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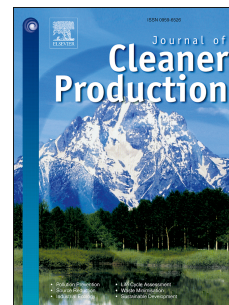
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## **Transformation of India's transport sector under Global Warming of 2°C and 1.5°C Scenario**

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### **Abstract**

The Paris agreement stresses on concerted efforts to limit global temperature increase to 2°C and make efforts towards achieving 1.5°C temperature stabilization. Countries announced actions under the Nationally Determined Contributions outlining domestic mitigation actions to achieve the global target. Understanding the impact of these actions on achieving these ambitions requires an assessment of long term national level scenarios. Limited studies currently exist that model long term scenarios at national level addressing the impacts of Nationally Determined Contributions and the additional actions required, especially at the sectoral level. The paper compares four alternate future scenarios for India spanning till 2050, with a specific focus on the passenger and freight transportation. The analysis is performed using the ANSWER MARKAL model and complemented with methodologies to estimate transportation demand under strong decarbonisation pathways. The results show that 1.5°C scenario would need immediate actions and deep transformations. Demand side actions would, in addition to infrastructure investments require transforming human behaviour through use of information technology, internet and sharing economy. Clean vehicle technologies need to play a much bigger role and fossil fuel dependence would be moderated with the dominance of electricity, hydrogen and biofuels. The higher share of electricity in transport is complimented with accelerated decarbonisation of electricity. This transformation required for 1.5°C scenario calls for innovations that would be driven through national and sectoral policies and explicit carbon prices.

Key words: Nationally Determined Contributions, low carbon transport, 1.5°C scenario, price elasticity, implicit carbon price

### **1. Introduction**

The Paris agreement established firmly the global goal to limit temperature increase to 2°C and set out the enhanced ambition to 1.5°C (UNFCCC, 2016). Globally, countries have announced Nationally Determined Contributions (NDC) that outlines domestic actions to

achieve emission reductions. Studies show that the implementation of NDC by countries will fall significantly short of the mitigation level required for meeting the above targets (UNEP, 2016). Recent studies stress on the need for significant enhancement over NDC actions including additional, sub-national actions to meet the global target (Rogelj et al., 2016). As NDC actions take effect at the subnational and sectoral level, analysing sectoral contributions would help guide policymaking toward specific policies and interventions for individual sectors.

Transportation sector is an important sector for GHG mitigation in Asian countries (Lee et al., 2016) and is a part of India's NDC actions. Transport sector contributed to around 13 % of India's energy-related CO<sub>2</sub> emissions in 2010 (GoI, 2015a). Increased per capita incomes in future are expected to drive transportation demand (Schafer and Victor, 2000) and result in increased energy demand and CO<sub>2</sub> emissions from the transport sector (IEA, 2014). The dominance of fossil fuels now and in future, will pose unique sustainability challenges besides climate change- for energy security and air pollution (Taylor, 2017). Air pollution is a significant problem in Indian cities (WHO, 2014) and vehicular emissions and road dust are major sources of air pollution (Guttikunda and Jawahar, 2012). Transport sector is the largest consumer of oil and its high dependence on imports raises significant concern for energy security.

NDC of India aims to achieve 33-35% decarbonisation of Indian economy by 2030 from 2005 level. Sustainable and green transport is a key focus area to achieve this ambition (UNFCCC 2015). Actions within the NDC are strongly rooted in the ongoing government policies and programs (See supplementary materials, Table SM1). Globally, a majority of NDC interventions in the transport sector focus on improve strategies (141), followed by shift strategies (66) and a small number of avoid strategies (17) (Gota et al., 2015). India's NDC is also overwhelmingly focussed on shift and improve strategies.

In the fifth assessment of Intergovernmental Panel on Climate Change (IPCC), 1,184 scenarios were analysed, most of which included pathways consistent with 2°C stabilisation target. Few studies have explored scenarios that lead to greenhouse gas concentrations below 430 ppm CO<sub>2</sub>eq in 2100 (Rogelj et al., 2015), which have a 66 % chance of returning to 1.5°C by the end of the century (IPCC, 2014). IPCC has commissioned a report on 1.5°C scenarios to synthesise the literature and address the gap at the global level.

In the run up to COP 21 at Paris in 2015, 167 parties submitted their Intended Nationally Determined Contributions (INDCs) and out of these 148 parties ratified Paris agreement and upgraded their INDCs to Nationally Determined Contributions (NDCs). The understanding of NDCs and their mitigation potential is vital for planning and implementation of these actions, and to identify additional actions to achieve the 2°C and 1.5°C goals. India's NDC has a strong focus on transport sector and therefore understanding the mitigation impact of NDC requires sectoral analysis. Transport sector and its contribution towards mitigation under a 2°C stabilisation target has been analysed, however post Paris agreement, the analysis of NDC and their mitigation potential is not available.

The paper addresses this gap. The study analyses the contribution of India's NDC towards achieving the mitigation ambition of 2°C and 1.5°C temperature stabilization and the additional measures that would be required beyond the NDCs to meet the global targets. The paper also analyses what the mitigation goals can contribute towards cleaner environment and energy and also identify cleaner technologies that enable the transition. The paper provides a methodology to estimate transportation demand and decarbonisation solutions for the 2°C and 1.5°C. As India embarks on the implementation of NDCs, results from the paper deliver timely and important insights for policy makers.

## 2. Methods

### 2.1. Overall Modelling Approach

The paper involves an analysis of NDC actions independently and in combination with global climate stabilization target for 2°C and 1.5°C. Climate policy analysis requires long term assessment. The assessment period taken for this study is till 2050 with an intermediate horizon of 2030 to align with Paris agreement. The strategies articulated in the NDC are at a sub sectoral level and include both the transport demand side as well as technologies that service this demand (supply side). A description of how transport demand has been modelled, across scenarios, is described in section 2.3. The transport demand is divided into demand for different modes e.g., the passenger transport demand is divided into two wheeler, three wheeler, four wheeler, bus, and rail.

The demand from a particular mode can be serviced by more than one technology e.g., travel demand by four wheelers can be met by different drive trains such as internal combustion engines, electric motors, etc. and different fuels such as petrol, diesel, biofuels, electricity, hydrogen, etc. A range of energy system models can perform a techno economic analysis of these alternative technologies (Connolly et al., 2010). The paper uses ANSWER MARKAL model from MARKAL /TIMES family of energy system model for analysis since this model is also well suited for analysis of climate policies. The demands for different modes are provided as exogenous inputs to the ANSWER/MARKAL model. The ANSWER MARKAL model is an optimisation model. For a particular demand, the model chooses a technology and fuel mix that minimises the overall system cost (Loulou et. al., 2005). The model is run in a dynamic manner with the future divided in equal time periods (5 years in the present case) and the model solves each time period starting from the base year. The model has full information of technology costs and end use demands in future time periods (Loulou et. al., 2005). The ANSWER MARKAL model has been extensively used for analysis of energy and climate policies of India.

### 2.2. Modelling 2°C and 1.5°C CO<sub>2</sub> Emission Scenarios

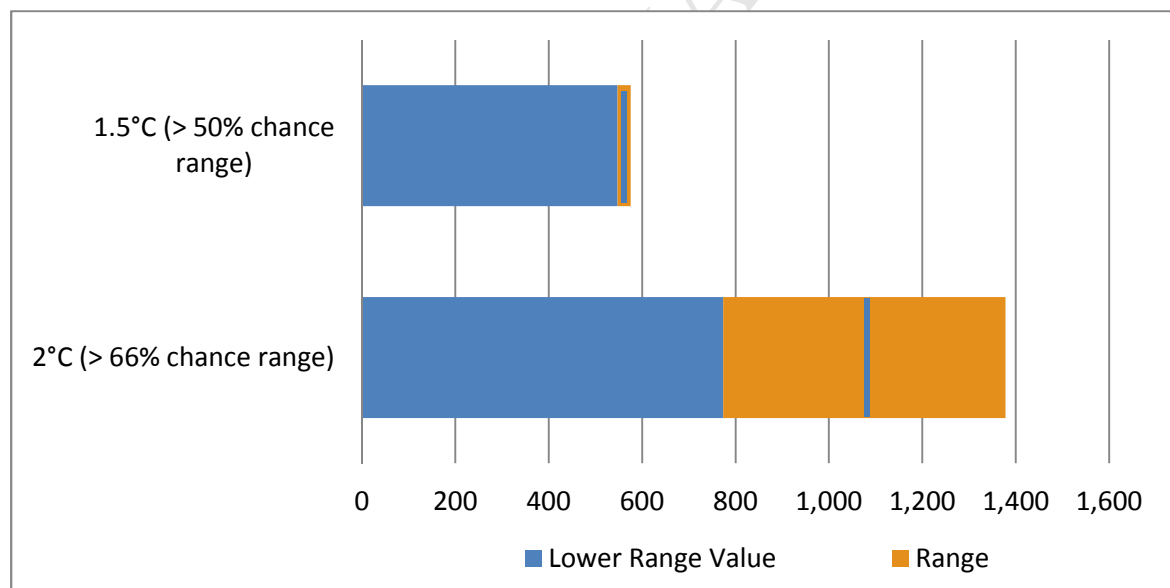
#### *2°C Scenario*

The literature on 2°C stabilisation target at global level is comprehensive and synthesised within the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC, 2014). A number of global modelling studies for the 2°C scenario have used

integrated assessment models relying on carbon prices to deliver the transformations. For India's transport sector, carbon prices alone are inadequate to transform the transport sector since major investments into transport infrastructures would be needed in future and these would be decided on the basis of contribution to social (equitable access, safety, health), economic (balance of payments, congestion) and environment (air quality, ecosystem) development and not just climate. The study adopts a hybrid approach where national decarbonisation policies and interventions are principal drivers complimented by carbon prices. The carbon price based on global studies is assumed in line with global goal of 2°C.

### 1.5°C Scenario

Compared to 2°C scenario, the literature on 1.5°C scenario is limited. The IPCC AR5 Scenario database does not have scenarios that have a probability beyond 50% of limiting global warming below 1.5°C (IPCC, 2014; Rogelj et al., 2015). There is limited information on the corresponding future carbon price trajectory in existing literature for 1.5°C scenario. Instead of using exogenous global carbon price for 1.5°C scenario, the paper considers a CO<sub>2</sub> emissions budget. Globally, carbon budgets for achieving 2°C and 1.5°C have been analysed to understand the effort needed and also the actions required for achieving the global ambition of 1.5°C (Fig. 1).



**Fig. 1. Global CO<sub>2</sub> budgets (GtCO<sub>2</sub>) for 2°C and 1.5°C scenario** (adapted from UNEP, 2016)

India's share of global carbon budget for the 1.5°C scenario is apportioned in the same fraction as 2°C scenario (Table 1). This is derived from mean values of global CO<sub>2</sub> budget provided in Fig. 1 (for 2°C and 1.5°C scenarios) and CO<sub>2</sub> emissions for India in a 2°C scenario are based on Shukla, et al. (2015). The budget for 1.5°C scenario is derived using the following identity and includes the whole energy system of India.

$$CO_2EmissionsIndia_{1.5^\circ C} = CO_2EmissionsIndia_{2^\circ C} \times \left( \frac{CO_2EmissionsGlobal_{1.5^\circ C}}{CO_2EmissionsGlobal_{2^\circ C}} \right) \quad --$$

[1]

where

$CO_2EmissionsIndia_{1.5^\circ C}$ ,  $CO_2EmissionsIndia_{2^\circ C}$  are  $CO_2$  emissions from India's energy sector from 2011 to 2050 under the two scenarios

$CO_2EmissionsGlobal_{1.5^\circ C}$ ,  $CO_2EmissionsGlobal_{2^\circ C}$  is the global  $CO_2$  budget under the two scenarios

The  $CO_2EmissionsIndia_{1.5^\circ C}$  for energy sector of India between 2011 and 2050 for a  $1.5^\circ C$  scenario comes to 43 Gt $CO_2$  using the values provided in Table 1.

**Table 1. Assumptions for calculating the  $CO_2$  budget for the  $1.5^\circ C$  Scenario**

Variable	Value Gt $CO_2$	Description	Reference
$CO_2EmissionsGlobal_{2^\circ C}$	1,076	Global $CO_2$ budget (Average Value) available for $2^\circ C$ Scenario (with a more than 66% confidence level) from 2011	(UNEP , 2016) Emissions Gap Report 2016
$CO_2EmissionsGlobal_{1.5^\circ C}$	561	Global $CO_2$ budget (Average Value) available for $1.5^\circ C$ Scenario (with a more than 50% confidence level) from 2011	- do -
$CO_2EmissionsIndia_{2^\circ C}$	82	$CO_2$ Emissions from energy sector of India between 2011 and 2050 for the $2^\circ C$ scenario. Least cost pathway consistent with operating under uniform global carbon price, implementation of INDCs and additional sustainability measures	(Shukla et al. 2015), Deep Decarbonisation Pathways Analysis

The allocated emissions budget would limit  $CO_2$  emission space for a developing country like India and therefore the scenario assumes availability of additional support for technology R&D, finance and capacity building. The limited  $CO_2$  emissions budget under  $1.5^\circ C$  scenario dictates radical changes in drivers of emissions between now and 2030. This necessitates a change in the scenarios storyline and modelling approach. The scenario assumes

supplementing carbon price with additional targeted short-term mitigation actions that deliver near-term sustainability co-benefits along with CO<sub>2</sub> mitigation.

### 2.3. Modelling of Demand for Transport

#### *Business as Usual (BAU) & NDC Scenario*

Travel demand estimation for passenger and freight transport for the BAU and NDC scenario follows the methodology adopted by Dhar and Shukla (2015). The methodology for passenger transport demand provides an approach for separating demand into urban transport and intercity transport (Refer Supplementary Materials). Such a process allows for differentiation of travel demand across BAU and NDC scenario since the implementation of NDC policies, programs and projects is different for urban and intercity transport.

#### *2°C Scenario*

The 2°C scenario assumes strong climate policies operationalised through a global tax on CO<sub>2</sub> or equivalent explicit market price for removal of a ton of CO<sub>2</sub> under a global ‘cap and trade’ regime. The resultant increase in the cost of fossil fuels due to the CO<sub>2</sub> price will favour competing low carbon resources and technologies. The higher cost of energy will also translate into lower travel demand depending on the price elasticity of travel demand. The price elasticity of travel demand would depend on altering consumer choices through e.g., use of lower energy intensive transport modes, reduction of trips and change of destinations or trip lengths (Litman, 2013).

The transport demands for different modes are estimated using the price elasticities of demand. The changes in demand in 2°C scenario are estimated with reference to NDC scenario and based on Eq. [2] (Kesicki and Anandarajah, 2011)

$$\mathbf{Demand\ Travel}_{2^{\circ}C} = \mathbf{Demand\ Travel}_{NDC} \times \left( \frac{\mathbf{Fuel\ Price}_{2^{\circ}C}}{\mathbf{Fuel\ Price}_{NDC}} \right)^{\mu} \text{-----}[2]$$

where  $\mu$  = Fuel Price elasticity of demand

$\mathbf{Demand\ Travel}_{2^{\circ}C}$  ;  $\mathbf{Demand\ Travel}_{NDC}$  are travel demand in scenario 2°C & NDC scenario

Since the purpose is to assess the changes in travel demand due to carbon tax, the increase in price of fossil fuels will depend on the CO<sub>2</sub> intensity of fuel as shown in Eq. [3].

$$\mathbf{\Delta\ Fuel\ Price} = \mathbf{\Delta\ CO_2\ Price} \times \mathbf{CO_2\ Intensity} \text{-----}[3]$$

Accordingly, Eq. [2] is modified to



$$Demand Mode_{2^{\circ}C} = Demand Mode_{NDC} \times \left( \frac{CO_2 Price_{2^{\circ}C}}{CO_2 Price_{NDC}} \times \frac{CO_2 Intensity_{2^{\circ}C}}{CO_2 Intensity_{NDC}} \right)^{\mu} \text{-----[4]}$$

The NDC scenario assumes actions induced by multiple policies and regulations that would drive public investments (into public transport modes, footpaths, cycle tracks, ITS systems, charging infrastructures for electric vehicles (EVs), etc.) in the near-term to deliver actions communicated as a part of NDC of India till 2030 and enhanced implementation beyond 2030 to sustain the momentum of change. These policy-driven changes that facilitate technology and finance to low carbon goals also consider an economy-wide implicit price of CO<sub>2</sub> (Aldy and Pizer, 2016).

### *1.5°C Scenario*

The limited CO<sub>2</sub> budget for meeting the 1.5°C scenario, calls for an increased effort beyond the actions for the 2°C scenario. Transport sector has a significant role to play, especially in Asia and policymakers should target to achieve the full potential (Lee et al., 2016). At a global level, CO<sub>2</sub> reductions from transport would be about 50% higher in a 1.5°C scenario than in a 2°C scenario in 2050 (Rogelj et al., 2015). These enhanced reductions are expected from greater use of electricity, demand reduction, shift to cleaner modes and increased use of biofuels. India's NDC includes these measures. Table 2 describes the qualitative difference across the scenarios.

The 1.5°C scenario is constrained with a very stringent cumulative emissions cap resulting in a higher price of CO<sub>2</sub>. Carbon price in the 1.5°C scenario could be 2.2 to 3.7 times higher than 2°C scenario in 2030 (Rogelj et al., 2015). The estimate of demand reduction in 1.5°C relative to NDC scenario follows these price estimates in Eq. [4].

## **3. Scenarios**

The paper assesses four future transport scenarios spanning a time period till 2050 - a BAU scenario, NDC scenario, 2°C scenario and 1.5°C scenario. The scenario architecture allows for a comparison of the NDC commitments with a baseline and to assess the gap between NDC achievements and the global goal of 2°C stabilisation and 1.5 °C since NDC actions are believed to fall short of the reductions needed for a 2°C and 1.5°C scenario (UNEP, 2016) . Decarbonisation solutions include national and subnational policy interventions, contribution of clean fuels and technologies, systems integration, land use and urban planning solutions.

### **3.1. BAU Scenario**

The business as usual (BAU) scenario assumes socio-economic development along the conventional path including continuation of ongoing policies and implementation of current and announced policies. The economic growth rate is assumed at 7.1 % between 2015 and 2050. The demographic transition, based on the projections for the medium scenario from United Nations, will result in an increase in population from 1.30 x 10<sup>9</sup> in 2015 to around 1.71 x 10<sup>9</sup> in 2050 (UN DESA, 2015).

**Table 2. Strategies for decarbonisation in relation to national policies/ programs /projects across scenarios**

Strategies in line with policies/programs/projects	BAU Scenario	NDC Scenario*	2°C Scenario	1.5°C scenario
<b>Climate Policies</b>	Weak climate regime	Implementation of voluntary and supported actions aligned with NDC	Global carbon price consistent with 2 °C stabilisation	CO <sub>2</sub> emissions budget consistent with 1.5 °C scenario
<b>Strategies that reduce or substitute urban passenger transport demand</b>	<ul style="list-style-type: none"> <li>Urban Transport Demand will grow at 4.9%</li> <li>The modal share for NMT will reduce</li> <li>Share of private motorised transport would increase</li> </ul>	<ul style="list-style-type: none"> <li>Improvement of mass transit in cities, and overall mobility (Smart city and AMRUT missions).</li> <li>Demand growth slower relative to BAU.</li> <li>Modal shares of NMT and Rail increase</li> </ul>	<ul style="list-style-type: none"> <li>Demand and modal mix changed relative to change in carbon prices</li> </ul>	Additional Measures: <ul style="list-style-type: none"> <li>IT for traffic management, transit promotion, congestion reduction</li> <li>Improved occupancy, less idle trips through ride-sharing</li> <li>Trip substitution through internet</li> </ul>
<b>Strategies that reduce or substitute Intercity passenger transport demand</b>	<ul style="list-style-type: none"> <li>Intercity transport demand will grow at a CAGR of 3.6%.</li> <li>Modal share for rail and road will decrease</li> <li>Modal share of air will increase</li> </ul>	<ul style="list-style-type: none"> <li>Investments in semi high speed rail corridors and construction of high speed rail corridors would facilitate a shift towards rail.</li> <li>High density on rail corridors would reduce demand.</li> <li>Demand will grow slower compared to BAU.</li> <li>Modal share of Rail increased to 30% by 2050</li> </ul>	<ul style="list-style-type: none"> <li>Demand and modal mix changed relative to change in carbon prices.</li> <li>High carbon prices incentivize rail electrification.</li> </ul>	Additional Measures: <ul style="list-style-type: none"> <li>IT for traffic management, rail promotion</li> <li>Improved occupancy, less idle trips through ride-sharing</li> <li>Trip substitution through internet</li> </ul>
<b>Strategies that reduce or substitute freight transport demand</b>	<ul style="list-style-type: none"> <li>Freight transport demand will grow at a CAGR of 4.2%.</li> <li>The modal share remains stable</li> <li>investments in freight infrastructures lead to small increase in share of rail</li> </ul>	<ul style="list-style-type: none"> <li>Integration of rail with coastal shipping &amp; waterways</li> <li>Implementation of dedicated freight corridors (DFC) shift freight to rail.</li> <li>Industrial Corridors along the DFC and strategic siting of large power plants reduce freight demand.</li> <li>Demand growth slower than BAU.</li> <li>Modal share of Rail increased to 48% by 2050</li> </ul>	<ul style="list-style-type: none"> <li>Demand and modal mix same as NDC Scenario though high carbon prices create incentive to electrify rail.</li> </ul>	Additional Measures: <ul style="list-style-type: none"> <li>Improving Information on rail freight services</li> <li>Technology - advanced signalling, synchronicity, automated wagon loading, etc.</li> </ul>
<b>Strategies that increase share of biofuels</b>	<ul style="list-style-type: none"> <li>No minimum blending shares defined. Only freedom for pricing of biofuels.</li> </ul>	<ul style="list-style-type: none"> <li>Aspirational blending target of 20% for biofuels by 2017 (GoI (Government of India), 2009) however the actual achievement very limited.</li> <li>The blending shares considered are: Ethanol 5% by 2020, 20% beyond 2030 Biodiesel : 1% by 2020, 10% beyond 2030</li> </ul>	<ul style="list-style-type: none"> <li>No blending shares defined</li> <li>Penetration driven by carbon price.</li> </ul>	Additional Measures: <ul style="list-style-type: none"> <li>R&amp;D in second gen biofuel conversion technology</li> <li>Improving supply chains for biomass collection, transportation and handling</li> <li>Investing in flex fuel vehicles to handle higher biofuels shares</li> </ul>
<b>Strategies that increase share of EVs</b>	<ul style="list-style-type: none"> <li>No duty or sales tax incentives.</li> <li>Limited investments into charging infrastructures</li> <li>Maximum share of 20% for EV 2 wheelers by 2035</li> </ul>	<ul style="list-style-type: none"> <li>Full duty exemption and half sales tax till 2025</li> <li>Further reduction on tax rate and parity by 2040.</li> <li>Increased investment in charging infrastructures.</li> <li>10% increased cost for transmission and distribution</li> <li>Maximum share constraints relaxed to 40% for both EV 2 &amp; 4 Wheelers.</li> </ul>	<ul style="list-style-type: none"> <li>Carbon Price facilitates cost competitiveness of EVs.</li> <li>EV prices are lower due to decarbonisation of electricity (Dhar et al., 2016)</li> </ul>	Additional Measures: <ul style="list-style-type: none"> <li>National and local enabling policies for EVs</li> <li>SMART grid technologies that enable use of EVs as a storage</li> </ul>
<b>Strategies that improve fuel economy</b>	<ul style="list-style-type: none"> <li>Fuel economy of existing vehicles to improve in line with the proposed corporate average fuel consumption standards</li> </ul>	<ul style="list-style-type: none"> <li>Fuel consumption standards + additional constraint</li> <li>Overall fuel economy for 4 wheelers below 4 lit/100 km</li> </ul>	<ul style="list-style-type: none"> <li>Carbon price facilitates cost competitiveness of fuel efficient vehicles</li> </ul>	Additional Measure: <ul style="list-style-type: none"> <li>Reduced registration fee for more efficient vehicles</li> </ul>

\*(UNFCCC , 2015)

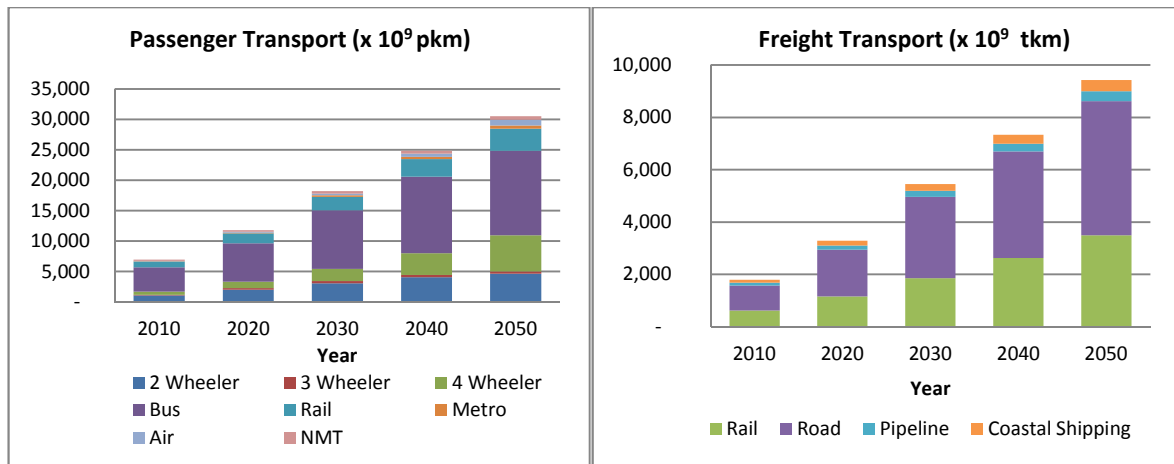


Fig. 2a.

Fig. 2b.

**Fig. 2. Mode wise transportation demand in BAU scenario. Fig. 2a. Passenger transport, Fig. 2b. Freight transport**

### *Passenger Transport*

Passenger transport demand would be driven by an increase of individual mobility. Per capita mobility is expected to increase by a factor of three from 5,685 passenger km (pkm) in 2010 to 18,837 in 2050. The overall demand for passenger transport would increase over four-times from  $6,962 \times 10^9$  pkm in 2010 to  $30,517 \times 10^9$  pkm by 2050 (Fig. 2).

Urban transport demand would witness a transition towards motorisation with increased use of private motorized modes and reduced reliance on non-motorised transport (NMT). The share of rail based modes e.g., metros, light rail, etc. would increase due to significant investments in public transport including mass transit. Implementation of fuel efficiency norms will facilitate investments in cleaner vehicle technologies including EVs and fuels (Table 2).

### *Freight Transport*

The per capita freight demand in India is quite low at 1,464 ton km (tkm) in 2010 compared to nearly 8,000 tkm in EU (EEA, 2013). Economic growth would result in an increase in the overall demand for freight transport from  $1,793 \times 10^9$  tkm in 2010 to  $10,052 \times 10^9$  tkm in 2050 (Fig. 2). Investment in dedicated freight corridors will increase the share of rail. Road based transport dominate the share of freight transport (Fig. 2). Natural gas, crude and bulk petroleum product would be transported through pipelines.

## **3.2. NDC Scenario**

This scenario is aligned with transport actions under India's NDC. The transport NDC actions encompass investments in urban mass transit, increasing the share of rail in freight transport, investments in high speed rail, improving water transport and actions for cleaner technologies and fuels (UNFCCC, 2015). The focus of the NDC is on strategies that improve the fuel efficiency of vehicles and shift demand to relatively cleaner and efficient modes.

### *Urban Mass transit*

The NDC's urban transport vision focuses on moving people rather than vehicles and Mass Rapid Transit System (MRTS) are expected to play an important role. The Indian government has recently launched the Atal Mission for Rejuvenation and Urban Transformation (AMRUT), with a focus on enhancing basic infrastructure, including transport in cities. A number of cities are building metro rail projects with financial support from central and state governments. Following the success of Delhi Metro in earning carbon credits, metro rail projects in other cities are making efforts to leverage climate finance.

### *Intercity Rail transport*

NDC of India aims to enhance the share of rail in total land transportation from 36 % to 45 %. One of the strategies to achieve this target includes creating dedicated freight corridors (DFC). Two DFCs are being constructed: The Western Dedicated Freight Corridor (1,520 km), and Eastern Dedicated Freight Corridor (1,856 km). The implementation of the two dedicated corridors would significantly reduce the transportation time between the connected cities across the country.

### *Coastal shipping and inland waterways*

Water borne transport e.g., coastal shipping, barges for inland water transport are energy efficient and environmentally friendly compared to road based modes (Sims et al., 2014) and this is a key focus area of India's NDC. The present share of water borne freight transport account for a minor share of overall tkm transported and historical growth of water based freight has been slower than rail and road. There are plans to establish an inland waterway transportation grid that would connect existing and proposed waterways to roads, railways, and ports; augment capacity of ports and improve road network along the coast to improve connectivity to ports (GoI, 2016).

### *Electric Vehicles and Fuel efficiency*

For India, EVs can improve energy efficiency, reduce air pollution from transport and contribute to development. In the long term, EVs will be an important mitigation option (Sims et al., 2014) with decarbonisation of electricity. India's NDC highlights the Faster Adoption and Manufacturing of Hybrid and Electric vehicles (FAME) India program aimed at accelerating the country's adoption and manufacture of hybrid and electric vehicles through financial incentives (GoI, 2015b).

Vehicle efficiency is a key focus in India's NDC. The government has initiated implementation of an average fuel consumption standard for manufacturers and importers of light duty vehicles from April 2016. The standard is linked to the weight of vehicles and would become more stringent post 2021 however much lower relative to targets set by EU and Japan for 2021, e.g., EU targets an emission standard of 95 gm of CO<sub>2</sub> per km by 2021 compared to Indian target of 113 gm of CO<sub>2</sub> per km by 2025 (UNEP, 2016).

### *Biofuels*

India's NDC proposes altering the current dependence on fossil by increasing share of clean and low carbon fuels. India's National Policy on Biofuels (GoI, 2009) has an aspirational

target of 20 % biofuel blending in both diesel and petrol with bbio-diesel and ethanol by 2017. The present share is much below this target as large scale blending of biodiesel has not started.

#### *Fiscal incentives for low carbon growth*

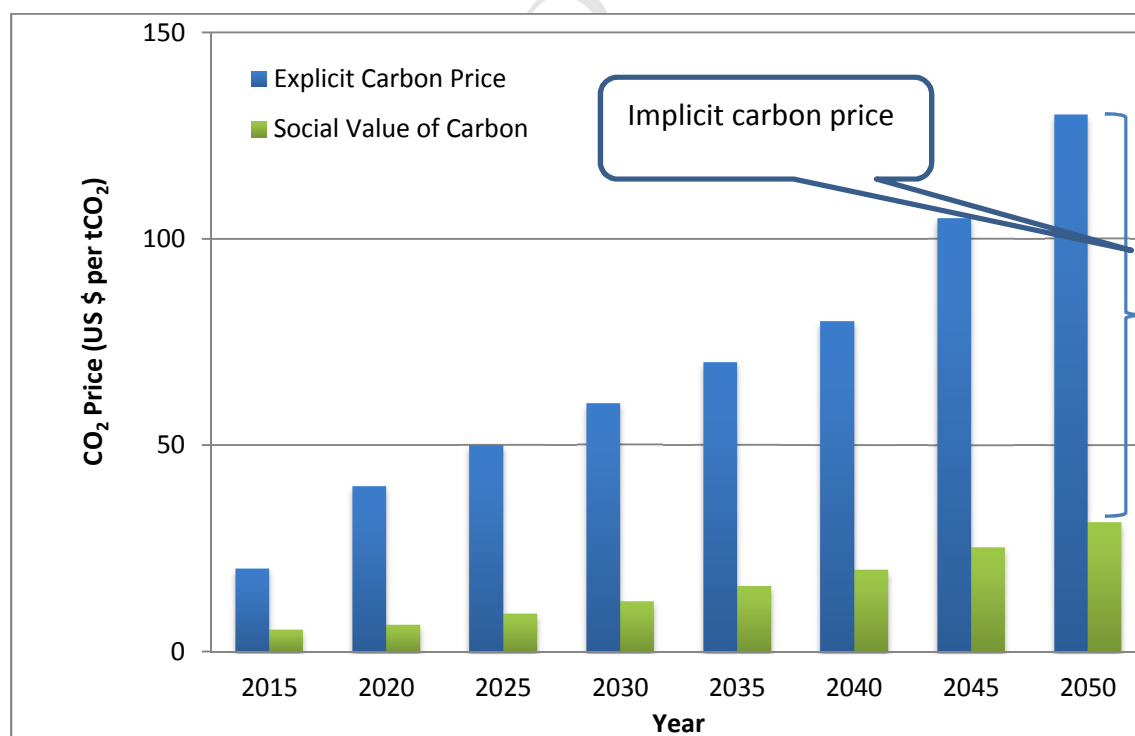
Transformation of transport sector for a low carbon growth would need financing for infrastructures and a level playing field across various transportation modes and technologies. India is cutting down subsidies on fossil fuels (petrol and diesel). In 2015 India cut its petroleum subsidy by about 26 %. Government of India is introducing tax-free infrastructure bonds, creating a National Infrastructure Investment Fund (GoI., 2015c) and a National Clean Energy and Environment Fund (GoI 2011). These funding mechanisms at national level will play an important role in achievement of targets proposed within the NDC of India.

### 3.3. 2°C Scenario

The scenario assumes a stronger push for climate targets. In addition to the implementation of the NDC actions, this scenario considers targeted actions towards meeting the global goal of 2°C temperature stabilization.

#### *Implicit and Explicit Carbon Prices*

The scenario considers a CO<sub>2</sub> price trajectory aligned with Copenhagen pledges planned to take effect post 2020. The CO<sub>2</sub> price trajectory as obtained from an integrated assessment model starts at 40 US \$ per tCO<sub>2</sub> in 2020 and increase gradually to reach 130 US \$ per tCO<sub>2</sub> by 2050 (Fig. 3) (Lucas et al., 2013). This is the explicit carbon price required when there is complete reliance on markets.



**Fig 3. Explicit CO<sub>2</sub> price and implicit CO<sub>2</sub> price for 2°C Scenario**

The reduction in travel demand due to this high carbon price is with reference to the NDC scenario (Eq. [2], section 2.3). There is no explicit carbon price for the NDC scenario however an implicit carbon price has been considered. This implicit price of carbon is estimated from the difference between the explicit global carbon price (stated earlier) and the social value of carbon that can achieve similar mitigation with a much lower carbon price. A lower carbon price is possible when mitigation is designed to result in co-benefits in terms of direct joint products (local air pollution, energy security, etc.), acceleration of technological change (resource efficiency, access to basic energy, less energy and material intensive demand patterns, etc.), and indirect macroeconomic and development benefits (Espagne et al., 2017). The social value of carbon is based on an analysis carried for 2°C scenario for India by Shukla, et al., 2015. The implicit carbon price in the NDC scenario (taken as difference of explicit carbon price and social value of carbon) will increase from 33 USD per tCO<sub>2</sub> in 2020 to 98 USD per tCO<sub>2</sub> in 2050.

#### *Demand for Passenger Transport*

The overall demand has a very small change however for demand from rail and 4 wheelers, some divergence in demand happens with time (Fig. 4). The demands have been estimated with respect to NDC scenario using Eq. [4] making use of elasticities provided in Table 3 .

**Table 3. Elasticities for transport and CO<sub>2</sub> Intensity**

Mode	Elasticity of travel demand with respect to	Short run Elasticity	Long run Elasticity	Reference	% Share of fuel cost in levelized cost <sup>1</sup>	Long run elasticity ( $\mu$ ) considered	CO <sub>2</sub> intensity (tCO <sub>2</sub> /M pkm)		
							2010 <sup>1</sup>	2050 NDC scenario <sup>2</sup>	2050 2°C scenario <sup>x</sup>
<b>2 Wheeler demand</b>	total cost		-0.10	a	46%	-0.05	31.9	26.7	11.5
<b>4 Wheeler demand</b>	fuel price		-0.55 to -0.05	b	36%	-0.25	99.1	55.1	50.1
			-0.26	c					
			-0.29	d					
<b>Buses</b>	Fare	-0.28	-0.55	e	36%	-0.20	14.6	13.1	5.3
		-0.29		f					
			-0.15	a					
<b>Metro</b>	petrol price	+0.07		f	1%	0	14.0	12.1	7
<b>Rail</b>	Fare	-0.65	-1.08	e	5%	-0.05	18.1	12.0	7
		-0.35		f					
<b>Air</b>	Fare		-0.20	a	27%	-0.06	80.0	62	48

1. Average value for base year in model
2. Based on outputs of the NDC scenario

#### Sources:

a TIMES Model, (Kesicki et al., 2011)  
b (Litman, 2013)(Johansson and Schipper, 1997)  
c (Litman, 2013) (de Jong et al., 2001)  
d (Goodwin et al., 2004)

e (Litman, 2013) (Goodwin, 1992)  
f (Litman, 2013),(Luk et al., 1993)  
x. Model Database for Deep Decarbonisation Pathways Study (Shukla, et al. 2015)

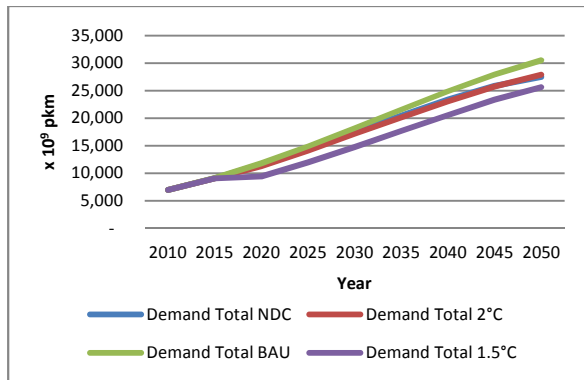


Fig. 4a.

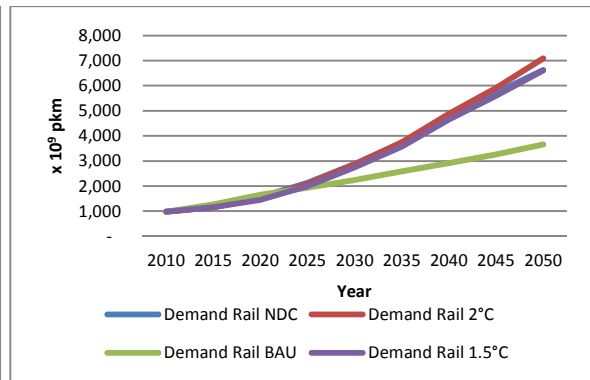


Fig. 4b.

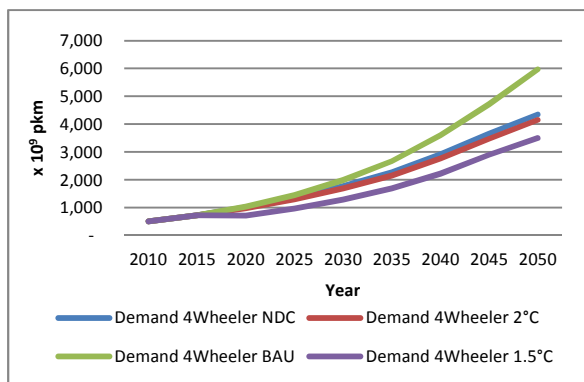


Fig. 4c.

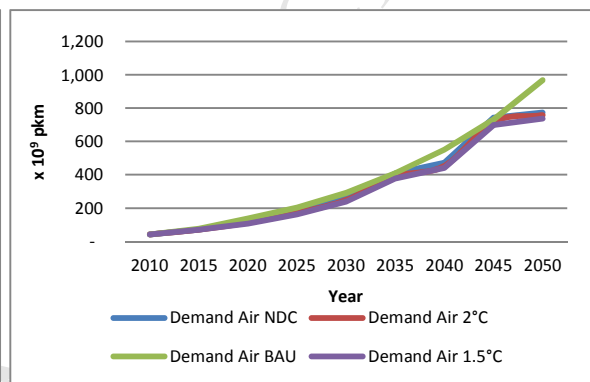


Fig. 4d.

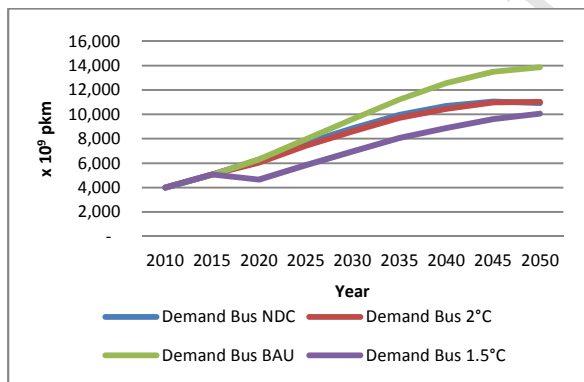


Fig. 4e.

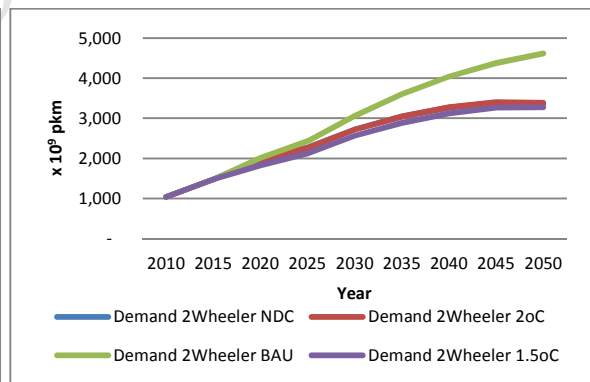


Fig. 4f.

**Fig.4. Passenger demand under different scenarios. Fig. 4a. Total passenger demand. Fig. 4b. Rail passenger demand (Rail). Fig. 4c. passenger demand (4-wheeler). Fig. 4d. Passenger demand (Air). Fig. 4e. Total passenger demand (bus). Fig. 4f. Total passenger demand (2-wheeler)**

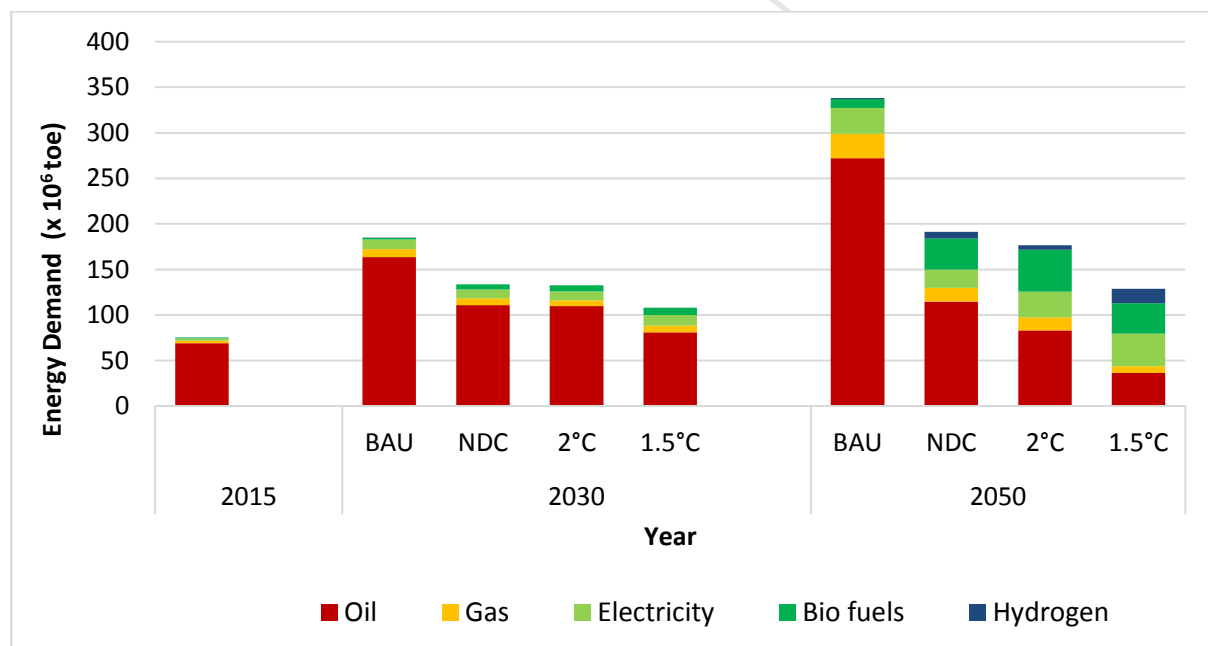
### 3.4. 1.5° C Scenario

This scenario assumes stronger actions to meet the global 1.5°C ambition. This scenario differs from the 2 °C scenario in two aspects i. a higher carbon price and ii. an enhanced implementation of NDC actions that lead to significant demand reduction and modal shift. This includes a higher focus on sustainability actions and ICT. Actions at the interface of ICT and transportation that reduce travel demand are among the key strategies in this scenario (Table 2). The higher carbon prices result in a much lower demand for transportation (Fig. 4).

## 4. Results

### 4.1. Energy and Emissions

Driven by the growth of population and GDP, transport energy demand both for passenger and freight increases significantly. As expected, the BAU scenario shows the highest energy demand. Our analysis shows that transport energy demand would increase by 4.5-times between 2015 and 2050 in BAU (Fig. 5) with a heavy reliance on oil. This would pose serious challenges for energy security and air pollution.



**Fig. 5. A comparison of transport energy mix across scenarios**

Policy interventions in alternate scenarios (NDC, 2°C & 1.5°C) slow down the rate of increase of energy demand. Energy consumption in NDC scenario is lower than BAU and this difference increases in 2050. Energy demand in 2050 relative to 2015, increases by 2.7 times in the NDC scenario and only 2.4 times in the 2°C scenario. The lowest energy demand is seen in the 1.5°C scenario. Oil continues to dominate the energy mix across all scenarios in the short run (2030). In alternate scenarios, policy effects begin to take effect from 2030 and by 2050 the share of electricity, biofuels and hydrogen increases. The introduction of carbon price in 2°C and 1.5°C results in higher penetration of cleaner technologies including fuel



efficient vehicles, alternate vehicles, and cleaner fuels. This penetration is higher in the 2°C and highest in the 1.5°C scenarios. The 1.5°C scenario shows a remarkable reduction in the share of oil with a corresponding increase in alternate sources. In the 1.5°C scenario, the combined share of biofuels, hydrogen and electricity meets two-thirds of the total energy demand.

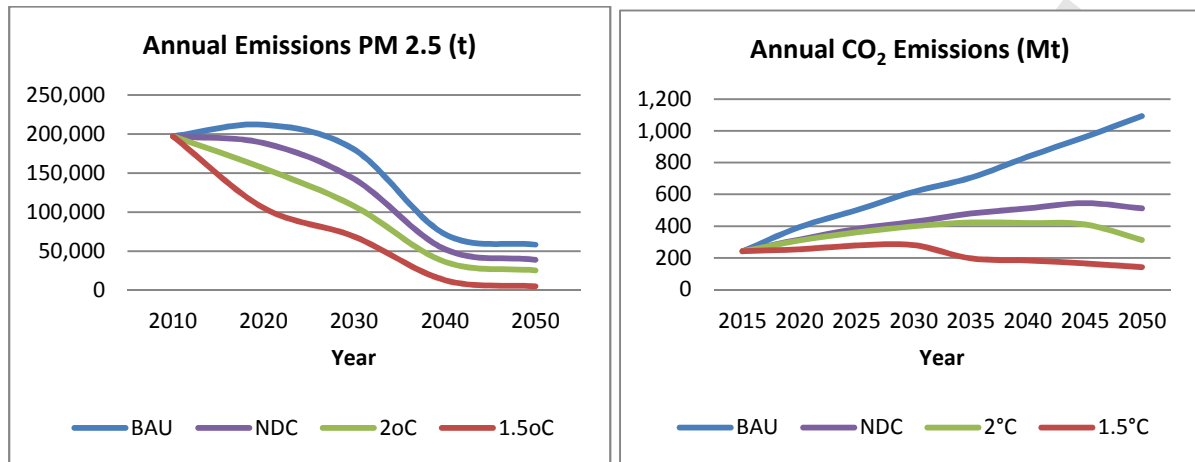


Fig 6a

Fig 6b

**Fig. 6. Environmental Impacts across scenarios from India's transport sector. Fig. 6a. Particulate matter (Annual PM 2.5) Emissions, Fig. 6b. CO<sub>2</sub> Emissions**

In the BAU scenario, CO<sub>2</sub> emissions increase by 4.5 times in 2050 relative to 2015 levels (Fig. 6). The policy driven NDC actions halve the CO<sub>2</sub> emissions in the NDC scenario compared to BAU. The peaking of CO<sub>2</sub> emissions does not happen until 2045. The peaking of CO<sub>2</sub> emissions in the 2°C scenario happens in 2035 earlier than the NDC scenario. The difference between the emissions in the NDC and 2°C scenario is small till 2030 however by 2050 the difference becomes significant. The 1.5°C scenario follows an emissions trajectory which starts at a lower level in the near-term and a sharp down turn in 2030 takes the emissions below emissions in 2015. Fine particulate matter (PM 2.5) emissions on the other hand decline throughout the assessment period for the NDC, 2°C and 1.5°C scenarios. In the 1.5°C scenario, PM 2.5 emissions are close to zero post 2040. This transformation happens through large scale diffusion of clean and energy efficient technologies coupled by aggressive reduction in demand.

#### 4.2. Passenger transport demand

Passenger transport was found to be sensitive to changes in carbon prices. The overall demand for passenger transport reduces by 8.3% in 2050 in the 1.5°C scenario relative to the 2°C scenario. The demand reduction is more for 4 wheelers and buses (Fig. 7). This demand reduction can deliver around 12.6% reduction in CO<sub>2</sub> emissions relative to 2°C scenario with other things remaining the same as 2°C scenario. In case of freight transportation, sustainable strategies would include shift to rail, vehicle fuel efficiency and optimizing routes for cleaner low carbon transportation (Hosseini-Nasab and Lotfalian, 2016).

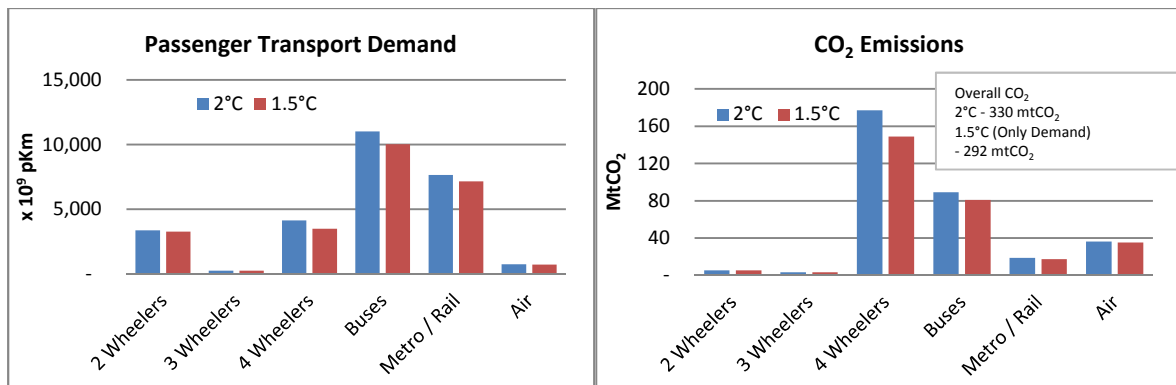


Fig. 7a.

Fig. 7b.

**Fig. 7. Role of passenger transport demand in decarbonisation. Fig. 7a. Demand reductions in passenger demand in 2050 across 2°C and 1.5°C, Fig. 7b. Corresponding changes in CO<sub>2</sub> emissions in 2050 across 2°C and 1.5°C**

#### 4.3. Technology Mix

The technology mix would diversify in the future within BAU itself however the dependence on oil remains. Vehicle technologies using oil however become cleaner to address environmental concerns within the cities. The local environmental concerns also lead to the diffusion of electric and CNG vehicles especially within the bus fleets (Fig. 8a). In the 2°C and 1.5°C scenario there is a marked increase in electrification across all vehicle categories (Fig. 8b).

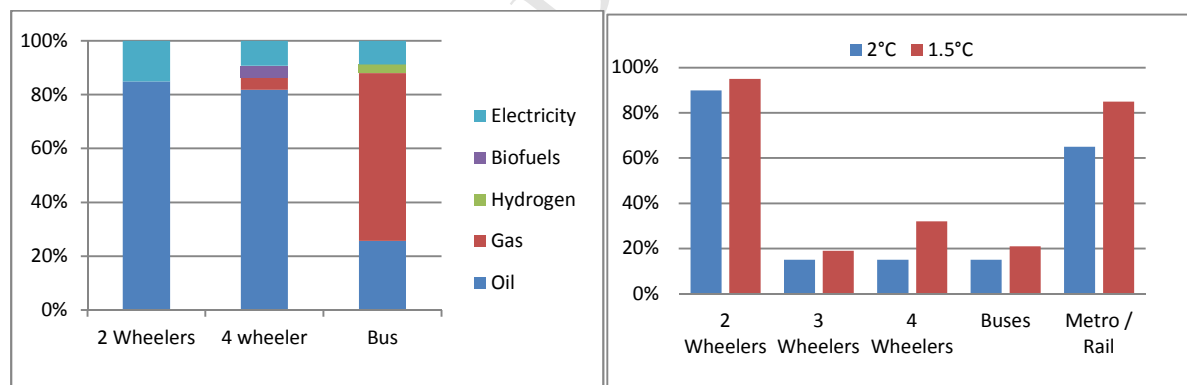


Fig. 8a.

Fig. 8b.

**Fig. 8. Technology transitions across scenarios. Fig. 8a. Fuel Mix in BAU in 2050, Fig. 8b. Share of electric and hydrogen vehicles in 2050: 2°C and 1.5°C scenario**

The increased use of electricity in 2°C and 1.5°C Scenario is assisted by a strong decarbonisation of electricity (Table 4). The decarbonisation of the electricity occurs rapidly in the 1.5°C scenario and by 2035 the electricity is almost fully decarbonised (Table 4). This brings down the CO<sub>2</sub> emissions by around 16.7% in the 1.5 °C scenario compared to the 2°C scenario.

**Table 4. CO<sub>2</sub> Intensity of Electricity (kg CO<sub>2</sub> per kwh): 2°C and 1.5°C Scenario**

	2020	2025	2030	2035	2040	2045	2050
2°C	0.80	0.64	0.44	0.31	0.22	0.13	0.09
1.5°C	0.51	0.22	0.17	0.02	0.01	0.01	0.00

## 5. Discussion on key strategies for deep decarbonisation

Results from this study show that achieving both the 2°C and 1.5°C scenario would need a significant shift from the NDC scenario. Global assessments, reveal that the 1.5°C scenario would require transformative technological advancements (Walsh et al., 2017) and an earlier and stronger implementation of decarbonisation strategies as compared to achieving the 2°C scenario. Deep decarbonisation for India can be delivered by supply side strategies that include clean vehicles, clean electricity and biofuels complimented by demand side strategies. This section discusses transport decarbonisation strategies in detail in light of the assessment in Section 4.

### 5.1. Demand side strategies

Measures that reduce the demand for travel or substitute travel are essential compliment to the supply measures to achieve higher mitigation benefits. In cities, better land-use planning, infrastructure and incentives to promote non-motorized transport in cities need a significant thrust beyond the ongoing efforts (Creutzig et al., 2016). Simultaneously, advances including social media, internet of things, big data, smart technologies and systems, shared economy platforms are revolutionizing human activities and these trends will heavily influence decarbonisation of transport. For example, online shopping can reduce trips (Smidfelt Rosqvist and Hiselius, 2016). These sustainable strategies are part of India's NDC and this explains the demand reduction in NDC scenario relative to the BAU. Strong sustainability actions are implicit in the assumptions for the 2° C scenario and more so for the 1.5 °C scenario. This is apparent in the result where sustainability strategies bring about some more demand reduction in 2° C and 1.5° C scenario (Fig. 4a-4f).

### 5.2. Clean vehicle technologies

Clean technology innovations have resulted in significant CO<sub>2</sub> mitigation in Europe and elsewhere (Cristina De Stefano et al. 2016). A shift from conventional vehicles to EVs can also deliver significant air quality benefits, as seen in a recent study in Seoul (Kim et al., 2016). While existing policy and its enhanced implementation within NDC scenario makes a good case for uptake of cleaner vehicle technologies, significantly higher carbon prices bring in increased penetration for cleaner vehicles in 2°C and more so in the 1.5 °C scenario.

### 5.3. Clean electricity

The future of Indian transport under 2°C and 1.5°C scenarios leans heavily towards electrification of all modes (Fig. 8). The case for EVs is much stronger in recent times due to the simultaneous focus on achieving decarbonisation of transport while delivering sustainable development benefits. This transformation is closely tied to the transformation of the electricity sector. In NDC scenario, the push for solar and renewable energy policies leads to

a reduced CO<sub>2</sub> intensity of electricity. In the 2°C and 1.5°C scenarios high carbon prices given additional push for clean power generation technologies and these include fossil fuels with carbon capture and storage.

#### 5.4. Biofuels

Conventionally produced biofuels have been associated with concerns of food security and land use changes. Emerging studies show the effectiveness of blending options that optimize CO<sub>2</sub> emission reductions and lower environmental impacts at reduced cost (Hashim et al., 2016). In this study the biofuel production is mainly based on the second generation pathway. National biofuel policies and targets (Supplementary Material, Table SM1) coupled with stronger implementation in the NDC scenario increase biofuel demand significantly. In the 2°C and 1.5°C scenario, the driver for biofuels is the high carbon price. The biofuel demand in the 2°C scenario increases from 1.3 Mtoe in 2015 to 46 Mtoe in 2050. This demand is slightly lower at 34 Mtoe in 1.5°C scenario (Fig. 5) mainly due to a lower overall demand for energy and emergence of hydrogen as an alternative fuel. The demand for biofuels is well within the technical potentials for second generation biofuels for India which are estimated at  $50.1 \times 10^9$  litres (around 43 Mtoe) in 2030 (Purohit and Dhar, 2015).

#### 6. Conclusions

The assessment of the mitigation potential of NDCs is of high interest to the scientific community as well as policymakers. The paper draws important insights on India's INDC achievements, its low carbon transformation towards 2°C and 1.5°C, especially the energy system and the final delivered transformation of 'transport' sector in India to respond to these low CO<sub>2</sub> emissions targets.

Four key findings from the study are:

- i. India's NDC measures are well crafted to improve sustainable development indicators while enhancing the decoupling of CO<sub>2</sub> emissions compared to BAU emissions pathway. However they fail to meet the targets outlined in the Paris Agreement and this is no different to NDC of many other countries in Asia (Fulton et al., 2017).
- ii. The transitions towards emissions pathways aligned to global 2°C scenario will require implementation of deeper decarbonisation actions in the transport sector such as policy support for clean transport technologies, electrification of transport and transition to low CO<sub>2</sub> intensity of electricity supply (Table 4). The 2°C scenario also depends on an increased shift towards public transport (Figure 4) since mode switching has been found to be a more effective mitigation policy when emissions from infrastructures are also considered (O'Brion and Guivarch, 2017)
- iii. The 1.5°C scenario is transformative and differentiates from other scenarios in the urgency and intensity of implementation. The required transformation in the 1.5°C scenario of the transport sector is line with other model based assessments (Rogelj et al., 2015). In both 1.5°C and 2°C scenarios, the role of demand side actions

cannot be overstated, both in terms of mitigation benefits as well as aligning with the mandates emanating from the sustainable development goals (SDGs) such as energy security, access to clean energy, etc. The resultant reduction in travel demand, modal shift and investment in cleaner fuels and vehicles technologies would deliver co-benefits in the form of improved energy security and reduced air pollution.

- iv. Penetration of clean technologies (EVs and decarbonisation of electricity) and fuels lie at the heart of a low carbon sustainable transition for India's transport sector and these are evident across all the alternate scenarios.

The analysis of deep decarbonisation scenarios shows the urgency for multipronged approach aiming to set-up institutions, policies and investments to promote clean and efficient vehicle technologies (EVs, NMTs), accelerate penetration of clean and low carbon fuels (hydrogen, bio-fuels), modal shift (dedicated freight corridors, mass passenger transport), rapid electrification of transport system and measures that reduce transport demands (e.g. avoid trips). Clean energy technology innovations, a key element in the low carbon transition, could be driven through national and sectoral policies (NDC approach to begin with), which would require upfront financing support to meet higher capital and operating costs.

The electrification of the transportation sector and integrating clean and renewable electricity sources requires an integrative approach to analyse implications for grid stability, electricity prices and capacity utilisation for conventional power plants. The analysis in the present study focuses on the transport sector and does not delve deeper into the electricity sector. Future work could explore in more detail the integration of electric vehicle technologies with clean electricity. For instance, a detailed analysis on how the integration of electric vehicle batteries can support stabilizing the grid could add value to the present analysis.

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**Highlights**

- India's INDC decouples CO<sub>2</sub> emissions and economic growth, but only marginally
- 1.5°C scenario would require urgent and deep decarbonization of transport sector
- Clean fuels and technology innovations are vital to crafting 1.5° C pathway
- 1.5° C pathways need profound changes in demand-side behaviour and technologies
- Methodology to model transportation demand under strong decarbonisation pathways