Technology and Commercialization Pathways for Zero-Emission Medium- and Heavy-Duty Vehicles in Mexico

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Acronyms & Definitions

ACT	Advanced Clean Trucks (regulation)
AMIA	Mexican Association of the Automotive Industry
ANPACT	National Association of Bus, Truck and Tractor-Trailer Producers
CARB	California Air Resources Board
COP26	26th Conference of Parties
COP27	27th Conference of Parties
GHG	Greenhouse gas
GVWR	Gross vehicle weight rating
ICT	Innovative Clean Transit (rule)
INEGI	National Institute of Statistics and Geography
IOO	Independent Owner Operator
ISAN	Mexican New Vehicles Tax
ISR	Mexican Income Tax
MHDV	Medium- and heavy-duty vehicle
MOU	Memorandum of Understanding
NGO	Non-governmental Organization
NOM	Official Mexican Norm
OEM	Original equipment manufacturer
PF	Preference factor
RAIAVP	Administrative Record of the Heavy Vehicles Automotive Industry
RAIAVL	Administrative Record of the Light Vehicles Automotive Industry
SEMARNAT	Ministry of Environment and Natural Resources
SICT	Ministry of Infrastructure, Communications and Transport
SUV	Sports Utility Vehicle
TCO	Total Cost of Ownership
ZE-MHDV	Zero-emission medium- and heavy-duty vehicle
ZEV	Zero-emission vehicle

Executive Summary

Medium- and heavy-duty vehicles (MHDVs) are responsible for a disproportionate share of on-road fuel consumption, greenhouse gas (GHG) emissions, and health-threatening pollutants. The adverse impact of MHDVs will only be exacerbated with the progression of time and inaction, as these vehicles are projected to continue to increase in volumes across global markets. To revert this trend and tackle harmful diesel emissions, accelerated efforts must be made to shift away from diesel-powered vehicles to cleaner, zero-emission vehicle (ZEV) alternatives.

In Mexico, the transportation sector accounts for over a quarter of the country's total emissions.[1] Trucks and buses represent 25% of vehicles on the road,[2] yet are responsible for 51% of GHG emissions from the transportation sector.[3] The sector is deeply embedded with the country's economic growth, employing over 2.1 million individuals whose work has positioned Mexico as the 7th largest vehicle manufacturer and the largest truck exporter in the world.[4,5]

The country has made some progress toward establishing a ZEV-supportive ecosystem, particularly for passenger cars and public transportation. Mexico has one of the largest networks of publicly available charging stations in Latin America; all zero-emission vehicles are exempt from import and sales taxes; and in some cities, zero-emission vehicles enjoy additional benefits such property tax exemptions and being able to operate at all hours and days of the week. Since 2021, Mexico committed to work intensely to accelerate ZEV adoption,[6] and in 2022, the government committed to increase light-duty ZEV sales and manufacturing to a total of 50% by 2030.[7]

Furthermore, 2022 saw an unprecedented uptake of zero-emission medium- and heavy-duty vehicles (ZE-MHDV) by fleets, with purchase orders exceeding 1,690 vehicles across all MHDV segments. This adoption is paired with an accelerated increase of truck and bus models available, which jumped from less than 10 in 2021 to 36 in 2022.[8]

Despite this progress, Mexico's long-term vision for carbon neutrality and the decarbonization of the MHDV sector is still unclear. To date, Mexico has not published targets for ZE-MHDV adoption, and is yet to follow regional leaders like Canada, United States, Uruguay, Chile, and the Dominican Republic in signing the Global Memorandum of Understanding on Zero-Emission Medium- and Heavy-Duty Vehicles (Global MOU). The Global MOU was launched by the government of the Netherlands and CALSTART during the 26th Conference of Parties (COP26) and has been signed by 27 countries as of November 2022. The Global MOU brings together countries committed to working toward 100% ZE-MHDV new sales by 2040, with an interim target of 30% by 2030.[9]

The projections outlined in this paper have been developed to identify Mexico's ability to meet the targets set forth in the Global MOU, considering existing market conditions, barriers, opportunities, and sales data for the Mexican MHDV market. The analysis uses CALSTART's Drive to Zero Market Projection Model to estimate the adoption rate of on-road ZE-MHDVs in Mexico.

The model projects how zero-emission sales could grow between 2020 and 2050, using best available data on Mexico's vehicle sales volumes, and the characteristics of the market in terms of technology readiness, fleet bias, supply scalability, infrastructure availability, and fleet innovation profile.

Mexico is well-positioned to increase its ambition to match international targets. Our results show that Mexico could achieve 36% ZE-MHDV sales by 2030, and close to 100% by 2040 in five of the six vehicle categories analyzed, which means the country could realistically aim toward the ambition of the Global MOU. Results by vehicle segment show early adoption for buses and passenger shuttles/vans, followed by single-unit trucks and cargo vans, and pickups/SUVs. Short-haul tractor adoption would follow, tailed closely by long-haul tractors (Figure ES-1). These results reflect the timing for technology readiness of zero-emission technologies for different vehicle vocations, types, and weights, and recognize that technology advances can be transferred across vehicle types as they mature and achieve cost reductions. Utility, urban refuse and construction trucks are expected to take longer to transition. Our assessment for this segment is conservative since it is based on the characteristics of heavier vehicles within the segment, so we expect adoption rates to increase faster than currently projected.

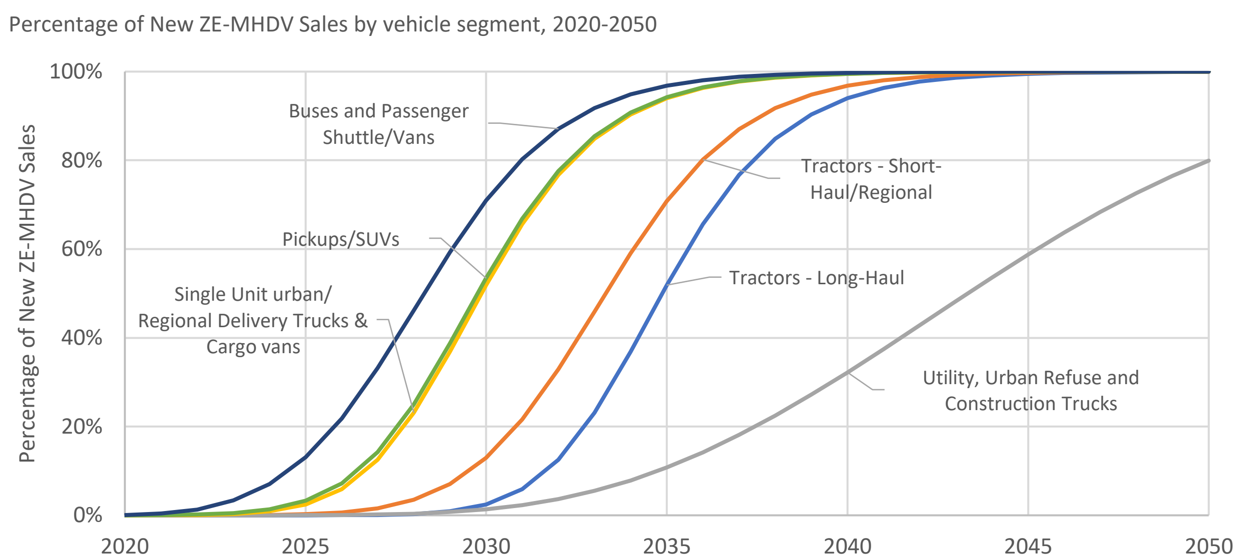


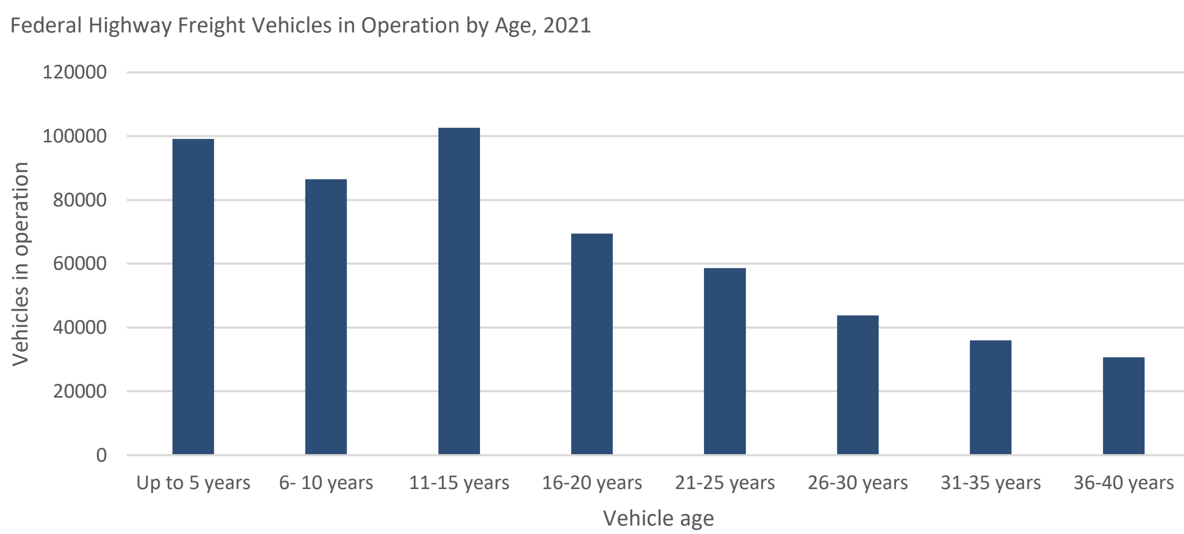
Figure ES-1. All major vehicle segments can approximate 100% ZE-MHDV sales by 2040

With strategic actions from the government and the private sector, Mexico can dramatically shift its transportation sector toward zero-emission technologies within the next 20 years. Failing to do so would risk strong economic downturns for the Mexican automotive industry and increased diesel emissions that would further exacerbate the health and environmental impacts felt by local communities. However, if the targets proposed in this analysis are achieved, Mexico could prevent consumption of close to 60,000 million gallons of diesel fuel by 2050. The annual GHG emissions avoided from eliminating this consumption would equal the removal of over 300,000 passenger cars from the road in 2030, over six million in 2040, and over 13 million in 2050.

1 Background and Motivation

In Mexico, the transportation sector accounts for over a quarter of the country's total emissions.[10] Trucks and buses represent 25% of vehicles on the road,[11], yet are responsible for 51% of GHG emissions from the transportation sector.[12] As of 2022, there are over 11 million trucks operating in Mexico.[13] If the growth trend in the sector continues, we can expect close to 15.5 million trucks on Mexican roads by 2050. Without meaningful actions to reduce transportation emissions, by 2050 the sector's GHG emissions could increase by 145% compared to 2016 levels.[14]

Trucks and buses powered by fossil fuels also have a huge impact on air pollution and health due to nitrogen oxides (NO_X) and fine particulate matter ($PM_{2.5}$) emissions. In 2015, over 32,000 premature deaths in Mexico were attributed to air pollution from fossil fuels.[15] Without meaningful action, by 2050 $PM_{2.5}$ emissions from transportation are expected to double compared to 2016 levels,[16] further contributing to asthma, respiratory and cardiovascular diseases, and premature deaths. Older vehicles contribute disproportionately more to air pollution, and Mexico's federal highway truck stock has an average age of over 20 years (Figure 2), twice the average age of trucks in Germany.[17]



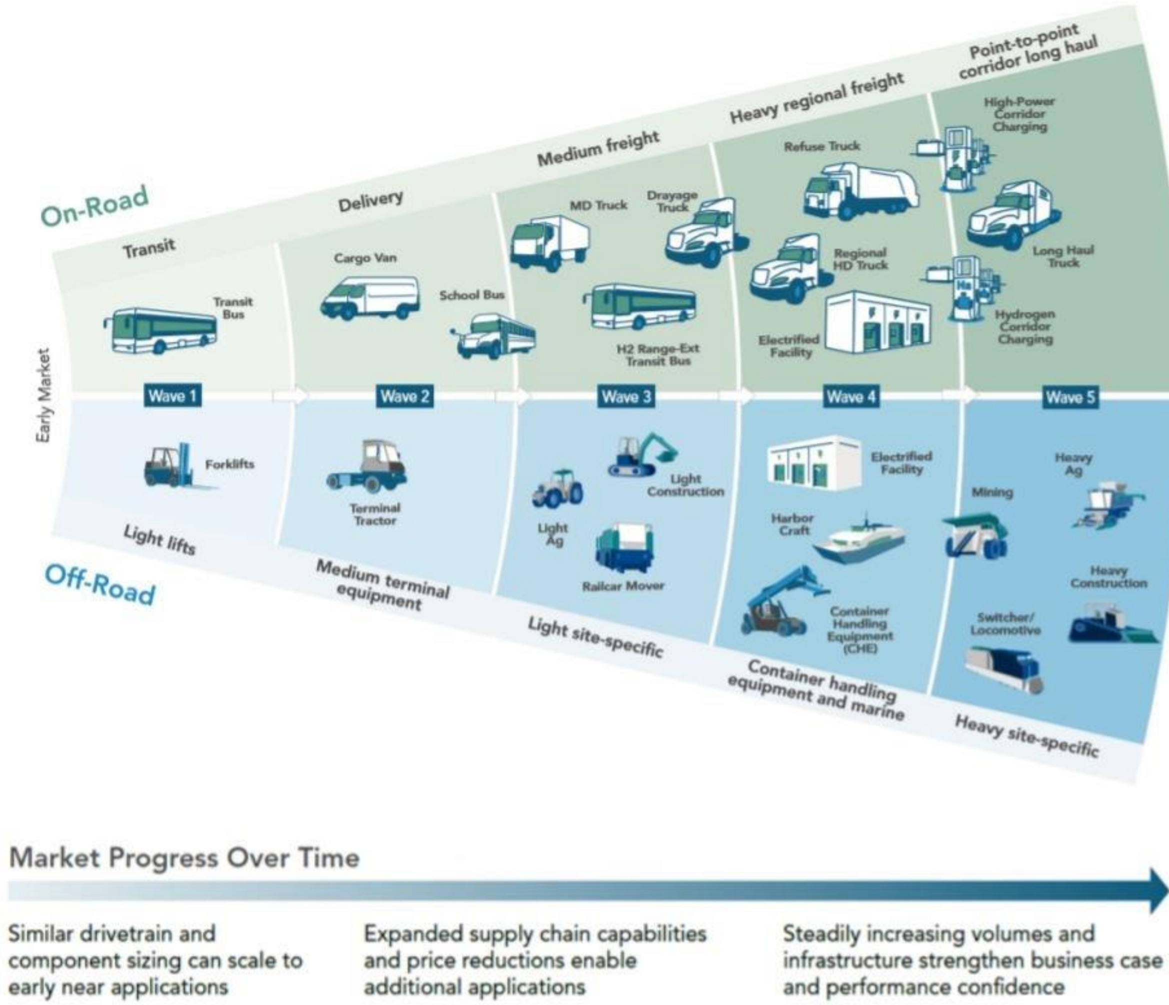
Vehicles older than 40 years (79,209) have been excluded from the chart for simplicity.
Source: SICT (2022)[18]

Figure 2. The average age of the MHDV stock in Mexico is over 20 years

The disproportionate impact that these vehicles have on GHG emissions and other harmful pollutants makes them a threat to both air quality and the climate, and therefore a major target for decarbonization. If meaningful action is to be taken against climate change, there must be a coordinated global undertaking to reduce the impact of MHDVs on the road and ensure the future of trucking does not have an adverse impact on the environment and public health.

In approaching the decarbonization of the transportation sector, passenger vehicles have been a top priority for policy, incentives, and technology development. However, considering the disproportionate emissions impact that such a relatively small share of the on-road fleet is responsible for, policy attention must also focus on the heavier vehicle segments. Awareness of ZE-MHDV technological capability and model availability lags what is being offered on the market today. Major barriers such as range and operational feasibility have largely been overcome for select segments such as transit buses, urban delivery, and regional haul, with all segments boasting models that can meet or exceed the characteristic drive cycle for these operations.[19] Additionally, cost analyses already predict that all ZE-MHDV applications will achieve cost parity in most markets before 2030.[20]

By focusing on the vehicle segments where zero-emission models can be deployed today, production can be scaled up more quickly and technology can be transferred across platforms. This approach reflects the Beachhead theory of change, a framework developed collaboratively by California's Air Resource Board and CALSTART to strategically accelerate ZE-MHDV deployments (Figure 3).[21] The Beachhead theory of change targets first-success vehicle applications (or "beachheads") where zero-emission technologies are readily viable, based on their duty cycle, business case, industrial capacity, and performance measures. These initial applications act as cornerstones for the development of adjacent applications and markets, which benefit from technology transfers. As such, zero-emission technology adoption advances in waves, beginning with applications ripe for electrification, and progressing toward other applications as technologies and business cases mature.



Source: CALSTART (2022)[22]

Figure 3. The Beachhead theory of change

With climate urgency building and nations aiming higher to meet the goals of the Paris Climate Agreement, ZE-MHDVs can lead to important climate emissions reductions and help nations achieve their climate commitments. Although zero-emission technologies are rapidly increasing their commercial viability and cost competitiveness across many MHDV applications, much stronger signals from national governments are needed to trigger faster vehicle deployment.

In a historic announcement at COP26, 15 leading nations pledged their support to a Global MOU that establishes targets for countries that will enable net-zero carbon emissions by 2050. The signatories of the MOU include a diverse array of national governments as well as endorsements from over 70 private sector organizations and subnational governments. As of November 2022, 27 nations have signed the Global MOU: Aruba, Austria, Belgium, Canada, Chile, Croatia, Curaçao, Denmark, Dominican Republic, Finland, Ireland, Liechtenstein, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Scotland, Switzerland, Turkey, Ukraine, United Kingdom, United States, Uruguay, and Wales. Through their signature, these countries have pledged their support to the Global MOU and agreed to enabling 30% new ZE-MHDV sales by 2030, and 100% by 2040.[23] As the findings from this assessment show, Mexico is well-positioned to adopt these targets and future-proof its automotive industry, reap the economic benefits of the decarbonization shift, and improve the health and well-being of its people.

1.1 The Mexican Zero-Emission MHDV Market

1.1.1 Zero-Emission MHDV Policy Landscape

Mexico has made progress toward establishing a zero-emission vehicle (ZEV)-supportive ecosystem, particularly for passenger cars and public transportation. Mexico has one of the largest networks of publicly available charging stations in Latin America[24]; all zero-emission vehicles are exempt from import and sales taxes; and in some cities, zero-emission vehicles enjoy operational benefits such as being able to operate at all hours and days of the week, which their diesel counterparts cannot do.

ZEV and GHG emission reduction commitments

In 2021, Mexico was among the 11 governments in emerging markets and developing economies to sign the COP 26 declaration on accelerating the transition to 100% zero-emission cars and vans, committing to work intensely toward accelerating ZEV adoption.[25] Mexico is also a signatory of the Clean Energy Ministerial's EV30@30 campaign, which sets the goal of 30% electric vehicle sales by 2030.[26] On the production side, in 2022 the country committed to increasing the number of ZEVs manufactured in Mexico to 50% of the total national production.[27] Preparing Mexico's manufacturing industry for the ZEV future is critical, since the sector is responsible for over 2.8% of the country's GDP.[28]

Despite this progress, Mexico's long-term vision for carbon neutrality and the decarbonization of the MHDV sector is still unclear. During COP27, Mexico increased its Nationally Determined Contributions to an unconditional 30% reduction target below a business-as-usual scenario by 2030, and 40% conditional to international support.[29] The previous targets were set at an unconditional 22% and a conditional 36%, which Climate Action Tracker ranked as "highly insufficient."[30]

The Ministries of Economy, Foreign Relations, and Environment and Natural Resources have all been working on transport electrification, but interinstitutional coordination needs to be improved. The Ministry of Environment and National Resources (SEMARNAT) has been working on the National Electric Mobility Strategy since 2018, and the final version of the document is expected to be published by early 2023. The strategy considers a comprehensive approach to advance transport decarbonization through regulation; transport company formalization; purchase, operation and scrappage incentives; and creation of zero- or low-emission corridors and zones. A draft shared in 2019 contained preliminary targets for hybrid and zero-emission vehicle sales (across all vehicle segments), set at 5% by 2030, 50% by 2040, and 100% by 2050.[31] Targets are expected to be updated to reflect Mexico's commitment to 50% ZEV sales by 2050 and increased NDCs. However, it is not yet clear how MHDVs will be accounted for. If unchanged or ignored, MHDV targets would fall short from the international targets that have already been adopted by countries like Canada, United States, Chile, Uruguay, and the Dominican Republic. Adopting ambitious sales commitments in line with international standards is a critical first step toward increasing certainty for the industry, and the creation of enforceable sales mandates, such as those adopted in California through the Advanced Clean Trucks (ACT) and Innovative Clean Transit (ICT) regulations.

ZEV technical norms

In terms of technical norms and specifications, Mexico has 10 voluntary norms (Norma Mexicana) which define technical standards for electric vehicles and charging equipment.[32] The automotive industry and government organizations have signaled that additional mandatory norms (Norma Oficial Mexicana) are required to establish minimum safety standards for ZEVs, vehicle components, and charging infrastructure; technical and safety standards for converting an internal combustion engine (ICE) vehicle into battery-electric; and standards for battery waste management.[33]

ZEV Incentives

Mexico offers the following tax exemptions for ZEVs:

- 100% exemption of the New Vehicle Tax (ISAN), which is usually between 2-5% of the vehicle's retail price. ISAN only applies to vehicles with a maximum passenger capacity of 15, and maximum cargo capacity below 4,250 kg.[34]
- 100% import tax exemption for all new electric vehicles. Import tax on new internal combustion engine vehicles is 20% of the vehicle's retail price. Exemption available until September 2024.[35]
- Reduction of import tax from 50% to 15% of the vehicle's retail price for used electric vehicles. Import tax on used internal combustion engine vehicles remains at 50% of the vehicle's retail price. Exemption available until September 2024.[36]
- Additional $75,000 MXN Income tax (ISR) rebate for battery-electric, plug-in hybrid, and hydrogen fuel cell vehicle purchases, on top of the $175,000 MXN rebate for all investments in vehicle purchases.[37]
- 30% ISR credit for investments in publicly available electric vehicle charging stations.[38]
- Additional $85 MXN ISR rebate per day for battery-electric, plug-in hybrid, and hydrogen fuel cell vehicle leases, on top of the $200 MXN rebate per day applicable to all vehicle leases.[39]

It is worth noting that while multiple tax incentives exist, their application is not exclusive to ZEVs. Diesel-powered MHDVs are exempt from ISAN by design and can benefit from 70% of the value of ISR rebates available to ZEVs. The availability of tax rebates for diesel-powered vehicles limits their efficacy to close the price gap between diesel and zero-emission technologies.

Most states also offer property tax exemptions (*tenencia* or *refrendo*) for battery-electric and hybrid vehicles. Mexico City, for example, exempts battery electric and hybrid vehicles from the annual property tax, which is based on the vehicle's value, set at 0.245% for vehicles under 15 tons, and 0.5% for vehicles between 15 and 35 tons.[40] Hybrid and electric vehicles also receive a 20% reduction on highway tolls in Mexico City and the State of Mexico.

Some states also offer operational benefits: in Mexico City and Jalisco, vehicles must comply with semi-annual emission assessments, based on which their operation may be restricted; electric and hybrid vehicles are exempt, which reduces administrative burden and increases operational competitiveness. Additionally, Mexico City has limited freight vehicles weighing over 3.8 tons from operating within the city from 6am to 10am and from 6pm to 8pm, Monday to Friday. Battery-electric, hybrid, gas-powered vehicles, and Euro VI/EPA 10 diesel-powered vehicles are exempt.[41]

Mexico is still in early stages as to the development of additional incentives for vehicle procurement. Nacional Financiera, the country's National Development Bank, is setting up a renewal and scrappage program with support from the German development bank KfW. 100 million euros in funding will be provided by the Federal Ministry for Economic Cooperation and Development of Germany (BMZ). The program will encourage fleet replacement among micro, small and medium companies (MiPyMEs), by covering a portion (yet to be defined) of the cost of a new vehicle, upon scrappage of a vehicle that is 15-25 years old. The incentive will be available to vehicles with cargo capacity under five tons, and allow for the purchase of battery-electric, hybrid, gasoline, and Euro V and Euro VI diesel-powered vehicles. The program would launch in Mexico City, focused on taxis and buses, and later on in Jalisco, focusing on freight vehicles, with the possibility to expand to other states.[42]

1.1.2 Barriers to Zero-Emission MHDV Market Acceleration

Mexico has a unique opportunity to increase its ambition and accelerate ZE-MHDV adoption. Doing so will require coordinated action across government agencies, original equipment manufacturers (OEM), fleets, financial providers, NGOs, and academia to overcome the most pressing barriers limiting technology adoption:

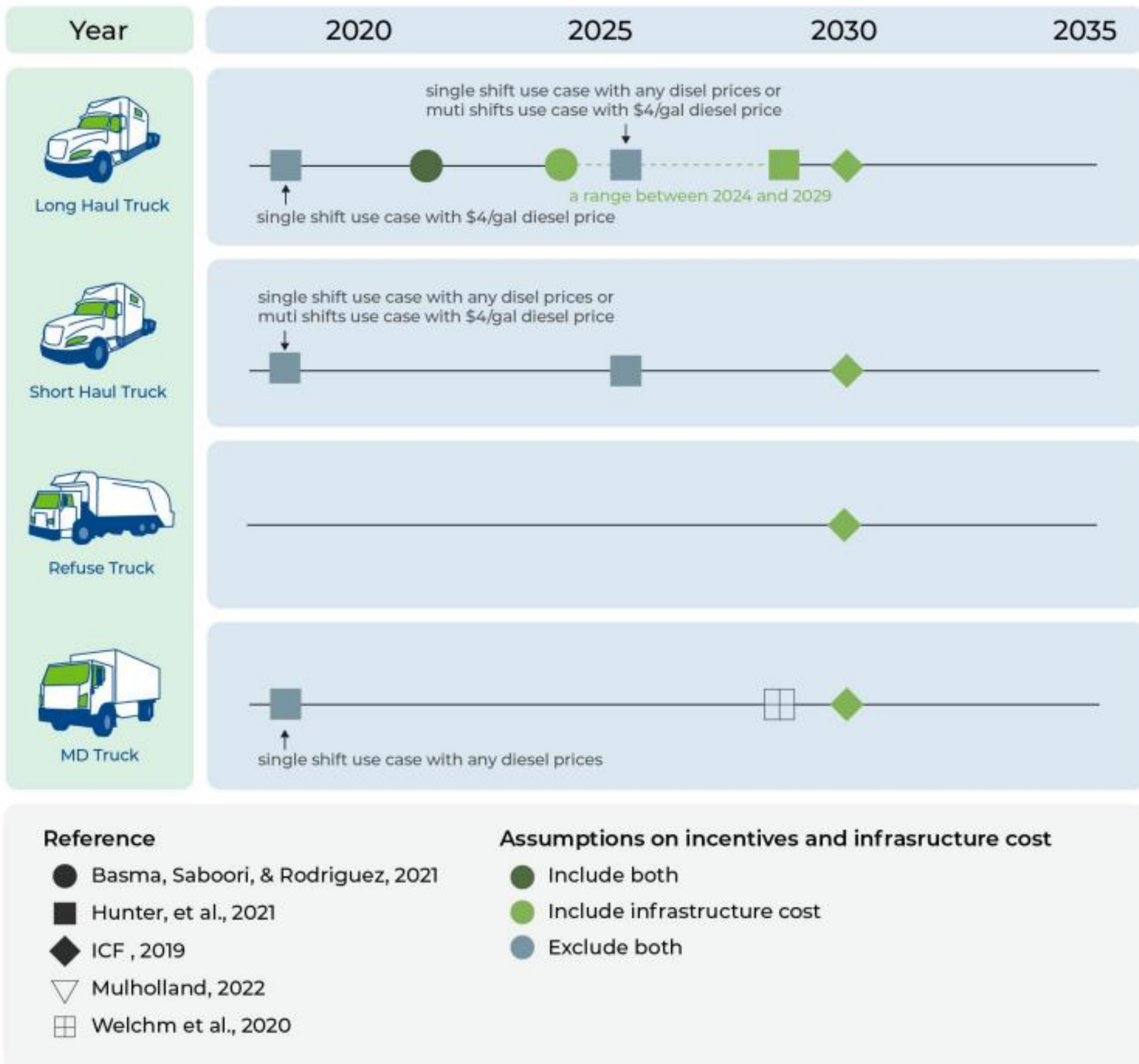
Technology costs

The cost of electric vehicles and associated charging infrastructure is the most cited barrier limiting adoption.[43] Depending on its class and model, a battery-electric vehicle can cost between 40% and 200% more than an equivalent ICE vehicle.[44] A 50 kW Direct Current Fast Charger (DCFC), which could charge even a heavy-duty tractor overnight, can cost between $400,000 and $720,000 MXN[45], plus grid interconnection and installation expenses. Added up, these upfront costs can be a considerable barrier for many fleets, and particularly for micro and small fleets with limited access to financing.

While ZE-MHDVs are more expensive upfront, they provide considerable operational savings over the long term. This is mainly due to the lower cost of electricity compared to diesel, and the lower maintenance costs of ZE-MHDVs compared to ICE vehicles. A case study of battery-electric buses for Mexico City's BRT system, Metrobús, showed that their total cost of ownership (TCO), meaning all capital and operational expenditures over the vehicle's lifetime, is 21% lower than their diesel counterparts over 10 years, and 32% lower over 15 years. This is mostly due to fuel cost savings, which are 78% lower for battery-electric buses compared to diesel.[46]

Technology improvements and economies of scale are rapidly bringing costs down across all vehicle segments, starting with transit buses and light-duty trucks. Commercial availability and TCO projections by ICCT show that ZE-MHDVs will be cost-competitive and commercially mature, and could reach 100% sales as early as 2030 and no later than 2035 in many markets, including Mexico.[47] Further analyses have shown that TCO of ZE-MHDV will reach parity with diesel before 2030, and much sooner with the right policies and incentives in place (Figure 4).[48]

Earliest TCO Parity Year Between Battery-Electric Trucks and Diesel



Source: CALSTART (2022)[49]

Figure 4. TCO will be on parity with diesel by 2030, and much earlier with incentives

In the short term, Mexico will need stronger incentives to encourage early adoption and cover the cost parity gap. These incentives will be temporary and can be scaled back as market prices come down.

Regulation

As mentioned above, regulation on minimum safety and technical standards for ZEVs and charging infrastructure is lacking. This can reduce fleet confidence on technology performance, and OEM confidence on technology's compatibility with future standards.[50] Developing this regulation is included in Mexico's National Electric Mobility Strategy and must be developed as soon as possible to create a ZEV-supportive ecosystem. Mexico also lacks mandatory phase-out regulations and purchase requirements, such as those adopted in California. Even if mandatory phase-out regulations take time to materialize, Mexico can begin to set industry expectations by raising their non-binding commitments, such as by joining the 27 countries that have signed the Global MOU.

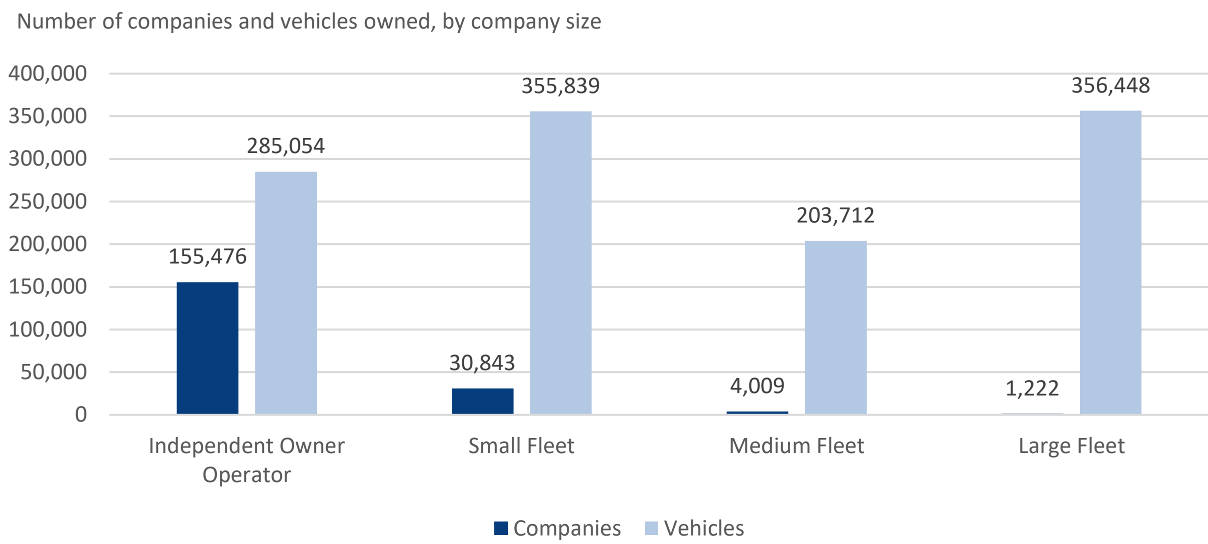
Charging infrastructure

Mexico must rethink its electricity tariffs to lower operational costs of ZE-MHDVs.[51] Some progress has been made for residential passenger car charging through discounted rates and free installation of ZEV-meters, but these actions are yet to be expanded to fleets. While existing tariffs have not limited first-mover fleets from deploying ZE-MHDVs, the Federal Electricity Commission is uniquely positioned to improve the economics of ZE-MHDV deployment and manage demand by encouraging off-peak charging through EV-friendly rates.

Lack of a robust publicly available charging infrastructure network is also commonly cited as a barrier to adoption.[52] Infrastructure availability reduces range anxiety and boosts technology confidence. In the long term, regional travel will require opportunity charging; however, publicly available charging infrastructure will not be a major barrier for ZE-MHDV electrification in the short or medium term, since most vehicle applications rely on depot charging to satisfy their needs.

Fragmented ownership

Small fleets and independent owner-operators (IOOs) play a large role in Mexico's freight sector. Over 81% of companies transporting goods on federal highways are IOOs, and over half of the vehicles and trailers on the road are controlled by IOOs and small companies (See Figure 5).



Source: SICT (2022)[53]

Figure 5. Small fleets and IOOs control over half of the vehicles on the road

These fleets require additional support to transition toward ZE-MHDVs, since they typically have lower access to financing, are further impacted by upfront cost hurdles, and tend make their living on low profit margins.[54] Lack of market knowledge, real estate availability for charging infrastructure installation, and experience with funding applications further complicate the transition. Due to these challenges, which are not exclusive to the Mexican market, larger fleets tend to lead as first adopters of ZE-MHDVs during early transition stages. As familiarity with technology grows, costs decline, and innovative business solutions and government programs are developed, small fleet participation in ZE-MHDV adoption is expected to grow. Government programs like California's Innovative Small e-Fleet pilot can help overcome these barriers by providing additional support to small fleets.[55]

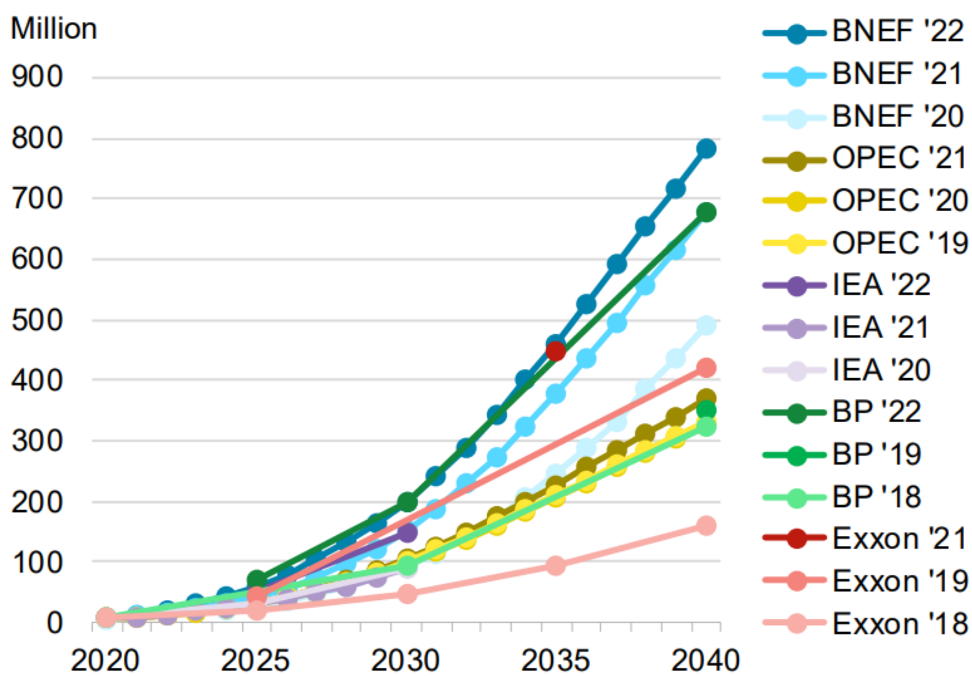
Consumer awareness

Studies have also pointed to the lack of knowledge about ZE-MHDV alternatives as a major barrier limiting adoption.[56] Fleet electrification can be a complicated process for fleets, since it requires detailed understanding of operating patterns and technology capabilities, grid capacity verifications, vehicle and charging station scouting and procurement, infrastructure deployment and route planning. While good resources exist to help fleets navigate this process, few are available in Spanish and able to reach fleets in Mexico.[57] Improving peer-to-peer knowledge-sharing and allowing Mexican fleets to learn from deployments and strategies happening in other geographies is critical to accelerate electrification learning curves, appease technology readiness concerns, and benefit from lessons learned that can reduce costs and mitigate risks.

1.1.3 Opportunities to Zero-Emission MHDV Market Acceleration

Technology costs, regulation, charging infrastructure, fragmented ownership and consumer awareness are the key barriers limiting ZE-MHDV adoption. However, as mentioned in the section above, costs are declining, regulation is planned, awareness is growing, and infrastructure availability and fragmented ownership are unlikely to hinder early adoption by medium and large fleets relying on depot charging. At a global scale, the transition to zero-emission vehicles is happening much faster than initially predicted, and annual ZEV outlooks continue to increase their expected adoption rates, mostly due to increased policy support and growing customer acceptance (Figure 6).

Global passenger and commercial ZEV fleet to 2040, various outlooks



Source: BloombergNEF (2022)[58]

Figure 6. ZEV fleet projections continue to increase year by year

Mexico is in a unique position to increase its ZE-MHDV ambition and adoption rates, and assume a leadership role in transport decarbonization worldwide by leveraging the country's comparative strengths and opportunities. Mexico is the 7th largest vehicle manufacturer and the largest truck exporter in the world.[59] The automotive industry employs over 2.1 million individuals, and as such is deeply embedded with Mexico's economic growth.[60] The country has a unique pool of skilled automotive workforce that can accelerate vehicle production, and a crucial need to transition to zero-emission technologies to keep its global leadership position. The transition is already underway, and Mexico will soon have nine assembly facilities producing zero-emission vehicles.[61]

Mexico has the sixth largest lithium reserves in the world.[62] In August 2022, the government created Litio para Mexico (LitioMX), a state-owned company that will be in charge of managing the mineral's supply chain.[63] Local lithium production can offer a competitive advantage for the national manufacturing industry, which can further decrease vehicle costs and expand national industry participation throughout the supply chain.

In the context of the National Electric Mobility Strategy, SEMARNAT has created five working groups that bring together all the major stakeholders in the ZEV space to collaboratively work toward accelerating the market. Close collaboration between the private and public sectors will be a cornerstone for the development of effective policies and regulations, while private sector networking can vastly accelerate vehicle deployments. On the international scene, Mexico and the United States have created a working group to develop a common roadmap to accelerate electric vehicle adoption, led by the University of California, which presents a unique opportunity to increase the country's ambition and leverage lessons learned from the United States' leading state in vehicle electrification.[64]

As reflected by Mexico's commitments to 50% ZEV production by 2030 the government is starting to think long term as pertains to ZEV production and light-duty vehicle sales. New targets are expected to be announced through the National Electric Mobility Strategy, which represents a timely opportunity to ensure Mexico is alongside leading nations in ZE-MHDV ambition. Adopting the international ZE-MHDV sales targets of 100% new ZE-MHDVs by 2040, and 30% by 2030 will boost private-sector certainty, encourage investment and boost Mexico's opportunities to learn from first-mover countries in the space.[65]

These sales targets have already been assumed by 27 countries and over 70 endorsers from subnational governments and the private sector. While government actions support private sector investments, government leadership is also strengthened by industry action and ambition. Through industry innovation, the number of truck and bus models commercially available in Mexico jumped from less than 10 in 2021 to 36 in 2022.[66] The increase in model availability shows how manufacturers are working toward achieving their own ZEV commitments, which are well aligned with the ambition of the Global MOU (See Table 1).

Table 1. OEM commitments to ZEV sales and carbon neutrality

OEM	Commitment	Date
GM Group	100% carbon neutral in global products and operations	2040
Stellantis	70% low-emission vehicle sales in Europe, and 40% in the US	2030
Ford Group	100% fossil free new vehicle sales	2040
Daimler Group	100% carbon neutral in driving operation in Europe, North America, and Japan	2039
Toyota Group	100% CO2 neutral in life cycle by 2050	2050
Changan Automobile Group	100% electric vehicle sales	2025
Great Wall Motor Company Ltd. (GWM)*	100% CO2 neutral, with interim target of 80% new energy vehicle sales by 2025	2045
Mahindra & Mahindra*	100% carbon neutral in operations	2040
VW Group	100% CO2 neutral balance sheet	2050
Renault	100% CO2 neutral worldwide, with interim target of 100% CO2 neutral in Europe by 2040	2050
Nissan	100% carbon neutral across operations and product life cycle	2050
Mitsubishi	100% carbon neutral, with 50% EV sales by 2030	2050
Isuzu	100% CO2 neutral in vehicle operation and plants sheet	2050
Paccar	100% fossil free new vehicle sales	2040
Suzuki	90% reduction in CO2 emissions in driving operation	2050
Volvo Trucks Group	100% fossil free new vehicle sales	2040
CNH Industrial	100% fossil free new vehicle sales	2040
Honda	100% battery-electric and fuel cell electric vehicle sales in North America, with interim targets of 40% by 2030 and 80% by 2035	2040
Mazda	90% reduction in CO2 emissions in driving operation	2050
Hyundai Kia Automotive Group	100% CO2 neutral in all operations	2050

** No on-road vehicles available in Mexico*
Research included all OEMs with >100,000 sales in 2020 and publicly available commitments to 70%-100% ZEV sales or carbon neutrality. Based on publicly available information as of July 15th, 2021.
Source: CALSTART (2021)[67]

Finally, 2022 was groundbreaking in terms of fleet's progress toward electrification. Transportes Marva acquired 120 electric heavy-duty Q3MA tractors from BYD, all of which will be delivered by early 2023.[68] Bimbo announced the purchase of 1,001 electric Vekstar Stellar delivery trucks, which will increase its electric fleet to over 2,300, the largest in Latin America.[69] PepsiCo will receive 320 electric e-Crafter delivery vans to operate in Mexico City, State of Mexico, and Guanajuato.[70] Mercado Libre increased its electric delivery fleet from 15 to 165 vehicles, becoming the largest electric e-commerce fleet in the country.[71] Grupo Modelo will have 50 ZE-MHDVs operating in Mexican streets by the end of 2022,[72] and DHL announced the inclusion of 50 more electric delivery vans into its Mexican fleet.[73]

These deployments send an irrefutable message: Mexico is ready to transition to a zero-emission transportation future. The technology is here, companies are interested in decarbonizing their operations, and the government has a unique opportunity to backstop and accelerate these unparalleled advances through regulation, policies, and increased ambitions.

2 Methodology for Target Development

2.1 Drive to Zero Market Projection Model

This section lays out the inputs, assumptions, and methodology used to determine the targets and vehicle-specific adoption curves for ZE-MHDVs in Mexico. The path to approximate 100% ZE-MHDV sales by 2040 has been segmented according to a vehicle weight and vocation classification that groups vehicles with similar duty cycles. The projections modeled in this study are based on national vehicle data and five quantitative and qualitative parameters on technology readiness, fleet demand, supply scalability, infrastructure availability, and fleet innovation profile.

Developing forecasts for the future adoption of ZE-MHDVs is crucial for policy planning and vehicle market evaluation, as well as fleet and infrastructure strategic planning and deployment. Projections of future market behavior depend on many assumptions that are informed by today's conditions and expectations about how quickly the market may adopt zero-emission technologies.

This analysis uses CALSTART's Drive to Zero Market Projection Model (the model) to estimate the adoption rate of on-road ZE-MHDVs in Mexico.[74] This model has successfully been used to estimate ZE-MHDV adoption in other markets, including United States, China, and Canada.[75] The model is an interactive input-output (I/O) model that incorporates CALSTART's Beachhead theory of change for ZE-MHDV adoption illustrated in Section 1. Background and Motivation.[76]

This means that the model considers the potential for technology transfer across vehicle segments as zero-emission technologies mature. For example, zero-emission technologies have been more readily available and applicable for transit buses because their vocational use allows them to navigate challenges to electrification.[77] Buses almost always travel along known and relatively shorter routes and return to depots for charging overnight. As zero-emission technologies mature over time, they are transferred to other vehicle segments such as urban delivery vehicles, medium-duty trucks, and eventually to heavier vehicles traveling along longer routes.

The model simulates decision makers' (fleet owners, OEM, and policy makers) technology adoption preparedness quantitatively and, where required, qualitatively. A more detailed description of this model and associated methodology, parameters, and results was published as a framework for applying global projections to a specific region or country.[78] Figure 7 illustrates the comprehensive analytical model components and interactions. The model estimates absolute ZE-MHDV sales and share of total MHDV sales (outputs) between 2020 and 2050 by vehicle application (see Section 3. Results).

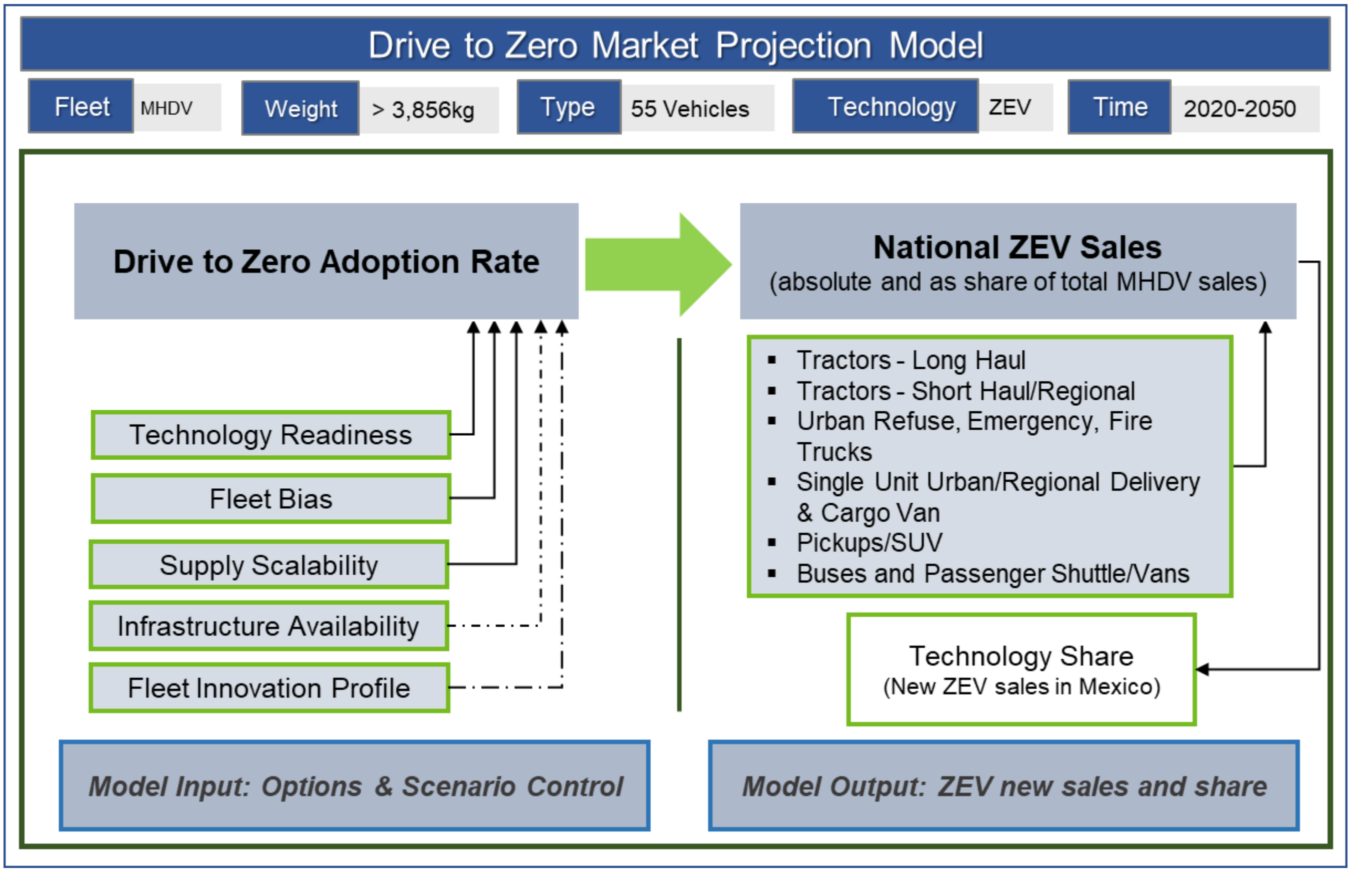


Figure 7. Drive to Zero Market Projection Model

The goal of these projections is to develop ambitious yet feasible targets for ZE-MHDVs, in terms of total sales and share of new vehicle sales by application through 2050. Within the feasibility limits set by the market barriers identified in the previous section, the projections are meant to align as closely as possible to the targets announced by world governments and global manufacturers, aiming for 100% of new MHDV sales to be zero-emission by 2040, with an interim target of 30% by 2030.

Fleet decisions to acquire ZE-MHDVs were approximated quantitatively and qualitatively. Beginning with the projected total market size, the demand response was modeled based on the five parameters listed in Table 2.

Table 2. Analytical model parameters

PARAMETER	DESCRIPTION
Technology readiness	Availability and suitability of the technology to an application, depending on technology, location, vehicle type, application, and timing
Fleet bias	Individual fleet preference toward a new technology, considering its risk and reliability and the time it takes for fleet owners to gain confidence in a new technology
Supply scalability	How fast manufacturers can scale up production, depending on size, purchase power, and operational capacity
Infrastructure availability	Fleet owners' behavioral response to charging/fueling infrastructure availability, depending on the use of private and public infrastructure
Fleet innovation profile	How quickly fleets will adopt a new technology, based on consumer behavior theory that stratifies fleets based on their technology adoption profile (e.g., innovators, early adopters)

These parameters are represented by probability curves that reflect different ZE-MHDV adoption rates by vehicle segment. The model control options for each parameter are informed by the market characteristics, barriers, and opportunities for ZE-MHDV adoption in Mexico (for model control options per parameter, see Appendix B: Drive to Zero Market Projection Model Parameters). This analysis considers zero-emission vehicles as those with zero tailpipe emissions, while recognizing that upstream emissions from energy production and distribution can be sizeable and need to be decarbonized in parallel with vehicle tailpipe emissions. Although this analysis is technology neutral, the assumptions used in the modeling are based on battery-electric technology due to its wider commercial availability in every MHDV segment considered. However, the targets for ZE-MHDVs in this analysis include not only battery-electric technology but other zero tailpipe emission pathways, such as hydrogen fuel cell vehicles.

2.2 MHDV Classification

The first step in the analytical process was to accurately identify current MHDV sales by vehicle type and vocation. MHDV classifications vary by country, and in the case of Mexico also by data source. To maximize cross-country comparison and accurately capture the technological readiness of varying vehicle segments, the model uses a standardized eight-category segmentation by vehicle type and vocation. This segmentation is based on the California Hybrid and Efficient Advanced Truck Research Center (CalHEAT)[79] approach and the Beachhead theory of change.[80]

The eight categories employed in the original framework were updated by removing the motorhome segment (uncommon in the Mexican market) and combining "Urban Refuse" and "Construction and Work site support" under one category (since data available does not allow for this level of disaggregation). Figure 8 illustrates indicative models for each of the six segments modeled for the Mexican market.

RAIAVP: Administrative Record of the Heavy Vehicles Automotive Industry, published by INEGI
RAIAVL: Administrative Record of the Light Vehicles Automotive Industry, published by INEGI

Figure 8. MHDV categorization

Official new vehicle data available for the Mexican market does not follow a standardized classification nor does it cover the entire vehicle population. This represents a considerable challenge for stakeholders to accurately compare data sources and understand the market as a whole.

The National Institute of Statistics and Geography (INEGI) reports vehicle sales through two records: the Administrative Record of the Heavy Vehicles Automotive Industry (RAIAVP), and the Administrative Record of the Light Vehicles Automotive Industry (RAIAVL). Sales data is provided by OEMs, mainly through two industry associations: the National Association of Bus, Truck and Tractor-Trailer Producers (ANPACT) (for heavy vehicles), and the Mexican Association of the Automotive Industry (AMIA) (for light vehicles, including some light-duty trucks). It includes the vast majority of MHDV sales in the country, except for some smaller or newer OEMs (such as BYD, Moldex, AEERSA, Grupo SR, and USIMECA). In 2021, it listed a total of 31,970 new MHDV sales. RAIAVP categorizes through two segments (passenger and cargo), and four classes (coach bus, other buses, tractor, other cargo vehicles). RAIAVL categorizes through two types (passenger cars and light trucks) and four light truck segments (SUVs, minivans, pickups, and vans); 20,014 vehicles listed in RAIAVL are considered as medium-duty vehicles, since their gross vehicle weight rating (GVWR) exceeds 3,856 kg.

Through the Basic Statistic of Federal On-Road Transport, the Ministry of Infrastructure, Communications and Transport (SICT) reports new registrations for vehicles that require a federal permit to operate on federal highways. As such, it does not include registrations of vehicles operating locally. In 2021, it listed a total of 24,157 new MHDV registrations, classified into 18 vehicle classes, 10 service classes, and 26 service types. Vehicle classes are based on Official Mexican Norms (NOMs), except for light trucks. While this database offers further clarity than INEGI on vehicle types and applications, its limitation in terms of vehicle population impede its utilization for population-wide assessments, such as the one carried out here. Appendix A: Vehicle Classification contains a table comparing vehicle categorizations across INEGI, SICT, and official norms.

Since INEGI provides the most accurate data for new vehicle sales in Mexico, it was used as the basis for the analysis. To further segment INEGI's vehicle classification into the model's standardized segmentation, alternative sources where utilized: SICT vehicle registrations were used to approximate the number of utility, urban refuse, and construction trucks. Following the same approach employed by the National Institute of Climate Change and Ecology in 2016,[81] U.S. EPA MOVES data was used to subdivide the tractor segment into long-haul and short-haul. Figure 9 illustrates the vehicle segmentation process.

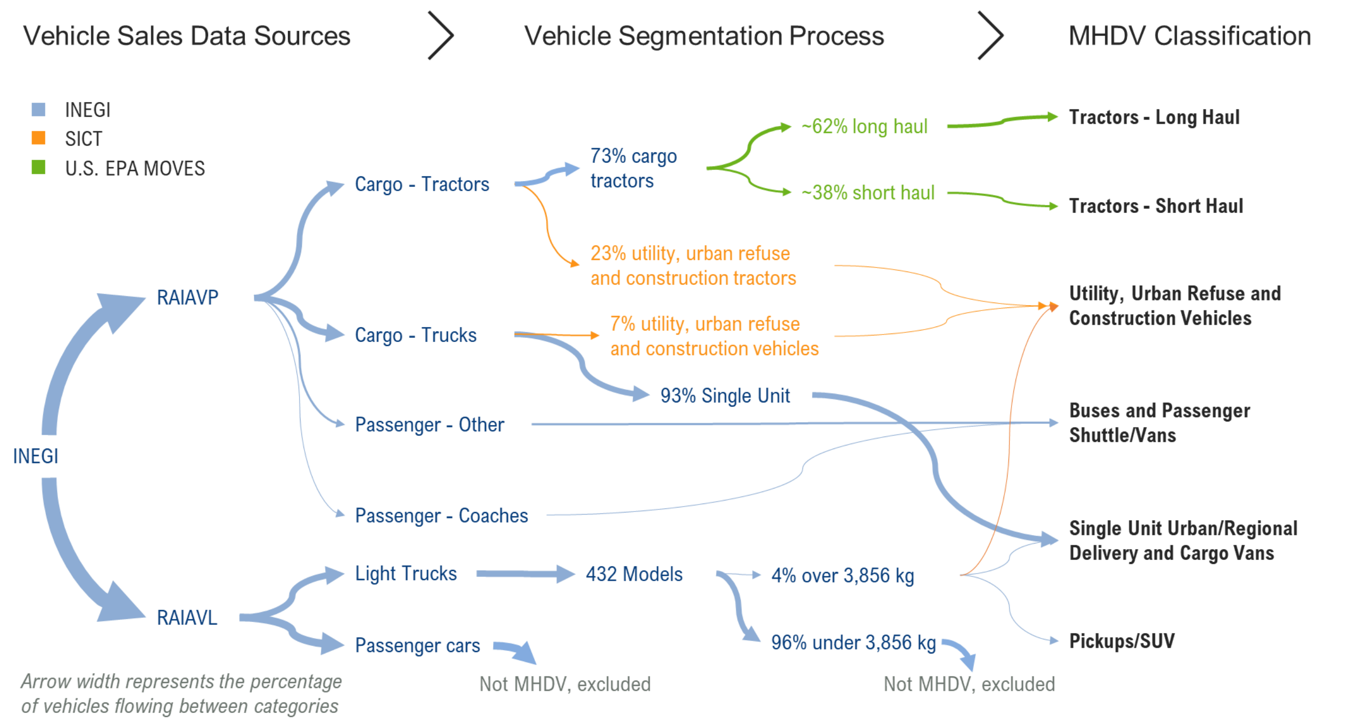


Figure 9. Vehicle segmentation process

By reclassifying INEGI's new vehicle sales data into the standardized MHDV classification, we identify the following numbers of new vehicle sales that took place in Mexico in 2021 (Table 3).

Table 3. New Vehicle sales in Mexico, 2021

VEHICLE SEGMENT	NEW VEHICLE SALES IN 2021
Tractors – Long-Haul	6,027
Tractors – Short-Haul/Regional	3,631
Utility, Urban Refuse and Construction Trucks	9,227
Single Unit Urban/Regional Delivery Trucks & Cargo Vans	27,202
Pickups/SUVs	956
Buses and Passenger Shuttle/Vans	4,941
Total	**51,984**

3 Results

This section details the results of our analysis of the Mexican MHDV market. It presents the model control parameters for each vehicle segment, the ZE-MHDV sales targets obtained through the Drive to Zero Market Projection Model, and a comparison of these targets to the first binding regulations for ZE-MHDV sales, namely California's ACT regulation and ICT rule. Finally, this section presents estimates for the diesel savings and GHG emission reductions that Mexico could achieve if sales targets are met.

3.1 ZE-MHDV Sales Targets by Vehicle Segment

The analysis applies parameter options for technology readiness, fleet bias, and supply scalability for each of the six vehicle categories, as shown in Table 4. Infrastructure availability and fleet innovation profile parameters are standardized across vehicle segments, and as such are not shown in Table 4 for simplification purposes. Parameter options were defined based on the research summarized in the policy, barriers, and opportunities sections of this report, as well as additional research on vehicle specifications, duty cycles, and manufacturers' production capacity. Technology readiness is reflected by the capability of vehicle models in existence to meet fleet needs (including range, charging times, and reliability). Fleet bias considered qualitative input obtained from conversations with fleets and OEMs, as well as empirical evidence of vehicle deployments happening under each vehicle category. Supply scalability considers the number of vehicle models and charging station models available for purchase, as well as the ability of OEMs to scale up production. The vast majority of inputs are based on publicly available information.

Table 4. Model control options by parameter and vehicle segment

VEHICLE SEGMENT	TECHNOLOGY READINESS	FLEET BIAS	SUPPLY SCALABILITY
Tractors – Long-Haul	Medium Market	Slow	Medium
Tractors – Short-Haul/Regional	High Market	Slow	High
Utility, Urban Refuse and Construction Trucks	Low Market	Average	Slow
Single Unit Urban/Regional Delivery Trucks & Cargo Vans	High Market	Average	High
Pickups/SUVs	High Market	Average	Very High
Buses and Passenger Shuttle/Vans	High Market	Accelerated	Very High

Early electrification will rely on depot charging. Opportunity charging availability will play an important role particularly to electrify long haul tractors, which are not expected to be deployed at meaningful levels throughout this decade. As such, the infrastructure availability parameter is considered to have the maturity required to meet vehicle needs across all vehicle segments. It is also worth noting that the difficulties of zero-emission long-haul tractor deployments in the near term are captured in the technology readiness profile as range limitations to satisfy fleets' duty cycles. More mature markets have shown that fleet adoption is policy-driven. Without clear policy direction, fleet adoption rates are expected to follow Roger's innovation curve, which segments the market across innovators, early adopters, early majority, late majority, and laggards. With the National Electric Mobility Strategy expected by early 2023, we assume that policy directions will overwrite the fleet innovation profiles from Roger's innovation curve, and as such would not affect the projected curves. Additional information on all parameters is included in Appendix B: Drive to Zero Market Projection Model Parameters.

Based on the five parameters and control options describe above, we calculate the realistic ZE-MHDV sales targets for the Mexican market over the six vehicle segments, as shown in Figure 10 below.

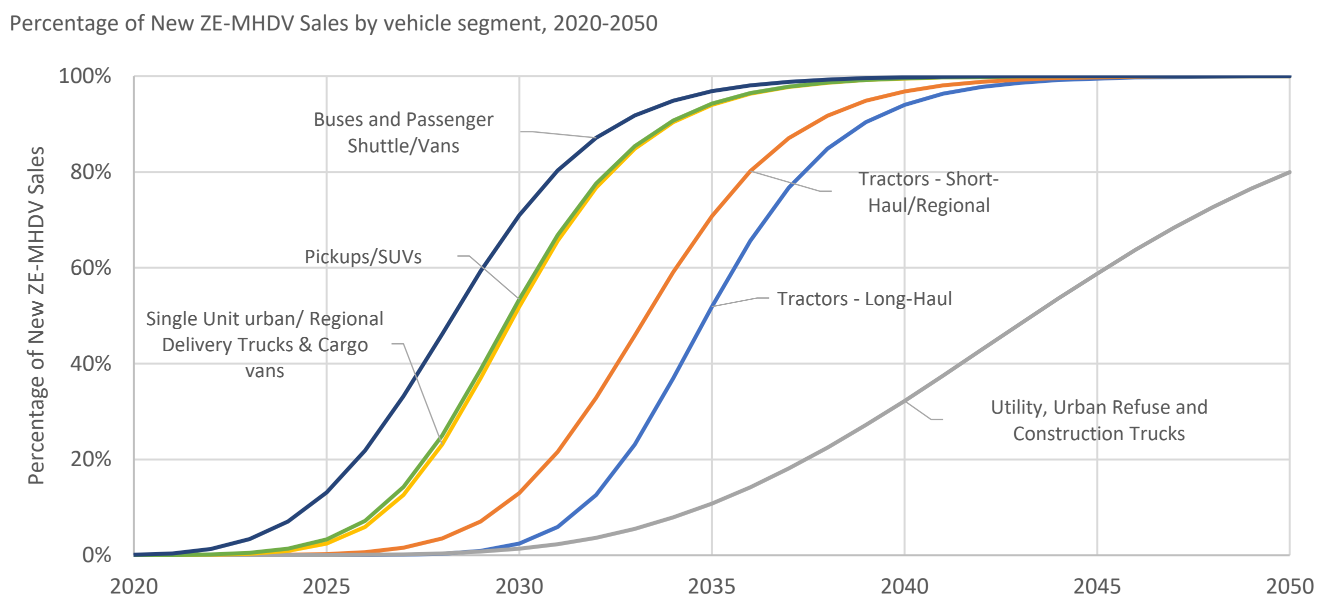


Figure 10. All major vehicle segments can approximate 100% ZE-MHDV sales by 2040

Results show early adoption of zero-emission buses and passenger shuttles and vans (dark blue line). These results match observed deployments in Mexico, with Mexico City procuring 60 electric buses for its Metrobús and STE systems, Guadalajara procuring 36 for its Mi Transporte Eléctrico system, and Nuevo Leon recently releasing a solicitation for 12 electric buses for the Sistema de Transporte Colectivo Metrorrey. Furthermore, the curve reflects how battery-electric buses have become commercially available, mostly from Chinese OEMs, and the technology is not only reliable but can already offer a lower TCO. Our model shows that by 2030, close to 70%

of new purchases in the segment could be zero-emission, with the vast majority of purchases being zero-emission after 2035.

Single-unit urban trucks and cargo vans (yellow line) and pickups and SUVs (green line) are the following applications to ramp up zero-emission technology adoption. Both applications benefit from traveling along relatively shorter distances in urbanized environments and usually charge overnight at depots (like transit buses). Single-unit urban trucks and cargo vans have wider model availability and have begun to gain scale across private sector deployments. Due to their lower GVWR compared to other segments, cargo vans, pickups, and SUVs need smaller battery packs to satisfy most applications, which improves their TCO and supports accelerated adoption. The vast majority of recent deployments, such as those from Group Bimbo, Grupo Modelo, DHL, and Mercado Libre, have occurred in the single-unit urban truck and cargo van segment, which further demonstrates technology maturity. The model shows that by 2030 over 50% of new sales in the segment could be ZE-MHDVs, jumping beyond 90% by 2035.

Short-haul and regional tractors (orange line) follow, with ZE-MHDV procurements starting to ramp up after 2030 and approximating a full market-share takeover by 2040. Available battery technology today is most suitable for regional haul and drayage applications due to available weight, range, and infrastructure compatibility, since charging occurs at private depots. The first large electrification project for this segment took place in Mexico in 2022, with Marva purchasing 120 electric heavy-duty tractors from BYD. Long haul tractors (light blue line) will take longer to transition since they require larger battery packs or opportunity charging solutions. Hydrogen fuel cell tractors, which offer ranges sufficient to meet long-haul applications, are expected to play a role in the future, although no commercially available models have been identified in Mexico to date. Even so, optimism from global OEMs is driving innovation in zero-emission long-haul trucks and there is indication that commercialization of this segment will happen more rapidly than expected.[82]

The last segment expected to electrify are utility, urban refuse, and construction trucks. The parameters assigned for this segment are conservative, since they are based on heavy-duty vehicles. However, close to 57% of the vehicles in the segment are smaller (under 4,536 kg GVWR), and as such are likely to electrify much sooner. The segment's late start and slow adoption curve are due to their lower production volumes and vocationally specific duty cycles. These specialty vehicles span a wide range of drive cycles and applications, often haul very heavy loads, and may have additional power take-off requirements, which further complicate technology readiness and fleets' perceptions of model availability. As other zero-emission segments mature, technology transfer is expected to accelerate development of zero-emission specialty vehicles, but data available at present is limited.

By understanding the current market breakdown of MHDVs by the six categories this analysis employs, and using the projections derived from this analysis, we are able to approximate the absolute volumes of ZE-MHDVs to be sold in Mexico through 2050 (Table 5). Zero-emission buses, single unit delivery trucks and passenger and cargo vans are expected to dominate the landscape in this decade, with other ZE-MHDVs gaining major market shares after 2030.

Table 5. ZE-MHDV sales by segment, 2020-2050

Vehicle segment	2020	2025	2030	2035	2040	2045	2050
Tractors – Long-Haul	0	0	160	3,594	6,843	7,613	8,039
Tractors – Short-Haul/Regional	0	0	514	2,954	4,246	4,597	4,844
Utility, Urban Refuse and Construction Trucks	0	3	137	1,142	3,591	6,886	9,843
Single Unit Urban/Regional Delivery Trucks & Cargo Vans	1	688	15,433	29,388	32,694	34,524	36,299
Pickups/SUVs	0	32	558	1,035	1,149	1,213	1,275
Buses and Passenger Shuttle/Vans	4	673	3,834	5,499	5,953	6,272	6,593
Total	**5**	**1,396**	**20,636**	**43,612**	**54,476**	**61,105**	**66,893**

For comparison purposes, we also ran the model using vehicle sales data for Mexico but calibrating the five parameters to the characteristics of the U.S. market. The results of this model run are included in Appendix C: Applying U.S. market characteristics to the Mexican market. This run shows faster adoption rates across all vehicle segments, which could become more feasible as the ZE-MHDV ecosystem matures.

3.2 ZE-MHDV Sales Targets for the Entire Vehicle Population

By applying the target curves to available sales data for each vehicle segment in the Mexican market, we approximate what future ZE-MHDV sales could look like through 2050. The projections in this analysis show a rapid but feasible transition to ZE-MHDVs, backed by large investments in charging and refueling to meet vehicle needs, expected reductions in the TCO of ZE-MHDVs, and the rapid scaling of vehicle production by manufacturers.

Considering INEGI's MHDV sales data for 2021 (see Table 3) and assuming the same growth factor for all segments, we derive a single adoption curve for the entire MHDV population in Mexico (Figure 11). The results show that Mexico could achieve 36% of new ZE-MHDV sales by 2030 and 87% by 2040. These results are conservative, particularly due to our assumptions around utility, urban refuse, and construction trucks. These penetration rates are closely aligned with the targets set forth in the Global MOU, and adoption could increase even further by 2040, as ZEV outlook projections demonstrate that ZEV adoption is happening much faster than expected a couple of years ago (see Figure 6).

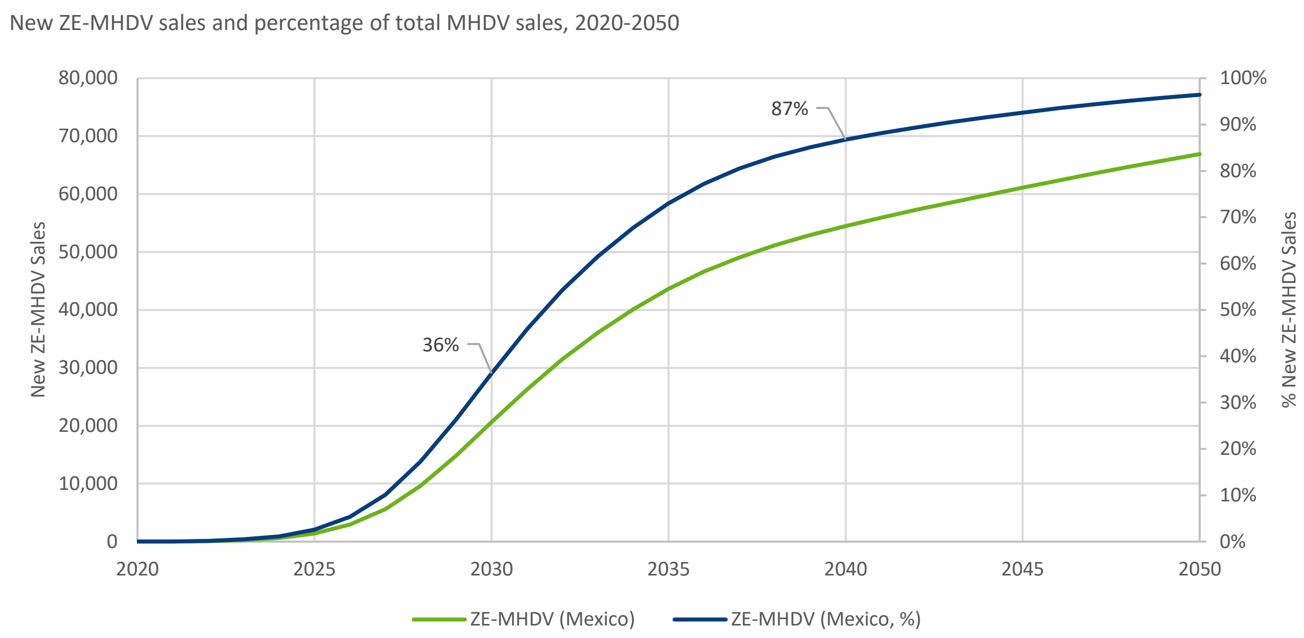


Figure 11. Mexico can realistically aim for 30% new sales of ZE-MHDV by 2030, and 100% by 2040

3.3 Comparison of Mexico Sales Targets to California ACT and ICT Regulations

This section contrasts the projected ZE-MHDV adoption rates in Mexico with California's ACT and ICT regulations, to verify the country's relative position with the leading U.S. state in ZE-MHDV adoption (Figure 12).

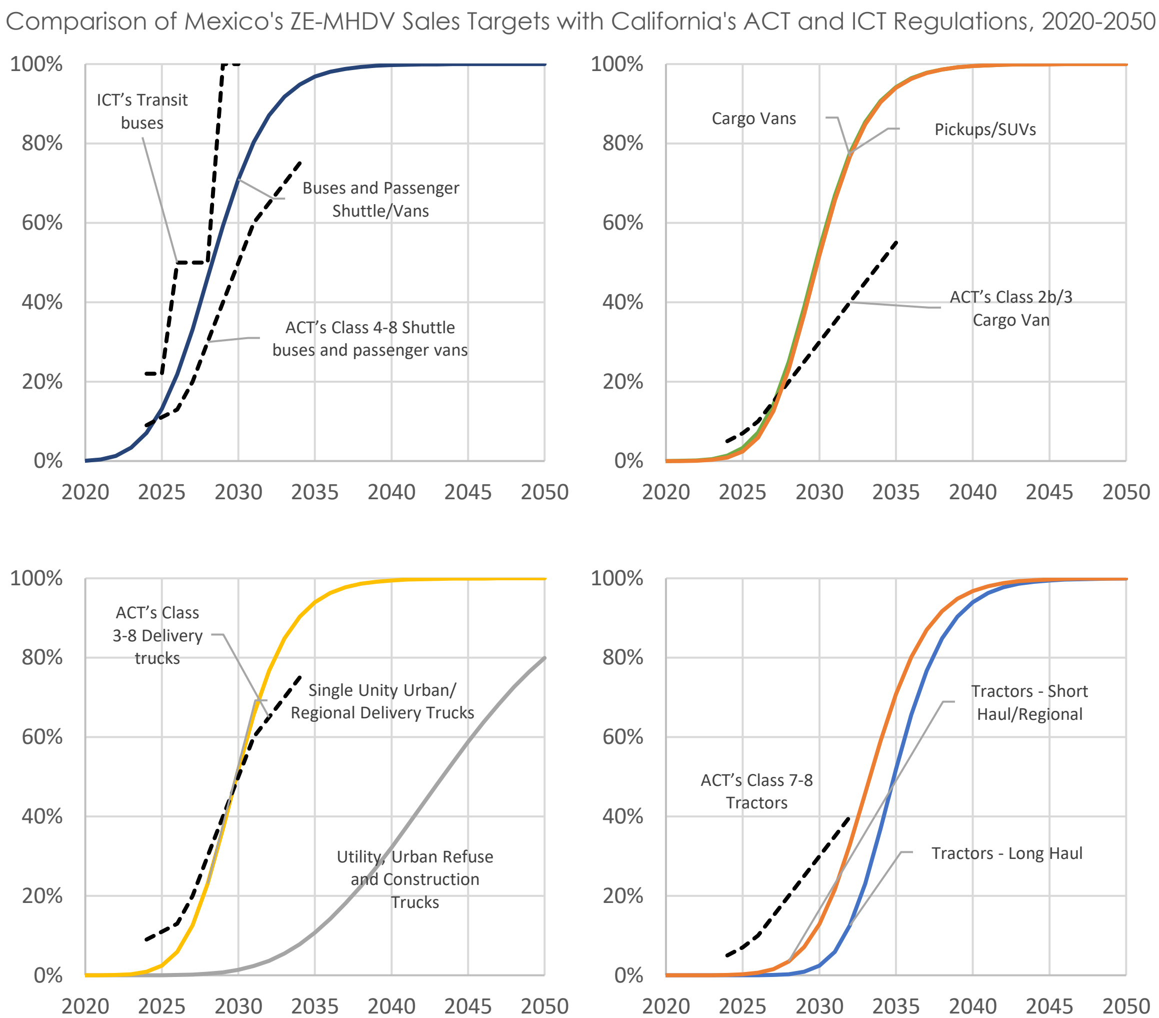


Figure 12. Mexico can meet the sales targets of California's ACT and ICT regulations in most vehicle segments

In the short term, California's ACT and ICT regulations are more ambitious than the targets identified for the Mexican market. However, Mexico could match or even surpass California's required adoption rates in some segments. In the case of buses (top left), Mexico could match California's requirements up to 50% ZE-MHDV sales, although scaling to 100% will likely take longer than what is required by ICT regulations. For cargo vans, pickups, and SUVs (top right), the Mexican market is poised to surpass California's required adoption rates in this decade. In the case of single-unit trucks (bottom left), the curve modeled for Mexican delivery trucks is consistent with ACT regulation, except for specialty vehicles (e.g., construction, refuse, fire, and emergency trucks), which represent a relatively small share of MHDV sales, and whose duty cycles are yet to be fully satisfied by vehicles commercially available. Finally, for both long- and short-haul tractors (bottom right), the Mexican market will likely take longer to gain traction than what California's regulation requires; however, the targets set forth in ACT regulation could be met by the Mexican market with less than three years of delay.

3.4 Benefits from Avoided Diesel Consumption under ZE-MHDV Targets up to 2050

This section estimates expected annual diesel fuel consumption and GHG emissions[83] avoided from achieving the ZE-MHDV sales targets presented in this report, from 2021 to 2050. The analysis assumes average vehicle activity (in vehicle kilometers traveled) and fuel economy for each vehicle segment in Mexico, an average vehicle lifespan of 10 years, and a tailpipe GHG emission factor of 0.01035 per gallon of diesel fuel consumed.[84] This assessment only considers tank-to-wheel emissions avoided from reduced diesel consumption, and as such does not consider upstream emissions from diesel or electricity production.

If the ZE-MHDV sales targets presented in this analysis are met, Mexico could avoid a cumulative 290 million gallons of diesel fuel consumed by 2030, 12,906 million by 2040, and 59,830 million by 2050 (Figure 13).

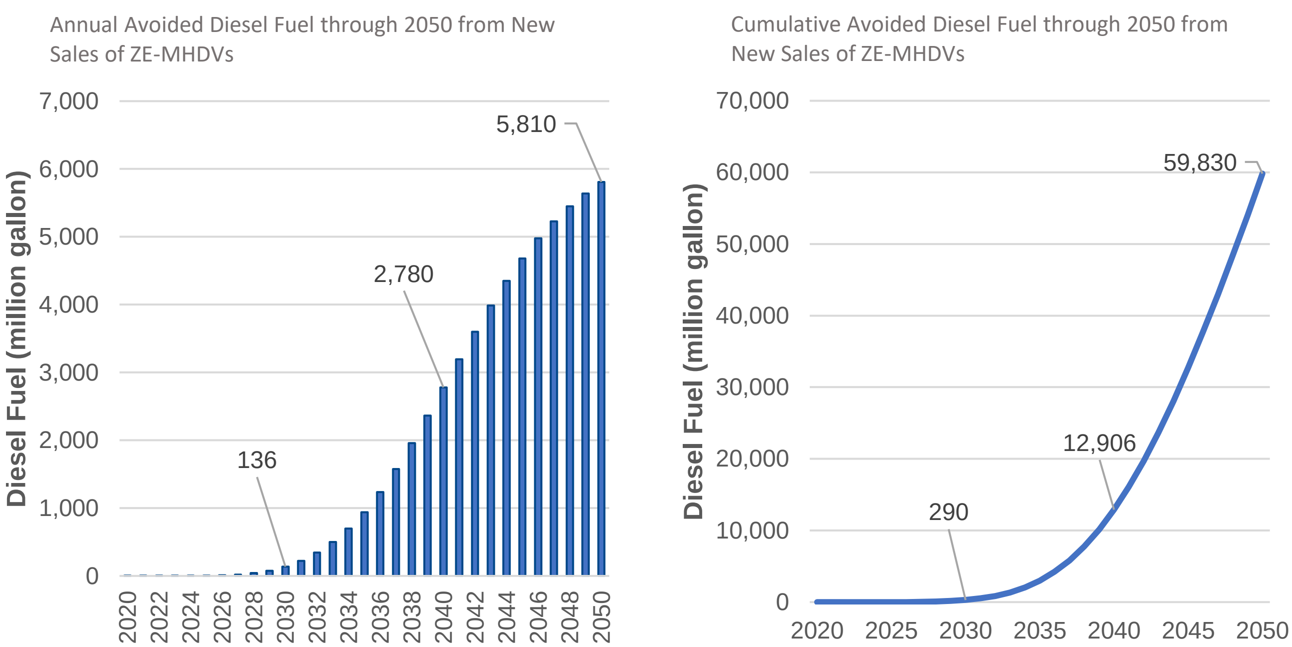


Figure 13. Avoided diesel fuel consumption through 2050 if Mexico's ZE-MHDV sales targets are met

The cumulative GHG emissions that would be produced by this diesel fuel consumption represent three million tons by 2030, 134 million by 2040, and 619 million by 2050 (Figure 14). The annual GHG emissions that could be avoided are roughly equal to removing over 300,000 passenger cars from the road in 2030, over six million in 2040, and over 13 million in 2050.

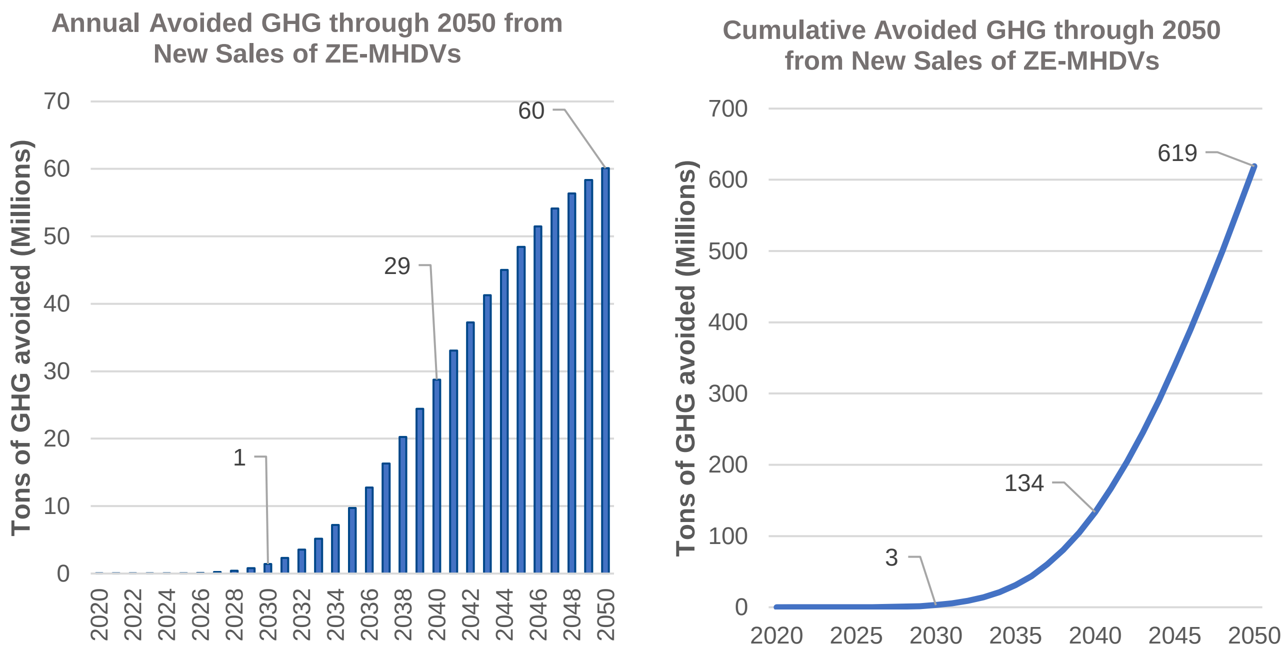


Figure 14. Avoided GHG emissions from MHDVs up to 2050, if Mexico's ZE-MHDV sales targets are met

4 Conclusions and Outlook for Future Research

The targets established by the Global MOU at COP26 are a key milestone in the efforts to curb harmful global MHDV emissions. Our assessment shows that, despite short-term barriers, Mexico is well positioned to increase its ZE-MHDV ambition to match international targets, and accelerate adoption so ZE-MHDVs represent 30% of new sales by 2030, and 100% by 2040.

TCO parity will be achieved within this decade across all vehicle applications. Regulation is still lacking, but its development is expected within the next few years. Infrastructure availability is mature enough to service the needs of beachhead segments that rely on depot charging, though increased investment in the sector will be required to electrify long-haul tractors. Large fleets, which tend to be first movers, control a large share of the Mexican market which can be activated early on. The large number of smaller fleets will require tailored programs and additional support by government agencies until TCO parity is achieved. Once TCO parity is achieved, business model innovation by the private sector can take over electrification of this segment to achieve a full transition.

By assessing Mexican vehicle sales data and market conditions, we find that not all vehicle segments will shift toward ZE-MHDVs at the same speed. Our analysis shows that transit buses will be the first segment to electrify, which matches empirical data observed from early deployments. This segment will be followed by single unit urban trucks and cargo vans, which have also seen a considerable uptake in 2022 driven by vehicle availability and technology readiness. Zero-emission tractors, particularly for long-haul applications, will take longer to deploy since increased batteries and opportunity charging will be required. Finally, specialty vehicles will likely lag other segments, as is happening in other markets around the world, since lower demand and specialized applications make the segment less of a priority for OEMs during early stages.

The main question this paper sought to answer was what are ambitious yet feasible targets for ZE-MHDV adoption in Mexico, given existing market characteristics. Having answered this, our focus must shift toward the most effective ways to accelerate equitable adoption, ensuring barriers are removed for large fleets to act as early adopters and programs and products are developed to support smaller fleets in their transition. Innovative financing products will deserve particular attention since they provide a pathway toward electrification that does not rely indefinitely on government support.

Appendix A: Vehicle Classification

Table A 1. MHDV classifications in Mexico

INEGI Statistics[a]		Official Norms[b]		SICT Statistics[c]	
Segment	**Class**	**Class**	**Class & Axles**	**Class**	**Service Class**
Passenger	Coach Bus	Bus (B)	2-4 Axles (B2, B3, B4)	Coach Bus	Passenger, Tourism
	Other Buses			Conventional Chassis Bus	Passenger, Tourism, Private Transport
				Bus	
Cargo	Tractor	Tractor (T)	2 Axles (T2)	Tractor 2 Axles	Cargo, Private Transport
			3 Axles (T3)	Tractor 3 Axles	
	Other Cargo Vehicles	Straight Truck (C)	2-3 Axles (C2, C3)	Straight Truck 2 Axles	Cargo, Specialized Cargo, Leasing, Parcel Delivery, Private Transport, Transfer, Towing Services
				Straight Truck 3 Axles	
		Industrial Crane (GI)	Industrial Crane (GI)	Industrial Crane	Specialized Cargo, Private Transport
		Tow Truck	A (2,300 kg min GVWR)	Tow Truck Class A	Specialized Cargo, Private Transport, Towing Services
			B (3,500 kg min GVWR)	Tow Truck Class B	
			C (4,300 kg min GVWR)	Tow Truck Class C	
			D (7,500 kg min GVWR)	Tow Truck Class D	
Light Trucks	Pickup	Light Truck	Truck	Van (Pick up)	Cargo, Specialized Cargo, Private transport
	Minivan		M2 (8 or more passengers)	Van [*camioneta*]	Passenger, Cargo, Specialized Cargo, Leasing for private use, Parcel Delivery, Private Transport, Tourism
	SUV		N1 (Payload <3,500 kg)	Station Wagon / Van [*camioneta*] / Van	Tourism, Parcel Delivery, Private Transport
	Van		N2 (Payload	Station Wagon	Passenger, Tourism,

[a] Administrative Record of the Heavy Vehicles Automotive Industry (RAIAVP); Administrative Record of the Light Vehicles Automotive Industry (RAIAVL)
[b] NOM-012-SCT-2-2008; NOM-053-SCT-2-2010; NOM-194-SE-2021
[c] National Statistic of Federal On-Road Transport

			between 3,500kg – 3,857 kg)	Van	Parcel Delivery, Private Transport

Table A 2. Vehicle type definitions

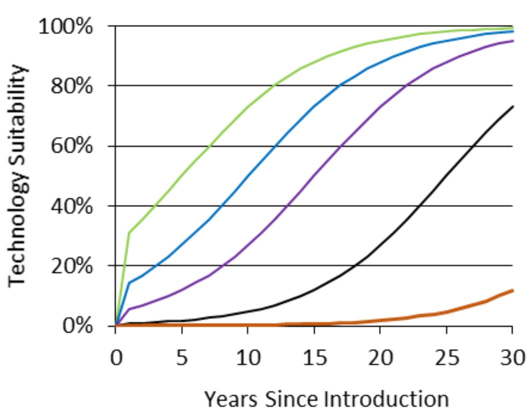
SEGMENT	
Bus	Any other bus that is used to transport people
Cargo Van	One-piece vehicle: cargo area can be conveniently accessed from inside the vehicle for loading and unloading of cargo
City Bus	City bus that operates within the city (also big bus, commuter bus, transit bus, town bus, urban bus, stage bus, public bus, or simply bus) is a type of bus used on shorter-distance public transport bus services
Coach	Bus used for longer-distance service
Construction Truck	Heavy-duty vehicles used for heavy equipment or heavy machinery operations including utility work, specially designed for executing construction/ maintenance tasks, e.g., dump/cement truck
Drayage	Drayage is the transport of goods over a short distance in the shipping and logistics industries. Drayage is often part of a longer overall move, such as from a ship to a warehouse
Emergency Truck	A vehicle used by emergency services to respond to an incident. (e.g., ambulance)
Fire Truck	Trucks used to transport firefighters and their equipment—ladders, rescue gear, and power
Heavy-Haul Truck	Long distance heavy equipment transport tractor
Long-Haul Truck	Tractor freight for long distance transport (transports materials and goods through the country)
Motor Home	A motorhome (or motor coach) is a type of self-propelled recreational vehicle (RV) which offers living accommodation combined with a vehicle engine
Passenger Van	One-piece vehicle like cargo van but with seats to transport people
Pickup	A pickup truck or pickup is a light truck having an enclosed cab and an open cargo area with low sides and tailgate
Refuse	A garbage truck specially designed to collect municipal solid waste and transport it to a solid waste treatment facility, such as a landfill
Regional Truck	Delivery truck, box truck, furniture truck, or beverage truck that runs in a specific area
School Bus	Bus to transport Students to/from school

Shuttle Bus	A bus that travels regularly between two places (shuttles people from one main location such as an airport, hotel, convention center, or sports stadium to one or more satellite locations).
Step Van	Walk-in delivery van
SUV	All use a car-based unibody design, typically an off-roading capable car, an SUV (sports utility vehicle).

Appendix B: Drive to Zero Market Projection Model Parameters

Technology Readiness

Technology readiness refers to the availability and suitability of the new technology to an application, dependent on technology, location, vehicle type, vocation, and timing. Each curve represents the share of the selected vehicle sales that are suitable for zero-emission technologies (Figure B 1), based on the year when the technology is operationally suitable for 50% of the market in that segment.



Option	Description
Very high market	Technology is suitable for over 50% of the market after 5 years
High market	Technology is suitable for over 50% of the market after 10 years
Medium market	Technology is suitable for over 50% of the market after 15 years
Low market	Technology is suitable for over 50% of the market after 25 years
Very low market	Technology is suitable for over 50% of the market after 40 years

Figure B 1. Technology readiness curves and parameter options

Fleet Bias (Logistic Curve)

The logistic curve for fleet bias, or evolution of experience/risk/preference over time, represents the attitude of individual fleet owners toward new technologies. Fleets' attitude toward a new technology is critical in this assessment. It identifies the fraction of the market that a technology option could attain over time when its costs attributes (capital and operational costs) are equal to the baseline technology. To include this adjustment, a preference factor (PF) is integrated.

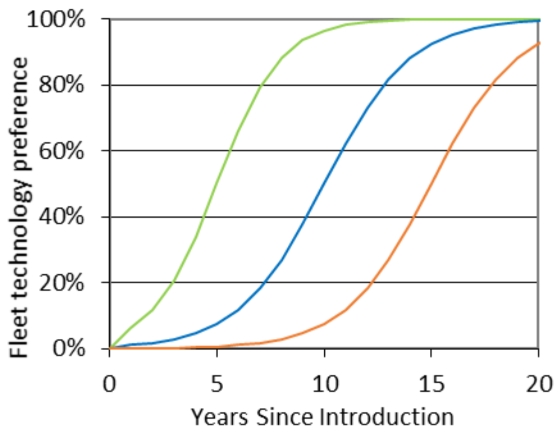
This decimal value (between 0 – 1.0) captures positive or negative non-cost attributes and individual fleet owners' biases. This parameter specifies how attracted or averse a fleet owner is toward a new technology, resulting in a share of the market that the technology option would achieve if its cost attributes were identical to the baseline (Table B 1). For example, a value of 0.5 is technology neutral, meaning 50% of the buyers would choose the alternative technology if it cost the same to buy and operate as the baseline vehicle. By contrast, a value of 0.3 is technology averse, meaning 70% of the buyers would choose the baseline technology if the cost were the same to buy and operate as the baseline vehicle.

Table B 1. Fleet bias preference factor

Sentiment	Preference Factor (PF)
Technology neutrality	PF = 0.5
Bias against a technology	0 < PF < 0.5
Bias toward a technology	0.5 < PF < 1

The initial year and starting value for PF is specified by a fleet as well as the expected PF specified at a future point in time representing a fleet's willingness to acquire ZEVs as their familiarity and confidence grows with the new technology (Figure B 2). In short, when a new technology is introduced to a market, in this case ZE-MHDVs, it takes a significant amount of time for fleet owners to build confidence in the new technology and its operational capacity. Therefore, irrespective of cost, individual fleets will adopt new technology faster or slower based on their experience, preference, and knowledge of benefits or risks associated with the operating and using ZEV technology.

Figure B 2 includes three curves that indicate the time it takes for fleet owners to reach 50% purchase preference. As time progresses and fleets become more aware of the benefits of the technology, the PF will continue to increase and result in fleets' preference toward the new technology over the baseline technology. For example, following the accelerated scenario it will take fleet owners five years to reach 0.5 PF (50% fleet technology preference).

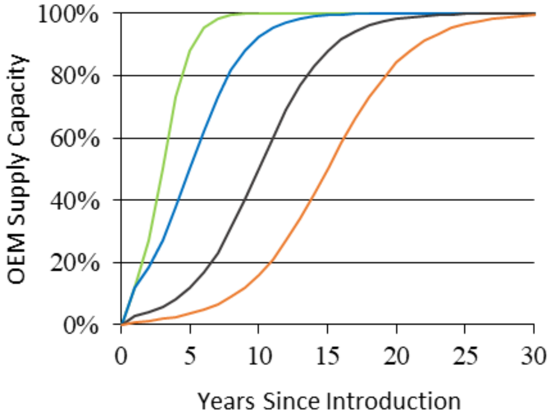


Option	Description
Accelerated	Option where technology attracts 50% of fleet owners after 5 years
Average	Option where technology attracts 50% of fleet owners after 10 years
Slow	Option where technology attracts 50% of fleet owners after 15 years

Figure B 2. Fleet bias curves and parameter options

Supply Scalability

OEMs play a critical role in realizing the ambitions of the Global MOU and are positioned to benefit greatly from the shift to innovative ZEV technology. Supply scalability refers to how fast OEMs can scale up production of zero-emission technology, depending on their size, purchasing power, and manufacturing capacity. The model associates different levels of supply scalability with OEM types, which account for vehicle technology supply limitation under each vehicle segment. The OEM supply capacity and limitation is due to brand, size, market share, and financial position. Figure B 3 below describes the input options for this parameter and the corresponding supply curve options.

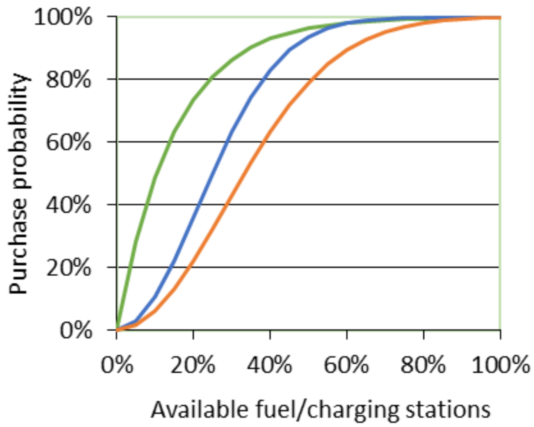


Option	Description
Very High	**Global OEM** (10,001-100,000 capacity), where OEM can supply 50% of new segment sales after 3 years
High	**National OEM** (1,001-10,000 capacity), where OEM can supply 50% of new segment sales after 5 years
Medium	**Emerging OEM** (101 -1,000 capacity), where OEM can supply 50% of new segment sales after 10 years
Low	**Startup OEM** (1 -100 capacity), where OEM can supply 50% of new segment sales after 15 years

Figure B 3. Supply scalability curves and parameter options

Infrastructure Availability

Whether fleet owners rely on private or public charging/fueling, access to infrastructure is a significant factor in ZE-MHDV purchase decisions. This parameter is reflected in the model as three possible adjustment curves reflecting different levels of infrastructure availability (accelerated, average, slow). The curves in Figure B 4 represent fleets' probability of purchasing a ZE-MHDV against the relative availability of refueling/charging stations. Refueling/charging station availability is a factor in fleets' decision to acquire ZEVs, but fleets are willing to invest in those technologies even with limited available refueling infrastructure. In short, the relationship between refueling/recharging availability and vehicle purchase decision is not one-to-one and fleets will acquire ZEVs even with limited infrastructure availability compared to the base case. For example, fleets are willing to purchase a technology at 70% availability even when refueling availability is 30-40% as compared to diesel fueling station availability. For the purposes of developing this analysis of strong ZE-MHDV targets, this analysis assumes that infrastructure is readily available and does not pose a constraint in fleet purchase decisions.



Option	Description
Accelerated	Fuel/energy is available at 50% after 3 years and 100% after 10 years.
Average	Fuel/energy is available at 50% after 9 years and 100% after 15 years
Slow	Fuel/energy is available at 50% after 15 years and 100% after 20 years

Figure B 4. Infrastructure availability curves and parameter options

Fleet Innovation Profile

Fleet innovation profile refers to how quickly fleets as a whole will adopt a new technology, borrowing heavily from consumer behavior theory. Vehicle purchase decisions are not the same across fleets. While parameters described above have options that represent the behavior and decision-making of a spectrum of individual stakeholders, this parameter groups fleet owners into different profiles based on whether they are financially driven, technology driven, environmentally driven, and/or socially driven. This is distinct from the fleet bias parameter, which examines individual fleet decisions over time through the lens of experience and knowledge of the new technology and appetite for uncertainty/risk. This parameter allows for simulating different types of fleet behavior based on Rogers' innovation curve, which stratifies fleets/consumers in five groups: innovators, early adopters, early majority, late majority, and laggards (Figure B 5).[d] For example, the first buyers of a new technology that costs more than the baseline vehicle are grouped as innovators. Late majority and laggards represent those who buy when the technology is well-established, similar, or provides more benefits as compared to the baseline vehicle. Although the model allows stratification of different innovation profiles based on a fleet's driving factor (where the result would ultimately be the combined penetration of each fleet based on its size), the assumption is that fleets will follow the target analysis at 100%, grounded in the ambitions of the Global MOU of 100% sales of ZE-MHDVs by 2040.

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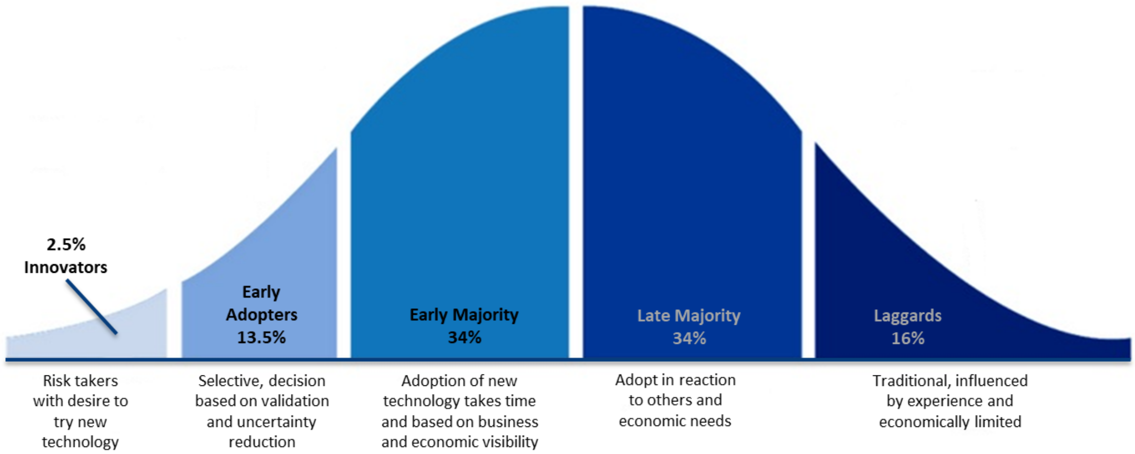

Figure B 5. Fleet innovation profile (Rogers' innovation curve)

Appendix C: Applying U.S. Market Characteristics to the Mexican Market

Table C 1. U.S. model control options by parameter and vehicle segment

VEHICLE SEGMENT	TECHNOLOGY READINESS	FLEET BIAS	SUPPLY SCALABILITY
Tractors – Long-Haul	High Market	Average	Medium
Tractors – Short-Haul/Regional	High Market	Average	High
Utility, Urban Refuse and Construction Trucks	Medium Market	Average	Medium
Single Unit Urban/Regional Delivery Trucks & Cargo Vans	High Market	Accelerated	Medium
Pickups/SUVs	High Market	Average	High
Buses and Passenger Shuttle/Vans	Very High Market	Accelerated	Very High

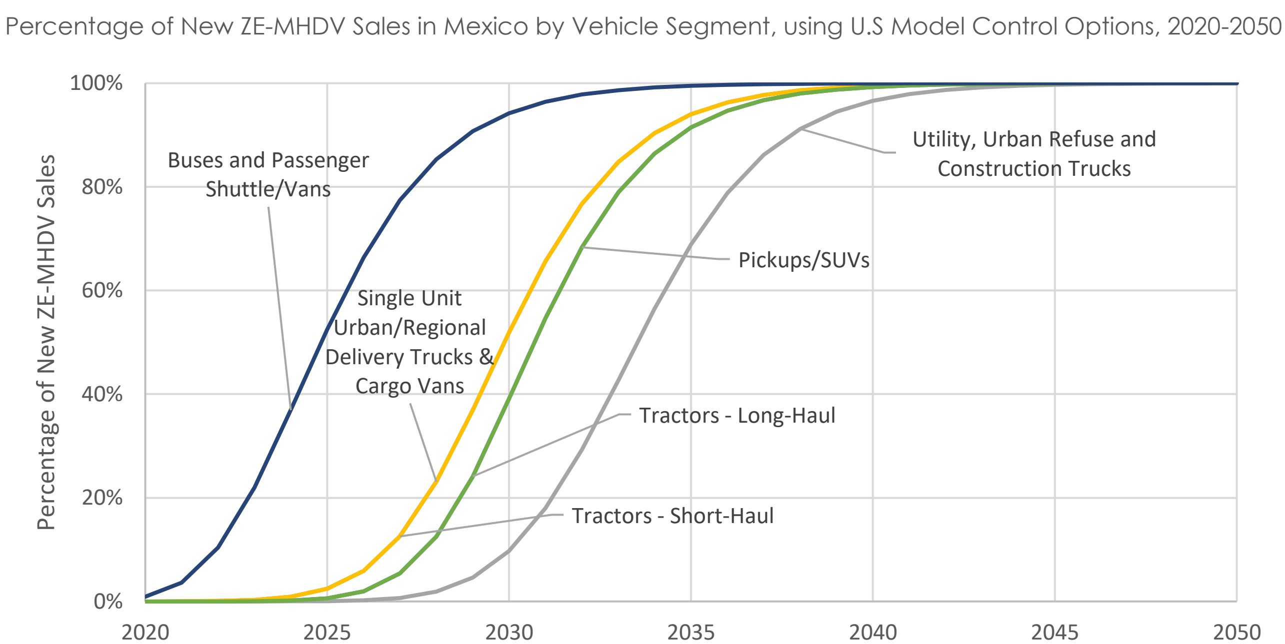

Figure C 1. With U.S. market maturity, Mexico would see accelerated adoption across all vehicle segments

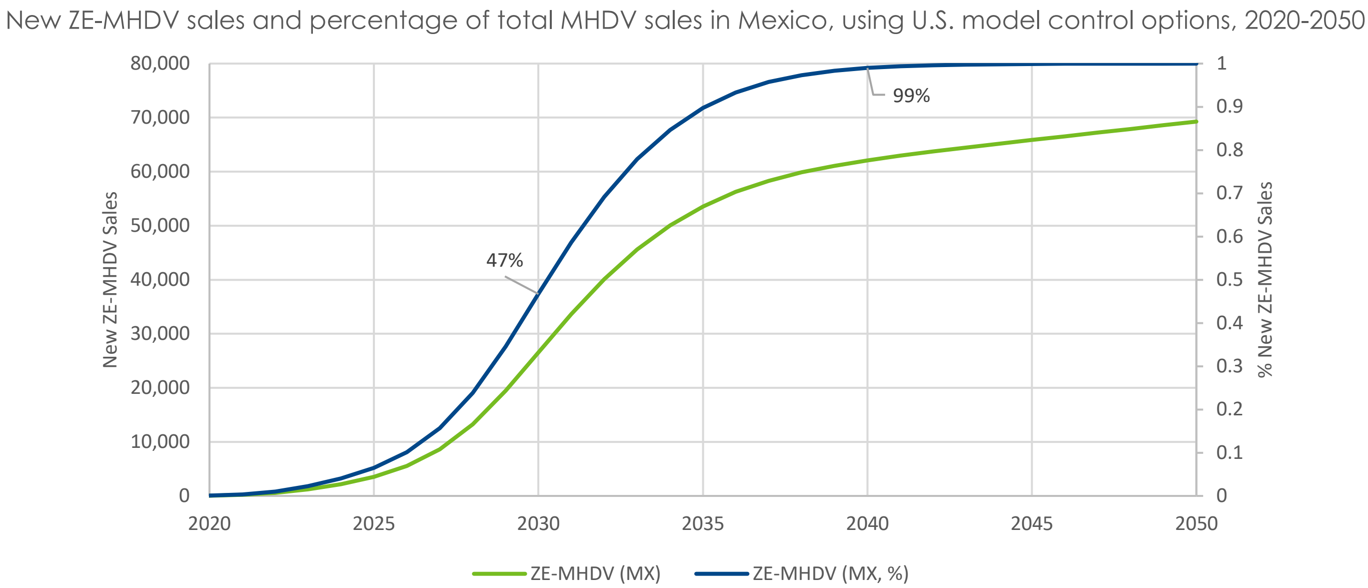

Figure C 2. With U.S. market maturity, Mexico could see 47% ZE-MHDV sales by 2030 and full transition by 2040

Comparison of Mexico's ZE-MHDV Sales Targets under U.S. market conditions, with California's ACT and ICT Regulations, 2020-2050

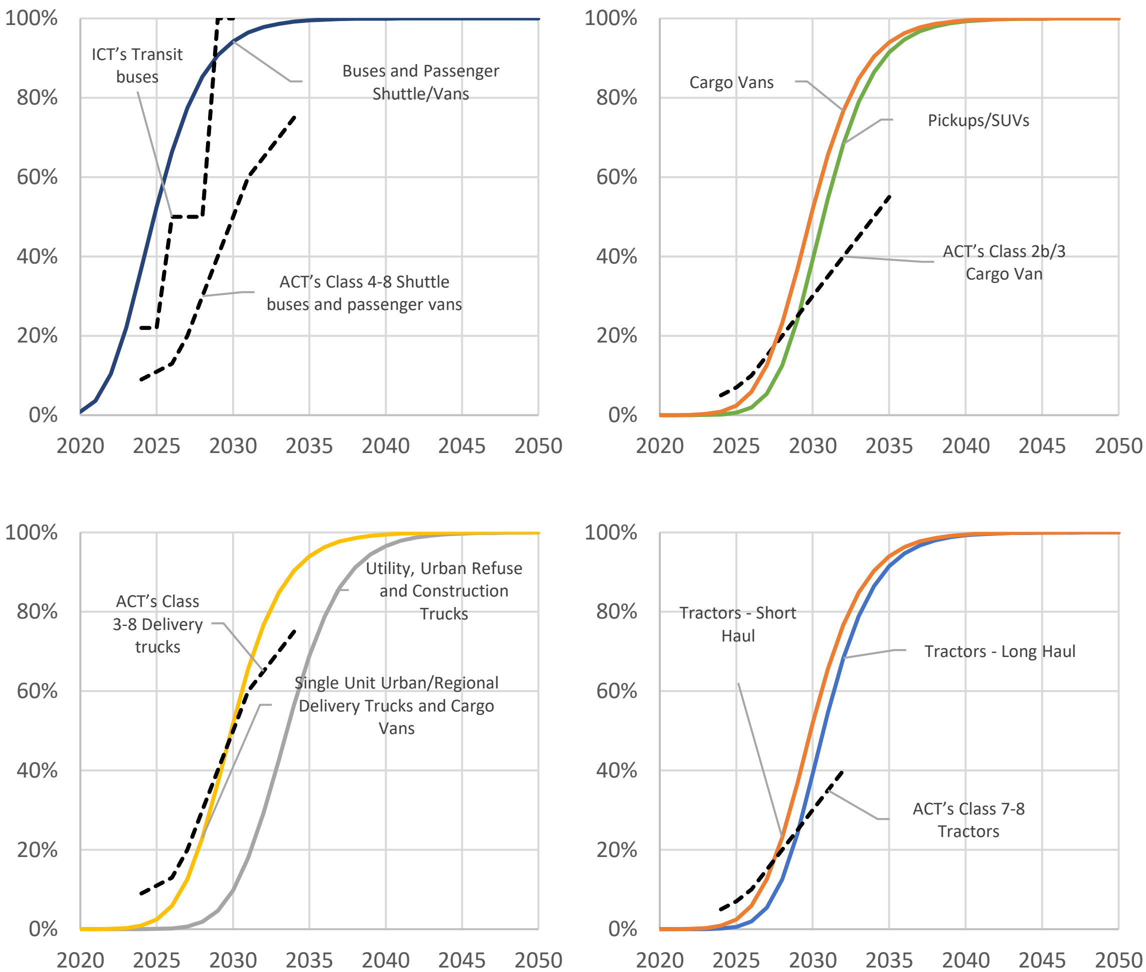

Figure C 3. With U.S. market maturity, Mexico would exceed California's ACT and ICT regulation requirements in most vehicle segments

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