PATHWAYS TO DEEP DECARBONIZATION

of the passenger transport sector

IN MEXICO

Jordi Tovilla, Daniel Buira,
Tempus Analitica

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THE TRANSPORT DEEP DECARBONIZATION PATHWAYS PROJECT (DDPP-T)

The Transport Deep Decarbonization Pathways Project (DDPP-T), an initiative of the Institute for Sustainable Development and International Relations (IDDRI), aims to demonstrate how countries can transform their transport system by 2050 in order to implement a deep reduction in their greenhouse gas emissions, consistent with ambitious climate goals.The DDPP-T builds on the Deep Decarbonization Pathways Project (DDPP), which analyzed the deep decarbonization of energy systems in 16 countries in the lead-up to COP21. The two projects share key principles. The analysis is conducted at a country scale, by in-country research teams, working independently of their governments. It adopts a 2050 time horizon to reveal the short-term requirements of long-term climate and development objectives. Finally, country research teams openly share methods, modelling tools, data and results in order to enable knowledge sharing among project partners in a highly collaborative way and to facilitate engagement with sectoral experts and decision makers.

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Disclaimer

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Foreword

This analysis considers passenger transport, encompassing the mobility of resident citizens including domestic and international air flights and non-motorized travel. Freight transport will be considered in future work.

The analysis starts from an acknowledgment that profound transformations of the passenger transport sector, that could deliver deep greenhouse gas emission reductions consistent with an ambitious climate goal, go beyond technological change. They require considering a more systemic approach to build decarbonization storylines, including key drivers like the evolution of demographic and economic situation, individual behaviours, lifestyles, infrastructures and spatial organization. The approach also recognizes the need to provide quantification of these storylines for key indicators characterizing mobility patterns such as distances travelled by trip purposes, by location of people, by modes or budget and time dedicated to transport activities. The methodology of the DDPP-T, adopted by all country research teams in the project, connects these two complementary approaches to long-term deep decarbonization analysis of the transport sector consistent with emission reductions computed in previous DDPP national scenarios..

The structure of the report reflects this approach. The key determinants of mobility are described by the storylines in the second section. These storylines are then translated into a quantitative sector-wide representation of the transport sector, which form the core of the third section. Finally, a sub-set of these indicators have been chosen as key quantitative metrics to engage stakeholders and decision makers, and are presented in the Annex.

Executive summary

Introduction and scope

This study uses a common developed methodology to explore passenger transport low carbon futures to 2050, consistent with 2°C global scenarios.

Greater granularity allows spatial and motivation-based disaggregation of travel to explore economic, social and behavioral dimensions. In the Mexican case, two distinct types of human settlements are characterized: the five largest cities with over two million people (*Metropolitan*), and medium and small cities containing the rest of the population and expected to absorb the largest share of future population growth (*Non-Metropolitan*). This allows for an analysis on two fronts:

- Analyze options available to make large cities—where urban sprawl and population already seem to be stabilizing at high levels—more efficient in terms of mobility
- Explore scenarios to prevent medium and small cities from following the inefficient pathways of the largest cities

The present analysis takes account of previous work[1] which explored transport dynamics according to the projected growth of cities and which refined vehicle fleet size estimates.

A further level of granularity is added by distinguishing between travel demand due to *Non-Constrained* activities as opposed to *Constrained* travel. The former relates to occasional activities that might imply longer distances per trip, typically holidays, weekend recreation or family visits. In the category *Constrained*, we include all travel demand related to daily activities such as going to a job, a school, or a supermarket.

New analysis reveals high demand for long-distance travel, previously only partially considered. Roughly a fourth of long-distance travel is due to work-related activities, which was already considered in previous mobility demand estimates. However, long-distance travel due to non-constrained mobility (such as international aviation and domestic intercity buses), as well as non-motorized travel, have now been included in overall mobility demand estimates.

The analysis contained herein presents an initial exploration of the solution space. As such, it does not present "best" or "recommended" trajectories of change, but potential trajectories established on simple assumptions (which are subject to review and refinement) with the intention to enable the discussion of what might be required to deeply decarbonize passenger transportation in Mexico by mid-century. The Deep Decarbonization work of 2015[2] is used as the framework within which the overall Mexico target sectorial breakdown is determined, as well as the macroeconomic and social development assumptions driving future activity and emissions.

Passenger transport in Mexico and scenarios

Current and historical patterns of uncontrolled urbanization and poor public transportation strongly encourage the use of private vehicles with an ever-lower occupancy rate in increasingly congested roads. The increasing surface of cities effectively expands the distances commuters need to travel everyday. The resulting rise in gasoline consumption has exceeded domestic refining capacity and imports account for half of total supply. The transport sector is the single largest source of GHG emissions in Mexico with a fourth of the total.[3]

Two scenarios are presented, both leading to a 50% reduction in annual CO_2 emissions of the passenger transport sector by 2050 (50 $MtCO_2$) compared to the level in 2010.

1 Transport experts Thalia Hernández and Ulises Hernández conducted this study under the research efforts leading to the publication of the Mexico 2050 Calculator. [http://www.calculadoramexico2050.org/]

2 Tovilla & Buira. (2015). Pathways to deep decarbonization in Mexico, SDSN - IDDRI

3 INECC/SEMARNAT. (2015). Mexico's First Biennial Update Report to the United Nations Framework Convention on Climate Change. (BUR1) Available at http://unfccc.int/resource/docs/natc/mexbur1.pdf BUR1

The Demand Scenario is the one in which the broadest range of levers is acted upon. Here a 10% reduction in constrained mobility by 2050 is projected as the result of a better urban design, a more dynamic and developed society, and of the partial adoption of home-based activities (working and shopping).

In highly urbanized areas commuters shift from cars to a multimodal system integrating metro lines, lightweight and suburban trains, and buses. From these, 40% are electric and 20% operate under high-occupancy BRT schemes. In smaller cities areas, the presently short distances travelled daily could triple by 2050, so car use increase is partially restrained by the development of an intermodal network of buses and trains.

For non-constrained trips car and bus use is kept at today's levels and intercity trains satisfy the emerging demand. Domestic air travel is also partially substituted by train, particularly over medium distances (500-800 km). Metropolitan areas are connected through high-speed trains.

Internal combustion engine cars are 60% more efficient by 2050, and electric cars reach 23 million by 2050 (45% of the fleet). All new railroad infrastructure is 100% electric.

The Demand Scenario results in 17% lower overall energy consumption for passenger transportation in 2050 compared to 2010, and energy carriers satisfy more than double today's transport demand with nearly half the carbon footprint. The annual demand for fossil fuels is halved over that period virtually eliminating the need for imports.

The Technological Scenario explores what would be needed to reach the same end-year emissions as in the Demand Scenario, assuming no demand reduction from changes in urban organization or the behavior of commuters.

In this scenario a more marked modal shift is required to reduce car use and meet the emissions target. The total demand for train travel is 21% higher than in the first scenario, and an additional 10% of the bus fleet is electric.

Energy consumption in this scenario is 3.9% higher than in the Demand one. The average person would travel longer distances, bringing up average mobility costs by 1.5% and metropolitan daily time required for travel increases by 10% in comparison to the Demand Scenario.

Key messages

The levers modeled in this study represent important changes unlikely to occur under an incremental extension of existing policy packages and frameworks, but rather require an in-depth re-visiting of the relevant policy space.

Structural change will be essential. Efficient achievement of such change will necessitate decisive early action to shift trends and commence decades-long changes in investment and behavior patterns. In practical terms, radical shifts in urban, fuel, energy, and transport programs must commence pre-2020. Delay until 2030 would imply far steeper gradients than those presented here, bringing into question the credibility of such a change program. This has implications for the formulation of the Long Term strategies of Article 4.19 of the Paris Agreement, and indeed for the NDC update process, both of which would be strengthened by presenting Passenger Transportation actions in frameworks similar or translatable to those utilized in this study.

Development of low-income sectors of the population should entail an increased access to mobility services at affordable prices, while avoiding inefficient past patterns. Closing the income gap would increase people's ability to adapt to new low-carbon urban paradigms.

Mobility can be more efficient if the design of cities helps reduce the distances travelled every day. High-density, mixed land use neighborhoods designed for non-motorized travel provide good conditions for the development of mass transport systems, reducing the amount of energy and cost required to transport each person. Unless the daily use of cars is limited, other decarbonization measures, such as electrification or the increase in vehicle mileage, will do little to reduce CO_2 emissions and energy expenditure.

The transformations implied are of very large scale and will require inter-sectorial and inter-level coordination between government branches. Early inclusion of the academia and the private sector in planning and execution is essential to draw upon their economic and technical resources.

Significant further research is still needed to improve data quality, forecasts, and assumptions, to strengthen and refine the conceptual framework, and to extend the scenario analysis and the granularity and causality of levers, so specific policies can be derived from them.

Description of the passenger transport sector

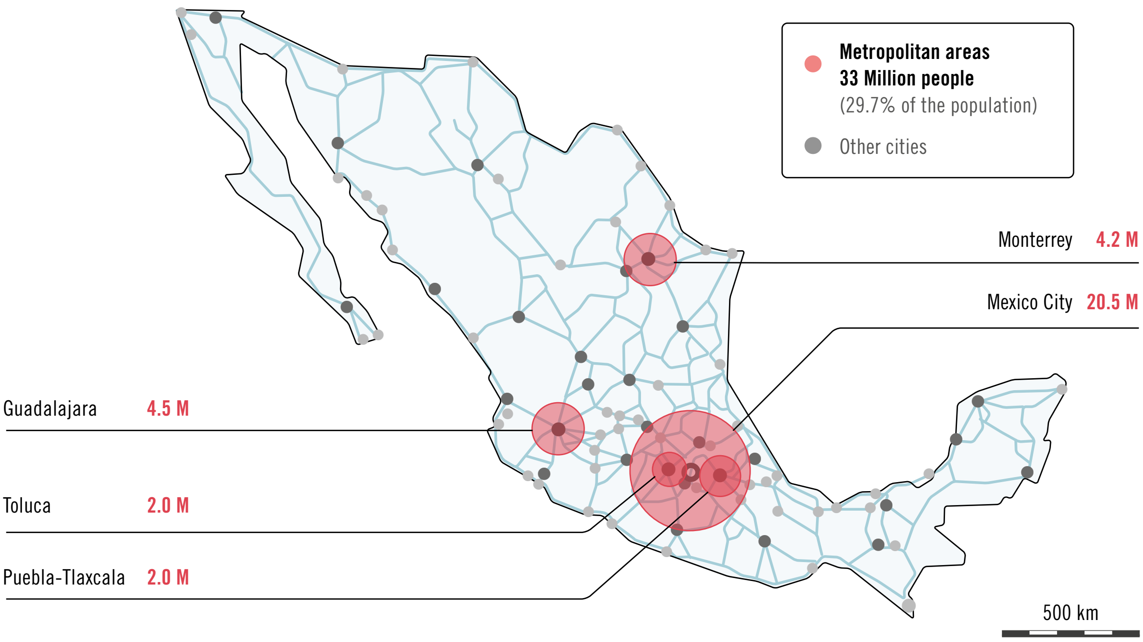
This section describes current passenger mobility dynamics, the historical patterns observed, the impact on CO_2 emissions, and the current national policy framework on mobility and climate.

Current and historical trends

With a population of 122 million inhabitants, Mexico is the world´s 15th economy by GDP and responsible for 1.4% of world GHG emissions according to its First Biennial Update Report[4]. The economic structure of the country is quickly evolving towards a greater share of the service sector in GDP. Extrapolating current trends, this sector could increase its share to 70% by the year 2050, and industrial activities could decline to 30% of GDP.

4 INECC/SEMARNAT, 2015. Mexico's First Biennial Update Report to the United Nations Framework Convention on Climate Change. (BUR1) [http://unfccc.int/resource/docs/natc/mexbur1.pdf]

Figure 1. Schematic view of Mexico, metropolitan areas, largest cities and main road network in 2010



The road network had a length of 300,000 km in 2010* (this map only shows main highways). The five largest cities are highlighted.

** According to information from the Ministry of Communications and Transport (SCT), 138,404 km of roads were paved, 150,404 km had some kind of surface covering, and 8,783 km were dirt roads. www.sct.gob.mx*

The UNDP´s Human Development Index for Mexico, at 0.756, places it as 71st of the 187 countries analyzed and 45.5% of the population is estimated to be living in poverty.[5] Some population segments have limited access to modern forms of energy and transportation, and have a high dependency on traditional biomass to satisfy their energy needs[6].

Average mobility demand in Mexico is not high by international standards, but this could change in the future as socioeconomic development proceeds. We estimate the average annual personal mobility in Mexico at around 8,930 passenger-km per capita, equivalent to 24.5 km per person a day. That includes both daily short-distance travel and occasional long-distance trips. Whereas in small cities the distances per trip can be small (2 km), in the largest cities it can be several times larger (>15 km). Socioeconomic differences between rich and poor areas extend to infrastructure development, determining local mobility options.

Current and historical patterns of uncontrolled urbanization and poor public transportation strongly encourage the use of privately owned vehicles with an ever-lower occupancy rate. Irregular land use policies and regulatory practices allow the establishment of new isolated neighborhoods away from city centers and existing distribution networks. The development of such settlements brings larger amounts of money into previously underdeveloped semi-rural areas, increasing the pressure on agricultural and forestry land surrounding urban centers, and effectively expanding cities' limits.

Commercial establishments inevitably emerge in the vicinity of these communities. Utilities and other services quickly move in to satisfy a geographically expanding market, creating areas with patchy yet distinct land uses (commercial and residential).[7]

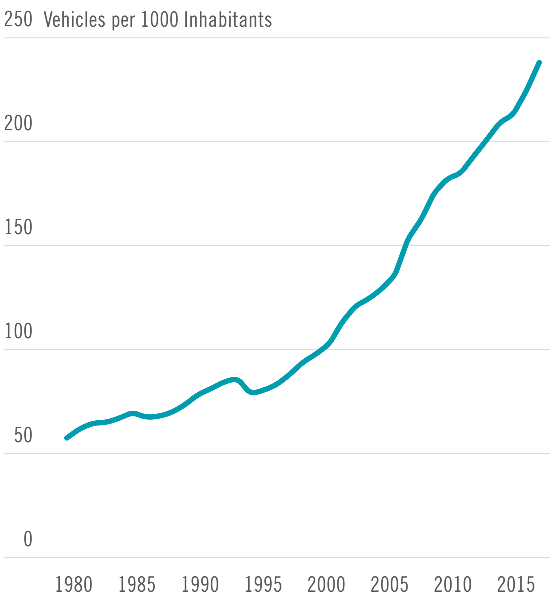
This model has led to high pressure for road construction, which in turn has reinforced the use of private automobiles, increasing congestion on even the newest roads. Historic fossil fuel subsidies have helped foster an increasing private vehicle fleet (see **Figure 2**).

From information on the average daily commuting distances in big cities and on long-distance trips,[8] we estimate that in 2010 annual constrained mobility accounted for 11,321 pkm/capita in big cities (152% above the national average of 4,497 pkm/capita) and 1,617 pkm/capita in the rest of the country (64% below the national average). Non-constrained mobility in 2010 is estimated at 5,780 pkm/capita in the same big cities and 3,867 pkm/capita in the rest of the county (the national average is 4,435 pkm/cap). Cars accounted for 45% of all passenger-km travelled in that year.

The resulting rise in gasoline consumption has exceeded domestic refining capacity and imports presently account for half of total supply (**Figure 3**).

The recent liberalization of the fossil fuels market and the phasing-out of state subsidies have already impacted gasoline and diesel prices, but it is still too soon to identify the effects of these on transport dynamics.

Figure 2. Officially registered vehicles, 1980-2015



Registered vehicles (not all of them still in operation) per capita have increased at an average of 5.4% annually since 2000.

Own estimate with information from the National Institute of Statistics and Geography (INEGI): [http://www.inegi.org.mx/est/contenidos/proyectos/registros/economicas/vehiculos/default.aspx]

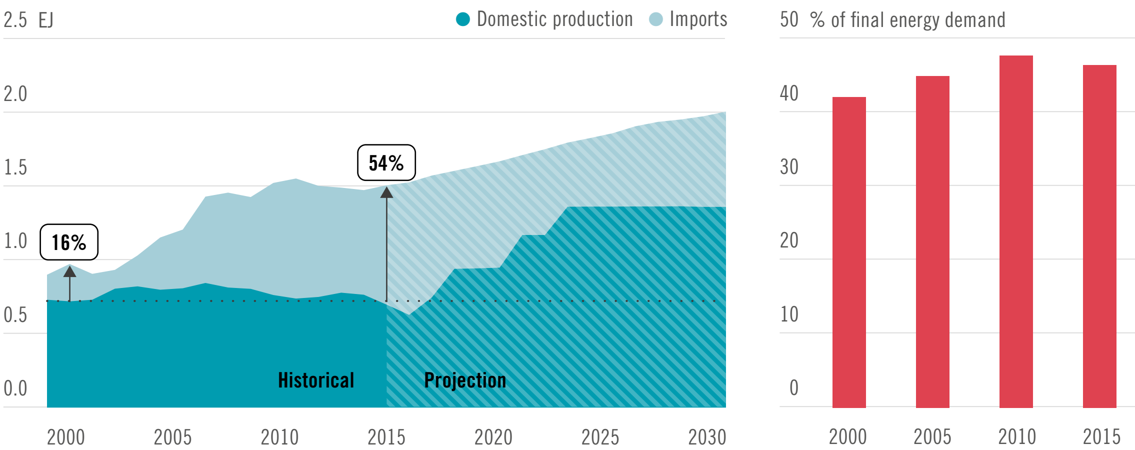
5 The National Council for the Evaluation of Social Development Policy (CONEVAL) sets the poverty threshold income at around 155 USD/month in urban areas and 100 USD/month in rural areas (May 2017). [http://www.coneval.gob.mx/Medicion/Paginas/Lineas-de-bienestar-y-canasta-basica.aspx]

6 BUR1

7 Mixed land use areas are starting to be established in Mexico to boost activity in the commercial sector; if adopted widely this practice could help curb daily travel demand in the future.

8 SCT, *Indicadores Mensuales del Sector Comunicaciones y Transportes*. http://www.sct.gob.mx/fileadmin/DireccionesGrales/DGP/estadistica/Indicador-Mensual/INDI-2017/CI-Abril_2017.pdf

Figure 3. Gasoline production and imports, 2000-2030, and share of final energy consumed by transport, 2000-2015



Historic data (up to 2015) and official projection (2016-2030) of the domestic production and imports of gasoline (left). Imports have increased from 16% of total supply in 2000 to 54% in 2015. Virtually all gasoline demand is for transportation purposes. This sector represents over 46% of all total final energy consumption (right), industry is second with 31% and households come in third with 15% in 2015.

Own estimate with information from the Energy Information System of the Ministry of Energy (SIE-SENER) [http://sie.energia.gob.mx/]

CO_2 emissions profile

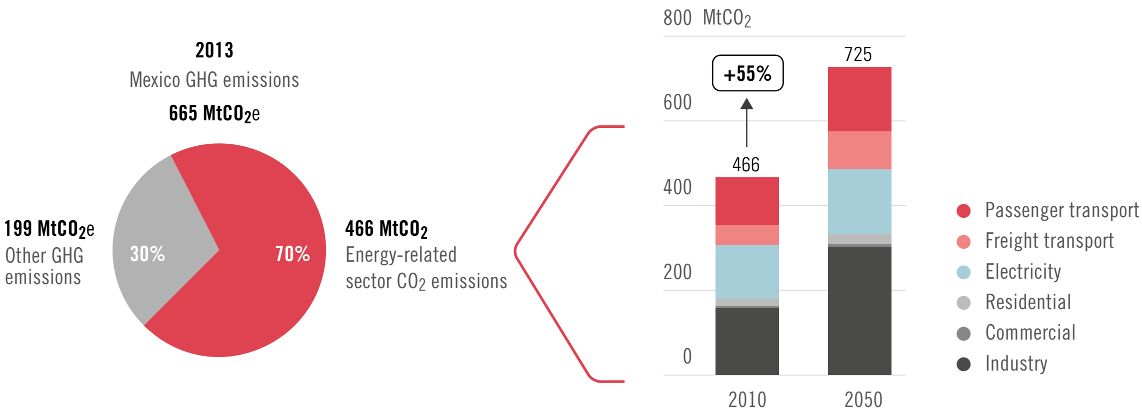
Mexico´s gross GHG emissions were 665 $MtCO_2e$ in 2013. Around 78% of those emissions were from energy-related sectors: 25% from transportation, 19% from power generation, 31% from industry (the oil & gas sector alone contributed to 12% of the total), and 4% from household and commercial buildings[9]. The other 22% of GHG emissions come from non-energy-related sectors: waste, agriculture, and land use and forestry.

Under the current policy scenario, energy-related CO_2 emissions alone would increase to more than 700 $MtCO_2e$ by 2050[10] (see **Figure 4**).

9 BUR1

10 Own estimate based on original DDPP work, with updated projection of the power sector CO_2 emissions according to official plans: http://www.gob.mx/sener/documentos/prospectivas-del-sector-energetico, and http://www.gob.mx/conuee/acciones-y-programas/estrategia-de-transicion-para-promover-el-uso-de-tecnologias-y-combustibles-mas-limpios-64062

Figure 4. Total GHG and CO2 emissions from energy-related sectors in Mexico, 2013 & 2050



Gross GHG (left) and CO_2 emissions from the combustion of fossil fuels for energy uses (right). Under current policies, CO_2 emissions from energy-related sectors alone could increase 55% by the year 2050, driven mainly by transportation and industry.

The transport sector is the single largest source of emissions and represents a fourth of the total share of emissions.

The importance of fossil fuels for transportation is reflected in sectorial CO_2 emissions, which attained 160 $MtCO_2$ in 2013. Gasoline vehicles accounted for 66% of this total, followed by diesel vehicles at 27%, aviation at 4% and waterborne and rail transportation together at 2.5%.[11]

According to our estimates, in 2010 passenger transport emissions amounted to 100 $MtCO_2$. The five largest cities containing 30% of the population contributed to two thirds of the total CO_2 emissions. From these *metropolitan emissions* cars are the main source with 91.5% of the share. Under the current mobility patterns and policies, passenger transport CO_2 emissions in Mexico could increase by 60% and final energy consumption could double by 2050 (**Figure 5**).

National policy framework on mobility and climate

In 2012, the Mexican General Climate Change Law (LGCC for its name in Spanish) was enacted to establish the key elements of Mexico´s climate policy. Ambitious emissions reduction targets by 2050, broadly consistent with limiting global temperature increase to 2°C, were set.[12] Since then, Mexico has rolled out both the required institutional framework as well as a suite of dedicated high-level planning instruments at the national level (NDC[13] and MCS[14]). Several states have also developed State Climate Action Plans, just as some municipalities and cities have developed their own local plans. However, despite the considerable work carried out, this set of policy documents does not provide full clarity on how the high level of ambition stated in the Law will be achieved.

The NDC includes an indicative GHG emissions target for transport of 218 $MtCO_2e$, representing a reduction of 18% compared to the value estimated under a baseline scenario (266 $MtCO_2e$); however this target still represents a growth of 25% from 2013 levels (174 $MtCO_2e$). Mexico's Climate Change Mid-Century Strategy (MCS)

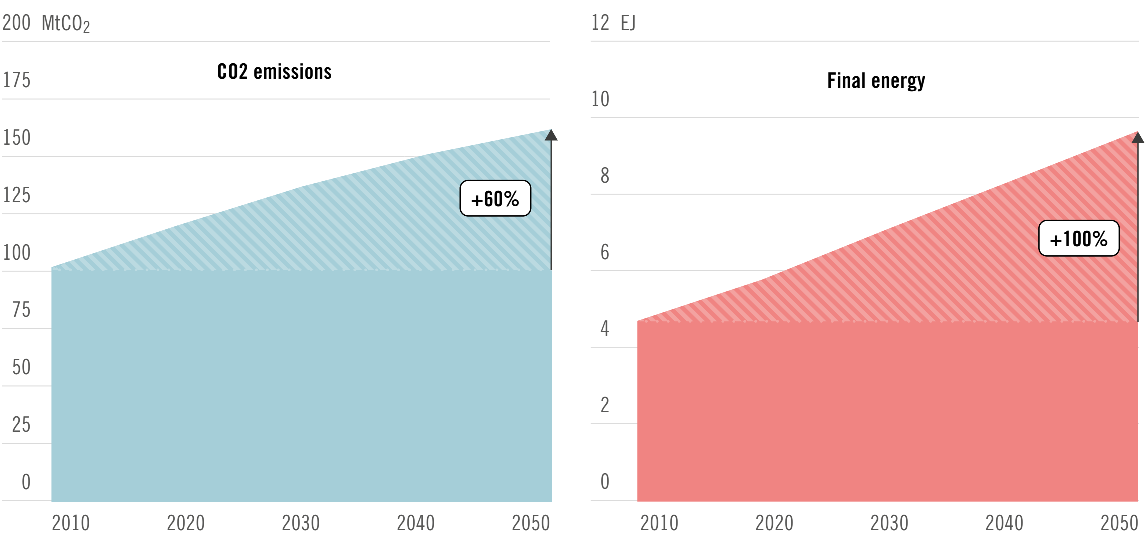
11 BUR1

12 The LGCC sets a nation-wide reduction of 50% of GHG emissions by 2050 compared to what was recorded in 2000, setting the target at around 300 $MtCO_2e$ a year.

13 SEMARNAT/INECC, 2014, Compromisos de Mitigación y Adaptación ante el Cambio Climático para el Periodo 2020-2030, (NDC). [http://www.inecc.gob.mx/descargas/adaptacion/2015_indc_esp.pdf]

14 SEMARNAT/INECC, 2016, Mexico's Climate Change Mid-Century Strategy, (MCS). [http://unfccc.int/files/focus/long-term_strategies/application/pdf/mexico_mcs_final_cop22nov16_red.pdf]

Figure 5. Evolution of emissions and energy under the reference case, 2010-2050



Projected CO_2 emissions (left) and final energy demand (right) for passenger transport under a *current* policy scenario used as a reference in this study.

acknowledges that “the transportation sector requires fast new efficient technologies in a short timeframe”,[15] and even describes how rapid the energy efficiency gains must be within the sector (in the form of improvements to the miles-per-gallon indicators) to yield meaningful emissions reductions.

In parallel to these Climate Change developments, Mexico has undergone a deep Energy Sector Reform with an initial focus to boost declining domestic production of oil and expand emerging natural gas production. Although the results of this reform are yet to materialize, lower oil and gas prices could, in principle, strengthen the drivers against transport decarbonization.

Passenger transportation suffers from institutional and administrative fragmentation and is often shaped by social pressures rather than strategic planning.

The main focus of the Ministry of Communications and Transport in Mexico (SCT, for its name in Spanish) has been around construction and maintenance of road infrastructure. The planning and execution of transport and urban-structure related policies tend to be responsibilities of the local governments, often at the municipality level.

As local administrative periods are short (3 years), project continuity is hard to achieve and many potentially beneficial projects with long lead-times are not considered. Geographical fragmentation also leads to tunnel vision of the local decision-makers and to sub-optimal regional coordination.

The transport sector has also been affected by historic and systemic underinvestment in public infrastructure.[16] Overcrowded road-based public transportation systems are inefficient (they suffer from and contribute to heavy road congestion), highly polluting and increasingly dangerous.

15 MCS

16 For example, Mexico City metro needs an investment of around 1.66 BUSD (30 BMXN) for maintenance in 2017. [http://www.milenio.com/df/fallas_metro-jorge_gavino-iluminacion_tuneles-costos_mantenimiento-linea_12_0_1012698996.html]

Storylines for the mobility determinants of two contrasting deep decarbonization pathways: Demand (DEM) and Technological (TEC)

The two scenarios presented in this paper correspond to alternative narratives of the evolution of passenger transportation in Mexico. In the first scenario, called *Demand*, we explore potential reductions of mobility demand due to structural changes of cities and of people's behaviors.

The second scenario, called *Technological*, illustrates what would be the technological evolution required to achieve an equivalent decarbonization trajectory in a future in which these changes take no place and the current socio-economic patterns are maintained through 2050.

Transformations common to Demand and Technological scenarios

Demographic and economic changes

The population in Mexico will continue to grow from 114 million in 2010 and stabilize by 2050 at around 151 million[17]. The share of the population between 20-60 years old, the most active in terms of mobility, will remain stable at around 60% over the same period. Under current trends, households will reduce their average size from 4.1 to 3.2 people per household by 2050.

In all the scenarios presented, GDP is modeled to grow at a 3% annual rate from 682 billion USD in 2010 to 2,225 billion USD in 2050 (exchange rate: 18 MXN/USD). The GDP share dedicated to household income is assumed to remain stable around 30% over the same period. For this condition to be met, the average annual household income must double from 7,116 USD in 2010[18] to 14,000 USD in 2050. We estimate that in 2010 about 15% of the monthly monetary expenses of households were dedicated to transportation needs, however this figure goes up to 43% if the purchase of a car is included in the mobility costs. In the scenarios presented in the study, the income share dedicated to transportation activities could reduce to 36% of the total expenditure of households by 2050.

Population centers and territorial distribution

In 2010, about 30% of the population was located in the five largest metropolitan areas: Mexico City, Guadalajara, Monterrey, Puebla-Tlaxcala and Toluca; under current trends this share will remain stable by 2050.[19] In the present study, these five cities constitute the *metropolitan areas*, and they are expected to keep some degree of control over their future expansion. The rest of the population, presently in cities with less than 2 million and rural areas, herein called *non-metropolitan areas*, are expected to absorb the largest share of future growth.

The average income per capita in the metropolitan areas was around 89% higher than the national average, while in the non-metropolitan areas it was 37% lower.[20] Future economic and social development of non-metropolitan areas should partially close the present income gap by 2050.

17 Projections by the National Population Commission (CONAPO) [http://www.conapo.gob.mx]

18 Estimate with information from INEGI, Encuesta Nacional de Ingresos y Gastos de los Hogares 2014. [http://en.www.inegi.org.mx/]

19 CONAPO, Delimitación de las Zonas Metropolitanas de México 2010. [http://www.conapo.gob.mx/es/CONAPO/Zonas_metropolitanas_2010]

20 Estimate using data at the municipal level from: CONEVAL, Tablas de Ingreso corriente total per cápita mensual por municipio. [http://www.coneval.org.mx/Medicion/MP/Paginas/Medicion-de-la-pobreza-municipal-2010.aspx]

Vehicle transformations

The efficiency improvement projected by 2050 for internal combustion engine (ICE) cars and buses in all decarbonization scenarios is ambitious and consistent with the Blue Scenarios of the IEA, which aim to halve global energy-related CO_2 emissions by 2050[21].

Electric car efficiency improves 15% from 2010 to 2050, while electric trains improve 5% over the same period.

The increase in air transportation efficiency is more ambitious, 25% from 2010 to 2050. In all decarbonization scenarios, domestic flights are limited to the long distances within the country. In addition to improvements resulting from technological innovation in aircrafts, this increases overall flight efficiency due to the relative energy-intensity of the inefficient processes of landing and takeoff compared to cruising.

Energy system transformations

The carbon intensity of electricity is important when electrification of transport is deployed as a deep decarbonization strategy. In all scenarios analyzed, the power grid evolves towards extremely low CO_2 emissions, consistent with all deep decarbonization scenarios produced for Mexico to date. Carbon intensity of electricity generated reduces from around 600 gCO_2/kWh in 2010 to 19 gCO_2/kWh by 2050. In all decarbonization scenarios, biofuel substitutes 15% of gasoline and diesel used in the remaining non-electric road vehicles, and 15% of bio-kerosene is used in jet fuel mixtures for domestic and international aviation.

The Demand Scenario explores a future with transformations of mobility needs

The Demand Scenario is the one in which the broadest range of levers is acted upon to construct a diverse and balanced pathway. To encompass a larger spectrum of possibilities, we include assumptions of future changes in the behavior of people and in the spatial organization of cities that will lead to reductions in mobility demand. The most important driver of mobility demand (and hence passenger transport emissions) is the travel required by everyday activities. This scenario explores the potential role of managing increasing demand for constrained travel as a decarbonization lever.

21 IEA, Energy Technologies Perspectives 2010, Scenarios & Strategies to 2050.

Spatial organization and income redistribution

Today's income gap prevents people from living close to their respective income sources. The Demand Scenario projects a preliminary estimate of the combined effect of two phenomena that would reduce the average daily distances travelled:

By 2050, urban settlements are better planned and land use policies reinforced, producing a more compact and versatile urban structure that allows for workplaces, shops, restaurants, etc. to be closer to citizens, effectively limiting the surface expansion of cities and increasing density in their centers

A more equal income distribution gives a greater share of the population increased resources to move closer to their daily activities

We consider that these assumptions could enable 10% of the population to be 30% closer to their daily activities by 2050, both in metropolitan and non-metropolitan areas.

Adoption of remote activities

In addition to the reduction in distances, people could also adopt home-based activities that allow them to avoid some travel activities in the future.

As a preliminary estimate we assume that 50% of the people working in the services sector by 2050 (24% of the total employed population) work two out of five days a week from home. This would mean a reduction of 10% in work-related travel.

A similar reduction of 10% in travel for regular shopping is assumed by 2050.

Infrastructure and urban planning

The Demand Scenario envisages the redesign and adaptation of urban spaces in cities. Mixed land use neighborhoods, with extended pedestrian zones and bike lanes enable non-motorized travel for short trips. An expanded interconnected network of metro lines, suburban trains and electric buses are considered the optimal choice for longer commuting distances. Long-distance travel is satisfied by a new network of electric trains, including high-speed services along most crowded routes. Development of infrastructure is redirected from the expansion of domestic airports to the railroad network, connecting main cities in the center of the country. The secondary road network present in 2010 is still used by buses in 2050 to connect smaller settlements to larger cities acting as intermodal network nodes. International airports continue the increase in capacity currently observed.

Vehicle transformations: electrification

In this scenario, electric lightweight vehicles comprise 45% of the overall fleet by 2050; electric buses 40% of the bus fleet, and 100% of the trains are electric.

The average lifetime of cars in Mexico is 15 years. Thus, projecting that by 2050 half the fleet (estimated at around 50 million cars) is electric is an ambitious target. Conversely, there is practically no railway legacy infrastructure in Mexico at present,[22] thus no retrofit of fossil-specific equipment (locomotives, for example) is needed, and the train network could be built all electric from the start.

The Technological Scenario explores deeper technological changes to achieve decarbonization under current mobility patterns

The second scenario explores what would be needed to reach the same end-year CO_2 emissions as in the Demand Scenario, assuming no demand reduction from changes in urban organization or the behavior of commuters.

Spatial organization and income distribution remain as today

The Technological Scenario projects a future demographic and spatial evolution of cities no different to the one observed today. As the urban share of the population increases from 72% in 2010 to 83% by 2030[23], small and medium cities replicate the same growth patterns as metropolitan areas: sprawling growth of cities with arbitrary zoning, variable population density, and increasing commuting distances.

Remote activities are not widely adopted

This scenario also assumes that activities from home (working and shopping) are not widely adopted by people in the future. This assumption is actually too conservative; even now practices are changing. The Technological Scenario has been defined to demonstrate, by contrasting with the Demand Scenario, the importance of managing future travelling demand in Mexico.

Infrastructures and urban planning

Under the conditions described above, there is a greater demand for mobility, and a more intensive modal shift towards mass-transport systems is needed in order to reduce automobile emissions to levels consistent with deep decarbonization (35 $MtCO_2$/year).

Vehicle and energy system transformations

The assumptions regarding the rate at which electric vehicles become available are the same as in the Demand Scenario, as is the rate of electrification of transport in general.

In addition to the larger modal shift, an increased electrification rate (up to 50% of all buses) is also needed to reach the same emissions targets by 2050. The share of electric cars within the fleet projected in the Demand Scenario is deemed already high at 45%, thus it is assumed to be the same in the Technological Scenario.

22 Only one passenger diesel train service remains in Mexico (*El Chepe*), besides electric sub-urban and metro systems.

23 SEDATU, Programa Nacional de Desarrollo Urbano 2014-2018. [http://dof.gob.mx/nota_detalle.php?codigo=5342867&fecha=30/04/2014]

Table 1. Synthesis of the Demand and Technological scenarios storylines: common and diverging features

Determinants	Demand Scenario	Technological Scenario
Demographic and economic changes	Population and economic growth Income gap narrows	Population and economic growth Income gap does not narrow
Population centers and territorial distribution	Today's medium and small cities in the center of the country grow	- same -
Lifestyles and mobility services	Wealthier population lives closer to daily activities Partial adoption of working and shopping from home	No change of current trend
Infrastructures and urban planning	High-density cities, with mixed land use Mass transit-oriented organization; pedestrian-friendly neighborhoods Development of railway networks, including high-speed services	No change of current trend based on car oriented design
Vehicle transformations	Electrification of mobility Energy efficiency improvement	- same -
Energy system transformations	More electricity generated from renewable sources Development of electric network for transport (buses, trains and cars)	- same -

Results – Evolution of emission drivers and related transformations for Demand and Technological scenarios

Two scenarios are presented, both leading to a 50% reduction in annual CO_2 emissions of the passenger transport sector by 2050 (50 $MtCO_2$) compared to the level in 2010. This target represents the same level of annual emissions as in previous DDPP exercises, which already proved their consistency with the goal of limiting global temperature increase to no more than 2°C.

Demand Scenario: individual mobility demand reduction facilitates deep decarbonization

Changes in individual behavior and demand

The difference observed in personal constrained mobility between the metropolitan and non-metropolitan areas in 2010 (**Figure 3** in the Annex) is due in large part to the much larger distances each person has to travel in the big cities. Based on the projected growth of today's medium and small cities this gap in constrained mobility demand between metropolitan and non-metropolitan areas will be partially reduced by 2050.

The Demand Scenario projects a 10% reduction in constrained mobility by 2050 (equivalent to 134 Gpkm / year) due to better urban design, a more dynamic and developed society, and to the partial adoption of remote activities.

Part of that reduction comes from assuming that 50% of the service sector labor force works from home two days a week, and that 10% of shopping-related travels is substituted by online shopping. The result of adopting these remote activities would be a reduction of 7% in all constrained travel across zones.

At the same time, a more affluent and dynamic population living in cities with a better spatial organization combines solutions like working at a rented office near home or even moving closer to work. Assuming that 10% of the commuters are 30% closer to their daily activities by 2050, both in metropolitan and non-metropolitan areas, there could be a 3% reduction in constrained mobility.

Regarding non-constrained mobility, the disparity of income between metropolitan and non-metropolitan areas (**Figure 6**, right) is partially reflected in the total non-constrained mobility demand in each of them in 2010 (**Figure 7**, right), but more importantly, in the modes chosen to satisfy this demand: air transportation is more widely used in metropolitan areas whereas intercity buses are the preferred choice in non-metropolitan areas. As the economic gap between these areas narrows in the future, the difference in non-constrained mobility is also expected to shrink.

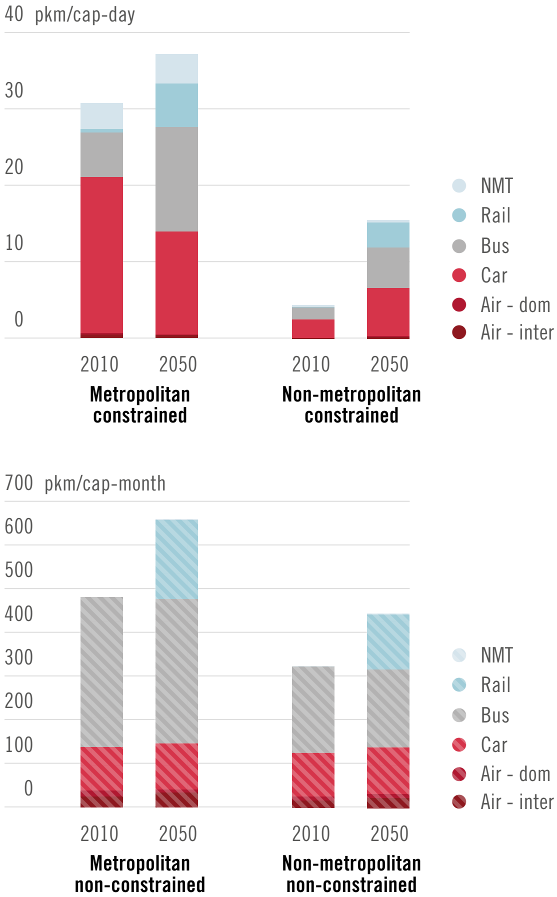
Changes in modal structure

In metropolitan areas, car use is reduced (34% vs. 2010 levels) and commuters shift from cars to a multimodal system integrating metro lines, lightweight and suburban trains, and buses.

In non-metropolitan areas, the presently short distances travelled daily could triple by 2050 (**Figure 6**, top-right) so car use increase is partially restrained by the development of an intermodal network of buses and trains.

The distance people travel daily in non-motorized modes is kept at present levels in all scenarios throughout 2050. For non-constrained trips (**Figure 6**, bottom) car and bus use is restricted to today's levels and intercity trains satisfy the emerging demand from a larger and wealthier population. Domestic air travel is also partially substituted by train, particularly over medium distances

Figure 6. Personal mobility by transport mode under the Demand Scenario, 2010 & 2050



Average kilometers travelled per person in 2050 for daily constrained (top) and monthly non-constrained (bottom) travel in metropolitan (left) and non-metropolitan areas (right).

(500-800 km). The shift from air to train is more notable in metropolitan areas, with high-speed train connections amongst them.

International air travel for non-constrained purposes increases as income per capita does. In non-metropolitan areas the increase is slightly larger as the income gap compared to metropolitan areas narrows by 2050.

Technological perspectives for vehicles

Fuel efficiency improvement aligned to ambitious international practices is projected in all decarbonization scenarios. For example, new internal combustion engine (ICE) cars are 60% more efficient by 2050 (see **Table 2**).

Electric cars are already global technologies and they will be more common in the future. If electrification of transport occurs under today's mobility dynamics favoring the use of cars on congested roads the burden on the power system would be very high. It is vital to harvest the results of all energy efficiency measures implemented (better urban design, adoption of remote activities and modal shift) before electric cars are widely adopted by the general public. It is also worth noting that unless electricity generation is effectively decoupled from CO_2 emissions before transport electrification, CO_2 emissions would only change source but would not be reduced.

In the Demand Scenario car *usage* is reduced, yet car *ownership* is not modified, and it is projected to keep its current trends towards 2050. As the fleet keeps expanding, total car sales also remain unaffected, and only the composition changes to accommodate a larger number of electric vehicles (see **Figure 6** in the Annex).

Vehicles fuelled by natural gas retain a marginal share by 2050. Localized efforts to transform some vehicles to compressed natural gas are concentrated on taxi, lightweight commercial, and microbus fleets. As the average lifetime of vehicles in Mexico is 15 years, at the date of publication of this report (2017) only two full-life cycles remain before 2050. There is simply not enough time to switch to a *transition* technology, such as to natural gas-fuelled cars. By assuming a minimum share of these vehicles in the scenarios, we avoid large investments in infrastructure that would quickly become obsolete.

In this exercise, we assume that the market share of gasoline lightweight vehicles reduces in favor of only battery-electric vehicles. This technology was chosen for several reasons:

- Given that information on the specific technology that will dominate the future automobile market is uncertain, this technology was chosen to exemplify a "generic" electric car

Table 2. Fuel efficiency improvement of main transport modes from 2010 to 2050

Technology	Efficiency Improvement 2050 vs. 2010
ICE car	60%
Electric car	11%
ICE bus	35%
Electric bus	15%
Electric train	5.4%
Air travel	25%

In all decarbonisation scenarios analysed, the same ambitious targets of energy efficiency improvement were projected. Electric vehicles are estimated less potential increase than those based on ICE because they already use energy quite efficiently.

- With two full vehicle generations left between now and 2050, it is unlikely that several different technologies could be deployed
- This type of car is "full electric", implying a complete transfer of energy from fossil fuel to electricity, which allows consideration of the additional power required in this kind of "high-case" of electrification.

Technological perspectives for the energy system

The Demand Scenario results in 17% lower overall energy consumption for passenger transportation in 2050 compared to 2010, due to a better urban organization, a modal shift to mass public systems integrating trains and buses, and a steep improvement of fuel efficiency in the remaining ICE vehicles.

By 2050, energy carriers satisfy more than double today's transport demand with nearly half the carbon footprint. The annual demand for liquid fossil fuels (gasoline, diesel and jet fuel) is halved over that period from 1.36 EJ to 0.66 EJ (see **Figure 1d** in the Annex) virtually eliminating the need for imports. However, even with these reductions, gasoline is still the main energy carrier in 2050, supplying 41% of all passenger transportation energy requirements.

The partial displacement of gasoline is mostly due to electricity, increasing its share from 0.2% to 30% of all energy demand in the sector. Biofuels come in third with 13%, with jet fuel and diesel having the lowest shares (9% and 7%, respectively).

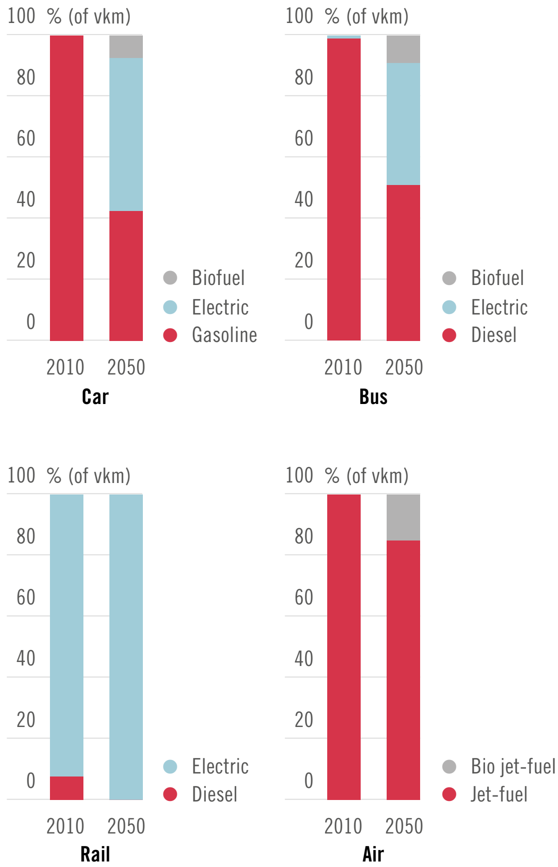
The additional electricity required by 2050 amounts to 100 TWh/year and represents 32% of the total electricity generated in 2015 (309.5 TWh).[24]

Biofuels play a limited role in all scenarios. Their production and deployment could indeed help to ease the pressure on the required cost reduction rate of technologies as well as on the expansion of the power sector. However, as production is still dominated by first generation methods, there remain questions regarding their long-term sustainability and impacts on the food sector.

In both decarbonization scenarios, the remaining fossil fuel vehicles by 2050 are powered with a mixture of 15% ethanol in gasoline, diesel and jet fuel. In the Demand Scenario, the total amount of ethanol required is estimated at around 5,600 million liters a year. If this biofuel were produced using a combination of sources, for example 40% from sugarcane and 60% from corn, it would require 40% of the national plantations of sugarcane and 15% of the corn cultivated at present.[25] The combined corn and sugarcane area dedicated to biofuels would amount to more than 5% of all cultivated land.[26]

Some biofuel production methodologies are already promising to increase the potential sources from which biofuels could be made, such as cellulosic ethanol made from biomass waste from forestry and agriculture, or algae farming producing high yields of biodiesel with low requirements for land or fresh water. Although such

Figure 7. Fuel employed by mode under the Demand Scenario, 2010 & 2050



A comparison of the fuel employed in each mode under the Demand Scenario shows how electricity is a centerpiece of passenger transport decarbonization.

24 SENER, Programa de Desarrollo del Sistema Eléctrico Nacional 2017-2031 (PRODESEN). [https://www.gob.mx/sener/acciones-y-programas/programa-de-desarrollo-del-sistema-electrico-nacional-33462]

25 Ethanol yield per crop: sugarcane 7,560 L/ha & corn 3,630 L/ha.

26 Cultivated area in 2016 reached 21.938 million hectares, the surface dedicated to sugarcane in the same year was 865 thousand ha and to corn 8.368 million ha. Information from SAGARPA-SIAP. [http://infosiap.siap.gob.mx/gobmx/Siacon_datos_Abiertos.php]

technologies could present viable solutions in the near future, the consumption of both gasoline and biofuels must be reduced to effectively increase national energy security. This entails an ever more limited use of ICE vehicles in the future.

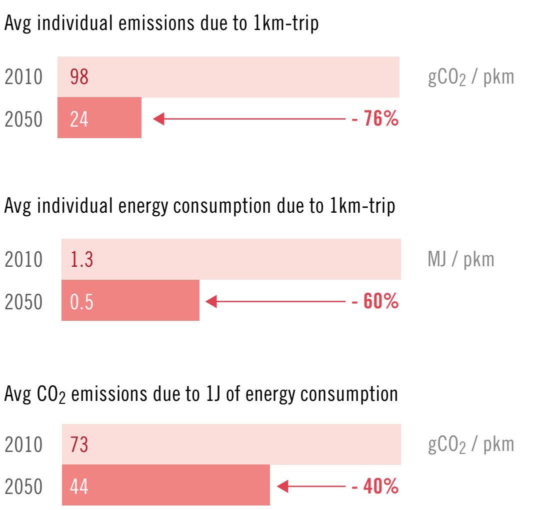
Technological perspectives for infrastructure

In the Demand Scenario, the requirements for new road capacity stabilize at around 94,000 km a year by 2050. Assuming that 15% of all buses operate as Bus Rapid Transit, these systems will need the construction of around 450 new kilometers of road every year by that time.

Development of a completely electric passenger railroad network, from expansion of current urban and suburban lines to new intercity lines and high-speed train services, necessitates the expansion of new infrastructure at a constant pace of around 1,100 km per year. Supposing that 20% of train services are high-speed by 2050, this type of service could reach 3,800 km by that year and would link all metropolitan areas (at present such a network is non-existent in Mexico).

Electrification of transport will require an expansion of the power grid beyond electricity generation to accommodate the extra electricity supplied as well as infrastructure required by derived services, like recharging stations, energy storage systems, etc. In the Demand Scenario, charging stations reach 750 thousand by 2050 to supply the increasing electric vehicle fleet.

Figure 8. High-level indicators of the Demand Scenario, 2010-2050



Variation in three key decarbonization indicators corresponding to the Demand Scenario trajectory.

Technological Scenario: unmanaged mobility demand necessitates greater modal shift and electrification

Changes in individual behavior and demand

The Technological Scenario does not assume a better organization of space in cities, or the large-scale adoption of remote activities. Although this scenario projects that the income gap between metropolitan and non-metropolitan areas narrows in equal measure compared to the Demand Scenario, its effect on creating a more dynamic society is offset by the increasing surface area of urban centers and hence no reduction of commuting distances is observed.

Metropolitan constrained mobility increases from 11,320 km/cap-year in 2010 to 15,200 km/cap-year in 2050, and non-metropolitan constrained mobility increases from 1,620 km/cap-year in 2010 to 6,340 km/cap-year by 2050. The increase in non-constrained mobility is the same as in the Demand Scenario.

Changes in modal structure

This scenario induces a deeper modal shift away from cars compared to the Demand Scenario with 3% less in terms of total pkm travelled in cars. The share of buses in constrained mobility increases only marginally. The total demand for train travel in this scenario is 21% higher than in the Demand Scenario.

Technological perspectives for vehicles

Fuel efficiency improvements are assumed to be the same as in the Demand Scenario (**Table 2**).

However, a higher rate of electrification of passenger transport is required to reach the emissions target. The penetration of electric vehicles in the market assumed in the Demand Scenario is already optimistic. Hence, even more significant electrification of buses is required in the Technological Scenario, reaching 50% of all vehicle-km by 2050.

Technological perspectives for the energy system

The Technological Scenario results in 13% lower overall energy consumption for passenger transportation in 2050 compared to 2010. Electricity demand in this scenario by 2050 is 407 PJ (14% higher than in the Demand Scenario). The required biofuel supply, on the other hand, is marginally lower in this scenario due to a more limited use of ICE vehicles and demand of liquid fuels in general.

Technological perspectives for infrastructure

In this scenario, the requirements for new road capacity are the same than in the first scenario, however a higher capacity expansion of railroad infrastructure is needed.

Scenario comparison

If transportation demand could be managed, by reduction of distances and trips, the transformations required for decarbonization would not only become easier and cheaper, but there would be additional benefits.

From a personal perspective

In the Demand Scenario the total average cost of mobility is 1.5% lower than in the Technological Scenario. The time required every day for travelling is 9% less in the Demand Scenario, reaching an average of 55 min/day per person in metropolitan areas, and the daily distances travelled are 10% shorter than in the Technological Scenario.[27]

From a policy-making perspective

The differences in final mobility demand between scenarios in turn require different levels of deployment of decarbonization measures to reach the same emissions trajectory by 2050 (see **Figure 10**).

The Technological Scenario requires a more marked modal shift to reduce car use to only 29% of all passenger-kilometers travelled (in the Demand Scenario the share is 31%). Additionally, a deeper decarbonization of final energy used for transportation is also needed.

Even with a greater modal shift that increases efficiency, energy consumption in the Technological Scenario is 3.9% higher than in the other scenario.

27 Preliminary indicative estimates; specificities of traffic congestion in Mexican cities have not yet been modelled.

Figure 9. Comparison of mobility costs and metropolitan travel between scenarios, 2010 & 2050

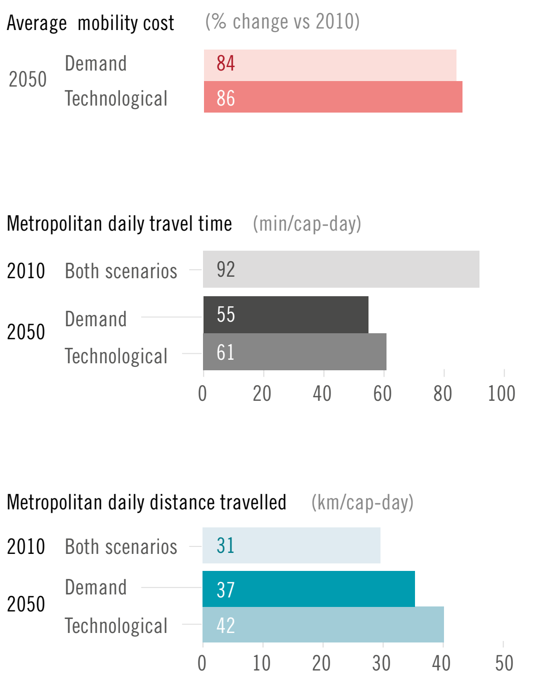
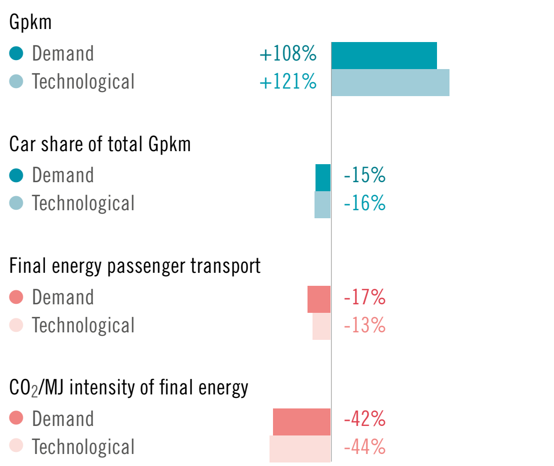


Figure 10. Changes in mobility demand and decarbonization levers by scenario vs 2010



Since total mobility demand increase is greater in the Technological Scenario it requires a stricter control of car use and a lower carbon intensity of energy carriers. Even so, this scenario results in higher energy consumption than the Demand Scenario.

The present study is a bottom-up exercise and does not explore demand responses due to increases in fuel prices. An incremental CO_2 tax trajectory is used only to estimate mobility costs.

Key conclusions

The levers modeled in this study represent important changes unlikely to occur under an incremental extension of existing policy packages and frameworks, but rather requiring an in-depth re-visiting of the relevant policy space.

Structural change will be essential. Efficient achievement of such change will necessitate decisive early action to shift trends and commence decades-long changes in investment and behavior patterns. In practical terms, radical shifts in urban, fuel, energy, and transport programs must commence pre-2020. Delay until 2030 would imply far steeper gradients than those presented here, bringing into question the credibility of such a change program. This has implications for the formulation of the Long Term strategies of Article 4.19 of the Paris Agreement, and indeed for the NDC update process, both of which would be strengthened by presenting Passenger Transportation actions in frameworks similar or translatable to those utilized in this study.

Development of low-income sectors of the population should entail an increased access to mobility services at affordable prices, while avoiding inefficient past patterns. Closing the income gap would increase people's ability to adapt to low-carbon urban paradigms consistent with deep decarbonization.

The transformation of infrastructure implied in the decarbonization scenarios is of very large scale and will require coordination between different government institutions (horizontally between different ministries and vertically between federal, state and local levels). Early inclusion of the academia and the private sector in planning and execution is essential to draw upon their economic and technical resources.

Mobility can be more efficient if the design of cities helps reduce the distances travelled every day. Best practices of urban planning have been published elsewhere.[28] In general high-density, mixed land use neighborhoods designed for non-motorized travel provide good conditions for the development of mass transport systems, reducing the amount of energy and cost required to transport each person.[29] As cities have a spatial structure largely set in place that changes rather slowly[30] there is an urgency to act as soon as possible to achieve decarbonization targets by 2050. Given the already wide income disparities between larger and smaller cities, public intervention in land management and urban and transport planning is required to ensure both efficiency and equality.

Limiting the use of cars is crucial as a decarbonization measure. Results show that unless this is accomplished, other decarbonization measures, such as electrification or the increase in vehicle mileage, will do little to reduce CO_2 emissions and energy expenditure.

While the efficient use of energy for transportation is already of high importance, optimizing the amount of passenger-kilometers travelled per unit of energy used is even more pressing if the impending electrification of the sector is considered. Under the present mobility dynamics (the extensive use of private cars, low occupancy rates and congested roads) electrification of transport could result in burdensome energy expenditure in the future and an increased pressure on the power sector.

Beyond car use, managing future mobility demand is worth exploring the potential alternatives to travel, such as working and shopping from home, and promoting non-motorized short-distance travel.

Significant further research is still needed to improve data quality, forecasts, and assumptions, to strengthen and refine the conceptual framework, and to extend the scenario analysis and the granularity and causality of levers, so specific policies can be derived from them.

28 ClimateWorks Foundation, Planning Cities for People. A Guide to Prosperous, Low-Carbon Urbanization. 2011

29 UNEP, Sustainable Cities. Building cities for the future. 2012

30 United Nations Human Settlements Programme (UN-Habitat), Planning Sustainable Cities. Global Report on Human Settlements 2009.

Standardized DDPP graphics for Mexico scenarios

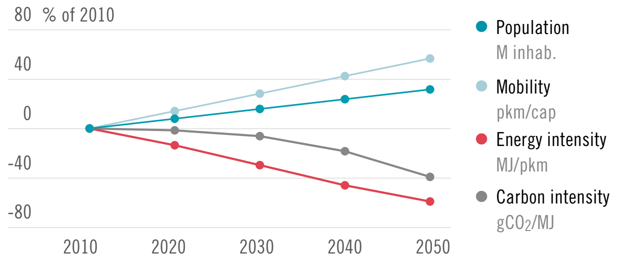
Demand (DEM) Scenario

Technological (TEC) Scenario

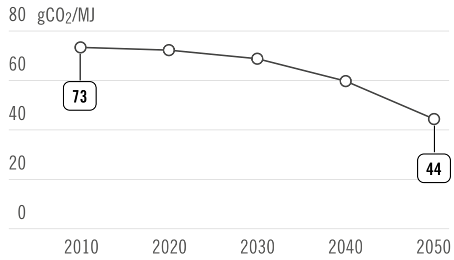
MEXICO - Demand (DEM) Scenario

A1. National energy consumption and related emissions

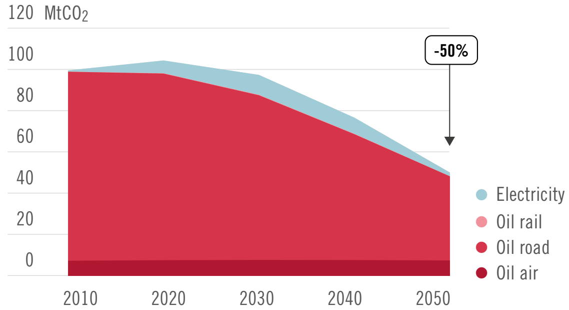
1.a Emission drivers



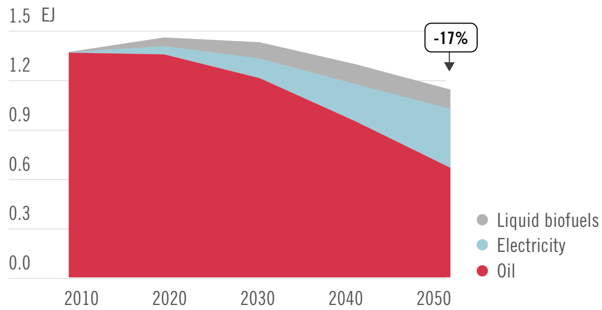
1.c Carbon content of energy



1.b CO_2 emissions



1.d Final energy consumption



A2. The pillars of decarbonization

Pillar 1
Energy efficiency

Individual Mobility

9 → + 57%
14

000s pkm/cap

Energy intensity

1.3
0.5 ← - 60%

MJ/pkm

● 2010 ● 2050

Pillar 2
Decarbonization of electricity and fuels

Carbon content of electricity

569
19 ← - 97%

gCO_2/kWh

Biofuel in blended fuels *

0 → + 15 pt
15

% blended fuels

** Liquid fuels and pipe gas*

Pillar 3
Shifting to low carbon fuels

Non fossil fuel energy **

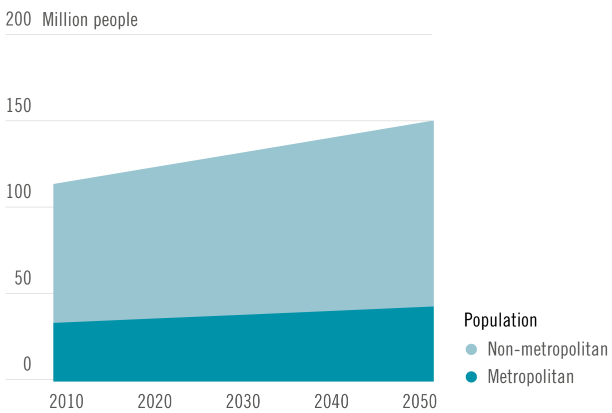
0 → + 42pt
42

% of total energy

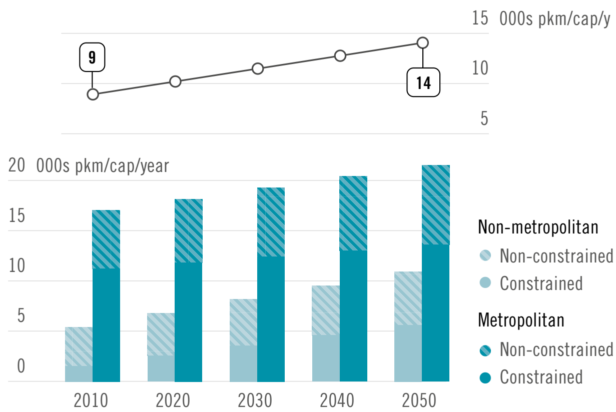
*** Integrating electricity, liquid and gaseous biofuels, hydrogen*

A3. Population and mobility

3.a Metropolitan and non-metropolitan population

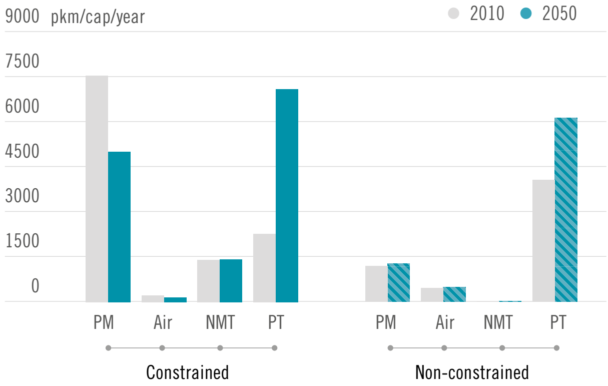


3.b Constrained and non-constrained mobility

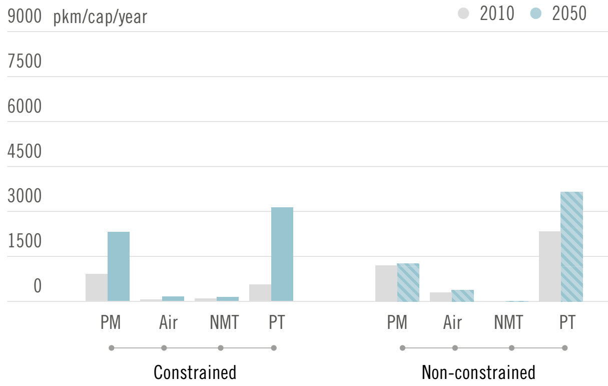


A4. Modal structure

4.a Metropolitan



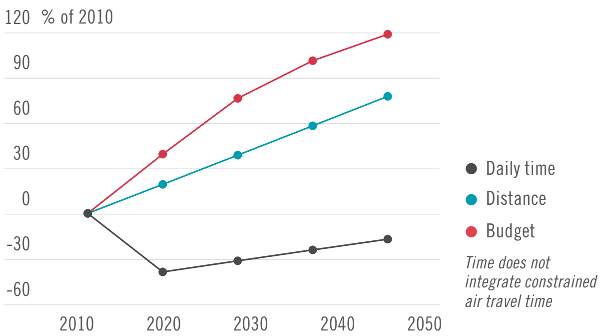
4.b Non-metropolitan



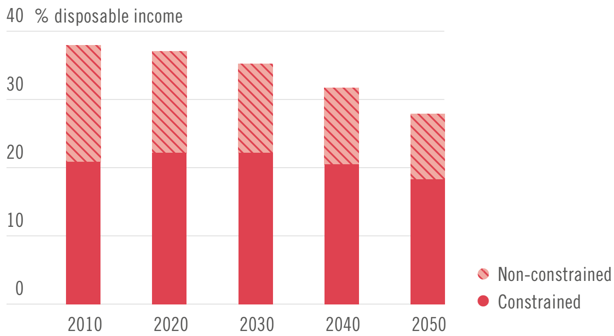
PM = Private Mobility (car and 2W), NMT = Non-motorized transport (walking, biking…), PT = Public transport (bus and rail)

A5. Mobility indicators

5.a Indicators for constrained mobility

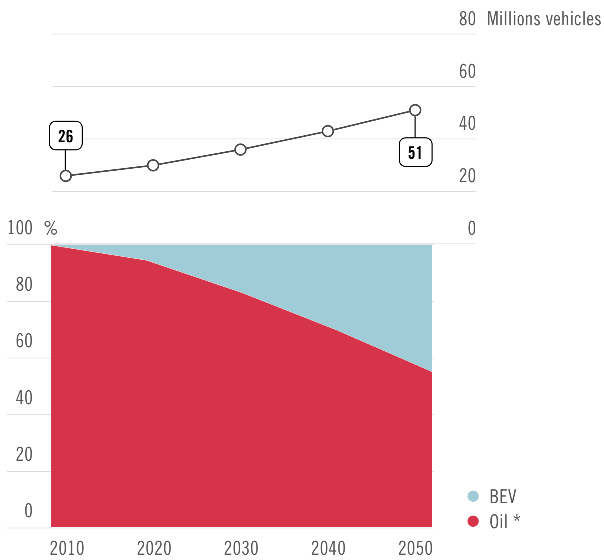


5.b Transport budget

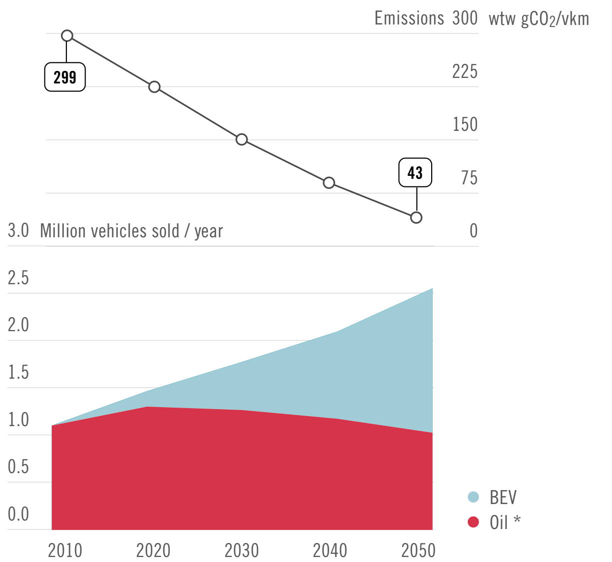


A6. Car mobility

6.a Car stock



6.b Car sales and related emissions



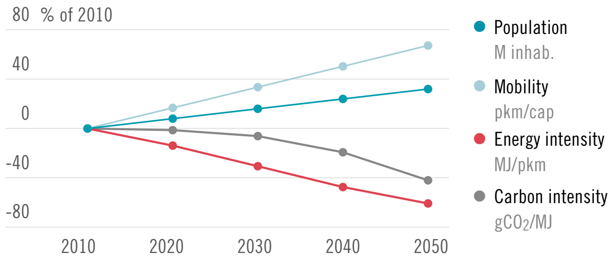
** "Oil" means thermal motorization fueled by liquids (gasoline, diesel, liquid biofuels)*

*** Emissions of average car sales is expressed in "well-to-wheel" gCO_2 per vehicle-km travelled*

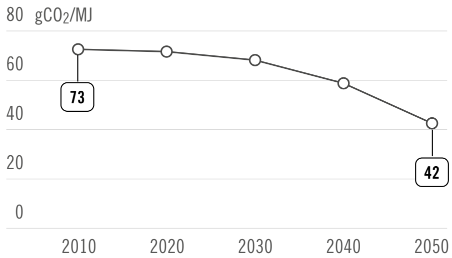
MEXICO - Technological (TEC) Scenario

A1. National energy consumption and related emissions

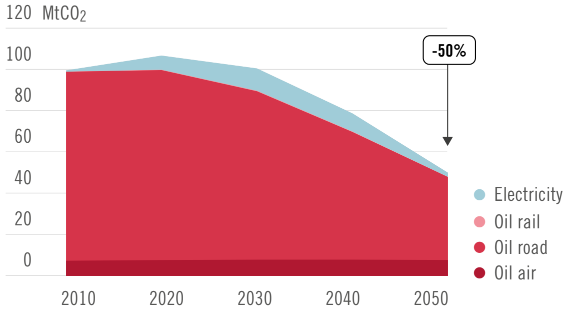
1.a Emission drivers



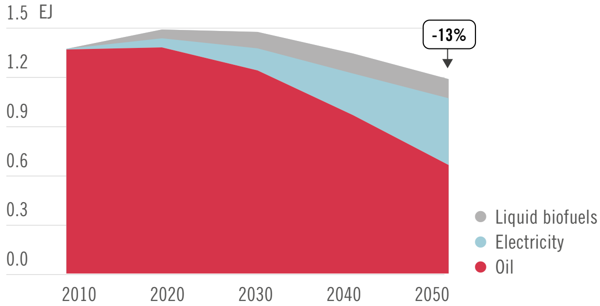
1.c Carbon content of energy



1.b CO_2 emissions



1.d Final energy consumption



A2. The pillars of decarbonization

Pillar 1
Energy efficiency

Individual Mobility		Energy intensity	
9	→ + 67%	1.3	
15		0.5	← - 61%
000s pkm/cap		MJ/pkm	

● 2010 ● 2050

Pillar 2
Decarbonization of electricity and fuels

Carbon content of electricity		Biofuel in blended fuels *	
569		0	→ + 15 pt
19	← - 97%	15	
gCO_2/kWh		% blended fuels	

** Liquid fuels and pipe gas*

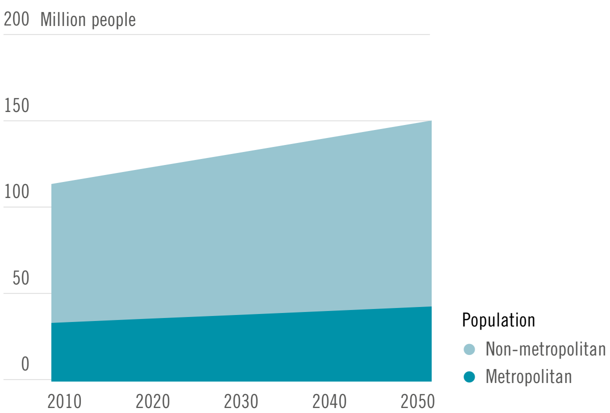
Pillar 3
Shifting to low carbon fuels

Non fossil fuel energy **	
0	→ + 44pt
44	
% of total energy	

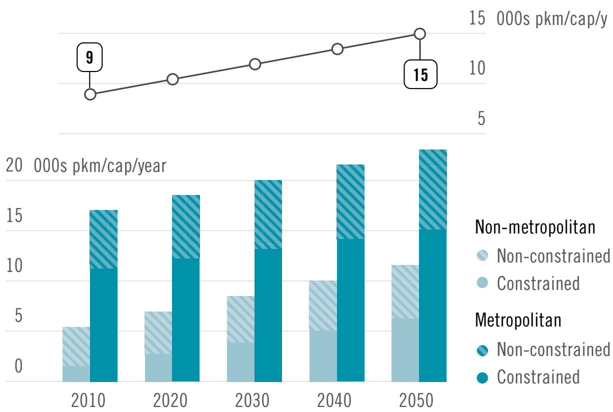
*** Integrating electricity, liquid and gaseous biofuels, hydrogen*

A3. Population and mobility

3.a Metropolitan and non-metropolitan population

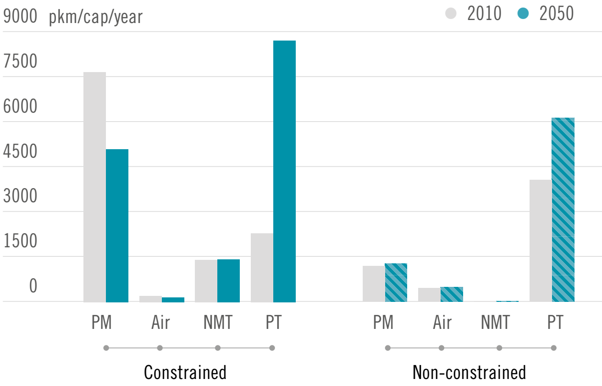


3.b Constrained and non-constrained mobility

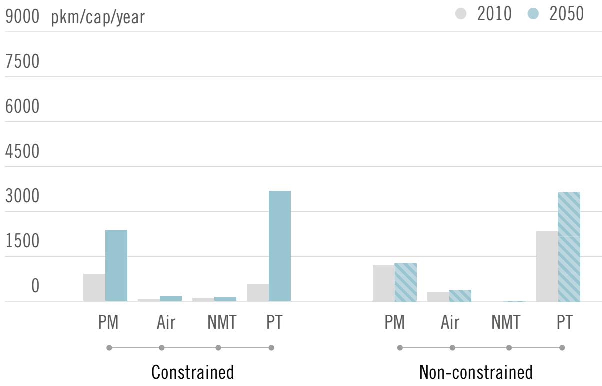


A4. Modal structure

4.a Metropolitan



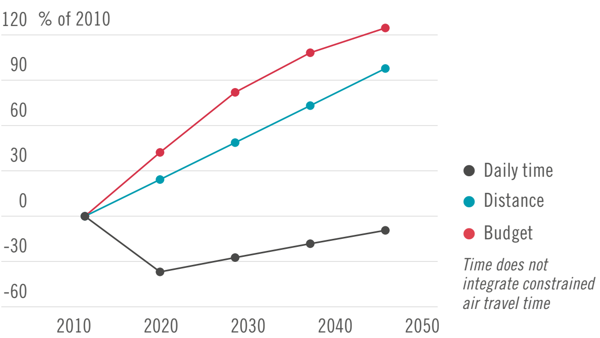
4.b Non-metropolitan



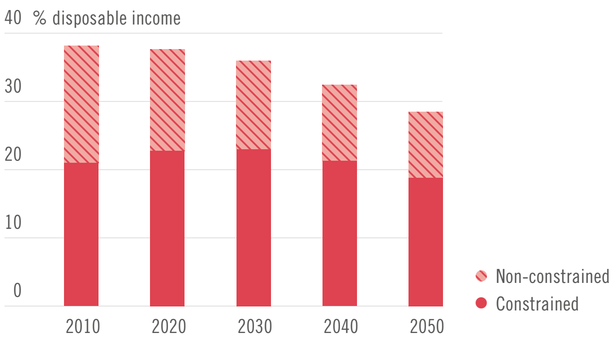
PM = Private Mobility (car and 2W), NMT = Non-motorized transport (walking, biking…), PT = Public transport (bus and rail)

A5. Mobility indicators

5.a Indicators for constrained mobility

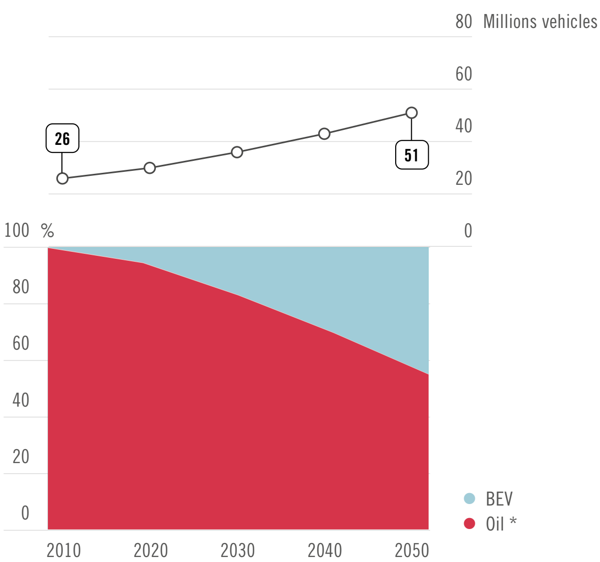


5.b Transport budget

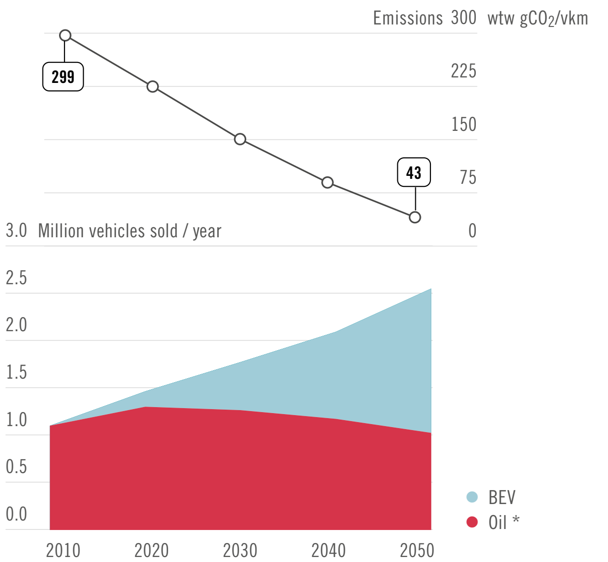


A6. Car mobility

6.a Car stock



6.b Car sales and related emissions



** "Oil" means thermal motorization fueled by liquids (gasoline, diesel, liquid biofuels)*

*** Emissions of average car sales is expressed in "well-to-wheel" gCO_2 per vehicle-km travelled*

Notes

Tempus Analítica A.C. is a not-for-profit research institute based in Mexico whose objective is to drive sustainable development by generating and disseminating analytically-based strategies and solutions, both at national and international level, which empower governments, businesses, and civil society to achieve their sustainability goals. By considering the rational balance of short, medium, and long-term imperatives, the Tempus approach has developed or strengthened energy system and GHG reduction plans by contributing to several high-impact initiatives within Mexico, including the NDCs (Mar 2015), the Deep Decarbonization Pathways Project (Oct 2015), and the design of Mexico´s Energy Transition Strategy (Nov 2016).

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