Economic Impact of Green Transition in Odisha: A subnational CGE-based IAM model for India

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Abstract

With the Government of India announcing its goal of achieving net-zero emissions by 2070, all states are mobilizing to adopt low-carbon pathways for their economies. Now, energy is one of the key sectors in India, which is inter-linked with almost all other sectors. Especially for a state, where industrial sector has significant share in GDP, such transition would have impact on all the sectors of the economy. Odisha, a state situated in Eastern coastal part of India, produces 23% of total coal in India. In this study, we want to explore the economic impact of transition to low-carbon pathway for Odisha capturing the inter-sectoral dependence and its linkage with the other states of the country and the world. For our analysis, we have adopted an Integrated Assessment Modelling (IAM) approach by soft linking a macroeconomic top-down CGE model with a bottom-up (MESSAGEix) energy model. Our study shows that development of renewable energy sector through imposing tax on fossil fuel sector would hamper growth, but this can be overcome with suitable policy interventions targeted at increase in energy efficiency and productivity, while reducing emission. Direct employment in energy sector of the coal-mining state are affected, but overall employment increases.

key words: Integrated Assessment Model, Sub-national level CGE modelling, Energy system modelling, Odisha, Green transition, Macro-economic impact, employment

JEL classification: C68, C61, Q43, Q47

article highlights:

- Assesses economic, energy, employment impact of green transition at sub-national level
- Uses top-down recursive dynamic CGE model with bottom-up energy model (Messageix)
- Development of renewable sector by taxing fossil fuel would reduce economic growth
- Economic growth will higher with improvement in energy efficiency & productivity
- Transition does not lead overall loss in employment even in coal rich state

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1. Introduction

The path of decarbonization requires shift to low-carbon options. But in India, coal is still the dominant source of energy for power generation with a share of 73% in 2023 while the same for renewables amounts to only 12%. Naturally, the transition from fossil-fuels to non-fossil fuels for power generation is going to be a challenge for the country, especially for the regions whose economies are dependent on fossil-fuel sectors. No doubt, the economy of different states would be differentially impacted since resource endowment differs across states.

Odisha, a state situated in Eastern coastal part of India, produces 23% of total coal in India, and it has the highest share among the states of India. Though the state's growth rate (7.8%) is higher than India (7.0%) in 2022-23, as per the Economic Survey of Odisha, 2022-23, per capita income in Odisha (INR 150676) is lower than all-India level (INR 170620). According to the data provided by Ministry of Mines, Government of India, out of 1319 reported mines, 128 are located in Odisha in 2021-22. During the year 2021-22, Odisha accounted for 44% of the total value of mineral production in the country, i.e. the highest among the states. According to Economic Survey of Odisha 2021-22, mining and quarrying registers 24.6% of the GVA generated from industry; and electricity, gas and water supply registers 18.4% of the same. The country is dependent on Odisha for minerals especially coal, but at the same time Odisha economy is also dependent on mining, heavy industries and electricity generation. In this paper, we explore the economic impact of transition to low-carbon pathway for Odisha capturing the inter-sectoral dependence and its linkage with the other states of the country and the world.

Although Odisha makes up only 3.47 % of the population in India, its net GHG emissions are relatively high, contributing to 9.3 % of the country's GHG emissions (GHG Platform India 2022). In per capita terms, net emission from Odisha (6.15 tCO2e per capita) is higher than the national average (2.24 tCO2e per capita), and overall emission in Odisha has increased at a compound annual growth rate (CAGR) of 7.85 % from 2005 to 2018. Because of its large coal mining sector, Odisha is a major electricity-producing state in India, and that too is coal-based electricity. As of December 2022 (CEA), Odisha had an installed capacity of 12,322 MW of which 9,540 MW is for coal-based power plants. So, emission in Odisha is largely driven by high dependence on coal (90 %) as a source of power generation in the state (in 2021-22). Odisha is one of the few Indian states that is surplus in electricity production: only 33% of the produced electricity is consumed within the state and the rest is exported to other states.

To keep up the pace of growth and development for the state, the state needs to continue generating electricity and exploit her mining resources, but there is a need to move towards renewable energy sources and adopt a low carbon pathway for its economic growth. In this context, this paper intends to analyze the impact of adopting low-carbon pathway for the state of Odisha using an integrated assessment modelling (IAM) tool.

The plan of the rest of the paper is as follows. Section 2 provides a brief overview of literature in this area. The following section outlines the methodology adopted for our analysis. Section 4 analyzes our results and finally section 5 summaries our findings.

2. Review of Literature

To comply with national and international climate targets, it is essential for India to phase out coal-fired power plants and substantially increase the use of solar-PV and wind power (Ordonez et al. 2023). Some of these studies have utilized economic models to understand the general equilibrium implications through capturing the effect of such transition on the economy. The study by Gupta et al. 2019 suggests that the low-carbon transition is not likely to affect the economic growth despite high investment costs. Vishwanathan et al. 2023 talks about other positive impacts like job creation, energy import reduction, improvement of local environment and human health, while Gupta et al. 2020 argues regarding the improvement of the trade balance in the process.

On the employment front, studies observe both positive and negative effects, which vary from region to region. Ordonez et al. 2023, in the context of India, observes an adverse impact in eastern region of India, especially in coal- mining states, while the employment creation is found to be more in India's Western and Central states through deployment of renewables. Kanitkar et al. 2019, utilizing the Integrated Modeling Framework (IMF), shows that in some scenarios, higher investments in green energy negatively affects low income households significantly more as compared to other households.

A study by Mittal et al. 2018 finds that there are significant emission gaps between NDC and global climate stabilization targets in 2030, and the energy system requires changes based on renewable energy and carbon capture and storage (CCS) technology. Gunatilake et al. 2011 emphasizes that expanding biodiesel production to meet the national target is a welfare-improving strategy. Shukla et al. 2017 emphasizes that penetration of renewable technologies, end-use demand management and improvement in energy efficiency are important to reduce emission. Vishwanathan et al 2019 talks about the necessity of efficiency improvement to facilitate such transition, while Ruamsuke et al. 2015 opines that clean electricity generation technologies play a key role in emissions reductions.

Pradhan & Ghosh 2022 emphasizes that the carbon pricing instruments like coal cess would help in achieving the low carbon target along with economic gains and facilitate technological shift by lowering relative prices of non-fossil fuel energy. On the other hand, some studies talk about undesirable trade-off between economic growth and climate change mitigation while deploying carbon tax, and discourses that recycling carbon tax can overcome the issue (Ojha, Pohit S & Ghosh 2020, Pradhan & Ghosh 2021, Ordonez et al. 2023). Rana et al. 2001, however, opines that carbon tax reduces carbon dioxide emissions but there is also a loss of GDP. Chang et al. 2023, however, shows that carbon tax policy though is likely to impact GDP negatively at the early stage. However, with technological progress, it is possible to turn negative GDP impacts into positive at the late stage. By contrast, Jiang et al. 2022 shows that for India, if co-benefits are considered, marginal abatement costs and total abatement costs to achieve NDC targets can be effectively offset (Jiang et al. 2022). A detailed analysis of the application of computable general equilibrium on issues related to climate change mitigation measures and policy interventions can be found in a systematic review by Babatunde et al. 2017 and An et al. 2023.

Very few studies have considered combining different approaches to analyze the issue (Bastarrica et al. 2023 for Spain, Villamar et al. 2021 for Ecuador). IAMs are useful in designing GHG emissions reduction pathways at the global and national levels and are used in energy planning (Welsby et al. 2021, Zhang & Chen 2022). Kanitkar et al. 2019 utilizes the Integrated Modeling Framework (IMF) for India combining index decomposition, constrained optimization and input-output analysis to estimate economic impacts. As an alternative, Gaur et al. 2019 uses unit commitment (UC) extension of North Indian multi-regional TIMES (NIMRT) model for the power sector of Northern Region to analyze the impact of adding short-term operational constraints to a long-term power system planning model. However, integrated assessment framework is not used in the context of a subregion (state) of a country to estimate the mitigation cost and benefits. Our study aims to understand the effect of transition to renewable energy sources for power generation, through an integrated assessment model linking the CGE model and energy system model at sub-national level for India, which is done for the state of Odisha. In literature, there are some sub-national studies using the CGE modelling framework, like Schinko et al. 2020 for Austria, Bosello et al. 2018 for Euro-Mediterranean area, but none of them are in the context of a sub-national level for developing country, especially for India. Moreover, none of them consider integrated assessment modelling framework linking the CGE model to the bottom-up energy system model framework to outline the future requirement of energy. With impending transition of adopting green energy sources, we want to analyse the impact of green transition for a mineral-producing state like Odisha using CGE and energy system modelling framework, because (a) the economy of the state would also be affected through the loss in output in coal mining sector, which is predominantly the source of energy for power generation in India, (b) the above methodology can capture the inter-linkage of different sectors like heavy industries with the energy sectors, and (c) the framework can enable us to design a pathway of green transition at sub-national level, considering the impact on the economy through future projection. Our study aims to fill this gap in the literature in the context of India

3. Methodology

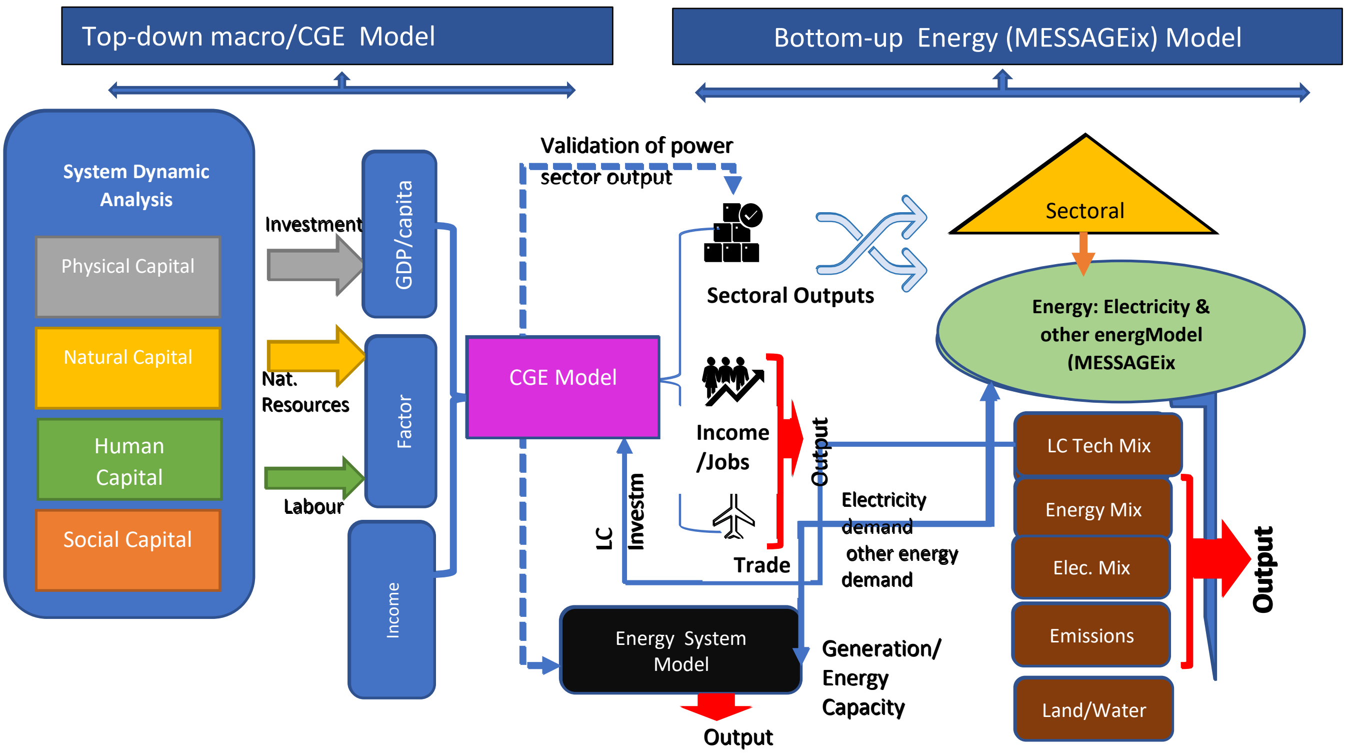
Below, we outline the methodological framework for our analysis.

3.1. Framework of Integrated Model (NCAER CGE Model – MESSAGEix)

As noted earlier, our approach involves soft linking of the macroeconomic top-down CGE model and bottom-up (MESSAGEix) energy model (Figure 1). The top-down macroeconomic CGE model used for integration is a multi-sectoral, multi-regional (Odisha, Rest of India and Rest of World) variant of the GTAP power model with detailed power sector. The advantage of such integrated model is that the sectoral outputs and prices are not exogenous to the system as in a typical bottom–up energy model, but are endogenously determined within the system. We have also considered the move towards energy transition in the rest of India while analysing Odisha's policy dilemmas because we believe that Odisha's economy cannot be studied in isolation.

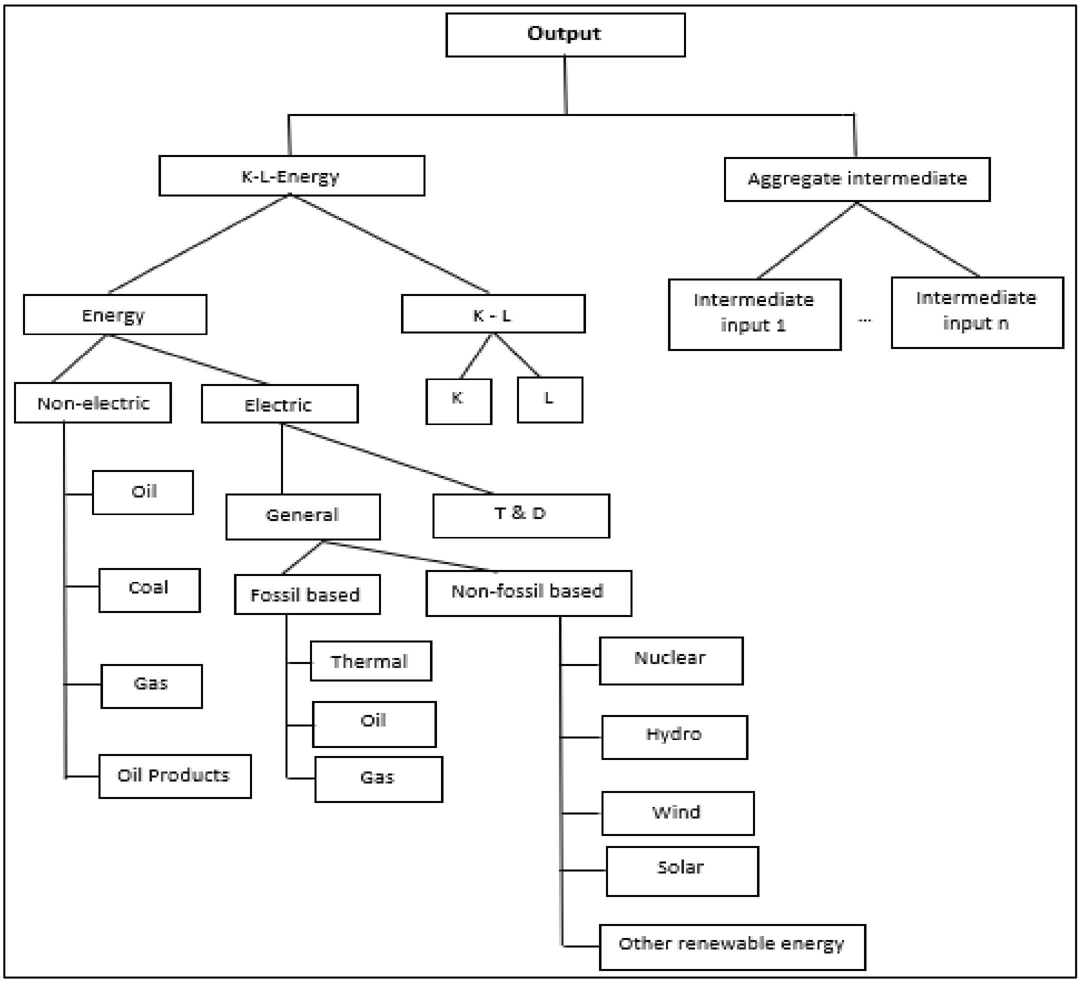
The recursive dynamic CGE model produces forecasts of sectoral output and prices for the business-as-usual and policy scenario. These CGE results are incorporated as exogenous input demand projections into the MESSAGEix model. The projected demands generated in the energy optimization model are met by supplies subjected to least cost optimizations along with policy constraints, such as environmental, resource, and capacity constraints. The energy system model provides technology-based solutions for each of its sectors capturing the target of reduced emissions and reports the cost of implementing those pathways in a given period. Figure 1 represents our integrated modelling structure.

Figure 1: Structure of the Integrated Model



The production structure of the energy and non-energy sectors is shown in Figure 2. In the CGE model, output is generated using capital, labour, energy and intermediate inputs. Energy is sourced from various sources, which can be classified into electric and non-electric energy sources. Non-electric sources consist of oil, coal, gas, oil products etc. Electricity is generated from various sources, which can be classified into fossil-fuel and non-fossil-fuel based electricity. Fossil-fuel-based electricity is generated from coal, oil, gas. Non-fossil-fuel-based electricity refers to electricity generated from wind, solar, nuclear and other renewable sources. A part of electricity is spent in transmission and distribution.

Figure 2: Production structure of the energy and non-energy sectors



The outputs of the sectors which are aggregated/ disaggregated sectors based on the model's requirement for the analysis, are obtained, using the concordance map in Table 1.

Table 1: Concordance map between 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 (on-shore/ off-shore)	32	Pharmaceutical	
12	Hydro electricity	Hydro electricity	33	Non-metallic minerals	
13	Oil power	Oil power	34	Ferrous metal	

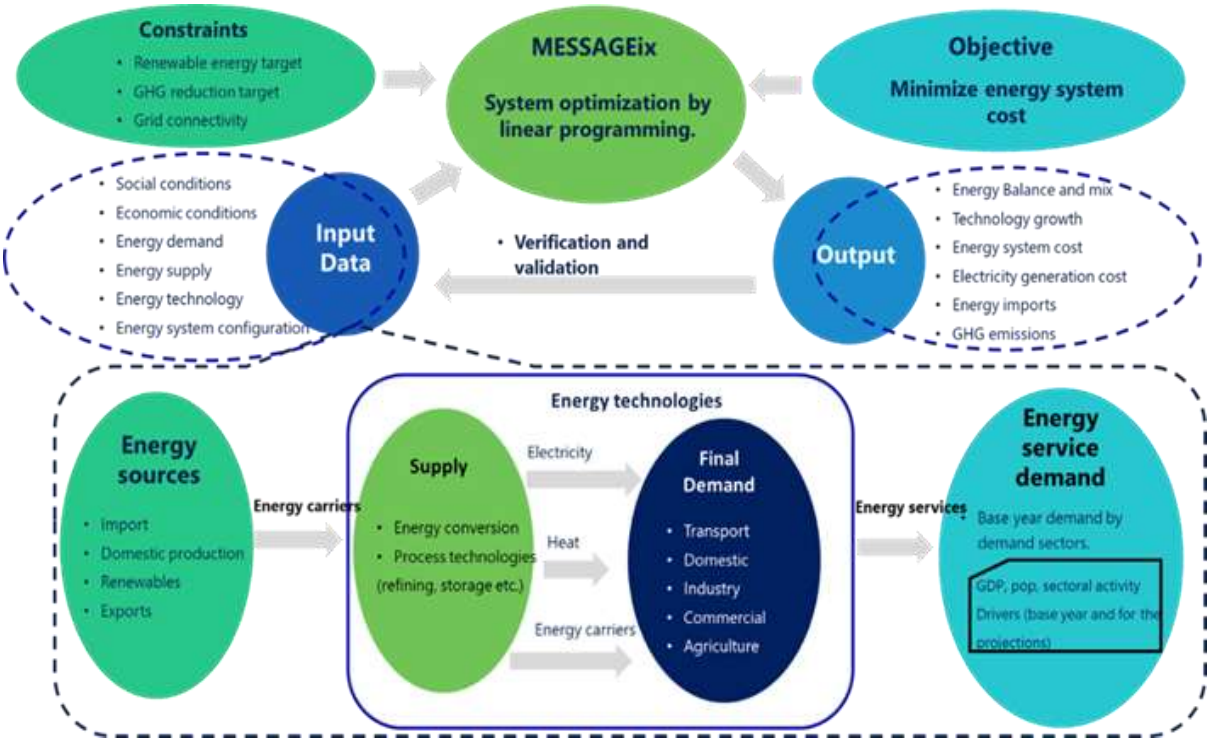
14	Solar electricity	Solar electricity (all forms)	35	Non-ferrous metal	
15	Other renewable	Other renewable	36	Batteries, electrical & electronics equipment	Commercial others
16	Land Transport	p_transport_road_OMNIBUS	37	Machinery	
		f_transport_road	38	Vehicles	
		p_transport_road_BUS	39	Transmission & distribution	
		p_transport_road_TAXI	40	Water distribution	
		p_transport_road_CAR	41	Construction	
		p_transport_road_2W	42	Trade	
		p_transport_road_3W	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 passenger, f for freight, IWT for inland water transport, 2W for two-wheelers, 3W for three-wheelers. *Source*: Authors' estimates.

The top-down CGE model recognises 49 industries producing 49 goods and services. Energy sectors are disaggregated into 13 industries, 3 primary fuels (coal, oil, and gas), 1 refined oil (petroleum products), and 9 electricity generating industries (Table 1). Electricity generation industries are defined according to their primary source of fuel and 1 electricity distributor industry is considered. Sectoral distribution also considers 14 industries where all the major energy-intensive industries are modelled separately. Patterned after GTAP-power model (Corong et al 2020), the model in this study is a multi-region model with the regions being Odisha, rest of India and rest of the world. We assume that the regions trade among themselves in commodities/ services. However, we assume that electricity trade only takes place between Odisha and the rest of India.

On the other hand, the MESSAGEix modelling framework, developed by the International Institute for Applied Systems Analysis (IIASA), is a dynamic systems-optimisation model and presents a framework for representing an energy system with all its 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 (Figure 3). The model has five major sectors as major energy consumption sectors; residential, commercial, industry, transport and agriculture. The residential sector is further broken down into sub-sectors 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 input to the model, the model optimises the energy system to the least cost scenario of energy activity in and around policy constraints of environment and resource availability.

Figure 3: Structure of MESSAGEix Model



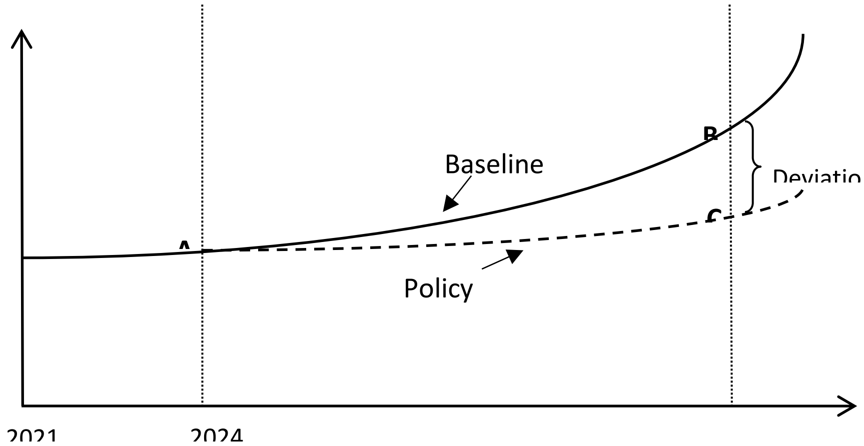
The bottom-up energy model also provides us with the investment numbers necessary to achieve these technology choices. These numbers are then fed back into the top-down CGE model to validate whether or not the growth path diverges. This process of two-way feedback continues until the differences in GDP numbers between the successive rounds converge.

3.2. Policy Analysis with a Dynamic Model and scenario setting

As illustrated in Figure 4, policy analysis with a *dynamic* CGE model requires two simulations (at least).[10] 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 the policy change under consideration. The second simulation is the *policy* simulation. In this, 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.

Figure 4: Policy Analysis with a Dynamic Model

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



To examine the macro-economic effect of transition to low-carbon pathway for Odisha, this study establishes a business-as-usual scenario with present energy policies and macro-economic situation. Expectedly, Odisha faces challenges in achieving low carbon due to heavy industries, mining activities and coal-based power generating stations. It is important that the state formulates adequate and appropriate policies to strike balance between development, economic growth and emissions mitigation. Below, we have undertaken the following illustrative policy scenario to understand whether these help Odisha move on a low carbon pathway along with their economic implications.

(a) Scenario 1: Capacity augmentation of renewable electricity (Aug_R_Elec)

Currently, Odisha is a major exporter of fossil-based electricity to the rest of India. Our baseline suggests that this trend would continue till 2050. When all other states move towards renewable energy instead of cheaper fossil-based electricity to reduce their carbon footprint, it makes sense for Odisha to augment its renewable energy capacity. The targeted intervention to renewable electricity is based on the actual and potential installed capacity of solar, wind, small and large hydro, nuclear and bio-power in Odisha and the rest of India. We assume that 50 % of the existing potential of renewable electricity by various modes is achieved in Odisha and the rest of India by the terminal year of our model run (2050). To achieve this transition, we impose an endogenously determined indirect tax on fossil-based electricity to dampen its growth and the revenue so collected is distributed as counter-veiling subsidy on electricity generated from clean energy sources. Simultaneously, to strengthen our emphasis on transition, we impose a ban on import of fossil-based electricity from the rest of India, so that cheaper imported fossil-based electricity does not substitute for state-produced fossil-based electricity. Since Odisha produces electricity sufficiently to cater the state's demand, and also in surplus amount, so the ban is not going to affect electricity generation or consumption significantly in present situation, but it would ensure self-sufficiency in electricity production in future years when the state and the country both would go for reliance on renewable technologies for electricity production.

(b) Scenario 2: Scenario 1 + Enhanced Energy Efficiency (Incr EE)

In this scenario, we consider increased energy efficiency to the tune of 1.5 % in Odisha and the rest of India concomitant with policy scenario 1. Further, we have assumed 1 % total productivity growth per year in all sectors. The range of total factor productivity (TFP) growth has been achieved in the past in India. Also, in our bottom-up energy model, we assume that sectoral intervention takes place in industry, building, transport, and agriculture so that low carbon technologies become more economically viable.

Energy efficiency has been the discussed widely in the policy document in Odisha. Moreover studies in the Indian context suggest that these are low-hanging fruits and are very effective in reducing the carbon footprint.

3.3. The Database

Our CGE model has been calibrated to the Odisha economy for the year 2021. The principal source of our data is an Odisha input-output table that we prepared for this study following the methodology outlined in Pal, Pohit and Roy (2014). The model also requires other parameters and elasticities that are drawn from literature surveys with a focus on India.[11]

Most of the parameters and elasticities are drawn from Ojha, Pohit and Pal (2009). The sectoral productivity numbers are collated from various Indian studies and the India KLEMS[12] database. The time series data on population for India and Odisha is available from Census of India and UB population projection[13]. To estimate the labour supply for India, we used data from the Labour Force Participation Rate (LFPR) of India/Odisha[14].

Finally, using a time series of the exogenous variables of the model, we generate a sequence of equilibria for the period 2021 to 2051. From the sequence of equilibria, the growth paths of selected (macro) variables of the economy are outlined to describe the baseline scenario, spanning the 30-year time interval from 2021 to 2050.[15]

4. Analysis of results

This describes the results of our model run both for base run and policy scenarios. First, the baseline scenario shows the present and business-as-usual projection values for Odisha. Then, the deviation of macro-economic indicators in policy scenarios from the baseline scenario are shown. The results are grouped under three heads: macro-effects, effects of electricity sector, sectoral fuel choices and finally employment implication of adopting a low carbon trajectory. Investment requirement of the transition is also estimated.

4.1 Macroeconomic effects

Table 2 shows baseline projections for key macroeconomic variables. We report results for both income and expenditure-side components of SDP, and for other variables such as SDP deflator and consumer price index. Results imply rapid growth in Odisha with a subdued growth at the end of the simulation period (2046-2050). On an average, in baseline scenario, annual growth in real SDP is likely to be sustained around 6.0 % during the period of study. In the baseline scenario, we see a reduction in growth of returns to capital, which may be caused by reduction in growth rate of investment. Growth in real wage of skilled labour is likely to be more than growth of real wage of unskilled labours, though major share of labour in Odisha is unskilled ones.

Table 2: *Macroeconomic results for 2022 – 2050 (%)*

Selected Variables	2022-2030	2031-2035	2036-2040	2041-2045	2046-2050
A. Income components of SDP (growth rate)					

[11] See Ojha, Pohit and Pal (2009), Pal, Pohit and Rajeev (2022).

[12] India KLEMS database compiled by the Reserve Bank of India for measuring productivity at industry level.

[13] The time series data on population for All India and states for the time period 2011 to 2036 is available from Census of India (July 2020). We used UN Population projection, 2022 thereafter from 2037 to 2050 for All India.

[14] To estimate the labour supply for India we used data from Labour Force Participation Rate (LFPR) of India. The extrapolation for CENSUS and LFPR 2021 were done for projecting the figures for future years.

[15] The time series data on population for All India and states for the time period 2011 to 2036 is available from Census of India (July 2020). We used UN Population projection, 2022 thereafter from 2037 to 2050 for All India. To estimate the labour supply for India we used data from Labour Force Participation Rate (LFPR) of India. The extrapolation for CENSUS and LFPR 2021 were done for projecting the figures for future years.

1 Real SDP	6.2	6.0	6.3	6.0	5.3
2 Demand for capital	5.3	6.2	6.4	6.6	1.9
3 Demand for skilled labour	0.5	0.1	0.1	0.1	0.1
4 Demand for unskilled labour	0.5	0.1	0.1	0.1	0.1
5 Multi-factor productivity	0.9	0.9	1.0	0.9	0.7
6 Real wage for unskilled labour	4.3	4.5	4.7	4.3	3.7
7 Real wage for skilled labour	5.0	5.3	5.7	5.2	4.3
B. Expenditure components of SDP (growth rate)					
8 Real private consumption	6.1	5.9	6.2	5.8	5.1
9 Real government consumption	5.7	5.5	5.9	5.7	5.3
10 Real investment	7.6	6.8	7.0	6.8	6.2
C. Other macro indicators (growth Rate)					
11 SDP deflator	5.3	5.2	5.5	5.7	5.8
12 Population	0.23	0.04	0.01	0.01	0.01
13 Consumer price index (CPI)	5.5	5.4	5.8	6.0	6.1
D. Other variables (growth Rate)					
14 CO_2 emissions	2.2	2.1	2.6	3.2	3.4

***Source*:** Authors' estimates.

In the policy scenarios, we see a deviation of economic growth from the baseline in different policy scenarios. Fossil fuel is the predominant source of energy in the mineral-rich state of Odisha. In Scenario 1, which considers augmentation of renewable energy production in Odisha, with tax imposed on fossil fuel, there is a marginally reduced growth in State Domestic Product (SDP), especially in initial years of the simulation (Table 3). However, the later years, this scenario shows higher growth in SDP as compared to the baseline. Scenario 2, which considers improvement in energy efficiency and productivity, shows significant increase in growth rate in initial years, since both reduces the dependence on energy for industries, which is a major part of Odisha's SDP.

Table 3: Average Year-wise Growth of Real GDP and Real Returns of Factors of Production (percentage deviation from baseline)

	2024-2030	2031-2035	2036-2040	2041-2045	2046-2050
	Percentage deviation of Policy Scenario1 from baseline				
Real SDP	-0.30	-0.13	-0.09	-0.08	-0.06
Land	-0.33	-0.26	-0.21	-0.11	-0.12
Unskilled labour	-0.13	-0.16	-0.13	-0.14	-0.27
Skilled labour	-0.09	-0.28	-0.28	-0.22	-0.30
Capital	-0.44	-0.41	-0.31	-0.27	-0.39
	Percentage deviation of Policy Scenario2 from baseline				
Real SDP	1.4	1.4	1.4	1.2	0.1
Land	-0.94	-0.52	-0.40	-0.31	0.09
Unskilled labour	1.51	1.34	1.26	1.20	0.37
Skilled labour	1.92	1.70	1.56	1.43	0.32
Capital	1.61	1.47	1.49	1.44	0.33

In Policy scenario 1, there is a negative deviation in growth rate as compared to BAU, but with improvement in energy efficiency and productivity, Policy Scenario 2 shows a significant positive deviation in SDP growth rate, especially till 2045. For the Policy scenario 2, there is around 1.4% increase in real SDP as compared to Business-as-usual scenario and it persists till 2045, but the growth rates converge in long run (Table 3).

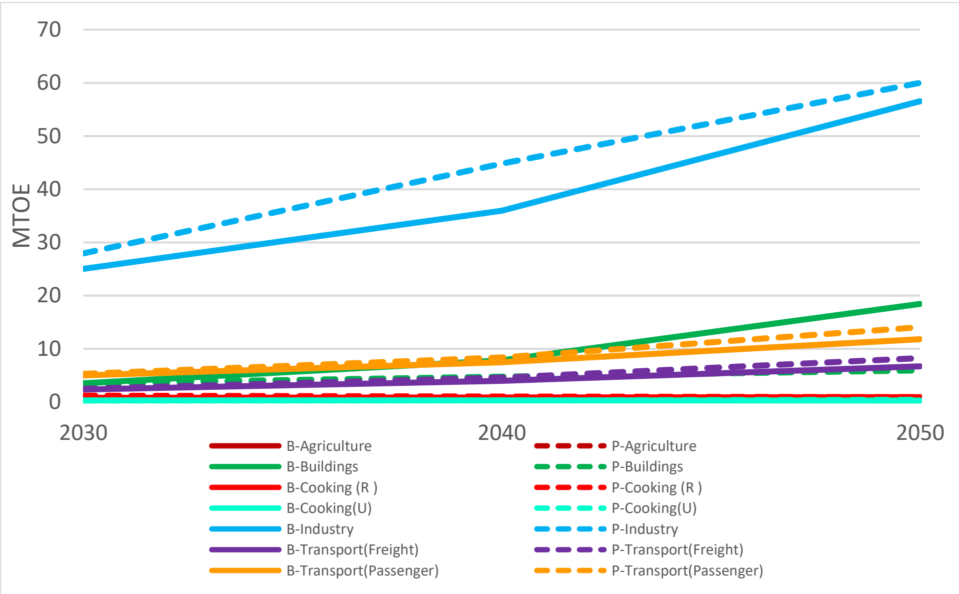
Policy scenario 1 considers the augmentation of renewable energy sector and ban on electricity. But to ensure energy security, it's imperative to improve energy efficiency and productivity. Attainment of energy security needs both demand and supply-side interventions to enable the economy to grow in sustainable manner. So, Policy scenario 2 considers a holistic approach, capturing development of renewable energy sector, energy efficiency and productivity. Due to space limitation, we henceforth are focusing on the results from Policy scenario 2, and are referring it as 'Policy scenario'.

4.2 Effects on energy demand, fuel mix and emission

4.2.1 Effects on energy demand

In this study, the effects of a policy shift towards renewable energy sources in power generation is assessed (Figure 5). In BAU, industry would generate the majority of the final energy demand, followed by building, passenger transport and freight transport. In Policy Scenario, it is perceived that despite implementing 1.5% increase in energy efficiency and 1% increase in productivity growth, final energy demand would increase in industry both in short run and long run as compared to BAU, but final energy demand in buildings is going to be less as compared to BAU. But passenger and freight transport are likely to increase marginally as compared to BAU. Odisha, a state with many industries and mining sector, is likely to continue with high demand for energy in industry sector, to cater the growing population of the country in both the scenarios.

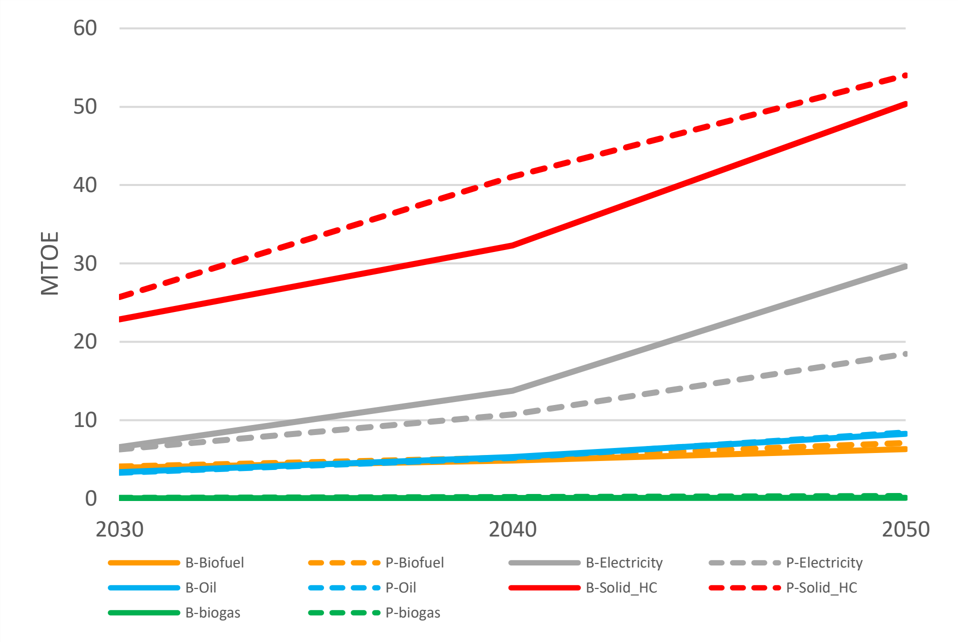
Figure 5: Final Energy Demand in Baseline and Policy Scenario



Source: Authors' estimation. Note: 'B-' represents BAU and 'P-' represents Policy Scenario.

In the fuel mix, it is found that solid hydrocarbon, which is the major source of energy in BAU scenario, is going to remain the major source of energy in Policy Scenario, despite the policy emphasis on renewable energy sources (Figure 6). Since mining has major share in Odisha economy, it has a major share of solid hydrocarbon like coal in fuel mix. Electricity is the second major share in fuel mix in BAU, but it is perceived that with improvement in energy efficiency and productivity, the share of electricity in fuel mix is going to reduce in Policy scenario.

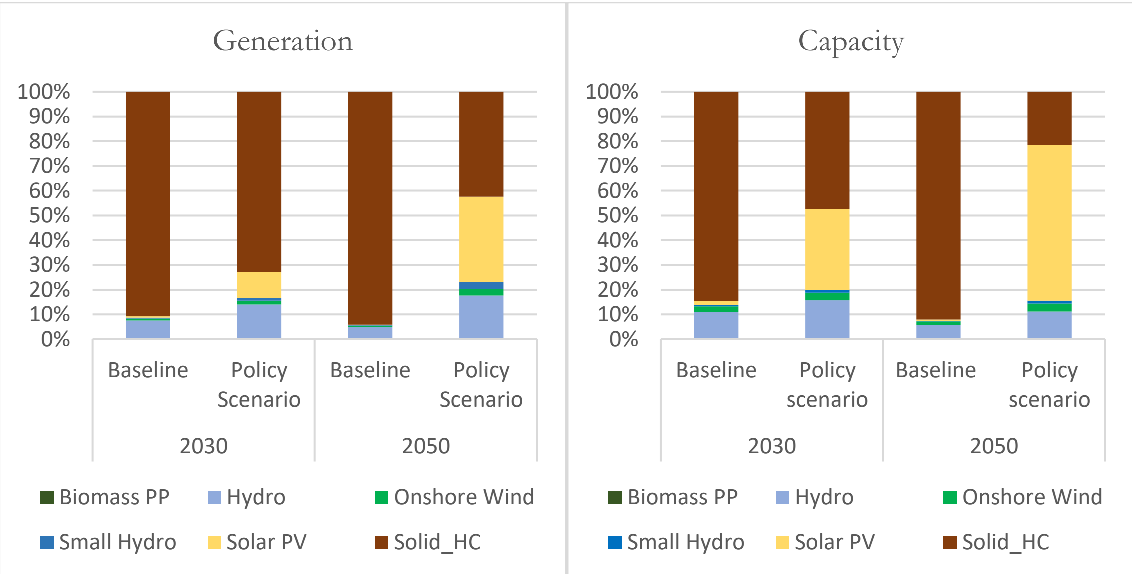
Figure 6: Fuel Mix in Baseline and Policy Scenario



4.2.2 Impact on capacity and electricity generation mix

Projection results show that the share of solid hydrocarbon is going to decrease in Policy scenario as compared to Baseline in 2050 (Figure 7). The share of solar PV and hydro are going to increase in 2050 in Policy scenario, both in generation mix and capacity mix. In Policy Scenario, the shift towards renewable energy sources is required along with improvement in energy efficiency and productivity, but the shift requires significant resource mobilization towards these sectors. To recollect, we are proposing imposition of tax on fossil fuel energy sources and provision of subsidy in renewable energy sources.

Figure 7: Electricity Generation and Capacity Mix in % (Policy Scenario)



4.2.3 Sectoral energy/fuel Choices and analysis of energy demand

Table 4 shows the sectoral demand in energy/ fuel choices for different components in MTOE terms and the share of different components in energy demand in percentage terms. In the baseline scenario, energy demand in the transport sector will rise from 5.7 MTOE in 2030 to 18.45 MTOE in 2050, while, despite different policy initiatives to increase non-fossil fuel in this sector, the increase in policy scenario is 22.25 MTOE in 2050. We decompose passenger (transport) into public, private and freight components. In the private transport sector, it is observed that there is marginal decline in cars, two-wheelers running on 20% blended biofuel and 20% blended ethanol fuel, and taxis running on 20% blended biofuel, and a marginal rise in electric taxis (Table 4). Our model explored the emergence of the following vehicles and fuel types in Odisha: taxi based on compressed biogas, car running on fuel cell, oil-based two-wheelers, three-wheelers, cars, and taxis. We find that hydrogen-based cars will play a minimal role in the private transportation sector until 2050. In public transport, we find that fuel choice in terms of share does change much in the future, except introduction of Fuel Cell Electric buses in policy scenario. There will be a marginal rise in the share of buses running on fuel cell (H2) technologies in the coming years, which is nearly absent in our base run. The role of rail (electric) seems to play a larger role by 2050. In freight transport, the share of electric heavy-duty vehicles in road transport will rise in the policy scenario in 2030 and 2050 relative to the baseline. The share of gas-based, heavy duty vehicles in road transport exhibit a small rise in the policy scenario relative to the baseline. The share of oil-based, heavy duty vehicles also falls in the policy scenario relative to the baseline. Our model also explored the emergence of the following vehicles and fuel types in Odisha: compressed biogas in heavy and light duty road freight transport, gas-based light duty road freight transport, oil-based air and rail freight transport, and oil-based ship freight transport. However, they do not seem to play any role in this scenario until 2050.

Table 4: Sector-specific energy demand (MTOE) and the share of different components in sectoral total (% in the parenthesis)

	2030		2050	
	Baseline	**Policy scenario**	**Baseline**	**Policy scenario**
Private transport				
2Wheeler (Ethanol blend 20%)	0.38 (9%)	0.39 (8%)	0.42 (4%)	0.43 (4%)
3Wheeler (Biofuel 20%)	0.95 (22%)	1.01 (22%)	2.53 (26%)	3.06 (27%)
3Wheeler (Ethanol blend 20%)	0.12 (3%)	0.13 (3%)	0.12 (1%)	0.13 (1%)
Car (Biofuel 20%)	0.63 (14%)	0.65 (14%)	0.62 (6%)	0.64 (6%)
Car (Ethanol blend 20%)	0.75 (17%)	0.77 (17%)	0.74 (8%)	0.77 (7%)
Taxi (Biofuel 20%)	0.87 (20%)	0.89 (19%)	0.88 (9%)	0.91 (8%)
Car (Compressed Bio-Gas)	0 (0%)	0 (0%)	0.03 (0%)	0.03 (0%)
2Wheeler (Electric)	0.02 (0%)	0.02 (0%)	0.12 (1%)	0.14 (1%)
3Wheeler (Electric)	0.01 (0%)	0.01 (0%)	0.02 (0%)	0.02 (0%)
Car (Electric)	0.07 (2%)	0.08 (2%)	0.4 (4%)	0.5 (4%)
Taxi (Electric)	0.43 (10%)	0.48 (10%)	3.81 (39%)	4.67 (41%)
3Wheeler (Gas)	0.14 (3%)	0.14 (3%)	0.15 (2%)	0.15 (1%)
Car (Gas)	0.04 (1%)	0.04 (1%)	0.04 (0%)	0.04 (0%)
Taxi (Gas)	0.01 (0%)	0.01 (0%)	0.01 (0%)	0.01 (0%)
Car (Fuel Cell Electric)	0 (0%)	0.01 (0%)	0 (0%)	0.02 (0%)
Total Private transport	**4.4 (100%)**	**4.61 (100%)**	**9.89 (100%)**	**11.51 (100%)**
Public Transport				
Air (Passenger, Oil)	0.26 (45%)	0.3 (46%)	0.77 (41%)	1.16 (46%)
Bus (Biofuel 20%)	0.2 (35%)	0.19 (30%)	0.72 (38%)	0.84 (33%)
Bus (Fuel Cell Electric)	0 (0%)	0.04 (6%)	0 (0%)	0.04 (2%)
Mini bus (Biofuel 20%)	0.06 (10%)	0.06 (9%)	0.27 (14%)	0.33 (13%)
Mini bus (Gas)	0.01 (2%)	0.01 (2%)	0.01 (1%)	0.01 (1%)
Rail (Passenger, Electric)	0.04 (7%)	0.04 (6%)	0.11 (6%)	0.13 (5%)
diesel Large Passenger ferry	0 (1%)	0 (1%)	0.01 (0%)	0.01 (0%)
Total Public Transport	**0.57 (100%)**	**0.65 (100%)**	**1.89 (100%)**	**2.53 (100%)**
Freight				
Rail (Freight, Electric)	0.06 (3%)	0.06 (3%)	0.05 (1%)	0.06 (1%)

Road Heavy duty vehicles (Electric)	0.09 (4%)	0.01 (0%)	1 (15%)	0.28 (3%)
Road Light duty vehicles (Electric)	0.03 (1%)	0.03 (1%)	0.09 (1%)	0.09 (1%)
Road Heavy duty vehicles (Gas)	0.02 (1%)	0.13 (5%)	0.03 (0%)	1.2 (15%)
Air (Freight, Oil)	0 (0%)	0 (0%)	0.06 (1%)	0.09 (1%)
Road Heavy duty vehicles (Oil)	2 (86%)	2.12 (86%)	5.35 (80%)	6.4 (78%)
Road Light duty vehicles (Oil)	0.11 (5%)	0.11 (5%)	0.1 (2%)	0.1 (1%)
Total Freight Transport	**2.32 (100%)**	**2.48 (100%)**	**6.67 (100%)**	**8.22 (100%)**
Industry				
Specific, Electricity	1.61 (6%)	1.78 (7%)	4.67 (8%)	6.25 (10%)
Thermal, Oil	0.54 (2%)	0.3 (1%)	1.53 (3%)	0.24 (0%)
Thermal, Coal	22.86 (91%)	23 (92%)	50.34 (89%)	55 (89%)
Solar industry specific	0 (0%)	0.02 (0%)	0 (0%)	0.19 (0%)
Thermal, Hydrogen	0 (0%)	0 (0%)	0.1 (0%)	0.21 (0%)
Total Industry	**25.01 (100%)**	**25.1 (100%)**	**56.63 (100%)**	**61.89 (100%)**
Residential Building				
Residential Electricity	2.51	16.86	2.51	4.35
Cooking- Rural				
Cooking (Biogas)(Rural)	0 (0%)	0.84 (95%)	0 (0%)	0.49 (90%)
Cooking (Electric)(Rural)	0.48 (100%)	0.05 (5%)	0.56 (100%)	0.06 (10%)
Total Cooking-Rural	**0.48 (100%)**	**0.88 (100%)**	**0.56 (100%)**	**0.55 (100%)**
Cooking- Urban				
Cooking (Biogas) (Urban)	0 (1%)	0.06 (28%)	0 (2%)	0.03 (19%)
Cooking (Electric) (Urban)	0.04 (83%)	0.01 (3%)	0.09 (97%)	0.01 (7%)
Cooking (PNG) (Urban)	0.01 (16%)	0.16 (69%)	0 (1%)	0.11 (74%)
Total Cooking- Urban	**0.05 (100%)**	**0.23 (100%)**	**0.09 (100%)**	**0.15 (100%)**

Source: Author's estimates

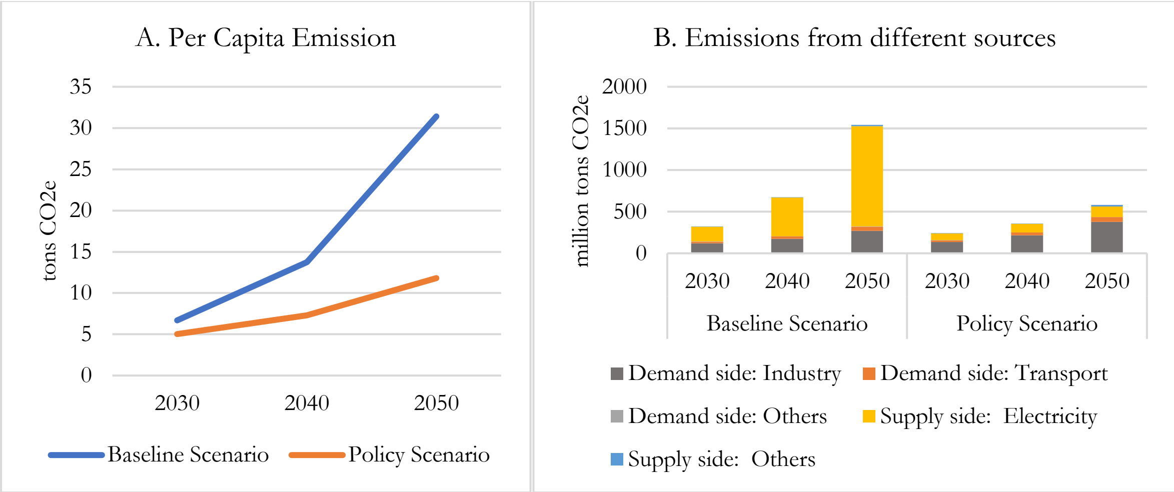
Table 4 also shows the trends in energy/fuel mix for the industry sectors for our base/policy run. Coal-based electricity will still play a dominant role in the industry sector. The rest of the energy/fuel choices in industries show a very marginal rise in policy scenario compared to the baseline, given the high reliance of industry sector on fossil fuel. The model also explores the emergence of the following energy/fuel choices in the industry sector in Odisha: biomass energy, compressed biogas energy, thermal electricity, solar off-grid electricity, and gas-based and hydrogen-based energy. Towards the end of our model run (2050), solar off-grid electricity and hydrogen-based energy exhibit some presence, albeit small.

There will be a significant decline in the demand for residential electricity in the building sector in our policy scenario relative to the baseline. The role of other choices such as diesel generator sets in commercial and residential buildings and solar heaters in commercial and residential buildings do not seem to emerge as a choice in our policy run. In Policy scenario, the demand of fuel for cooking reduces over time both in rural and urban area. We do not observe any major shifts in fuel choices in agriculture over the model period between Policy scenario and the business-as-usual scenario.

4.2.4 Effect on emission

One of the direct benefits of the shift of policy emphasis towards renewable energy sources for power generation is reduction in emission. Emission projections are estimated through Messageix, and it does not consider the improvement/ degradation of carbon content or ash content of the coal in future projections. The present quality of coal is assumed to be prevailing for the period of the study. This can be understood through reduction in both per capita emission and total emission (Figure 8). It shows that per capita emission in this low carbon pathway declines from 31.41tons CO2e in BAU to 11.81 tons CO2e in Policy scenario. The principal sources of emissions are shown in Figure 8 for the base run and this policy run. As this tables indicates, the reduction in emission from electricity is the major factor for the reduction in emissions.

Figure 8: Per capita emission and total projection under Baseline and Policy Scenario



Source: Authors' estimates

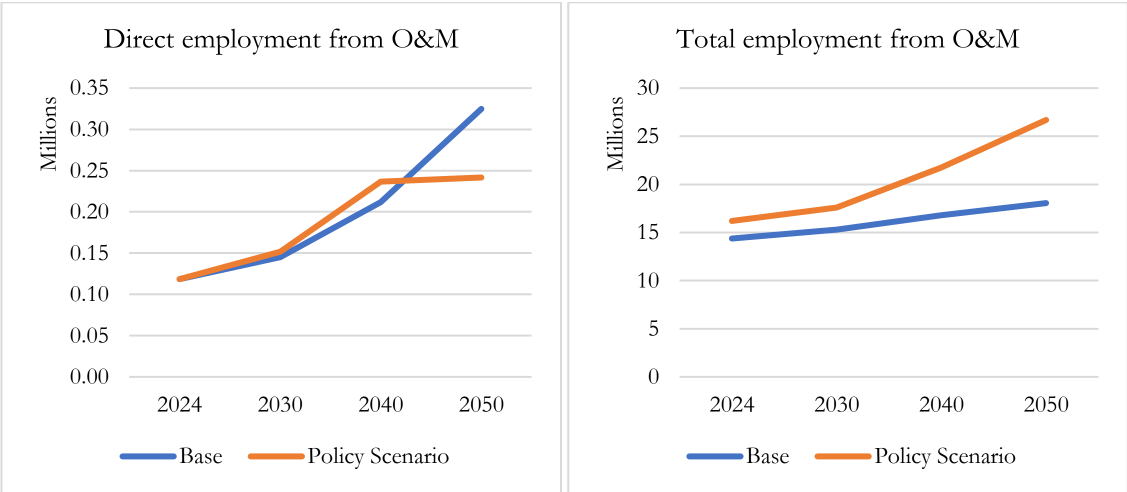
4.3 Implication on employment

Odisha is a mineral-rich state, and there is significant export of electricity and other energy-intensive commodities from the state. As a result, a low carbon pathway would have significant policy implications on the economy of the state, especially on employment. An analysis of the implications of environmental policies and targets on employment requires consideration of indirect job creation, especially that arising from the macroeconomic effects of policies (Hillebrand et al. 2006; Markaki et al. 2013; Oliveira et al. 2013; Ragwitz et al. 2009). Employment absorption in different energy sectors are different and, thus, transition to low carbon pathway would have an impact on direct/indirect employment generation in the economy. In this section, we estimate the employment generation projection of policy scenario for Odisha. This is viewed in relation to the baseline scenario to understand the employment consequences of a low carbon pathway in Odisha.

In this paper, employment coefficients are generated using PLFS data. Estimates for the labour force under this approach includes (a) persons who either worked or were seeking/available for work for a relatively long part of 365 days preceding the date of survey, and (b) persons from among the remaining population who had worked at least 30 days during the reference period of 365 days preceding the date of the survey. Estimates are adjusted for inflation and growth in labour productivity over the years. 'Direct jobs' refer to jobs that are directly related to core activities, such as operation and maintenance of a power plant. These jobs, along with jobs that are related to supply and support of the energy industry at a secondary level (indirect jobs), and jobs led by household spending based on income earned from the direct and indirect effects (induced effects) are included in total employment. Since sectors in the economy are linked through linkages, indirect jobs capture jobs that are created to support the respective energy industry for extraction and processing of raw material, manufacturing, construction and so on to support the operation and maintenance of power plants. Additionally, the study estimates the required employment absorption for manufacturing and installation of new renewable power plants. Employment numbers are estimated after adjusting inflation and labour productivity.

Our results show that direct employment from operation and maintenance of power plants would be affected by the shift towards green energy in 2050, since the coal mining and coal electricity sectors are still major providers of employment in the state. A major part of output from these sectors is also exported. With green transition, direct employment is these sectors would reduce, and employment in renewable energy sector would increase, but as a result the net effect on direct employment generated from operation and maintenance of power plants would still be negative, which amounts to a reduction of around 83 thousand direct employment in the energy sector by the year 2050 (Figure 9). However, this would not have a negative effect on total employment. Through the interlinkage of renewable energy with other sectors of the economy, the economy as a whole is not facing employment shrinkage as a result of transition to green energy. Total employment from operation and maintenance of power plants, which captures the direct, indirect and induced employment generated from all sectors including the energy sector, is expected to provide 8.6 million more employment under policy scenario at 2050 compared to the baseline scenario (Figure 9).

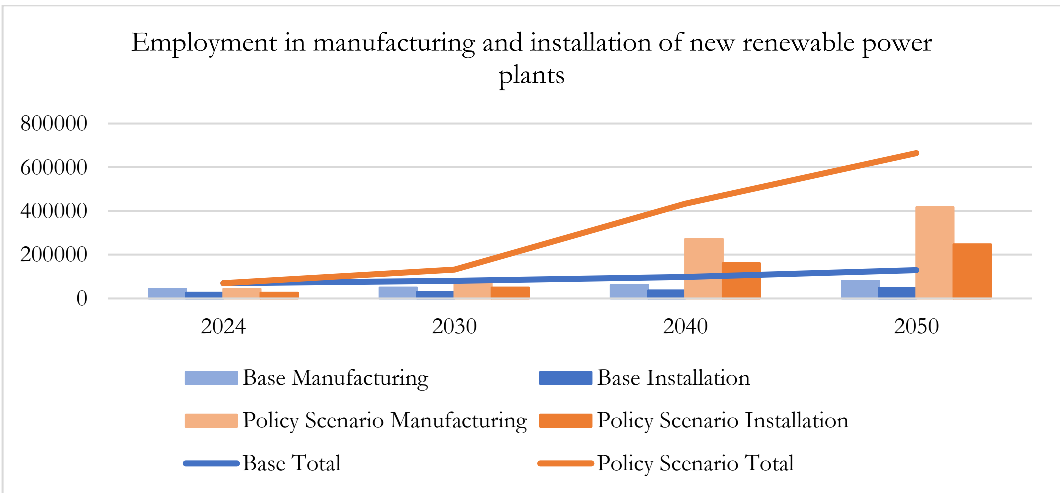
Figure 9: Direct and total (including direct, indirect and induced) employment in energy sector from operation and maintenance



Source: Authors' estimates.

Investment on renewable energy not only increases employment generated from operation and maintenance, but also from manufacturing and installation of new power plants. For this, the median values of direct employment factors for the main phases of deployment for wind and PV are utilised from Cameron and Zwaan (2015), and the estimates show that there would be significant addition in employment in Policy scenario for both manufacturing and installation of power plants. This scenario is expected to generate additional 0.5 million employment in Odisha in 2050 compared to the baseline scenario (Figure 10).

Figure 10: Employment in Manufacturing and Installation of New Renewable Power Plants



Source: Authors' estimates.

4.4 Investment requirement for green transition

Table 5 shows our estimated investment in US$ million required to achieve this low carbon transition. As expected, with an increase in energy efficiency and productivity growth, lower carbon emission pathway can be achieved with lower investment. These investment numbers are also subsequently fed into the macro model to check if macro growth numbers and prices change in a significant way. This process is continued till the divergence becomes small. In our case, we find that the numbers are close after a round of feedback and so the process was not continued.

Table 5: Cumulative investment for Base run and Policy scenario (US$ million)

Sector	Base Run		Policy Scenario		Additional Investment	
	2025-30	**2025-50**	**2025-30**	**2025-50**	**2025-30**	**2025-50**
Agriculture	616	2527	639	2608	23	81
Biofuel	84	135	88	152	3	17
Buildings	1725	14337	1725	5299	0	-9038
Cooking (Rural)	488	1696	677	1467	189	-230
Cooking(U)	98	350	93	355	-5	5
Domestic (Resource)	137	406	1600	5123	1464	4717
Electricity	11189	156143	4665	52888	-6523	-103255
Gas	2	11	9	40	7	29
Industry	8	39	41	82	34	43
Transport (Freight)	67	16999	82	23592	16	6594
Transport (Passenger)	9	223	143	286	134	63
Biogas	16079	83111	15990	77897	-89	-5215
Green hydrogen	28930	191819	31097	225539	2167	33721
Total	**59432**	**467796**	**56851**	**395329**	**-2581**	**-72467**
As Percent of Cumulative SDP	**3.34**	**7.34**	**2.21**	**6.51**		

Source: Authors' estimates.

5. Summary and Conclusion

Odisha, endowed with rich mineral and coal deposits, has many energy-intensive industries like iron and steel, and that contribute to large emissions from the state. Odisha is also one of the few states of India which is surplus in electricity production: But the concerning factor is that more than 90 % of Odisha's electricity comes from coal. At the same time, selling electricity is a source of revenue for the state. To keep up the pace of growth and development for the states and to meet the aspirations of the people, the state requires to continue generating electricity. The state has large potential of renewable electricity and, thus, it makes sense to augment the capacity of renewable electricity.

This transition involves the adoption of some technologies with their underlying financial costs. Hence, it is crucial to understand the fiscal burden vis-à-vis the benefits of each policy intervention as an alternative low carbon pathway. By incorporating the behavioral aspects of economic agents and relevant energy technological innovations interplaying with the markets and prices in the economic system, a coherent energy transition pathway can be developed. Our study utilizes the integrated modelling approach to quantify the gains and losses of low carbon transition and their financial implications.

The key message that comes out of our simulation is that energy transition requires improvement in energy efficiency and productivity to sustain economic growth and it will not take place without complementarity support polices towards renewable energy sector. There is a need for the government to play a key role in effecting the change. Also, it is pragmatic to augment the capacity of renewable capacity as far as possible.

In Odisha, heavy industry plays a crucial role in generating revenue for the State as well as employment. Transitioning towards the low carbon economy needs significant shifting of various transition including low-cost fossil fuel-based technologies in a phased manner. There are two major options for the State: a) shifting towards green and clean fuel use and b) Rationalization of energy demand growth through efficiency improvement and change in use pattern. Technological intervention is crucial for hard to abate sectors for reduction and elimination of GHG emissions. The thermal power plants and heavy industries like iron & steel, aluminum, fertilizer, petrochemicals etc. are key for Odisha's economic and social sector development including employment. It is observed that shifting towards RE based power does have negative impacts on the sectoral outputs and the economy as a whole. But despite different policy interventions, reliance on hydrocarbon in electricity generation and industry sector persists. Therefore, new technologies like Carbon Capture & Storage including process utilization or green hydrogen could be an option for the State to consider.

There are significant initiatives to facilitate energy transition in Odisha. Tata Steel plans to set up a pilot plant in Odisha to produce methanol from blast furnace flue gases, aiming at significant methanol production in India. NALCO in Odisha initiated a project for carbon sequestration through micro-algae cultivation, addressing the issue of greenhouse gas emissions. It is important that the State promotes these technologies with policy and R&D support for faster adoption. Nonetheless, for better uptake of renewable energy, there is a need of building infrastructure and the business ecosystem to overcome the technological and financial challenges. The Union Government has already launched programs like Climate Smart Cities Assessment Framework (CSCAF) under National Mission on Sustainable Habitat, the Smart Cities Mission under the Ministry of Housing and Urban Affairs (MoHUA). At state level also, climate change mitigation concerns are required to be integrated in with Urban Development programmes and schemes, and develop skill among the workers to facilitate the technology adoption. There is a strong need to mobilize resources both from the Government and the external sources through different financing mechanisms. Our study shows that energy transition may be a win-win situation; growth and employment creation can be attained with suitable policy intervention.

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