WORKING PAPER

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Assessing the scale of zero-emission truck deployment required for meeting India's net-zero goal

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INTRODUCTION

At the 2021 United Nations Climate Change Conference, the Government of India pledged to achieve net-zero emissions by 2070 (Press Information Bureau, 2022a). The Government later submitted an updated Nationally Determined Contribution to the United Nations Framework Convention on Climate Change that commits to reducing the carbon emissions intensity of the country's gross domestic product by 45%, relative to 2005 levels, by 2030 (Press Information Bureau, 2022b). Decarbonizing India's transport sector will be critical to reaching these goals: As of 2020, transportation contributed 14% of the country's energy-related direct CO_2 emissions, of which 90% came from road transport (Kumar et al., 2022).

Reducing heavy-duty truck (HDT) emissions will be particularly important. As of 2020, HDTs contributed around 40% of total on-road carbon emissions in India (Kumar et al., 2022). As the Indian economy grows, demand for HDTs will continue to rise, and if unmitigated this could result in emissions from HDTs quadrupling by 2070 (Yadav et al., 2023). Nonetheless, policy support for electrification of the HDT segment has lagged that of other vehicle segments. For instance, the government's Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India subsidy program, now in its second phase, covers two- and three-wheeled vehicles, cars, and buses, but not HDTs (Ministry of Heavy Industries, 2021). According to the Ministry of Road Transport and Highways (MoRTH), electric buses accounted for 6.17% of all new bus registrations in India in 2021 (MoRTH, 2023). Meanwhile, HDTs have fallen behind in the transition to zero-emission vehicles, both in terms of targeted government backing and market development.

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Governments around globe are making efforts toward transitioning to zero-emission trucks (ZETs). The European Commission has proposed a 90% CO_2 reductions target for HDTs by 2040 (Council of the European Union, 2024). The California Air Resources Board has adopted a regulation requiring that, beginning in 2036, 100% of HDTs sold must be ZETs (California Air Resources Board, 2020). In addition, more than 30 countries, including the United States, Canada, and the United Kingdom, have signed a global memorandum of understanding setting out a goal that 100% of new truck and bus sales will be zero-emission vehicles by 2040 (CALSTART, 2024). Two states in India, Telangana and Goa, have also signed this memorandum (CALSTART, 2023).

As India strives to achieve its climate and environmental objectives, it is critical for the country to have clear targets and defined intermediate milestones to help ensure that the pace of ZET adoption is in line with its national goals. A ZET penetration target would give a clear policy signal to manufacturers that will guide their investment decisions and guarantee the necessary ZET supply to support the transition.

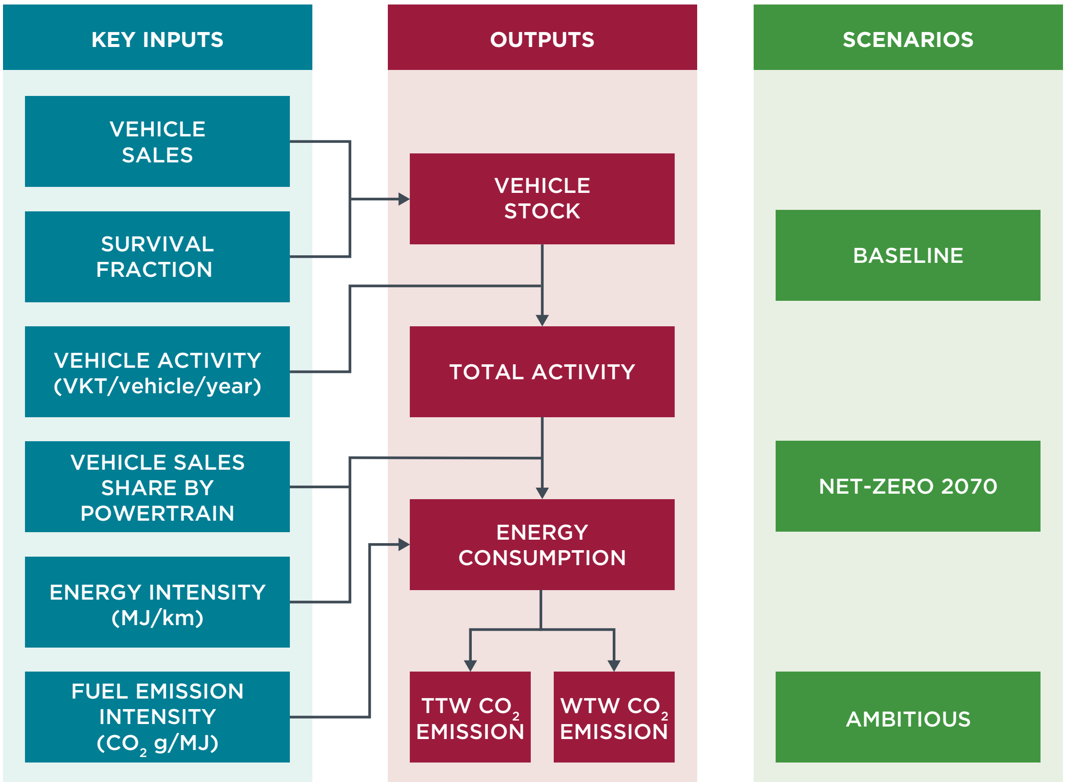
This working paper examines the ZET penetration required for India to achieve net-zero emissions from HDTs by 2070 under different policy and market scenarios. Specifically, it evaluates the impacts of ZET penetration on total fleet tank-to-wheel (TTW) and well-to-wheel (WTW) CO_2 emissions. For WTW HDT emissions, we varied the grid CO_2 emission intensity values and employed grey and green hydrogen as FCET options in trucks. The following sections cover the methodology, data sources, and assumptions used in the study. Thereafter, we explain the three scenarios analyzed in the study, before presenting the results of our analysis and discussing their implications. We conclude the study with key policy takeaways.

METHODOLOGY

To estimate on-road HDT emissions, we used the ICCT's Roadmap model (ICCT, 2022), a global transportation emissions model covering all on-road vehicle segments. Roadmap is a bottom-up model and is based on the activity, structure, energy intensity, and fuel carbon (ASIF) framework detailed in Schipper and Marie-Lilliu (1999). Here, activity refers to passenger or freight travel, including vehicle travel and load factors; structure is the mode split; energy intensity is vehicle fuel consumption per kilometers traveled; and fuel carbon reflects emissions per unit of energy. These input parameters are combined to estimate energy and emissions. The Roadmap model provides annual estimates of historical and future emissions disaggregated by vehicle segment, powertrain, and fuel type under various policy scenarios until 2070.

Figure 1 presents a simplified flowchart of the Roadmap model's methodology. Key input parameters are vehicle sales, survival fraction of vehicles (a function of their age in the fleet), vehicle activity in vehicle kilometers traveled (VKT), sales share by powertrain, energy intensity, and fuel emissions intensity. In this model, vehicle stock is derived from vehicle sales and the survival fraction of the given segment; in turn, vehicle stock, sales share by powertrain, and vehicle activity are multiplied to estimate total vehicle activity. Total activity multiplied by energy intensity gives the estimated energy consumption, which is then multiplied by fuel emission intensity to produce fleet-wide TTW and WTW CO_2 emission projections.

Figure 1
Flowchart of overall methodology



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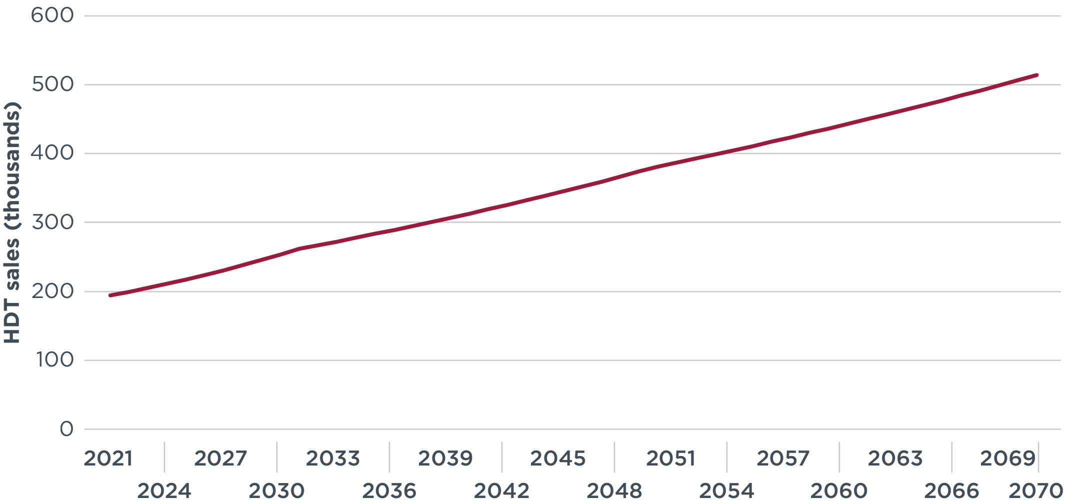
In our study, we have kept all inputs related to vehicle volume (i.e., sales and survival curves) uniform across scenarios, while varying energy intensity and ZET penetration levels to examine their impact on total CO_2 emissions.

ROADMAP MODEL INPUT DATA AND ASSUMPTIONS

Sales and survival curve

Historical sales data through 2021 for the HDT segment are taken from the Society of Indian Automobile Manufacturers (SIAM; 2022). To estimate future CO_2 emissions, we project HDT sales forward until the net-zero target year of 2070 (see Figure 2). Near-term market predictions are adjusted based on stakeholder consultations to account for the dip and recovery of vehicle sales related to COVID-19.

Figure 2
Projected HDT sales in India



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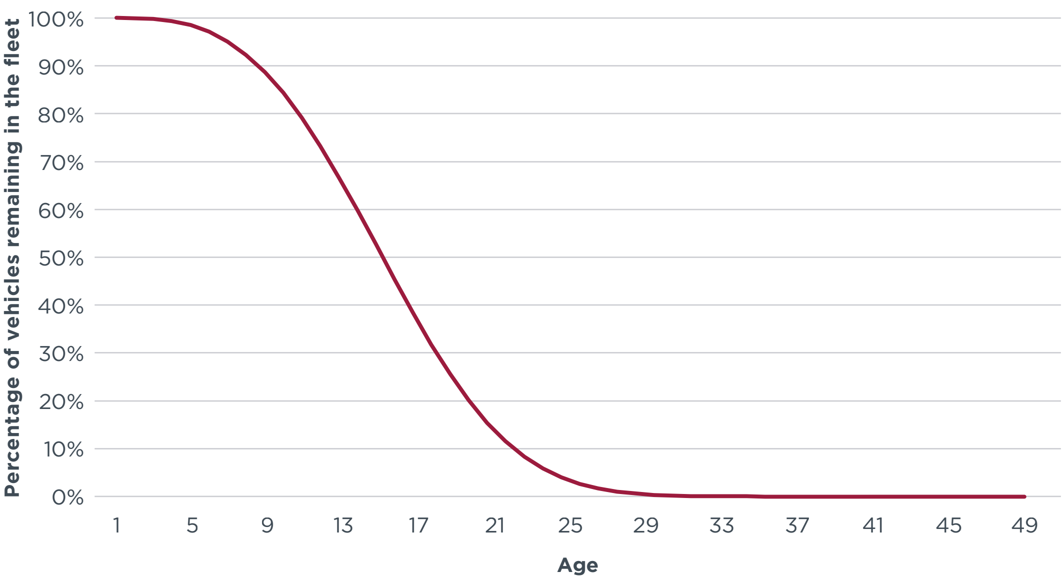
Annual HDT sales data were then used to estimate total HDT stock using survival fractions based on the age distribution of trucks on-road in India. We assumed an average HDT retirement age of 15 years, based on consultations with manufacturers and the existence of a voluntary vehicle scrappage program that incentivizes vehicle scrappage after 15 years in operation (MoRTH, 2021). Figure 3 shows the survival curve for the HDT segment in India. The curve is iterated using the from-age-zero survival curve formula in the Roadmap model documentation (ICCT, 2022), such that the average retirement age of trucks is 15 years of age. However, as reflected in the long tail of the survival curve, we assume that some vehicles would survive for a longer time horizon. In our analysis, we assume that any such vehicles still in operation in 2070 would be scrapped to remove residual emissions and meet exact net-zero by the government's 2070 target.

Figure 3
Survival curve of HDTs in India



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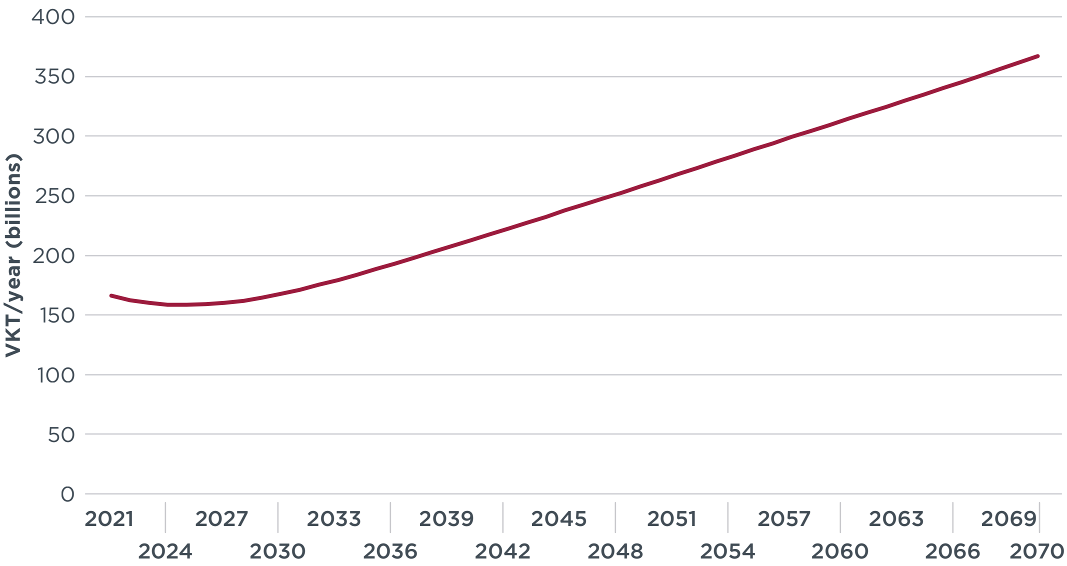
Vehicle activity

As noted above, vehicle activity is measured in VKT; for the present analysis, we assume an average VKT per vehicle per year of around 59,300 (ICCT, 2022). We multiply this average VKT by the total stock and sales share by powertrain type to obtain the total HDT activity per powertrain. Figure 4 presents the projected total annual VKT of the HDT segment between 2021 and 2070. These projections are within the range of total HDT VKT provided by different energy models reviewed in a 2022 ICCT meta-analysis of road transport emission models in India (Kumar et al., 2022).

Figure 4
Projected total VKT by HDTs in India



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Powertrains and energy intensity

Conventional diesel-fueled internal combustion engines (ICEs) are the leading powertrain in India. Our study analyzes two ZET alternatives: battery-electric trucks (BETs) and fuel-cell electric trucks (FCETs). BETs use an electric motor and battery instead of a conventional ICE to provide tractive power to the vehicle. This makes BETs much more efficient than ICEs due to reduced thermodynamic losses. FCETs convert hydrogen into electricity and ultimately into tractive power with zero tailpipe emissions.

India has launched a National Hydrogen Energy Mission with the objective of making India a leading producer and supplier of green hydrogen globally and promoting demand in specific sectors, including transport (Press Information Bureau, 2023). For the present study, however, we assume that up to 80% of ZETs deployed in the future will be BETs, based on sales trends and model availability in other vehicle segments in India and other global regions, in which battery electric powertrains have led the transition to electric vehicles (Basma & Rodriguez, 2021; MoRTH, 2023).

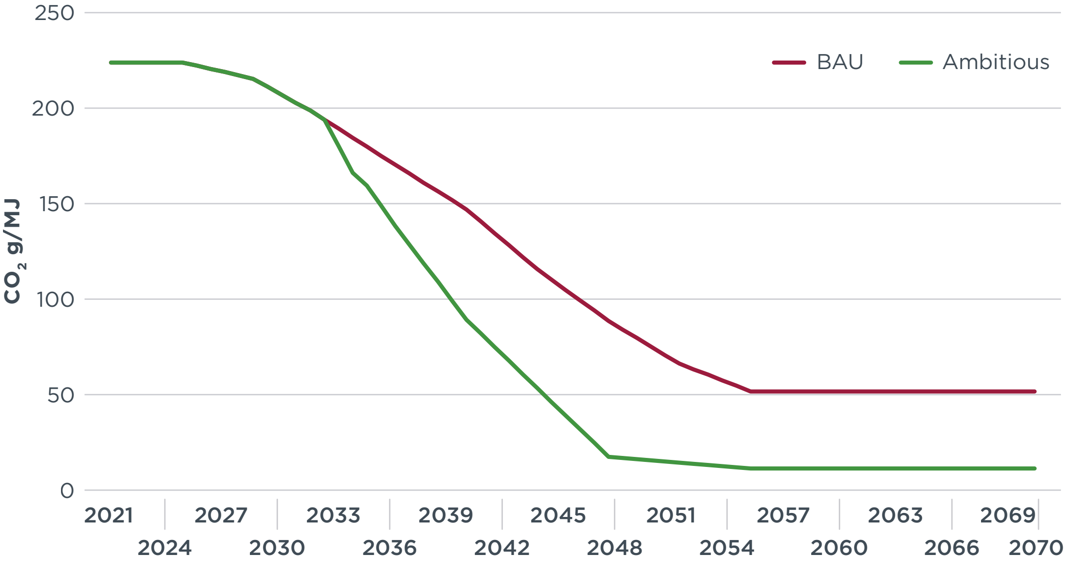
Energy intensity reflects vehicle energy consumption per kilometer and is measured in megajoules per kilometer (MJ/km). We base our energy intensity assumptions for diesel trucks and BETs on Yadav et al. (2023) and our assumptions for FCETs on the Roadmap model (ICCT, 2022). The energy intensity of diesel trucks is assumed to be constant in the baseline case, while in other scenarios, we assume up to 40% improvement in energy intensity (Yadav et al., 2023). We assume that the energy intensity of BETs and FCETs remains uniform throughout the period analyzed.

Grid emissions intensity

To estimate WTW CO_2 emissions, we also made assumptions related to the emissions intensity of the grid. (Grid carbon intensity does not affect TTW CO_2 emissions.) We analyze two scenarios: a business-as-usual (BAU) grid scenario and an ambitious decarbonized grid scenario. The BAU grid scenario is assumed from the International Energy Agency (IEA) Stated Policies Scenario (STEPS; IEA, 2020). The ambitious decarbonized grid scenario, which assumes a higher renewable share in the grid to reduce total carbon emissions, is based on Kumar et al. (2022). Figure 5 shows the emissions intensity values for each grid scenario.

Figure 5

Carbon intensity (CO_2 g/MJ) of the BAU and Ambitious grid scenarios



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Hydrogen emissions intensity

Most hydrogen currently used in India is sourced from fossil fuels, and in policy circles in India the hydrogen created from various fossil sources is referred to as grey hydrogen (Ministry of New and Renwable Energy, 2023). As noted above, however, the government has announced plans to expand domestic production and use of green hydrogen, which by definition must be generated using renewable energy sources, under its National Hydrogen Energy Mission. In 2023, Indian authorities issued a new Green Hydrogen Standard for India, which stipulates that hydrogen must have well-to-gate emissions (including both electrolysis-based and biomass-based hydrogen production methods) of not more than 2 kg CO_2 equivalent (CO_2e) per kg of hydrogen to be classified as green (Press Information Bureau, 2023).

In the present study, as an exploratory exercise, we examine the impact of both grey and green hydrogen on WTW CO_2 emissions across the scenarios analyzed. Figure 6 shows the carbon emissions intensity of grey and green hydrogen. Grey hydrogen emission intensity values initially improve over time, from 115.20 CO_2 g/MJ to 62.46 CO_2 g/MJ, accounting for reductions in emissions with process improvements and grid decarbonization (Bieker, 2021). According to India's official definition, the emissions intensity of green hydrogen is kept constant at 16.6 CO_2 g/MJ.[1]

1 This is derived from 2 kg CO_2 equivalent/kg H_2, stipulated in the new Green Hydrogen Standard for India.

Figure 6

CO_2 emission intensity for grey and green hydrogen

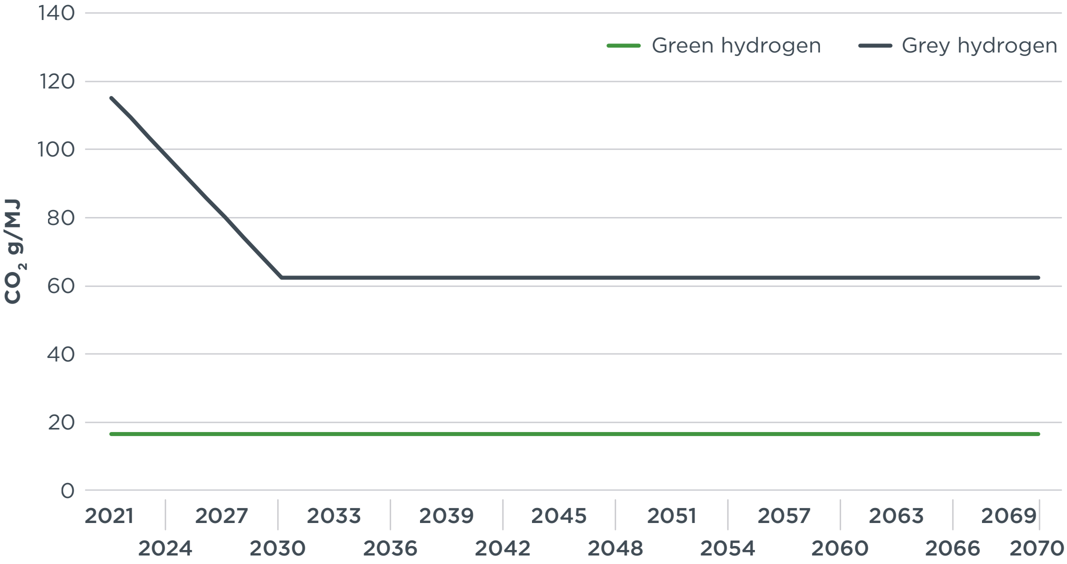

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Table 1 presents a summary of the input data, assumptions, and sources used in our modeling.

Table 1

Table of input data and assumptions

Input	Data and assumptions
Sales	Annual vehicle sales 2000–2021: SIAM (2022) Projected sales 2022–2070: Projected using growth rate based on expert's suggestion and literature review from Kumar et al. (2022)
Survival fraction	Age-wise survival rate of HDTs based on an average retirement age of 15 years: Roadmap Model (ICCT, 2022) and Pandey and Venkataraman (2014)
VKT/veh/yr	Average annual VKT of 59,300 km throughout the analysis period: Kumar et al. (2022) and ICCT (2022)
Powertrains	ICE diesel, BETs, and FCETs
Sales share by powertrain	2000–2021: MoRTH (2023) 2022–2070: Varies based on scenarios (Baseline, 2070 Net Zero, and Ambitious)
Energy intensity	2022–2070 for ICE diesel trucks: Yadav et al. (2023) 2022–2070 for BET and FCET: Bieker et al. (2021)
Fuel emission intensity	Bieker et al. (2021), Kumar et al. (2022), IEA (2020), Roadmap model (ICCT, 2022)

SCENARIOS

We constructed three policy scenarios based on different ZET penetration levels, energy intensity improvement rates, electricity grid CO_2 emission intensity levels, and FCET adoption. Table 2 briefly describes each scenario, which we examine in detail below.

Table 2
Summary of the scenarios analyzed in this study

Scenario	Brief description	Energy intensity (EI) improvement	ZET penetration	Electricity grid	Hydrogen	Additional policy assumptions
Baseline	Reference scenario, no new policies assumed after 2021	No improvement	Zero	BAU grid (IEA STEPS projected to 2070)	No FCETs	
India 2070 Net-Zero	Focuses on ZET penetration required to meet India's 2070 Net-Zero target	Ambitious energy intensity improvement of ~40% in diesel trucks	100% ZET sales by 2050	Ambitious decarbonized grid	Green hydrogen	Scrappage of vehicles causing residual emissions in 2070, all of which are at least 20 years old
Ambitious	Most aggressive decarbonization scenario	Ambitious energy intensity improvement of ~40% in diesel trucks	100% ZET sales by 2045	Ambitious decarbonized grid	Green hydrogen	Scrappage of 15-year-old diesel trucks and avoid-and-shift in VKT by improvements in freight logistics

BASELINE SCENARIO

The Baseline scenario reflects India's projected HDT emission trends in the absence of new policies. It assumes zero ZET penetration, no energy intensity improvements in diesel trucks since the reference year (2021), and CO_2 emission intensity values for the baseline grid drawn from IEA's STEPS model (IEA, 2020).

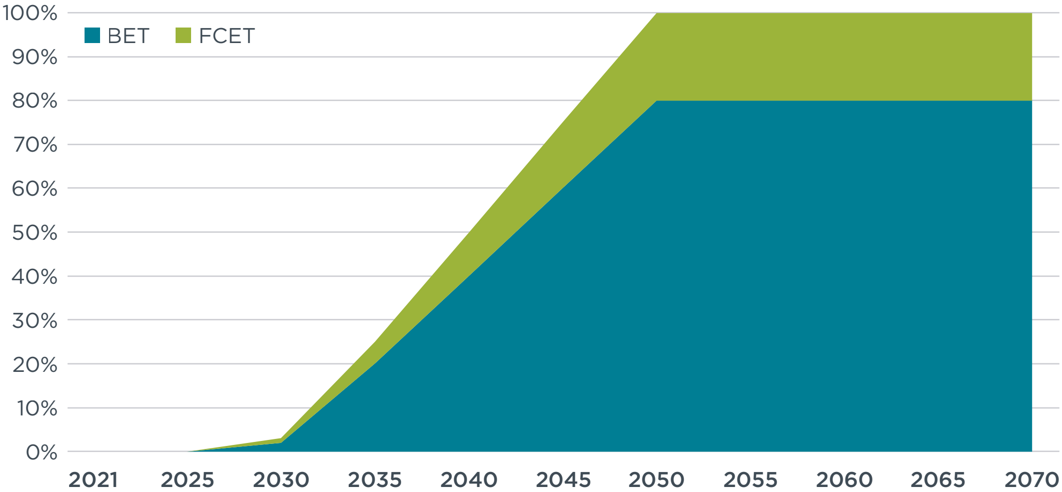
INDIA 2070 NET-ZERO SCENARIO

The India 2070 Net-Zero scenario estimates the ZET penetration level required to meet India's 2070 net-zero target. ZET penetration rates for both BETs and FCETs in this scenario are shown in Figure 7. We assume an ambitious energy intensity improvement of 40% from the reference year for diesel HDTs (Yadav et al., 2023). For WTW emissions, we assume the ambitious decarbonized grid CO_2 emission intensity outlook shown in Figure 6. As noted above, we also assume that any vehicles that cause residual emissions will be scrapped in 2070 to meet the net-zero by 2070 deadline.

We used a logistic function to determine the ZET penetration curve for this scenario and iterated the midpoint and steepness parameter with the aim of reducing TTW HDT emissions to reach net-zero by 2070. Each iteration had a different trajectory of ZET sales and associated emissions; for our analysis, we used the most conservative trajectory that reached 100% ZET sales by 2050 (see Figure 7). Any rate below this will lead to higher HDT emissions and result in failing to achieve the 2070 net-zero target.

Figure 7

Trajectory of BET and FCET sales share for the India Net-Zero 2070 scenario



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AMBITIOUS SCENARIO

The Ambitious scenario is the most aggressive decarbonization trajectory. Based on a 2023 ICCT study of emission pathways that are compatible with the Paris Agreement (Sen & Miller, 2023), it assumes an accelerated transition to 100% ZETs by 2045 to set the sector on a pathway consistent with keeping global warming well below 2 °C. Energy intensity levels, grid CO_2 emissions intensity, and FCET assumptions are similar to the India Net-Zero 2070 scenario, but this scenario considers two additional mitigation measures: avoid-and-shift policies for freight travel and the mandatory, continuous scrappage of trucks older than 15 years from the fleet to accelerate ZET uptake (Sen & Miller, 2023). The scrappage strategy is based on India's voluntary vehicle scrappage program, which incentivizes the scrappage of diesel trucks if declared unfit after 15 years of age (MoRTH, 2021).

Table 3 presents the ZET sales shares, broken down by BETs and FCETs, assumed in the Baseline, India 2070 Net-Zero, and Ambitious scenarios.

Table 3

ZET sales in Baseline, India Net-Zero 2070, and Ambitious scenarios

	Baseline		India Net-Zero 2070		Ambitious	
Year	**BET sales**	**FCET sales**	**BET sales**	**FCET sales**	**BET sales**	**FCET sales**
2020	0%	0%	0%	0%	0%	0%
2025	0%	0%	0%	0%	2%	1%
2030	0%	0%	2%	1%	24%	6%
2035	0%	0%	20%	5%	48%	12%
2040	0%	0%	40%	10%	72%	18%
2045	0%	0%	60%	15%	80%	20%
2050	0%	0%	80%	20%	80%	20%
2055	0%	0%	80%	20%	80%	20%
2060	0%	0%	80%	20%	80%	20%
2065	0%	0%	80%	20%	80%	20%
2070	0%	0%	80%	20%	80%	20%

Note: Green cells represent 100% ZET sales share in the given years.

RESULTS AND DISCUSSION

VEHICLE KILOMETERS TRAVELED SHARE BY POWERTRAIN

The VKT share per powertrain evolves throughout the analysis period due to fleet turnover to ZETs, which shifts the VKT from ICE vehicles to ZETs. With only ZET penetration but without additional supportive policies, the shift in VKT share in the India Net-Zero 2070 scenario is gradual, starting from 1% in 2030 to 95% in 2060 (see Figure 8). In the Ambitious scenario, with additional avoid-and-shift and scrappage policies, the shift in total VKT from ICE to ZETs is both higher and faster, increasing from 12% in 2030 to 95% in 2050 (see Figure 9).

In examining various decarbonization scenarios, it is noteworthy that a non-zero number of diesel HDTs remain by 2070, contributing to residual emissions. As noted above, this can be attributed to the extended tail of the survival curve, as a small fraction of HDTs operate for more than 15 years. There are 12,000 such vehicles remaining in the India Net-Zero 2070 scenario and 300 in the Ambitious scenario. To attain absolute zero emissions, it is assumed that these vehicles will undergo scrappage in 2070 to reduce their VKT share to zero.

Figure 8
Fleet VKT share of HDT powertrains in the India Net-Zero 2070 scenario

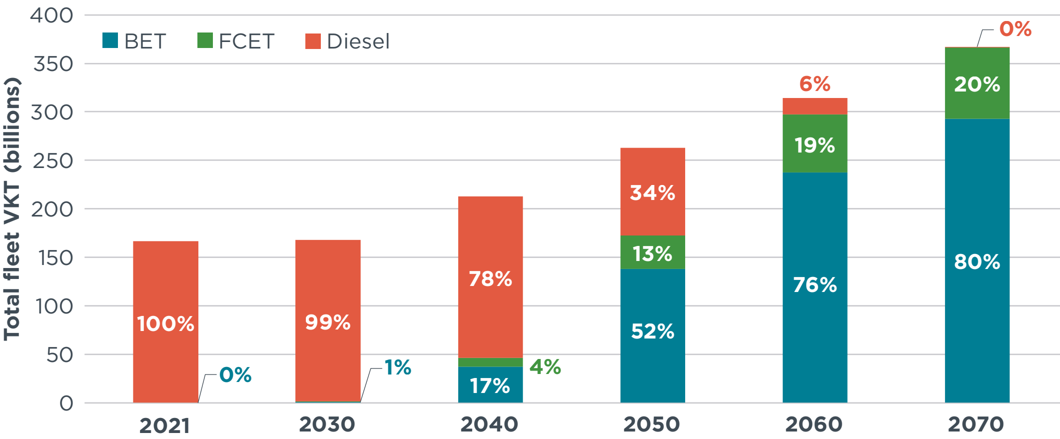

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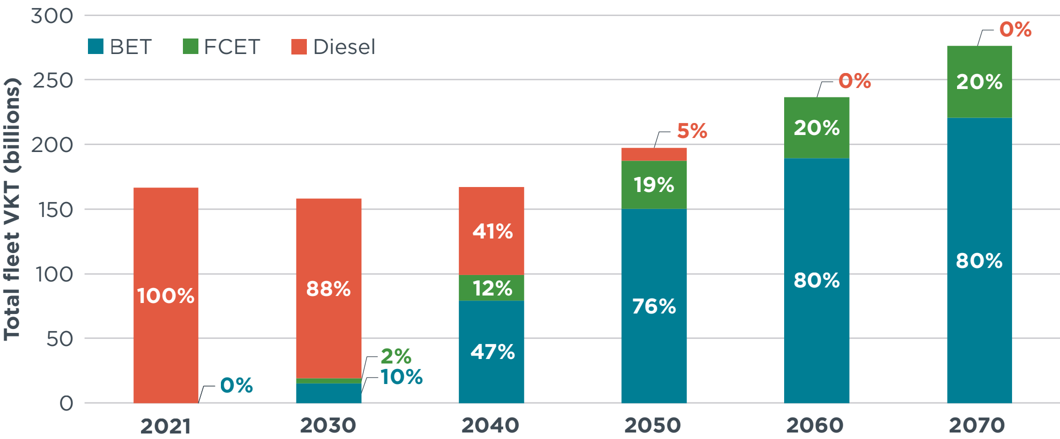
Figure 9
Fleet VKT share of HDT powertrains in the Ambitious scenario



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TANK-TO-WHEEL CO_2 EMISSIONS

Figure 10 illustrates TTW CO_2 emissions in our three scenarios. In our Baseline case, without any policy changes, diesel HDTs remain the dominant powertrain and CO_2 emissions continuously rise, reaching 365 million metric tons (MMT) in 2070—2.5 times greater than 2021 levels. The dashed line depicts the emissions trajectory assuming an ambitious energy intensity improvement of 40% from the reference year for diesel HDTs, still absent any ZET penetration. This results in a maximum 40% reduction in CO_2 emissions from the HDT segment in 2070 compared to the Baseline scenario.

In the India Net-Zero 2070 scenario, with 100% ZET sales in 2050 and energy intensity improvements for diesel HDTs, we reach 99.9% emission reduction by 2070. The remaining emissions are from surviving older vehicles, which we assume will be scrapped in 2070 to fully achieve net-zero emissions by the target year. Meanwhile, in the Ambitious scenario, with 100% ZET sales by 2045, ambitious energy intensity improvements for diesel HDTs, and additional vehicle scrappage and avoid-and-shift policies in place, we reach a 99% reduction in CO_2 emissions by as early as 2055. It would take 5 years to eliminate the remaining 1% of emissions through the continuous scrappage of 15-year-old vehicles that remain in operation. Both the India Net-Zero 2070 and Ambitious scenarios thus ultimately achieve the net-zero target by 2070.

Figure 10

TTW CO_2 emissions from the HDT segment

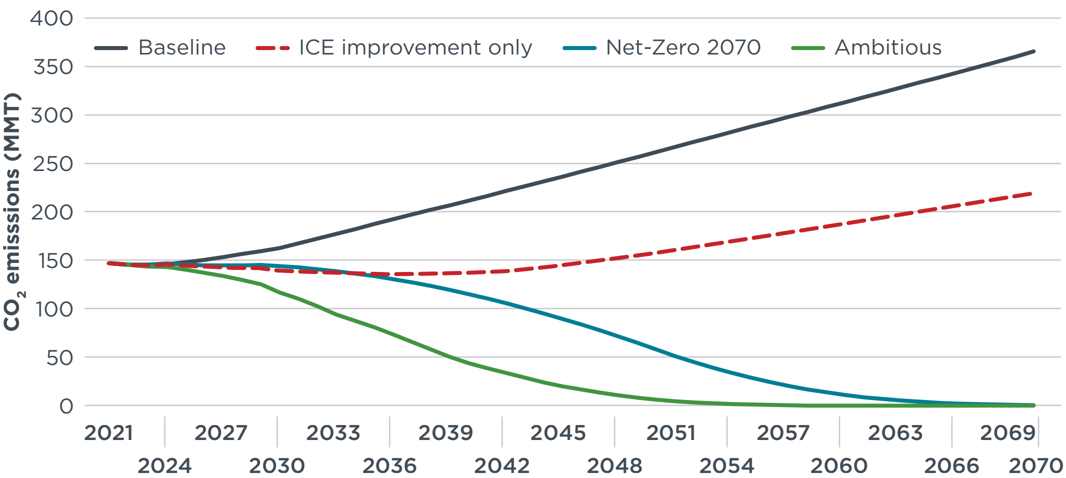

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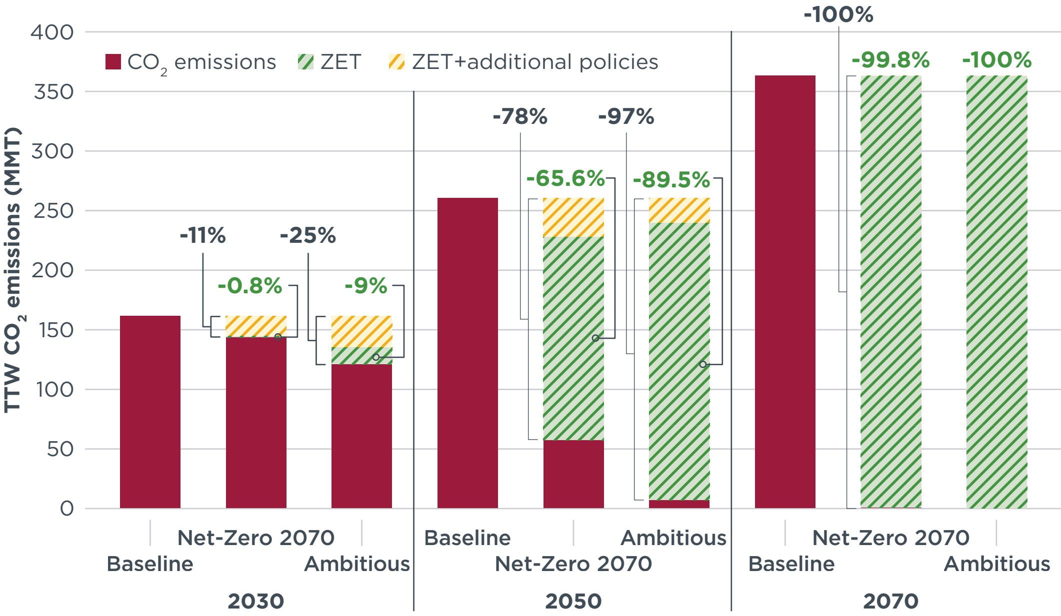
Figure 11 examines TTW CO_2 emissions in 2030, 2050, and 2070 across our three scenarios. As seen in the figure, in which percentages indicate relative emissions reductions over the Baseline with only ZET deployment and no additional supporting policies, the emissions reduction is limited in the initial years due to lower ZET penetration rates. In this period, additional polices play a more important role in curbing emissions: With improvement in energy intensity for diesel vehicles and avoid-and-shift and scrappage policies in place, the India Net-Zero 2070 and Ambitious scenarios show an 11% and 25% TTW emissions reduction over the Baseline, respectively, by 2030. As ZET deployment picks up, relative reductions over the Baseline increase to 78% (in the India Net-Zero scenario) and 97% (Ambitious scenario) in 2050. In 2070, TTW emissions are zero in both the India Net-Zero 2070 and Ambitious scenarios compared to the Baseline scenario, indicating the mitigation potential of these scenarios in reaching the India's 2070 net-zero target.

Figure 11

Annual TTW CO_2 emissions reduction achieved in 2030, 2050, and 2070 (percentages show relative reduction in emissions over the Baseline scenario)



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WELL-TO-WHEEL CO_2 EMISSIONS

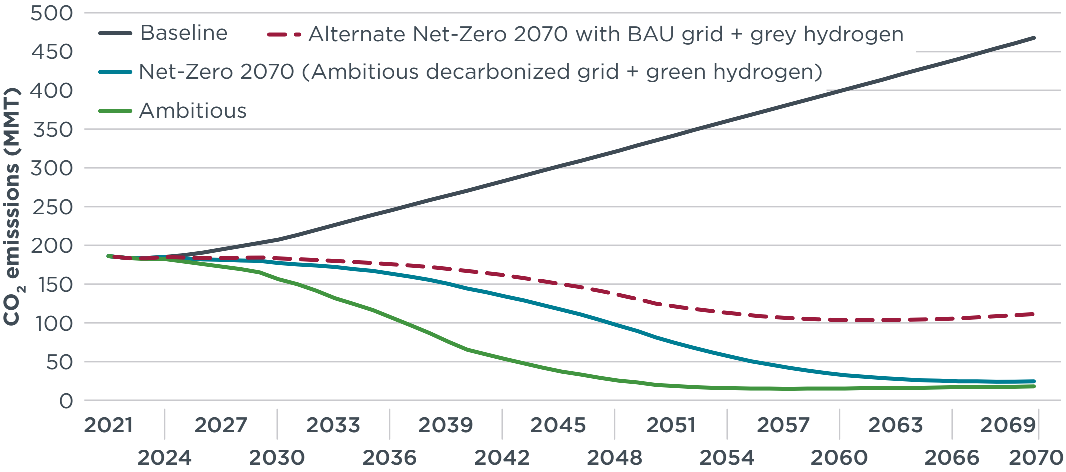
Along with tailpipe emissions, we also examined WTW CO_2 emissions from HDTs, including upstream emissions due to fuel extraction and electricity generation. In our study, WTW CO_2 emissions will change with variation in ZET penetration rates, relative shares of BETs and FCETs in future ZET deployment, relative shares of grey or green hydrogen used to fuel FCETs, and grid carbon intensity levels.

Importance of grid decarbonization

In the Ambitious scenario, the ambitious decarbonized grid and the use of green hydrogen results in a 97% WTW CO_2 emissions reduction in 2070. The India Net-Zero 2070 scenario with the same ambitious decarbonized grid and the use of green hydrogen results in a 96% reduction (Figure 12). Figure 12 also illustrates an Alternate Net-Zero 2070 scenario with a BAU grid and with continued use of grey hydrogen; here emission reductions reach only 76% in 2070, even with high ZET penetration. This outlines the importance of continued efforts in pursuit of grid decarbonization and the push for green hydrogen as fuel instead of grey hydrogen in FCETs.

Figure 12

Annual WTW CO_2 emissions by scenarios



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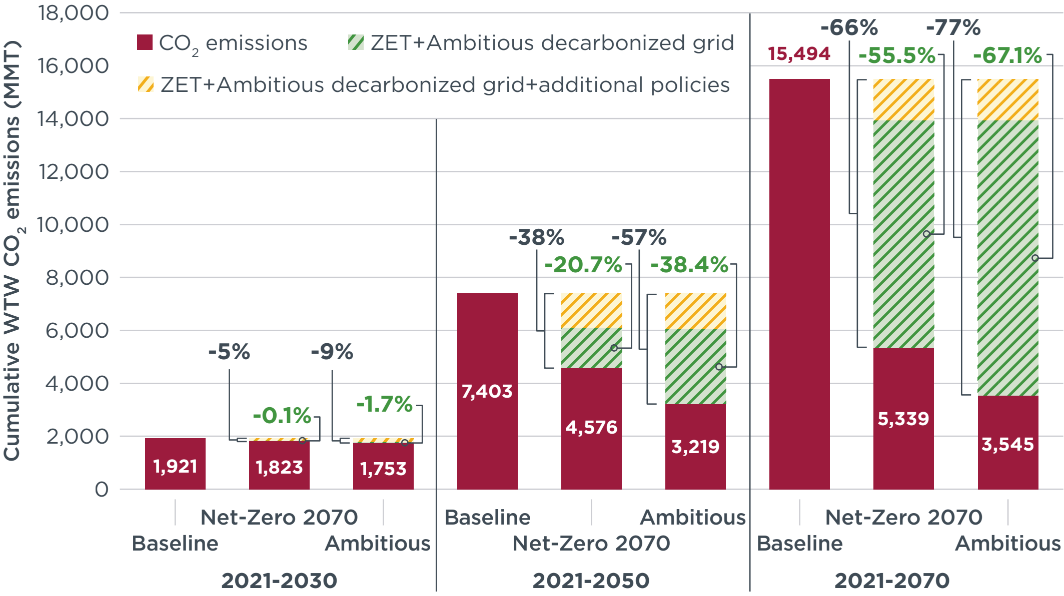
Cumulative WTW CO_2 emission impacts

Because global temperature change is a function of cumulative emissions, we also evaluated the impacts of each scenario on cumulative WTW CO_2 emissions from HDTs through 2070. Sen and Miller (2023) found that combining an accelerated zero-emission vehicle transition with improvements in ICE efficiency, accelerated fleet renewal, improved freight logistics, and zero-carbon electricity and hydrogen for trucks could align with a well-below 2 °C (1.7 °C) pathway. Because the Ambitious scenario in this study includes those additional measures, it can be considered compatible with a well-below 2 °C pathway, assuming similar actions in other countries.

Figure 13

Cumulative WTW CO_2 emissions from HDT segment through 2030, 2050, and 2070 (percentages show relative reduction in emissions over the Baseline scenario)



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If we consider the India Net-Zero 2070 scenario without supplementary policies, ambitious grid decarbonization results in minor emission reductions of 0.1% by 2030, as illustrated in Figure 13. Even in the Ambitious scenario, the emissions reduction attributable to ZET adoption is limited to 1.7% by 2030. This is explained by the lower number of vehicles in the stock displaced by ZETs in initial years, during which additional policies like scrappage and avoid-and-shift measures play a significant role in curbing emissions, as noted above. With these additional policies in place, by 2030, the cumulative emissions reduction is 5% in the India Net-Zero 2070 scenario and 9% in the Ambitious scenario.

The cumulative emissions reduction attributable to ZET adoption rises as the share of ZETs increases over the years. By 2050, fleet turnover to ZETs results in emission reductions of 20.7% and 38.8%, respectively, in the India Net-Zero 2070 and Ambitious scenarios. Yet, with additional policies in place, these reductions amount to 38% and 57% by 2050 in the Net-Zero 2070 and Ambitious scenarios, respectively. By 2070, assuming the ambitious decarbonized grid, the India Net-Zero 2070 scenario results in a 55.5% cumulative emissions reduction, reducing further to 66.0% with additional policies in place; without a decarbonized grid and the use of green hydrogen, however, the cumulative reduction over the Baseline in the India Net-Zero 2070 scenario would be limited to only 53%. Meanwhile, assuming the ambitious decarbonized grid, the Ambitious scenario results in a 67.1% cumulative reduction by 2070, reducing further to 77.0% with additional policies in place. These outcomes underscore the critical importance of the pace of decarbonization through ZET penetration in parallel with grid decarbonization and complementary measures such as accelerated fleet renewal, ICE improvements, and improved freight logistics to reduce VKT.

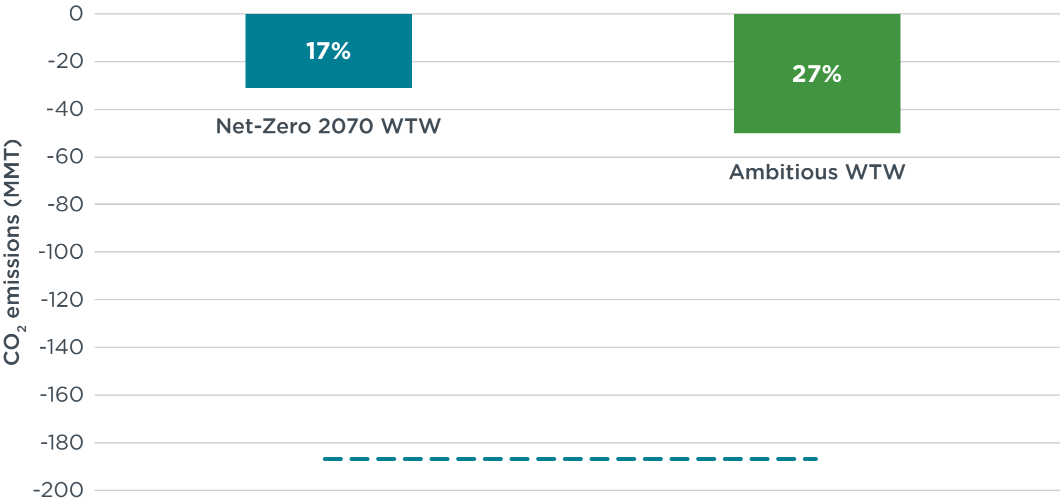
Comparison with the India 2030 emissions target

According to the government's Panchamrit climate action plan, "by 2030, India will reduce the carbon intensity of its economy to less than 45 per cent." The sectoral breakdown under the plan's energy efficiency domain suggests that a 187 $MtCO_2e$ emissions reduction from the transport sector would be necessary to help achieve this overall target (Central Electricity Authority, 2023).

Figure 14 compares WTW CO_2 emission reductions achieved by the HDT segment in the India Net-Zero 2070 and Ambitious scenarios. The Panchamrit target specifies CO_2e emissions from India's transport sector. This study estimates only WTW CO_2 emissions from the HDT segment of the road transport sector because we assume the shares of other greenhouse gases, such as nitrous oxide and methane, are comparatively very low. Based on our analysis, Figure 14 shows the estimated fraction of the target delivered by CO_2 reductions from HDTs in both scenarios.

Figure 14

Contribution of CO_2 from HDTs to the 2030 emissions reduction target under the Panchamrit plan



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As shown in Figure 14, under the India Net-Zero 2070 scenario, reductions in the HDT segment could constitute roughly 17% of the CO_2 emissions reduction envisioned in the Panchamrit by 2030, while under the Ambitious scenario, the HDT segment has the potential to achieve approximately 27% of this target. Therefore, along with ZET penetration and decarbonized grid, supporting policies such as scrappage and avoid-and-shift could increase the percentage share of that target achieved by the HDT segment.

CONCLUSION

In this working paper, we assessed the emissions trajectory of HDTs from 2021 to 2070 across various scenarios to ascertain the ZET penetration rate required to meet India's net-zero objective. Beyond the 2070 net-zero goal, we also examined more ambitious scenarios that involve a more aggressive ZET penetration rate, resulting in a trajectory that aligns more closely with the international ambition of achieving net-zero emissions by 2050.

Based on the results of this study, the following conclusions can be drawn:

» Without policy intervention, emissions from HDTs in India are projected to surge to more than 2.5 times 2021 levels by 2070.

» Even with the highest achievable energy intensity improvements in diesel engine powertrains, without ZETs, India reduces CO_2 emissions by only 40% by 2070, which is not enough to achieve the net-zero target.

» To align with the 2070 net-zero target, India would need to achieve 100% ZETs for new sales by no later than 2050. To align with a global pathway to limit warming to well below 2 °C, ZET sales would need to be further accelerated to reach 30% by 2030 and 100% by 2045.

» Grid decarbonization is a vital condition in all scenarios to meet the net-zero 2070 target. Without robust efforts to decarbonize the grid and source hydrogen from renewable energy, there would only be a 76% emissions reduction by 2070, even assuming ambitious ZET penetration.

» The Ambitious scenario results in a cumulative emissions reduction of 77% by 2070 relative to the Baseline scenario, whereas the India Net-Zero 2070 scenario results in a reduction of 66%. Without a decarbonized grid and the use of green hydrogen, this cumulative reduction over the Baseline is limited to only 53%. This underscores the critical importance of the pace of decarbonization through ZET penetration, grid decarbonization, and the implementation of other strategies, such as vehicle scrappage and logistics optimization, for the attainment of emissions-reduction objectives.

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