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Carbon Pricing Impact Evaluation on Transport Sector: A Comparative Analysis for India

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Carbon pricing mechanisms have been identified as a key strategy for reducing global greenhouse gas emissions to achieve the net-zero target. The present study aims to fill the gap by investigating the effects of carbon pricing under different specific target emission constraints and their potential implications for the transportation sector in India. A total of five scenarios have been developed, including a reference scenario with current policy assumptions and four climate policy scenarios. In the climate policy scenarios, emission constraints varied between the year 2030 and the year 2060, with implementation occurring in 10 y intervals until the year 2070. The net-zero year remains constant across all scenarios, which is set at the year 2070. These scenarios are developed using the global change assessment model (GCAM). The study reveals that a reduction in the time gap between the year of implementation and the year of achieving net-zero emissions will lead to an increase in carbon prices. The maximum projected cost of carbon will be 981.36 USD/t of CO_2 emission ($/t$CO_2$) if the carbon pricing is implemented starting in the year 2030 and 1062.79 $/t$CO_2$ if it is implemented from the year 2060. The implementation of carbon prices resulted in considerable emission reductions, as well as variations in service demand and energy usage patterns in the transport sector. The findings hold promise for positively influencing SDGs 11 and 13 and have significant implications for policymakers and other stakeholders.

1. Introduction

As the world moves towards a net-zero carbon emissions target, implementing carbon pricing mechanisms has become essential. Carbon price is applied to the amount of emission generated (Zakeri et al., 2015). Carbon pricing can manifest either as carbon taxes or as emissions trading systems (ETSs) (Zhunussova, 2022). In recent years, many countries, including Canada, the European Union, Sweden, China, South Africa, and some regions of the United States, have implemented carbon pricing policies to reduce greenhouse gas (GHG) emissions. These policies encompass carbon taxes and cap-and-trade systems, which are applicable to various sectors, including the transportation industry (The World Bank, 2021). In order to achieve India's net-zero emissions goal by 2070, the Energy Conservation (Amendment) Bill 2022 was passed by the Indian Parliament. The bill, as stated by the Ministry of Power (2022), aims to support India in achieving COP-26 objectives and expedite the decarbonization process by making non-fossil sources mandatory and introducing carbon credit trading (Ministry of Power, 2022).
Carbon pricing has been highlighted as the most expensive alternative, while it is the most effective measure to decrease GHG emissions (Quinn et al., 2023). Additionally, its implementation may result in a decrease in sectoral outputs (Khamphilavanh and Masui, 2021). The implementation of a carbon pricing is expected to have a minimal impact on service demand and modal, particularly in passenger transport, as indicated by the results of two integrated assessment models - the TIMES Integrated Assessment Model of the Energy Research Centre of the Netherlands (TIAM-ECN) and Global Change Assessment Model (GCAM) for Colombia (Calderón et al., 2014). Chaturvedi and Malyan (2022) involved in creating models for alternative peaking and net zero year scenarios in India and examining the implications for the transition in energy-intensive sectors. A few studies highlighted the importance of carbon price and its significance in net zero scenarios, but not for the Indian context (Silva et al., 2022; Patel et al., 2022). However, specific analyses that could inform how the cost of

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carbon will vary with changing emission constraints years are lacking in India. To address this gap, this study examines the impact of carbon prices with varying specific target emission constraints. Additionally, the study also highlights the implications of carbon pricing on service output, emission, and energy demand of the transport sector.

The study is organized into three primary sections to address the research question. The initial section, Section 2, delineates the research methodology employed. It encompasses a thorough explanation of the GCAM model, along with its equations, and an investigation of potential scenarios and the fundamental assumptions underlying them. Section 3 advances to present the study's outcomes, particularly the variations in carbon with alterations in the implementation year and the subsequent influence on the transport sector. This section also encompasses an examination of the service demands across various modes, final energy usage, and CO_2 emissions. Finally, the study concludes with Section 4, which discusses the future directions of research.

2. Methodology

In order to understand the implications of carbon pricing with respect to implementing year for India, five scenarios have been created with or without emission constraints and compared in this study (Table 1). The reference scenario has been created with existing policy assumptions. In four climate policy scenarios, emission constraint trajectories are provided exogenously within the GCAM structure to levy a carbon price at a specific level. The emission constraints varied between 2030 and 2060, with implementation occurring in 10 y intervals until 2070 (Figure 1). The emission constraints started at the 'start year' and then linearly declined up to 'net zero year' in each scenario (Table 1). Using the emission constraint approach, the model calculated the price of carbon needed to accomplish the targeted emission constraint in each period (Kaufman et al., 2020). The model takes into account the demand for transportation services, the energy consumption patterns of different modes of transport, and the associated emissions.

Table 1: Proposed scenarios

Scenarios		Start year	Net zero year
Reference	Considering current policies, electric vehicles (EVs) will achieve cost parity with internal combustion vehicles by 2030		
Climate policy			
2030_70	853 $MtCO_2$/y in 2030, then linearly decline up to 2070	2030	2070
2040_70	1,158 $MtCO_2$/y in 2040, then linearly decline up to 2070	2040	2070
2050_70	1,472 $MtCO_2$/y in 2050, then linearly decline up to 2070	2050	2070
2060_70	1,701 $MtCO_2$/y in 2060, then linearly decline up to 2070	2060	2070

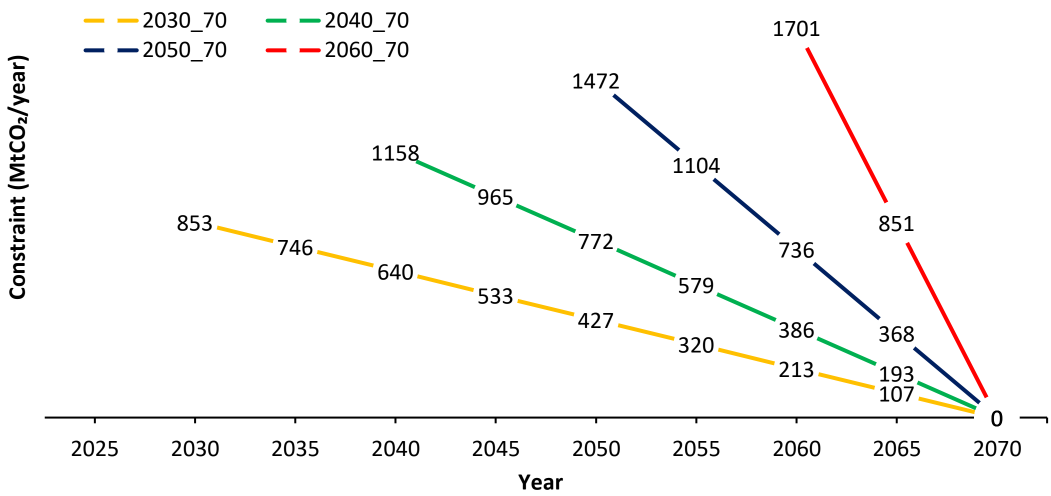

Figure 1: Emission constraint

GCAM is a dynamic-recursive and well-oriented model that encompasses detailed representations of various sectors such as global energy, water land use, and economy allied to a climate model that could be used to evaluate climate change mitigation approaches such as carbon taxes, emission trading, regulations, and accelerated energy technology deployment (Mishra et al., 2013). The GCAM is open-source software developed and maintained by Pacific Northwest National Laboratory (PNNL); it has 32 geopolitical regions, including India, and operates in 5 y intervals from 1990 to 2100. It has been used to explore the importance of emerging technologies such as renewable energy, hydrogen, bioenergy, carbon capture and storage, nuclear energy, etc., along with the consequences of specific policy measures in three end-use sectors- building, industry, and transportation. The model has exogenous and endogenous parameters, as illustrated in Table 2.

Table 2: Modelling parameters for the transport sector

Area	Parameters	Type of parameter	Assumption and formula
Socioeconomic factors and demand drivers	GDP	Ex	2015 USD 1.6 hundred to 2015 USD 10.5thousand in 2050 (considered covid negative impact in 2020)
	Population	Ex	1.5 billion in 2030 and 1.6 billion by mid-century, as the UN projection
	Passenger mode	Ex	4W (commercial +private), 2W, 3W and Bus
Fuels and vehicle technologies	Non-energy cost	Ex	The total cost of ownership without fuel, including upfront cost, maintenance cost, insurance cost, annual km travel, load factor, battery replacement, etc.
	Passenger service demand	En	$D_{r,t} = \sigma_r (Y_{r,t})^{\alpha} (P_{r,t})^{\beta} (N_{r,t})$ (1) where, σ = Base year (2015) calibration parameter, Y = Per-capita GDP, P = Total service price aggregated across all modes, N = Population, α and β = Income and price elasticities (Kim et al., 2006)
	Mode share	En	$s_{i,r,t} = \frac{(SW_{i,r})(P_{i,r,t})^{\lambda}}{\sum_i^n (SW_{i,r})(P_{i,r,t})^{\lambda}}$ (2) where, SW = Share weight, Pi = Cost of transport service, λ = Cost distribution parameter, and n = Number of modes in the given sector (Clarke and Edmonds, 1993)
	Cost of technology	En	$P_{i,r,t} = \frac{(FP_{i,r,t})(I_{i,r,t}) + (NFP_{i,r,t})}{LF_{i,r,t}} + \frac{W_{r,t}}{S_{i,r,t}}$ (3) where, FP = Fuel price, I = Vehicle fuel intensity, NFP = Vehicle non-fuel price, LF = Load factor (persons per vehicle), W = Wage rate, S = Vehicle speed (Kim et al., 2006)
	Fuel prices	En	determined by GCAM itself
	Energy intensity of fuel production	En	determined by GCAM itself
	Shares of fuel types within modes	En	determined by GCAM itself
	Efficiency levels within service, mode, fuel type	En	determined by GCAM itself
	Emission constraint	Ex	As per Table 1
	Carbon price	En	determined by GCAM itself

In the reference scenario, gross domestic product (GDP) and population are considered as two exogenous socioeconomic factors that drive overall energy demand and GHG emissions. For any technology, its non-energy cost and fuel intensity are considered exogenously in GCAM. In this study, the passenger sector has been explored to cover four-wheelers (4W), two-wheelers (2W), three-wheelers (3W), and buses. All modes are powered by fossil fuel and electricity. Electricity is generated by both renewable and non-renewable energy sources. In addition, 4W, 3W, and buses can be powered by natural gas. This study considered fuel cell technology with only 4W. The non-energy cost of every mode is estimated individually with its up-front cost, maintenance cost, insurance cost, battery replacement cost, load factor, operation cost, and annual kilometre (km) travel (Soman et al., 2020). The cost of an internal combustion engine (ICE) based vehicle, which is operated by gas and oil, will keep to historical trend across all modes. The cost of batteries would decrease in the future, and the upfront cost of EVs will drop according to the share of battery cost in each mode (Colin McKerracher, 2020). The capital cost of electric 4W will achieve cost parity with ICE by the year 2030 (Kamboj et al., 2022). In addition, all non-economic barriers, like the availability of charging infrastructure, EVs, and other behaviours barriers, will disappear by 2050. Based on all assumptions, the model has estimated passenger demand by Eq(1), modal share by Eq(2), and cost of technology by Eq(3), as shown in Table 2.

3. Results and discussions

In the reference scenario, CO_2 emission will continue to increase. However, it will decrease with the climate policy scenarios, dropping to zero in the year 2070 (Figure 2). The findings indicate that implementing a carbon tax in the year 2030 would result in lower emissions overall compared to implementing it in the year 2060. An early implementation of a carbon tax would lead to reduced emissions and facilitate the attainment of net zero targets.

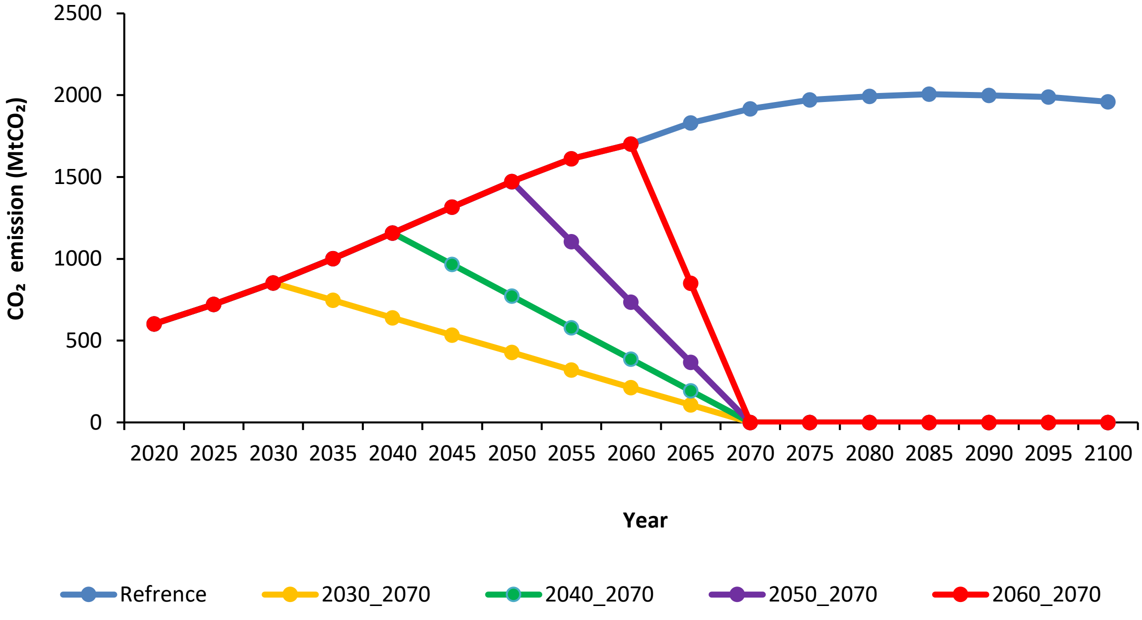

Figure 2: CO_2 emission

The model calculated the required carbon price to achieve the net zero target by 2070 based on emission constraints. If the carbon pricing is implemented from 2030, the maximum projected carbon price would be 981.36 $/tCO_2$ and1062.79 $/tCO_2$ if implemented from 2060 (Figure 3). The base price has been taken from the year 1990, i.e represent 1990 $/tC. Early implementation of the carbon tax would result in a lower cost per year in $/tCO_2$.

In the historical years, two wheelers dominated the transportation sector, while 4W is expected to dominate the transportation sector in the future due to high GDP growth. Consumers' income is directly related to service demand, as shown in Eq(3). If income increases, travel time costs increase, leading to consumers switching to faster modes. The carbon pricing will have less impact in switching between modes concerning the baseline scenario. The rapid rise of 4W suggests that the share of other modes, such as 2W and public transportation, would continue to fall, which is a cause for concern among policymakers.

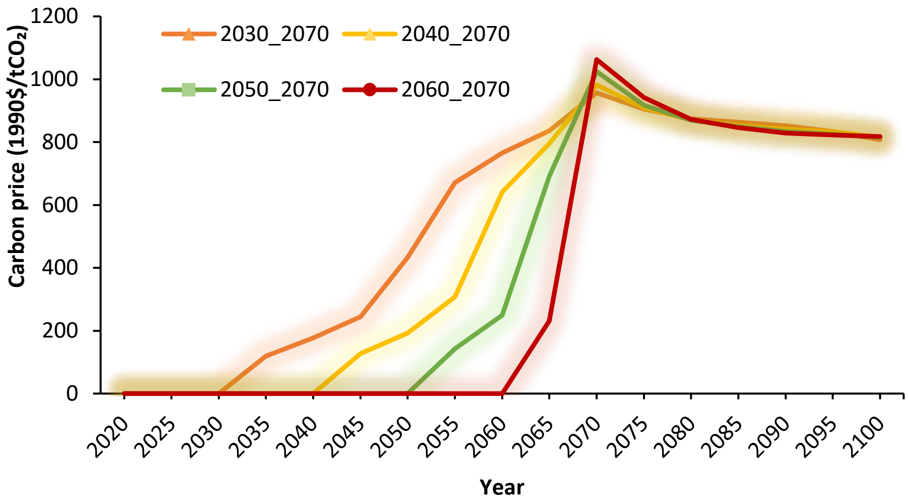

Figure 3: Carbon price

Over the century, the proportion of refined liquid fuels and non-renewable electricity sources in the reference scenario will have a greater dependence compared to other sources such as renewable electricity and hydrogen (Figure 4). The study emphasizes that carbon pricing results in the adoption of renewable energy sources.

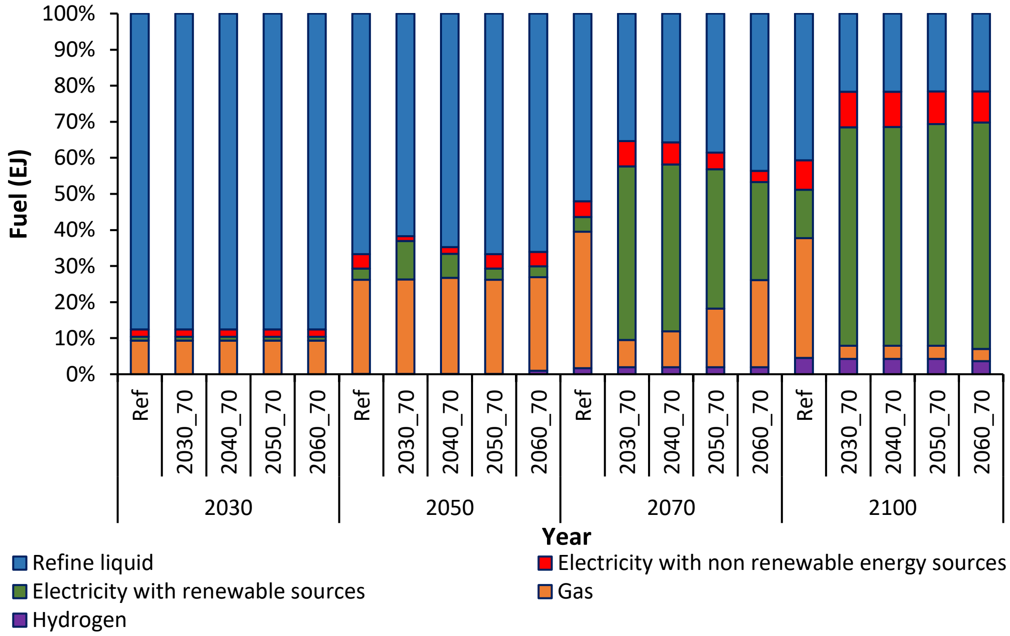

Figure 4: Total final energy and energy used by fuel

4. Conclusions

This study estimated and discussed the implications of carbon pricing with respect to implementing year for India and its impact passenger transportation sector. Based on the results, the following findings were drawn:

- The study's findings suggest that implementing a carbon tax earlier leads to a lower maximum projected carbon price required to achieve the net zero emissions target. Although carbon pricing alone is an expensive mitigation strategy, it is still a viable option for achieving net zero emissions.
- The study also found that the transportation sector will be dominated by 4W due to high GDP growth, and carbon pricing will have less impact on service demand. This dominance of 4W over other modes is a concern for policymakers as it leads to a decline in the share of public transport.

- Additionally, carbon pricing leads to a shift towards renewable energy sources and reduces carbon emissions, as non-renewable sources would dominate in the absence of a carbon tax.
- The findings hold promise for positively influencing SDGs 11 and 13 and have significant implications for policymakers and other stakeholders.
- The emission constraint in the study only focused on CO_2 emissions and did not consider GHG emissions other than CO_2, indicating a need for future research to explore the impact of non-CO_2 GHG emissions and their potential inclusion in the carbon tax.

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