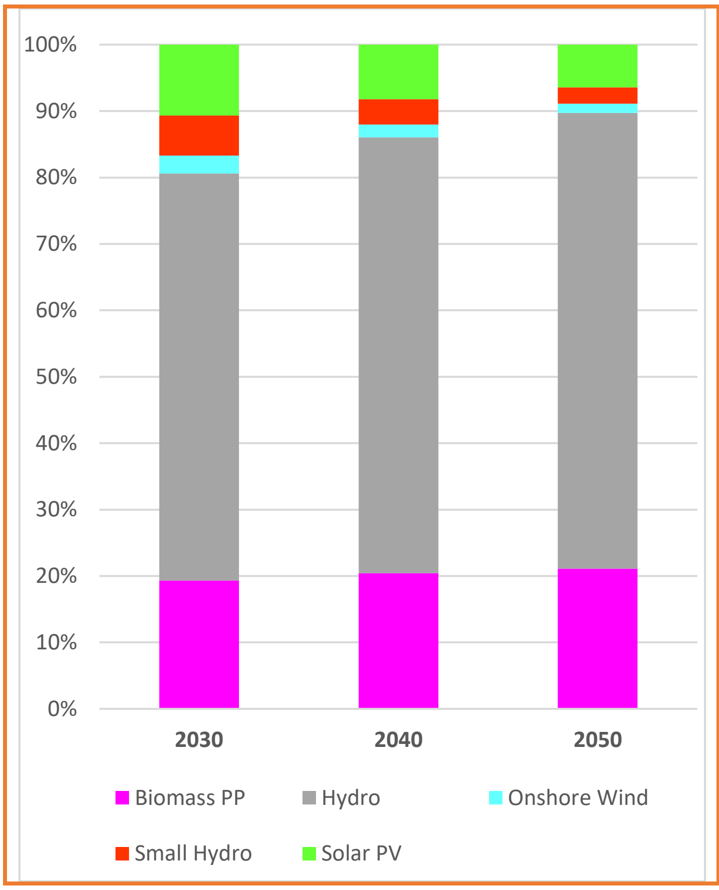
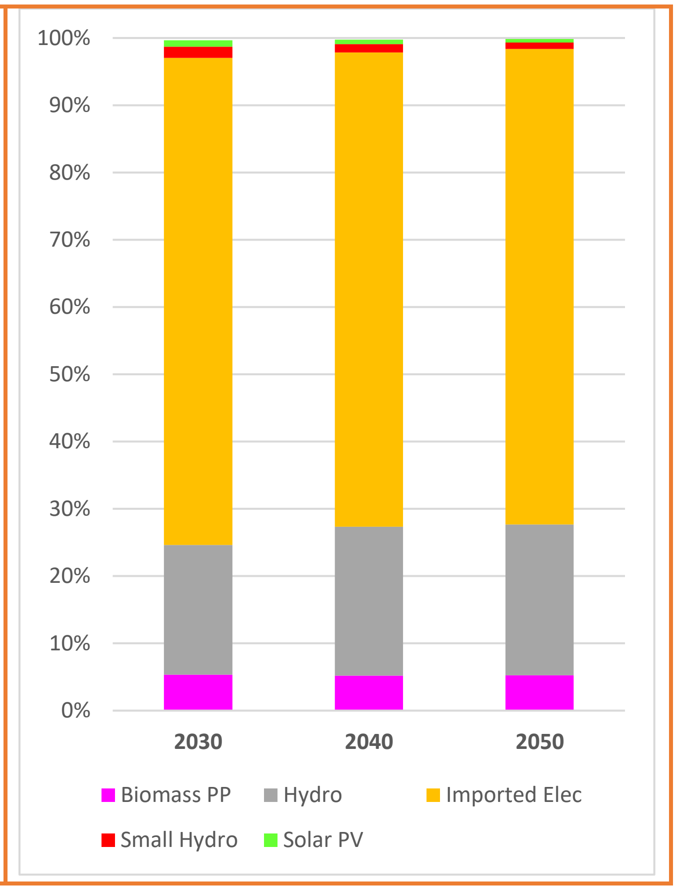


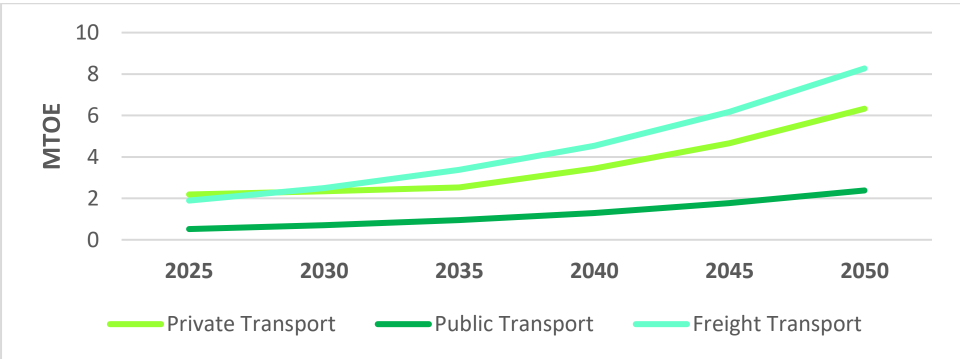
Figure 6 Electricity Generation



4.2.3 *Transport Sector: Energy/Fuel Choices*

The energy demand in the transport sector will increase from 4.6 MTOE in 2025 to 17 MTOE in 2050 (Figure 7). As this figure shows, freight transport's energy demand exceeds that of private and public transport. In the baseline, public transport remains very low in terms of energy demand.

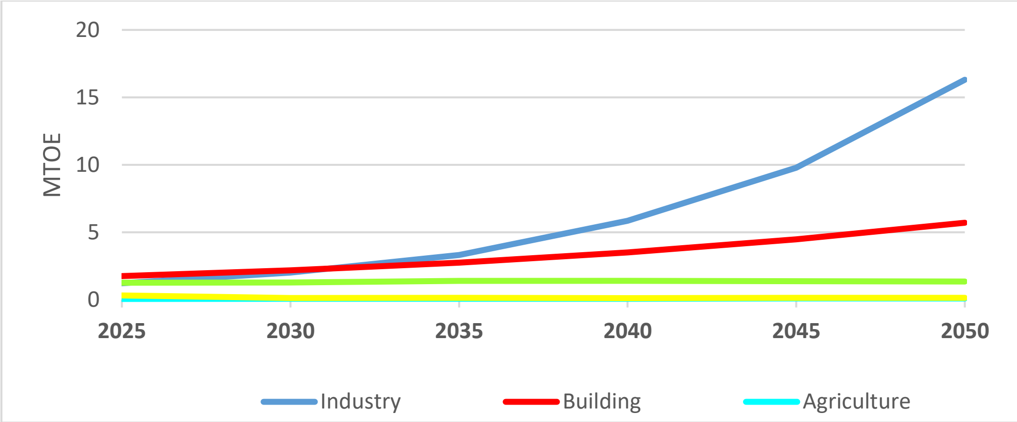
Figure 7 Energy Demand in the Transport Sector



4.2.4 *Energy/Fuel Choices for Other Sectors*

Figure 8 indicates that the energy demand in the transport sector will increase from 4.7 MTOE in 2025 to 23.6 MTOE in 2050. Agriculture has the lowest energy demand among all sectors in the baseline. Industry seems to have significantly rising energy demand in future years.

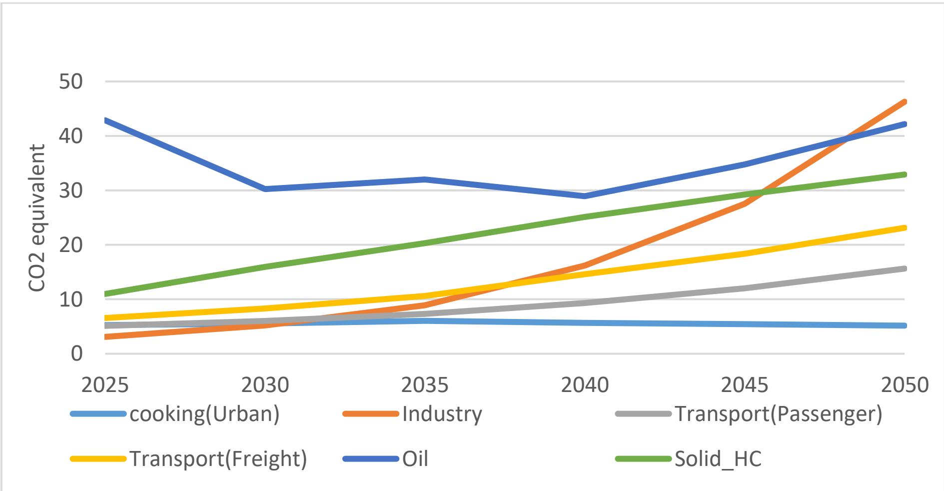
Figure 8 Energy Demand in Various Sectors



4.2.6 *Emissions*

Figure 9 shows the emissions over the baseline period. As this figure indicates, industry is the main source of emissions at the baseline.

Figure 9 Emissions



Of course, emissions of other gases, such as CH_4, also occur and are not accounted for above. Table 8 provides our estimates of total emissions in Kerala by 2050 and on a per capita basis. Total emissions on a per capita basis increase to 3.73 per person. With development, per capita electricity consumption will increase by 4.2 times by 2050. However, as Kerala is a significant importer of electricity (mostly coal-based), this does not add to the emission accounting of Kerala. However, this situation may change in the future as all states strive to clean their emission accounts.

Table 8 Stylized facts

Indicator	2025	2030	2035	2040	2045	2050
Total EMISSION(MTCO_2e)	25.5	31.5	40.8	56.7	85.2	138.2
Per capita emission (Tons CO_2e)	0.70	0.86	1.10	1.53	2.31	3.73
Per capita Electricity consumption (KWH)	28.2	38.7	52.4	72.1	98.3	135.9

5 Policy Scenarios

Below, we address the following policy scenarios to understand the economic implications of the low-carbon transition on Kerala's economy.

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

Currently, Kerala is a significant importer of fossil fuel-based electricity. Our base run indicates that this trend will continue until 2050. When all other states move towards renewable energy instead of cheaper fossil-based electricity, the import price of electricity may increase. This may have an economic impact on Kerala's economy. In this simulation, we explore the impact on the economy of direct policy intervention by restrictions on the import of fossil-based electricity and whether restrictions on the import of fossil-based electricity lead to an increase in the production of renewable electricity in Kerala or an increase in the supply of renewable electricity from the rest of India.

(b) Scenario 2: Scenario 1 + capacity augmentation of renewable electricity (Aug_R_Elec)

In this scenario, we assume that the restriction of the import of fossil-based electricity continues in Kerala. Additionally, we assume that 50 percent of the existing potential of renewable electricity by various modes is achieved in Kerala and the rest of India by the terminal year of our model run (2050). Of course, we assume that the fund of investment is not a constraint.

(c) Scenario 3: Scenario 2 + increased energy efficiency (Incr EE)

In this scenario, we consider increased energy efficiency to be 2.5 percent annum concomitant with policy scenario 2. Furthermore, we 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 India.

5.1 Results and Discussion: Policy Scenario 1 (Rest_F_Elec)

The majority of the electricity consumed in Kerala is imported from other states of India, and that electricity is generally produced from fossil fuel. As a result, in the base, the share of imports in fossil fuel-based electricity consumption is almost 100%. In this policy simulation, we assume a business as usual (BAU) situation with restrictions on the import of fossil power from the rest of India. The market determines the growth of investment in the renewable power sector in Kerala and the rest of India. This means that in 2024, when the transition began, the share of imports in fossil fuel-based electricity consumption was almost 100%, and it declined to nearly 0% by the beginning of 2040. Consequently, the share of renewable energy in total energy consumption will increase from 11% in 2024 to 97% in 2050 (Figure 10).

Figure 10 Policy scenario 1: Share of renewable and fossil fuel electricity in Kerala (%)

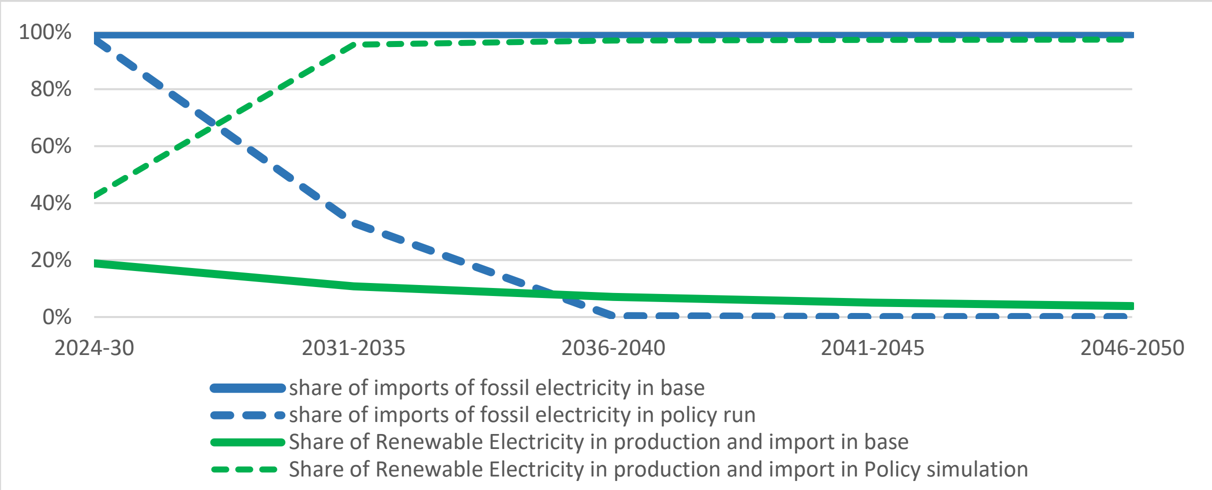
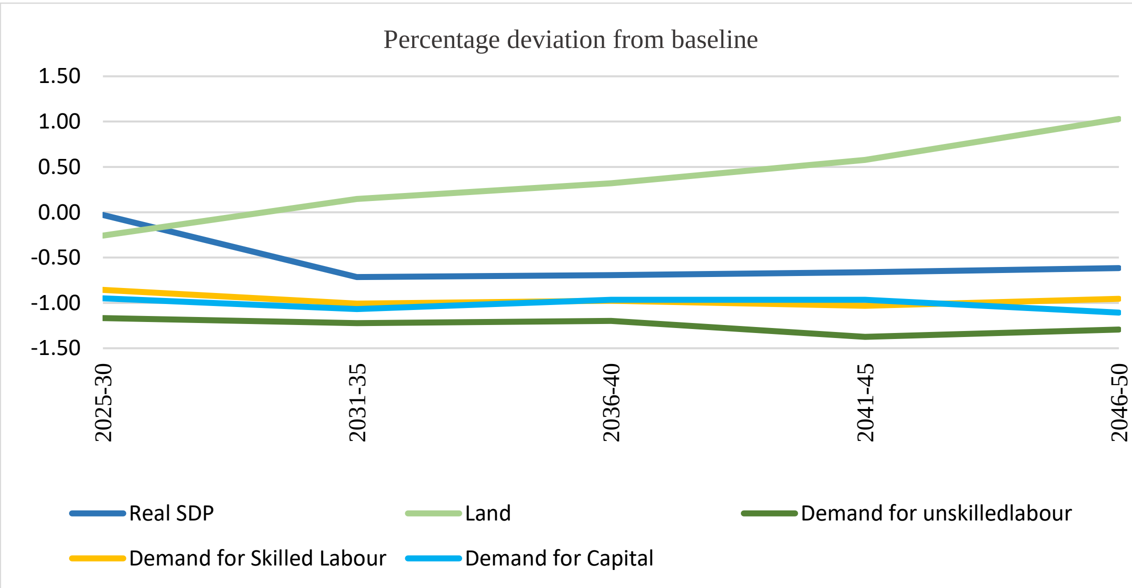


Figure 11 reports selected variables relevant to the determination of real SDP. Under this simulation, the real SDP deviation decreases throughout the simulation period, beginning at 1.5% in 2024–25 and increasing to 1.6% by the end of the simulation period. The real SDP deviation decreases throughout the simulation period because each year of the policy simulation is characterized by a growing shift from the import of electricity generated from fossil fuels. The negative real SDP deviation is attributable to negative deviations in the employment of labour, capital, and productivity. Since energy is an important input in all production activities, restricting the import of fossil fuel-based electricity would have an effect on all industries, leading to a reduction in the output of all industries.

Figure 11 Policy scenario 1: Average yearwise real returns of all factors



Since energy is an integral part of the production process, restrictions on the import of fossil fuel-based electricity affect the return to capital stock. In the short run, the imposition of restrictions has thus affected both labour and capital. In the long run, the economy adjusts to the change, and the deviation in the SDP decreases comparatively. The return to land, on the other hand, shows a positive deviation. In the short run, the deviation in return to land decreases marginally, but it increases in the long run. Land is a scarce resource in the small state of Kerala, and with increased urbanization, there is a growing demand for land. With restrictions on the import of fossil fuel-based electricity, the requirement of electricity generation from renewable energy would increase. Land, as one of the major inputs in the production of renewable electricity, will face increased demand, and as a result, the return to land will increase over the years.

5.1.1 *Industry Results*

Currently, the share of industries in Kerala is not very high in terms of gross value of output. In 2021, the share of the secondary sector (manufacturing, electricity, gas and water supply, construction) was 28.4 percent in Kerala, compared to the national average of approximately 29 percent. As noted earlier, Kerala has few industries that produce the majority of its industrial output. The major industries are other services (25.5%), construction (13.9%), trade (10.3%), agriculture and livestock (7.1%), dwelling (5.8%), public administration (5.7%), financial insurance services (5.7%), communications (3.9%), hotels (2.8%) and other transport services, including land transport (2.4%). Together, these industries produce 73 percent of the value added in 2021. Table 9 shows the sectoral growth of major industries in this scenario. As this table indicates, most of the industries register negative or small positive growth. The reason is that the restriction of cheap fossil fuel-based electricity imports affects growth, as all industries are dependent on electricity at all stages of the production process, directly or indirectly through input–output linkages.

Table 9 Policy scenario 1: Annual average growth rate of major sectors in Kerala (percentage deviation from base run)

Sectors	2024–2030	2031–2035	2036–2040	2041–2045	2045–2050
Other Services	-0.12	-0.14	-0.19	-0.13	0.48
Construction	-0.93	-1.12	-1.19	-1.53	-2.35
Trade	-0.31	-0.23	-0.15	-0.06	-0.02
Dwelling	-0.32	-0.63	-0.64	-0.59	0.40
Public Administration	-0.07	-0.36	-0.39	-0.31	0.60
Financial Insurance Services	-0.18	0.19	0.45	0.84	0.81
Communications	-0.13	0.16	0.32	0.62	0.81
Hotels	-0.39	-0.32	-0.20	-0.07	-0.30
Land Transport	-0.38	-0.21	-0.07	0.11	-0.21
Livestock	-0.33	-0.36	-0.38	-0.37	-0.04
Other Manufacture	-1.18	-0.56	-0.23	0.07	-1.01
Vegetables and Fruits	-0.26	-0.27	-0.25	-0.21	-0.25
Food Beverage & Tobacco	-0.97	-0.67	-0.67	-0.74	-1.69
Batteries, Electrical & Electronics Equipment	-1.32	-0.49	-0.16	0.15	-1.00
Machinery	-1.57	-0.85	-0.63	-0.57	-2.11
Non-Ferrous Metal	-0.87	-0.38	-0.23	-0.22	-1.25
Fishing	-0.30	-0.36	-0.37	-0.37	-0.24
Paddy	-0.19	-0.21	-0.19	-0.15	0.04

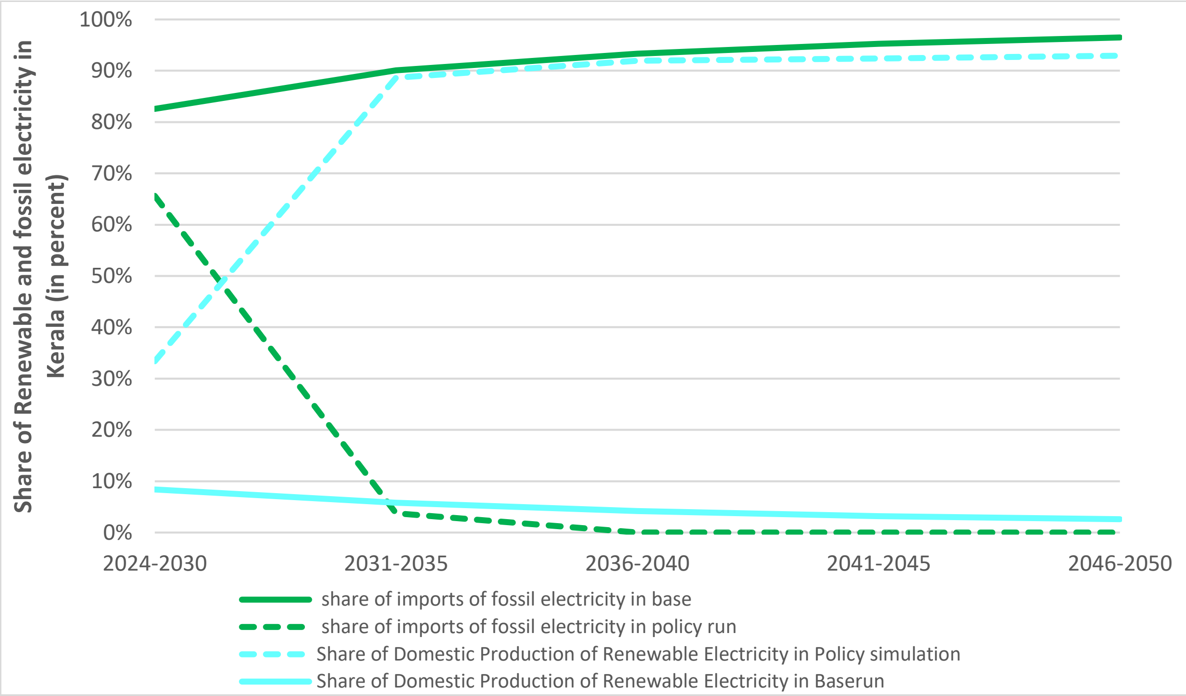
5.1.2 *Summing Up*

In sum, we find that a command and control type of imposition of a ban on fossil-based electricity does not lead to substitution for renewable electricity (import/production) to compensate for the shortage in the supply of electricity. As a result, the economy contracts. The market situation in renewable electricity has yet to be developed to address the demand supply gap. Most likely, government intervention is required to promote the growth of renewable electricity based on this potential.

5.2 Results and Discussion: Policy Scenario 2 (Aug_R_Elec)

At baseline, the share of imports of fossil fuel electricity is expected to reach 74% in 2022, and the share of domestic production of renewable electricity in 2024 is expected to reach 10%. In the policy simulation, renewable electricity capacity is augmented by policy intervention in Kerala as well as the rest of India. The extent of the increase, as noted earlier, is that 50% of the existing potential in Kerala and the rest of India is achieved by 2050. We assumed a uniform rate of increase over the policy period. In 2024, when the transition began, the share of imported fossil fuel electricity was approximately 78%, and it declined to nearly 0% in mid-2030. As Figure 12 shows, the share of renewable electricity in Kerala in the policy simulation reached approximately 93% by 2050.

Figure 12 Policy scenario 2: Share of renewable and fossil electricity in Kerala (%)



5.2.1 *Macroeconomic Results*

Figure 13 shows the deviations in the real SDP. As this figure indicates, compared to scenario 1, the increase in SDP growth is at the 1 percent level, and it marginally decreases from 2035 onwards. Thus, compared to policy scenario 1, the push for renewables pays off. We find that there has been an increase in investment over the years to augment the capacity of renewable electricity. We find that consumption spending by private and public entities is also on the rise in comparison to that in scenario 1.

Figure 13 Policy scenario 2: Macroeconomic results of Kerala (%)

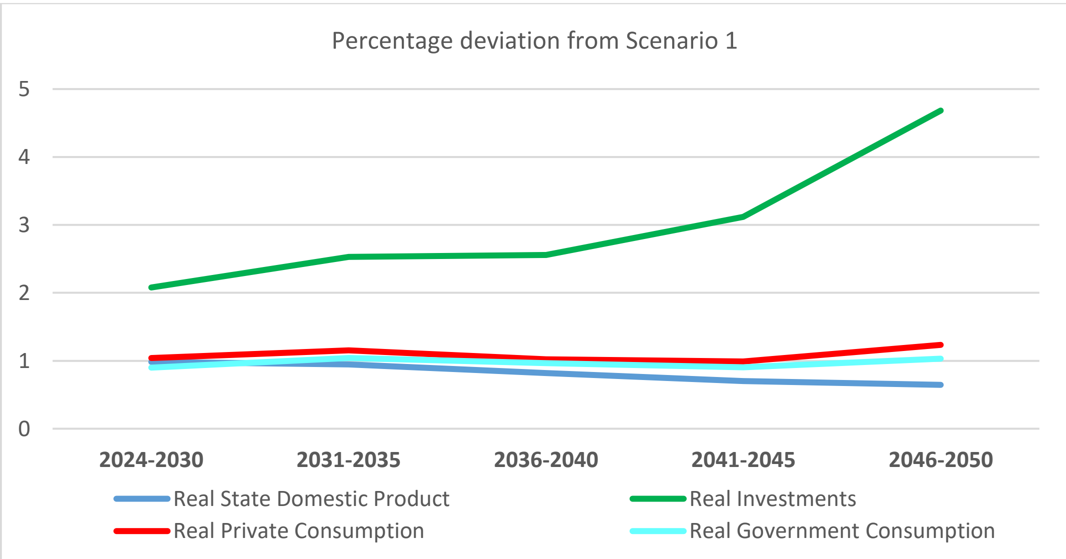


Table 10 shows the sectoral effect of this scenario. We find that there are some sectors that register negative, albeit small, growth. These sectors, which are dependent on energy, are affected by the increase in the price of electricity, which is induced by the increased mix of renewable energy sources in electricity generation.

Table 10 Policy scenario 2: Sectoral growth in Kerala (Percentage deviation from scenario 1)

Sectors	2024–2030	2031–2035	2036–2040	2041–2045	2045–2050
Other Services	0.23	0.38	0.52	0.48	0.29
Construction	0.94	1.12	1.19	1.62	2.61
Trade	0.26	0.12	0.07	-0.01	-0.17
Dwelling	1.15	1.32	1.21	1.18	1.44
Public Administration	0.81	0.91	0.82	0.73	0.74
Financial Insurance Services	-0.30	-0.81	-1.13	-1.68	-1.95
Communications	-0.22	-0.65	-0.81	-1.19	-1.25
Hotels	0.57	0.13	-0.19	-0.42	-0.83
Land Transport	0.06	-0.28	-0.53	-0.86	-1.53
Livestock	0.47	0.63	0.68	0.64	0.65
Other Manufacture	-0.27	-1.15	-1.49	-1.96	-1.27
Vegetables and Fruits	0.30	0.23	0.12	-0.02	-0.29
Food Beverage & Tobacco	0.04	-0.46	-0.42	-0.42	-1.07
Batteries, Electrical & Electronics Equipment	-0.64	-1.58	-1.77	-2.17	-1.73
Machinery	-0.31	-1.15	-1.22	-1.33	-1.26
Non-Ferrous Metal	-0.45	-0.95	-0.90	-0.79	-0.97
Fishing	0.44	0.44	0.45	0.43	0.41
Paddy	0.33	0.33	0.25	0.17	0.10

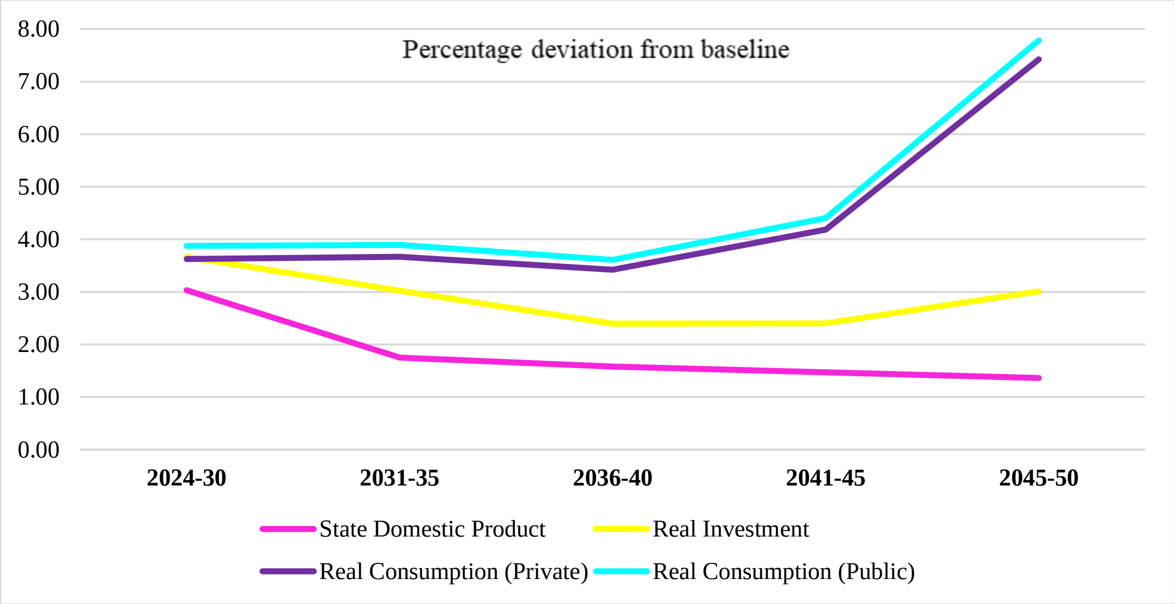
5.3 Results and Discussion: Policy Scenario 3 (Incr EE)

Energy efficiency is essential for adopting low-carbon pathways. There has been significant progress in this respect in India over the years. We assume an increase in autonomous efficiency in all energy sectors of 2.5 percent per annum in this scenario, which is a feasible target. Moreover, we assume TFP growth of 1 percent annum. In the past, India achieved more than 1% TFP growth per annum. These shocks are assumed both in Kerala and in the rest of India. This scenario is concomitant with scenario 2, which involves the imposition of fossil-based electricity in Kerala and the augmentation of renewable electricity in Kerala and the rest of India.

5.3.1 *Macroeconomic Results*

Figure 14 indicates that the SDP relative to the baseline registers positive growth, even though the rate decreases in the later years to 1.36 percent in 2050. The other components of SDP also exhibit positive growth.

Figure 14 Policy scenario 3: Macroeconomic results for Kerala



Coming to the real returns to the factors of production, we find that the returns are positive (Figure 15).

Figure 15 Policy Scenario 3: Real Returns on Factors of Production in Kerala

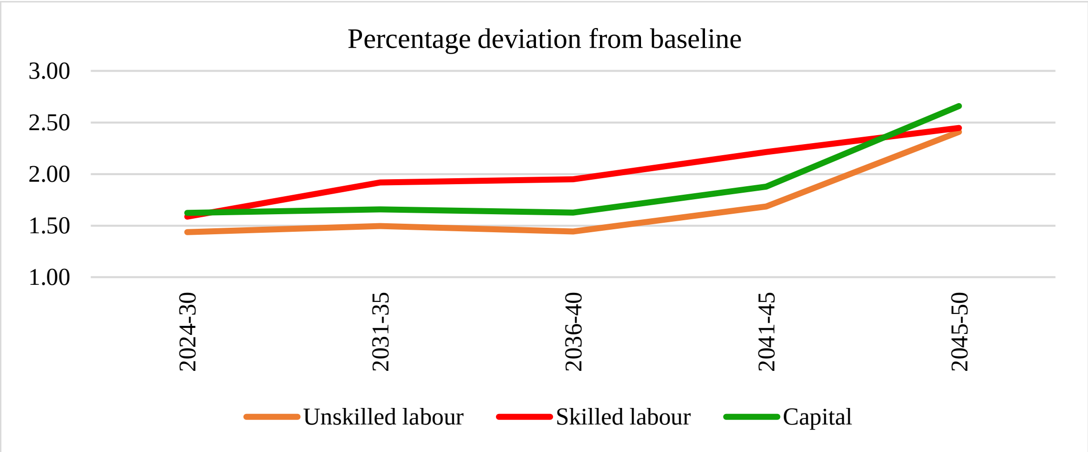


Table 11 shows the performance of the sectors in this scenario. The service sector seems to do well. The growth seems to tap off towards the end of the period.

Table 11 Policy scenario 3: Sectoral growth of output in Kerala

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	6.00
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	9.10	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	0.70
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

How do the above growth numbers compare with the base run? Table 12 shows the same. The average deviation rate of some sectors from the baseline is marginal, with positive and negative growth ranging between 0 and 1%.

Table 12 Average deviation (in percent) between policy scenario 3 and BAU

Sectors	Percent	Sectors	Percent
Other Services	1.22	Livestock	1.18
Construction	1.25	Other manufacture	-0.70
Trade	0.77	Vegetables and Fruits	0.50
Dwelling	2.18	Food Beverage & Tobacco	0.09
Public Administration	1.76	Batteries, Electrical & electronics equipment	-1.08
Financial Insurance Services	-0.54	Machinery	-0.61
Communications	-0.32	Non-Ferrous Metal	-0.40
Hotels	0.98	Fishing	0.97
Land transport	-0.38	Paddy	0.67

5.3.2 *Results from the Bottom-up Energy Model*

The results from the macro model are more aggregative in nature. Let us review the results from the linked energy model, which shows the breakdown of energy use at a more granular level.

5.3.3 *Energy Demand and Fuel Mix*

Figures 16-17 show the final energy demand and fuel mix, respectively, in this scenario. For comparison purposes, the results are shown for both the base run (B) and the policy run. As Figure 16 indicates, the final energy requirements in the transport and industry sectors fall sharply, whereas in agriculture, they remain the same (not shown in the figure).

Figure 16 Final Energy Demand

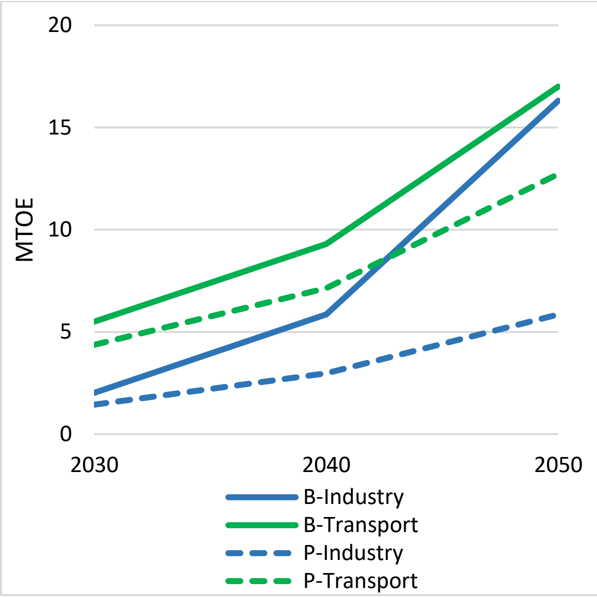
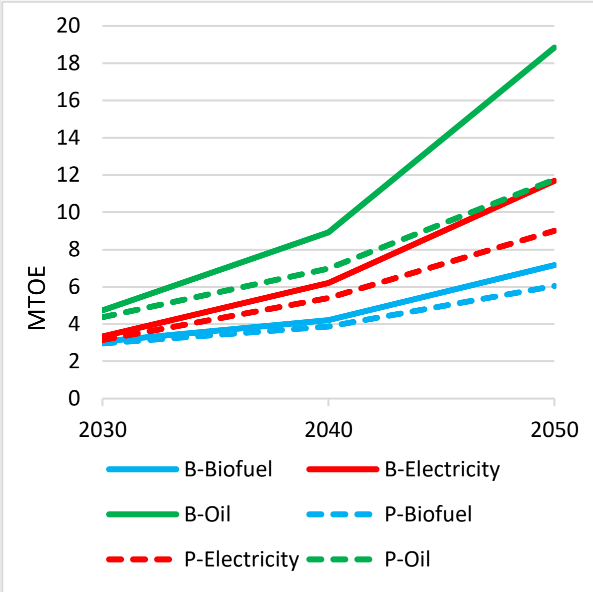


Figure 17 Final Fuel Mix



With increases in energy efficiency and productivity, oil demand decreases substantially, followed by that of electricity, biofuels, gas and solid hydrocarbons. The model explored the presence of the following fuel mix technologies: biogas, biomass, off-grid wind electricity, solar thermal, green hydrogen, and solar off-grid electricity in baseline and policy simulations. Except for biogas, green hydrogen and solar off-grid electricity, which showed a very marginal rise in the policy run, none of the other fuel mixes showed any presence in the baseline or in this policy run.

5.3.4 *Electricity Capacity and Generation Mix*

The share of final energy consumed by electricity in Kerala is expected to reach 24% by 2025. According to our model, it may hover approximately 28 percent in the 2040s. The per capita electricity consumption in Kerala will increase from 778 KWh in 2025 to 1951 KWh in 2040 and further to 3672 KWh by 2050.

The electricity capacity mix in scenario 3 is broadly similar to the baseline scenario with a combination of biomass polypropylene, hydro and small hydro, onshore wind, and solar photovoltaic electricity capacity in Kerala (Figure 18). However, one can see that in the policy run, there is a marginal decrease in the share of imported electricity.

Figure 18 Share of Electricity Capacity Mix in % (Policy Scenario 3)

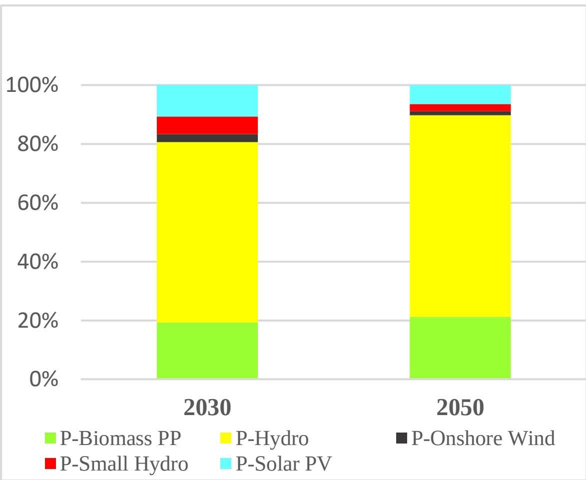
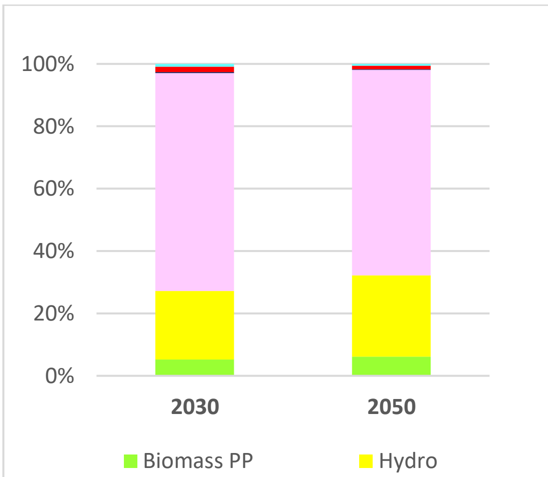


Figure 19 Share of Electricity Generation in % (Policy Scenario 3)



5.3.5 *Transport Sector: Energy/Fuel Choices*

Do we find any significant change in fuel demand in the private transport sector in this scenario? The answer is negative. We find only a marginal decline in the fuel demand for two wheelers and cars (ethanol blended), cars with compressed biogas, two electric wheelers, three wheelers, cars and taxis. Our model explored the emergence of the following vehicle and fuel types in Kerala: three-wheeler ethanol blended; gas-based three-wheeler, car, taxi; oil-based two-wheeler, three-wheeler, car, taxi; hydrogen fuel cell in cars; and compressed biogas in three-wheelers and taxis. However, they do not seem to play any role in this scenario until 2050.

In contrast, we find a moderate change in the fuel choice of public transport in policy scenario 3 versus the base run. (Figure 20, Figure 21) In buses and minibuses running on blended ethanol and electric passenger railways, we find an increase.

Figure 20 Energy/Fuel Choices for Public Transport in the Baseline

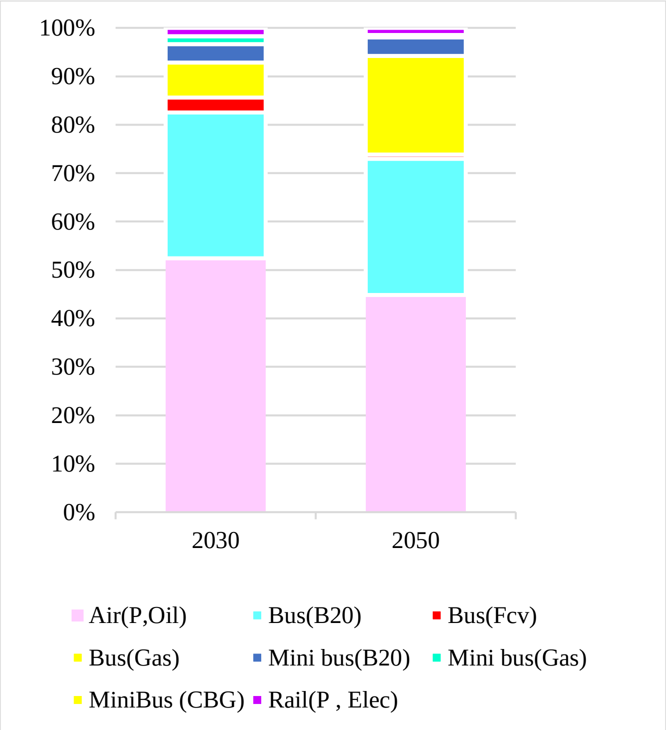
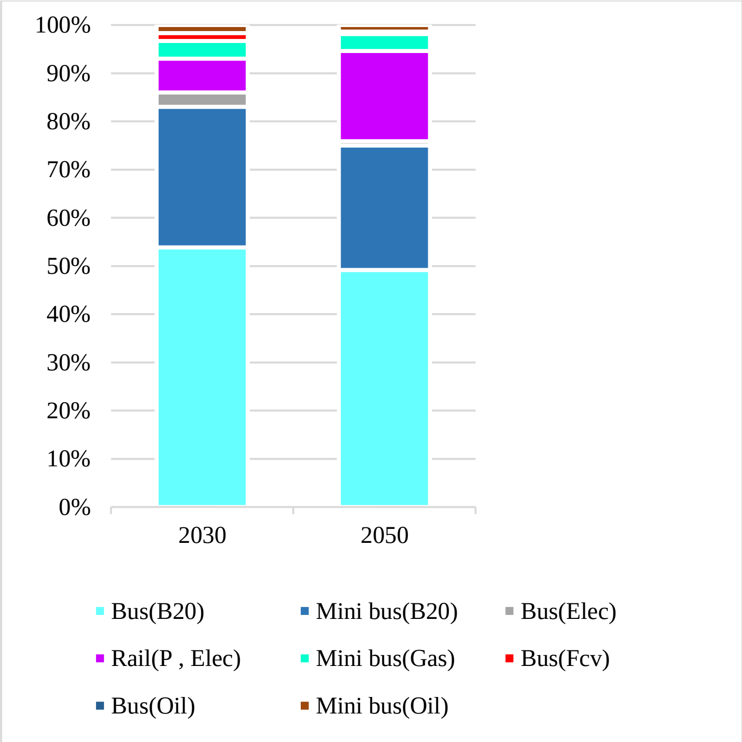


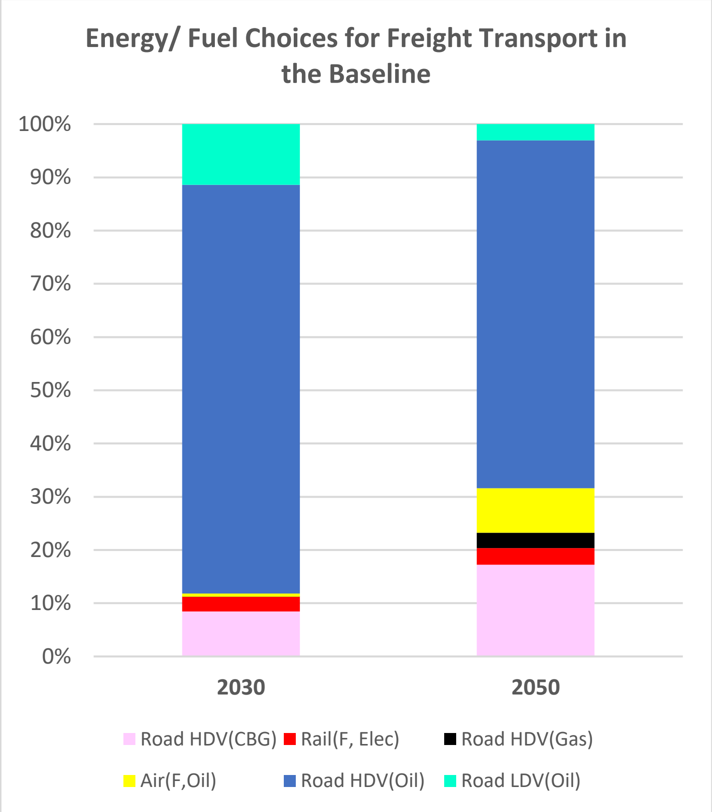
Figure 21 Energy/Fuel Choices for Public Transport in the Policy Scenario 3

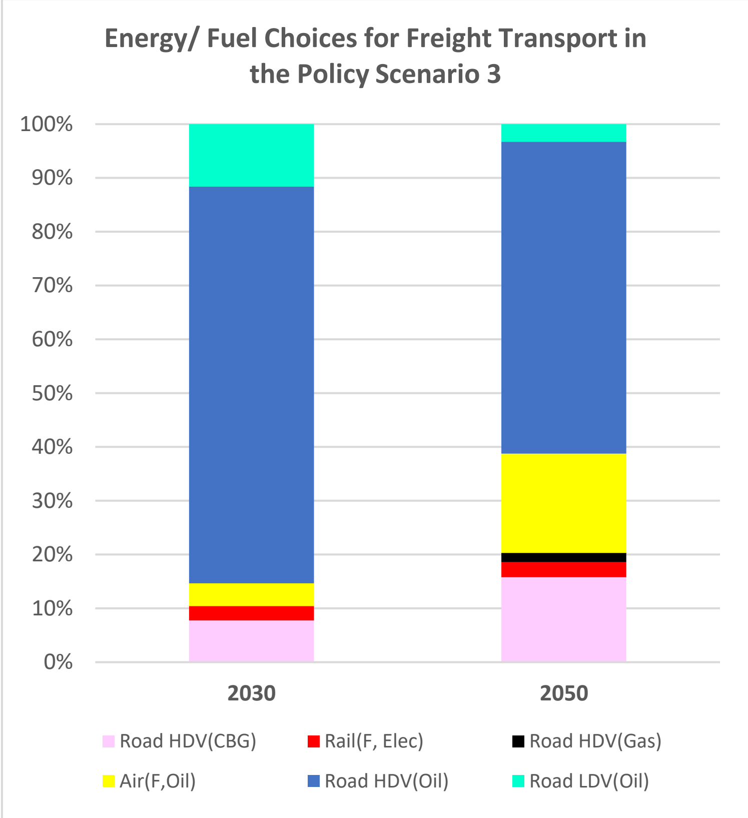


With regard to freight transport, the aviation oil in freight transport increases in policy scenario 3 compared to that in the baseline scenario. Road high-density vehicles in compressed biogas, gas, and oil categories and electric freight railways fall under the Policy scenario.

Figure 22 Energy/Fuel Choices for Freight Transport in the Baseline

Figure 23 Energy/Fuel Choices for Freight Transport in the Policy Scenario 3



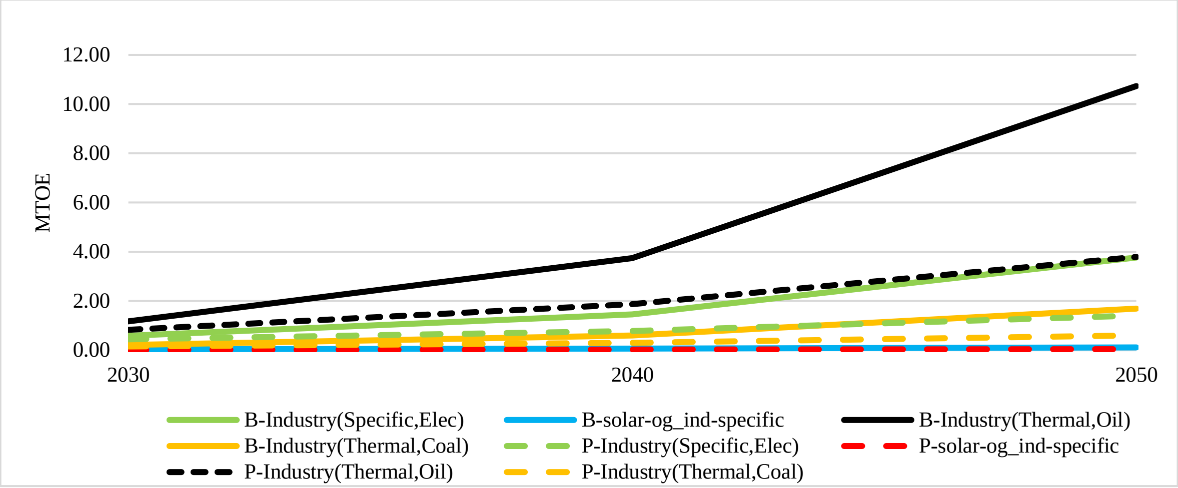


5.3.6 *Energy/Fuel Choices for Other Sectors*

Next, we discuss the changes in the energy/fuel mix in industry sectors. Figure 24 shows that there will be a significant decline in the industry sector in the oil-based/coal-based electricity sector in our policy run relative to the baseline.[5]

[5] As we do not observe any major shift in fuel choices in building, cooking and agriculture sector over the model period between the policy run (3) and BAU scenario, we do not discuss it here.

Figure 24 Energy/Fuel Choices for Industries (Policy run 3 and Baseline)



5.3.7 *Emissions*

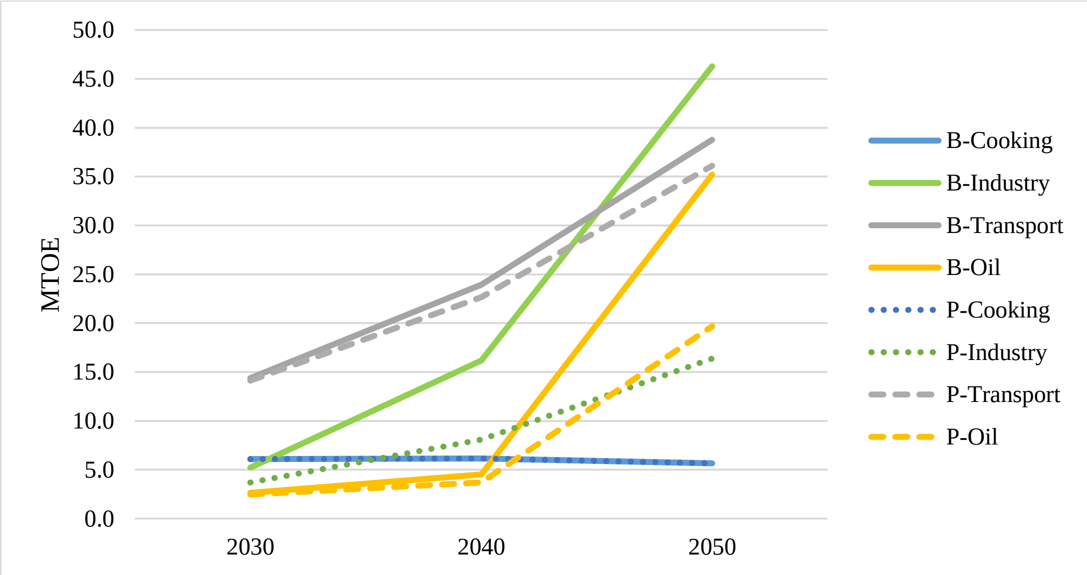
Table 13 shows the overall emissions in Kerala for the base run and policy scenario 3. As this table shows, per capita emissions under this low-carbon pathway decrease from 3.73 tons of CO_2e equivalent to 2.18 tons of CO_2e equivalent.

Table 13 Per capita emissions (tons CO_2e equivalent)

Per Capita Emission	**2030**	**2040**	**2050**
Policy Scenario 3	0.72	1.15	2.18
Base Run	0.86	1.53	3.73

The principal sources of emissions are shown in Figure 25 for our policy run and base run. The data are shown for sectors that are important contributors to emissions. As this figure indicates, with these policy interventions, we observe a significant decrease in emissions in the industry sector. The emissions from oil also decline sharply, partly due to the shift in the fuel mix.

Figure 25 Emission profiles (Policy Run 3 and Baseline)



In our policy scenario 3, the total CO_2e equivalent emissions in the policy run increase from 22 Mt CO_2e in 2025 to 43 Mt CO_2e in 2040 to 81 Mt CO_2e in 2050.

5.3.8 *Investments*

Table 14 shows our estimated investment number in US $ million required to achieve this low-carbon transition. As expected, with an increase in energy efficiency and productivity growth, a lower carbon emission pathway can be achieved with a lower investment.

Table 14 Cumulative investment in US $ million (base run and policy scenario 3)

Sector	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** *(3.6% of cumulative SDP)*	**262512** *(0.83% of cumulative SDP)*	**44560** *(3% of cumulative SDP)*	**230754** *(0.36% of cumulative SDP)*	**-3741**	**-31758**

It must be noted that these investment numbers are subsequently fed into the macro model to check whether macro growth numbers and prices change in a significant way. This process continues until the divergence decreases. In our case, we find that the numbers are close after a round of feedback, so the process does not continue further.

6 Employment Implications of Adopting a Low-Carbon Pathway

In the context of developing economies such as India, it is very important to analyse not only the broader implications of environmental policies and targets but also employment consequences. This also requires the consideration of indirect job creation, especially that arising from the macroeconomic effects of policies. As discussed in the earlier sections, a low-carbon pathway for Kerala would cause significant changes in the composition of different energy sectors in the economy. Employment absorption in different energy sectors is different, and thus, the transition to a low-carbon pathway would have an impact on direct employment generation in the energy sector. Moreover, power generation requires inputs from mining, manufacturing, energy, plastics, transport services and other sources, and the pattern of the linkage differs across different — fossil fuel-based or nonfossil fuel-based — industries. Therefore, there is a need to estimate the economy-wide implications of employment by capturing the interlinkage of industries. Additionally, since policy emphasis is on greater reliance on the renewable energy sector, there would be additional employment generation from the manufacturing and installation of renewable power plants such as solar photovoltaic or wind power plants, as outlined in policy scenario 3. In this section, we estimate the employment generation projection of our policy scenario 3 for Kerala. This is viewed in relation to the baseline scenario to understand the employment consequences of the low carbon pathway in Kerala.

6.1 Employment Effects

As discussed in earlier sections, the low-carbon pathway for Kerala would cause significant changes in the composition of different energy sectors in the economy. Employment absorption in different energy sectors is different; thus, the transition to a low-carbon pathway would have an impact on direct employment generation in the energy sector. Moreover, power generation requires inputs from mining, manufacturing, energy, plastics, transport services and other sources, and the pattern of the linkage differs across different fossil fuel- or nonfossil fuel-based industries; therefore, we have estimated the economy-wide implications for employment by capturing the interlinkage of industries. Additionally, since policy emphasis is on greater reliance on the renewable energy sector, there would be additional employment generation from the manufacturing and installation of renewable power plants such as solar photovoltaic or wind power plants in policy scenario 3. In this section, we estimate the projection of employment generation across different policy scenarios for Kerala.

According to the Periodic Labour Force Survey (PLFS) data, the unemployment rate, which is estimated as the percentage of unemployed persons in the labour force, was 9.6 for Kerala in 2021–22, which is higher than the all-India average of 4.1 for the 15 years and above age group, as per the usual status (ps+ss). In this paper, employment coefficients are generated using PLFS data. In the usual status (ps+ss) approach in the PLFS data, the estimates of unemployment rates are based on usual status considering principal status (ps) and subsidiary status (ss) together. Estimates for the labour force under this approach include (a) persons who either worked or were seeking work or were available for work for a relatively long part of the 365 days preceding the date of the survey and (b) persons from among the remaining population who had worked for at least 30 days during the reference period of 365 days preceding the date of the survey.

This paper differentiates between jobs by capturing the 'proximity' of a created job in a sector vis-à-vis other sectors, depending on how directly it can be attributed to a certain final energy demand. 'Direct jobs' refer to jobs that are directly related to core activities, such as operation and maintenance of the power plant. These jobs, along with jobs related to the supply and support of the energy industry at the secondary level (indirect jobs) and jobs led by household spending based on the income earned from direct and indirect effects (induced effects), are included in total employment. Since the sectors in the economy are interlinked through forward and backwards linkages, indirect jobs capture the jobs that are created to support the respective energy industry for the extraction and processing of raw material, manufacturing, construction and so on to support the operation and maintenance of power plants. Total jobs, thus, are the aggregate of all the types of jobs, which include direct, indirect and induced jobs from operation and maintenance of the power plants. Additionally, the paper estimates the required employment absorption for the manufacturing and installation of new renewable power plants.

Our results show that direct employment from the operation and maintenance of power plants would be significantly greater than the baseline employment projection from 2040 onwards, and policy scenario 3 is expected to provide 0.8 million more direct employment in the energy sector in Kerala compared to the baseline scenario (Figure 26). Total employment from the operation and maintenance of power plants, which captures the direct, indirect and induced employment generated from all sectors, including the energy sector, is also likely to surpass the baseline scenario from 2040, and it is expected to provide 1.1 million additional employees by 2050 (Figure 27). The difference in magnitude between total employment from operation and maintenance of the energy sector under policy scenario 3 and that of direct employment arises because the policy intervention also induces employment in other sectors through interindustry linkages.

Figure 26 Direct Employment in the Energy Sector from Operation and Maintenance

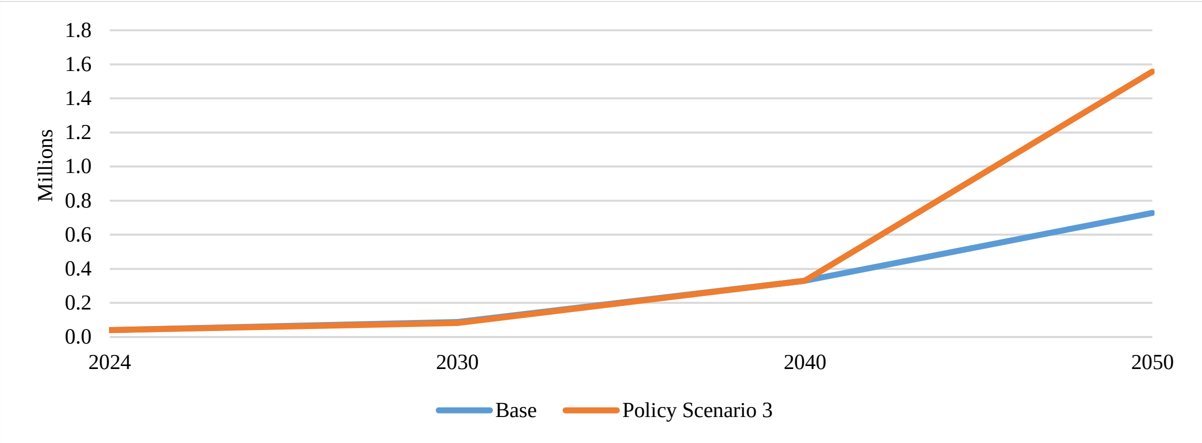
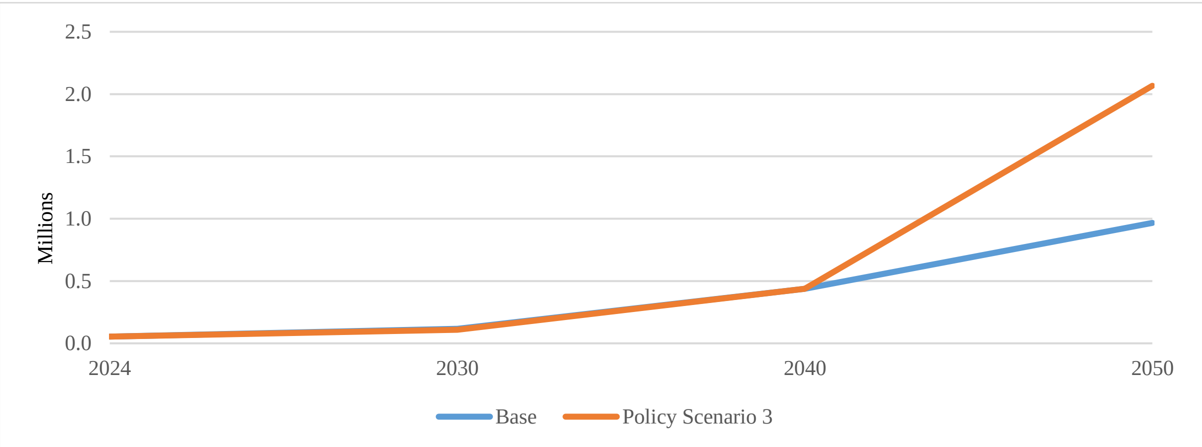
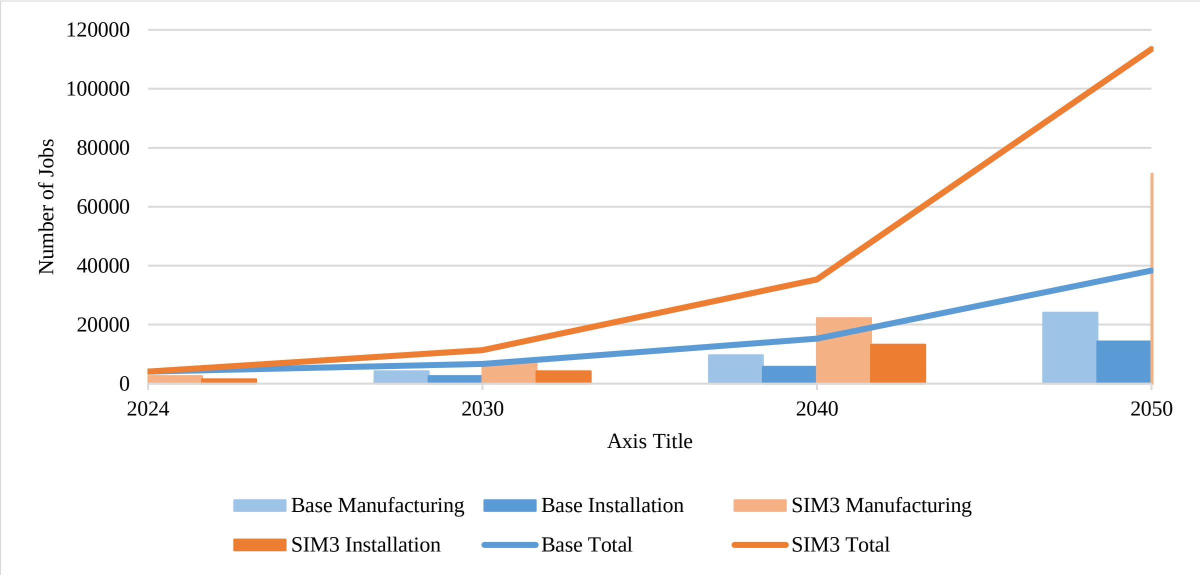


Figure 27 Total (Direct, Indirect and Induced) Employment in the Energy Sector from Operation and Maintenance



Investment in renewable energy not only increases employment generated from operation and maintenance but also from the manufacturing and installation of new power plants. For this purpose, the median values of direct employment factors for the main phases of deployment for wind and PV are utilized from Cameron and Zwaan (2015), and the estimates show that there would be significant increases in employment in policy scenario 3 for both the manufacturing and installation of power plants. This scenario is expected to generate 75 thousand additional employees in Kerala in 2050 compared to the baseline scenario (Figure 28).

Figure 28 Employment in Manufacturing and Installation of New Renewable Power Plants



7 Concluding Remarks

As India has embarked on the journey of fulfilling its net-zero emissions target by 2070, the states of India are steering up too to meet the target. The per capita emissions for Kerala are lower than the national average. The energy sector is the main contributor to GHG emissions in Kerala. A major share of 76 percent of electricity power is purchased from other states. When other states undergo an energy transition, the availability of imported electricity may be a challenge for Kerala. Hence, the State needs to harness its own potential for renewable energy sources and incorporate improved technologies leading to energy efficiencies in all sectors of the economy to save energy and thereby have a lower carbon footprint.

The state is gearing up to traverse through low carbon pathways by way of strategies for mitigation, adaptation and sector-specific policies for the abatement of GHG and air pollutants and for the promotion of the Electric Vehicles policy. Naturally, these transitions involve the adoption of some technologies with their underlying financial costs. Hence, it is crucial to understand the fiscal burden vis-a-vis the benefits of each policy intervention as an alternative low carbon pathway. Only by incorporating the behavioural aspects of economic agents and relevant energy technological innovations interplaying with the markets and prices in the economic system can a coherent energy transition pathway be developed. Accordingly, this report has undertaken integrated modelling (an approach with the primary objective of quantifying the gains and losses of low-carbon transition and their financial implications).

The integrated modelling approach involves soft linking of the macroeconomic top-down CGE model and bottom-up (Messageix) energy model. The top-down macroeconomic CGE model used for integration is a multisectoral, multiregional (Kerala, Rest of India and Rest of World) variant of the GTAP power model that has a detailed power sector.

The CGE model produces forecasts of sectoral outputs and prices for the BAU and policy scenarios. These CGE results were fed as exogenous input demand projections into the Messageix model, which is an energy optimization model. These projected demands are met by supplies subjected to least cost optimizations and other policy constraints, such as environmental constraints, resource constraints, and capacity constraints. The model provides technology-based decisions in each of its sectors in terms of reducing emissions and the cost of implementing those pathways in a given period of time. The integrated model is a recursive dynamic model with multiple periods of time to simulate changes as per the short-, medium- and long-term policy targets for the low-carbon pathway of the Government of India.

In this paper, we have undertaken a policy scenario in which (i) the imports of fossil-based electricity from other states of India are restricted to Kerala, (ii) 50 percent of the existing potential of renewable electricity by various modes is achieved in Kerala and the rest of India, and (iii) energy efficiency in all energy sectors is increased to the tune of 2.5 percent per annum along with 1 percent total productivity growth per annum in all sectors of the Kerala and India economies.

Our results show that the reduced import of fossil fuel electricity without any policy intervention to strengthen the renewable energy sector would hamper growth. On the other hand, investment in renewable energy to facilitate a complete energy transition with self-reliance on energy for the state would expand the economy, increase the returns to the factors of production, and increase employment.

The key message that comes out from our simulation is that the energy transition towards renewable energy will not take place without complementarity support polices towards this sector. There is a need for the government to play a key role in effecting the change. Additionally, it is pragmatic to augment the capacity of renewable energy as much as possible. Depending on imported electricity may be a risky proposition if other states face bottlenecks in the transition process towards renewable electricity. Additionally, it is very important to focus on improving energy efficiency in all sectors.

If all these factors are taken into consideration (policy simulation 3), we find that there will be a substantial decrease in per capita emissions in Kerala. With the change in fuel mix in favour of green sources of energy, there has been a sharp decrease in emissions from oil sources.

Our observation is that energy transition may be a win–win situation in the sense that growth and employment creation may be positive with suitable policy intervention.

It must be mentioned that the paper focused only on the energy sector. The developed model may be used in the future to focus on the economic implications of other policies, such as carbon sequestration.

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Annex A1 Top-Down CGE Model

Our top-down energy model is patterned after the GTAP model, which was designed and developed by the Center for Global Trade Analysis, Purdue University; see Hertel (1997). In our model, we consider 3 regions, namely, Kerala, the rest of India and the rest of the world.

The GTAP model is impactful in performing a comprehensive evaluation of a policy or regulatory shock. On the production side, the model assumes perfect competition and constant returns to scale. The production for every sector and every region in the model is identified and represented by a constant elasticity of substitution (CES) function. It also works on the basis of the Armington assumption, and thus, each firm employs a CES composite of domestic and imported intermediate goods in fixed proportions with endowment factors or value-added commodities such as land, labour, capital, and natural resources.

On the demand side of the model, total income is distributed following a fixed share across households, government, and savings expenditures. The model captures supply-demand linkages and equates them by accounting for changes in production, consumption, exports, and imports.

There are five factors of production (land, capital, national resources, unskilled labor and skilled labor), three types of domestic institutions (households, enterprises and government),

The behavioural equations in the model dictate production, private consumption, exports, imports, and market-clearing conditions that equate supply with demand. Elasticities determine the substitution between various input and output parameters in the production and consumption behavioural equation.

Figure A1-1 Simplified View of the Accounting Structure of the GTAP Model

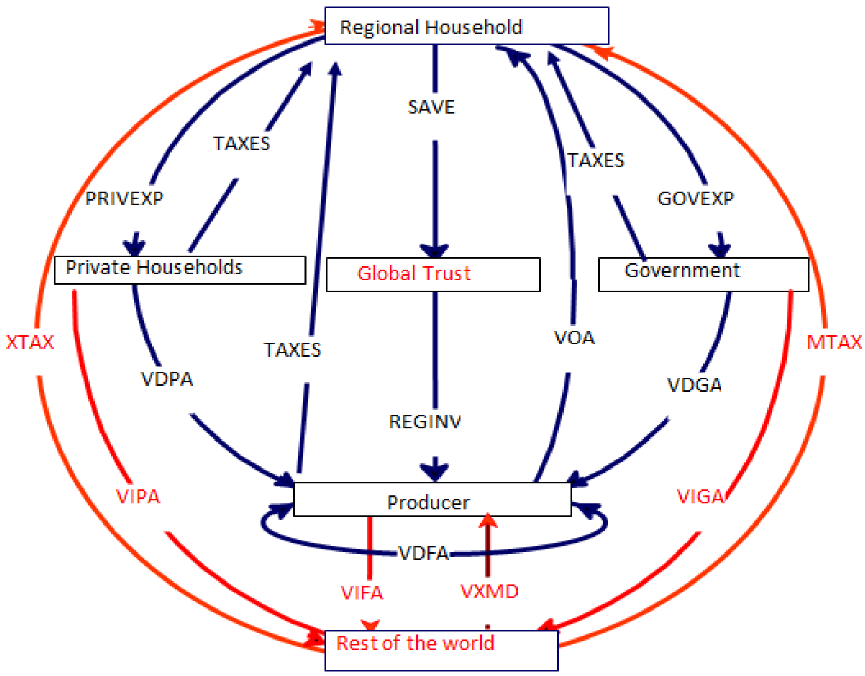
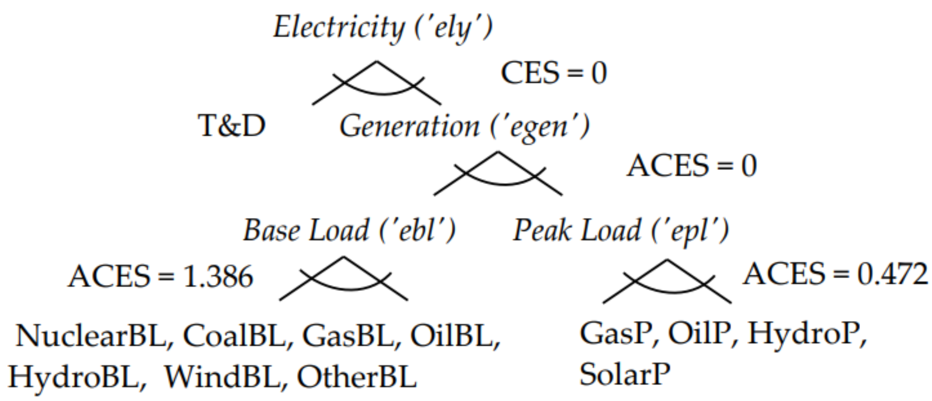


Figure A1-1 shows the simplified structure of the original complex GTAP model. Here, the regional household receives factor payments (VOA) from different agents, including private households, firms, and the government, for the supply of factors such as land, labour, and capital. The residual that remains after household expenditures on private consumption and government consumption is savings. The model is based on the Cobb–Douglas utility function, which preserves the share of private consumption and government consumption. Global trust accumulates savings and then distributes them across different regions as investments, and this happens based on the rate of returns. This becomes a capital input to the firms that also use factor inputs (VOA) and intermediate inputs from domestic (VDFA) and imported (VIFA) sources to produce the output. This output caters to the consumption demand of private households (VDPA) and the government (VDGA) and serves as an intermediate input to firms (VDFA). Private households and governments can consume domestic output (VDPA/VDGA) as well as imports (VIPA/VIGA), the consumption of which is governed by the Armington assumption. The international transactions in the figure are marked in red, and the domestic transactions are differentiated in blue.

According to the standard GTAP model, the electricity sector is considered an aggregate sector in terms of fuel, capital, and other production inputs. However, with policy and technical enhancements across different power generation technologies, it is important to account for the power generated from different sources and the substitution between them. The GTAP-Power database extends the standard GTAP database by including transmission and distribution while also accounting for power generated from different sources, including solar, wind, gas, oil, coal, nuclear, and hydro. The problem with electricity is that supply must instantly increase to cater to consumption demand, which in turn varies by, for example, season, work hours, day, and night.

The demand of coal power plants cannot be instantly adjusted, while the demand of gas or solar power can increase during peak periods. Additionally, it is unrealistic to assume that solar or nuclear power can meet all power demands given their operational constraints. Thus, based on their ability to cater to the requirements of the base and peak load, the power generation sectors are split into base- and peak-load technologies. The GTAP-Power database disaggregates electricity into 12 sectors with a transmission and distribution sector and 11 other generation sectors based on their sources and capacity to meet consumer demand. There are seven base load technologies, namely, 'NuclearBL', 'CoalBL', 'GasBL', 'HydroBL', 'OilBL', 'WindBL' and 'OtherBL', and four peak load technologies, namely, 'GasP', 'OilP', 'HydroP', and 'SolarP'. Other types of power sources include biofuels, waste, biomass, geothermal, and tidal technologies. Each of these power sources has different fuel efficiencies and demands different investments.

Figure A1-2 Nested Electric Power Substitution in the GTAP-E-Power Model



Source: Peters (2016b).

To build a GTAP-Power model for Kerala, the rest of India and the rest of the world, we modify the GTAP-E-Power model (Peters, 2016), which has the intricacies of the GTAP-E and GTAP-Power models. In other words, it extends the GTAP-E model to include transmission and distribution as well as accounts for substitution between power generated from different sources. GTAP-E, an energy environmental version, extends the standard GTAP model by incorporating energy substitution. It also accounts for carbon emissions from the combustion of fossil fuels and is a mechanism for the international emissions trade. Energy commodities in the GTAP model include coal, oil, gas, petroleum and coal products, and electricity. In the standard GTAP model, these commodities are treated as intermediate commodities, and the substitution parameters between these sectors are preset to zero. The

GTAP-E model accounts for interfuel substitution and fuel factor substitution in the production structure.

The construction of the balanced database for the GTAP-power was an extensive exercise. For this exercise, we had to construct an input–output for Kerala and the rest for India using the supply-use table for the year 2021. This also involved collecting various state-level data, macroeconomic data for Kerala and India and, of course, electricity generation by mode for Kerala and India. Most of the supplementary information was drawn from official statistics. We used information from official DGCIS statistics to collate data on exports from Kerala/the rest of India and interregional trade within India.

A3.1 Introduction

MESSAGEix is an energy system optimization model that optimizes the supply side of the model based on the projected energy demand provided as an exogenous input to the model. The model has 5 major sectors, namely, residential, commercial, industrial, transport and agricultural, as major energy consumption sectors. The residential sector is further broken down into subsectors such as appliances and cooking. The growth in energy demand in these sectors is directly linked to the growth of the sectors in terms of economic activity. With these projected demands as inputs to the model, the model optimizes the energy system to the least-cost scenario of energy activity in and around policy constraints of environment and resource availability. The optimization occurs at different levels of energy use, from useful energy demand to final and then to secondary consumption all the way up to primary and resource supply. A representation of the model in the general context is shown in Figure A2-1.

Figure A2-1 Representation of an Energy System Model in MESSAGEix

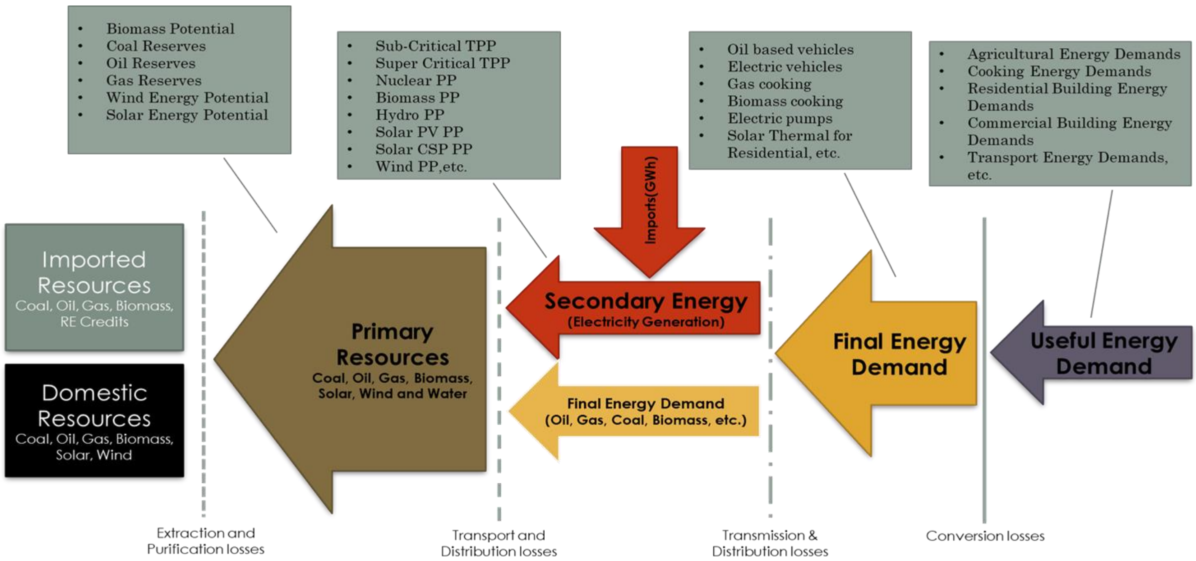
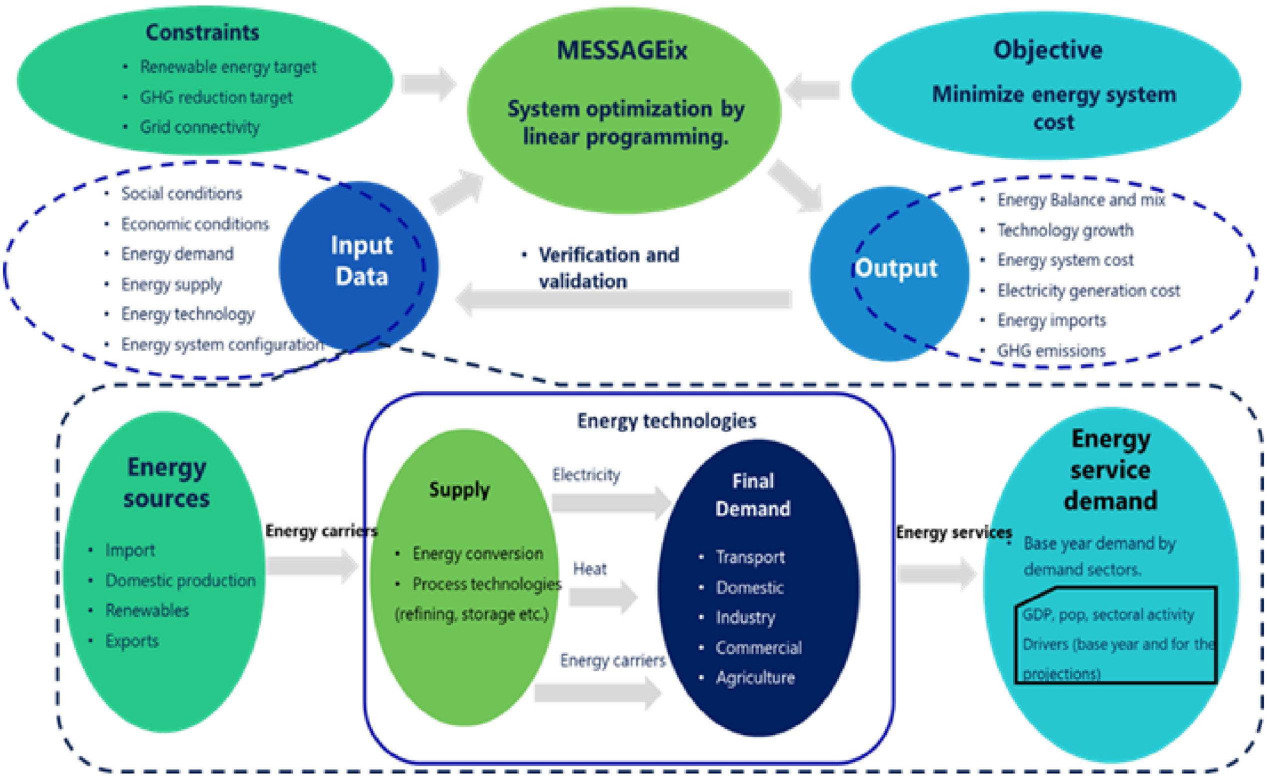


Figure A2-1 shows the granularity in the model used to make a technology-based decision on a low-carbon pathway. The total GHG emissions, investments and electricity generation capacity expansion profile are among the major outputs of the model. This approach provides a clear context for what alternative technology should a nation look at to reduce emissions and what the cost of implementation for those pathways will be. It also helps to implement policies that look at better demand management with a shift in fuel mix. However, the demand information remains fixed in the model, and hence, at a time, the scenarios can be developed only by assuming one case of economic activity. To produce meaningful scenarios, the variation in demand linked with economic activity is required to represent the scenarios at different levels of socioeconomic activity; thus, a framework with a seamless scope of looking at more insightful solutions to climate mitigation becomes key to a more suitable modelling approach where the demands can come from a CGE model (see Figure A2-2 below). The MESSAGE-ix modelling framework was developed by the International Institute for Applied Systems Analysis (IIASA). It is a versatile, open-source, dynamic systems-optimization model and presents a framework for representing an energy system with interdependencies from resource endowments and potentials to extraction rates, imports and exports, generation of electricity and conversion of fuels, transportation, transmission, and distribution to conversion of energy for end use demand in the form of heat, light, or kinetic energy. The optimization model obtains the least-cost solution subject to constraints over predefined fixed time periods.

The MESSAGE model has been a crucial part of various assessment reports of the Intergovernmental Panel on Climate Change (IPCC). MESSAGE-ix is a demand-driven bottom-up model. As a result, the estimation of energy demand is a crucial part of the modelling process. The objective is to minimize the energy system's costs to meet given energy demands in the economy over the model horizon.

Figure A2-2 Structure of the MESSAGEix Model



A3.2 Energy demand projection using the IM Framework

The MESSAGEix requires demand projections as an exogenous input to the model. Based on these projected demands, the supply side to meet these demands is optimized in the MESSAGEix model at different levels of consumption and supply. Optimization in MESSAGEix is constrained with least cost optimization, which means that optimization occurs for a least cost system expansion plan to meet future demands in and around all other policy constraints, such as environmental constraints, resource constraints, and capacity constraints. Hence, supply-side information is highly relevant because it covers most policy aspects. To make the model more robust in terms of linking the energy model to an economy based on economic performance, the energy demand that should be used as an input in the MESSAGEix model should be derived from a computable general equilibrium (CGE) model.

Here, we explain how the projected CGE model outputs at the sector level are used to derive the corresponding sectoral energy demand growth rates using concordance mapping.

A3.2.1 *Agriculture Energy Demand*

Factors from CGE model outputs

The effect of the CGE output on the 'grains and crop' productivity rate is the key indicator for the agricultural sector. The productivity rate helps determine the land use change and change in agricultural tractors and irrigation pumps by increasing/decreasing productivity rates.

Derived energy demand from CGE outputs

The factors are then applied to irrigation and land preparation through identification and percentage distribution between surface/ground water irrigation. Land use change is considered based on long-term historical data from national statistics.

A3.2.2 *Household/Cooking Energy Demand*

Factors from CGE

The direct productivity of household demand for 'electricity and gas supply' is obtained and applied to the base year energy demand of both households and cooking.

Derived energy demand from CGE outputs

The base year energy demand is calculated from national accounts and statistics. Cooking activity and its productivity rates are then obtained based on the weight distribution of fuel utilization, as in its historical trends.

A3.2.3 Commercial Sector Energy Demand

Factors from CGE

The intermediate demand for electricity is directly obtained by deducting the household demand for energy commodities from aggregate demand.

Derived energy demand from CGE outputs

The base year energy demand is calculated from national accounts and statistics. The identification and percentage distribution between appliance use and hot-water demand of the sector are based on the growth pattern of the sector.

A3.2.4 *Transport (Freight & Passenger) Energy Demand*

Factors from CGE

CGEs provide direct intermediated growth of 'rail transport, land, air and water transport'.

Derived energy demand from CGE outputs

Identification of freight and passenger distribution from historical data and current national statistics. Growth parameters are identified based on sectoral demand patterns, and then growth rates are directly applied.

A3.2.5 *Industrial Energy Demand*

Factors from CGE

To identify the growth rate of the industry sector, growth rates are directly sourced from different manufacturing services and other industries modelled in the CGE model. Furthermore, the mean value of all the production growth of manufacturing and other industries from CGE output is calculated, which is then directly applied to the calculation of energy demand projection in the industry sector.

Derived energy demand from CGE outputs

The base year energy demand is identified, and direct mean growth rates are applied.