MX 2015 Report

pathways to

deep decarbonization

in Mexico

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SUSTAINABLE DEVELOPMENT SOLUTIONS NETWORK
A GLOBAL INITIATIVE FOR THE UNITED NATIONS

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Deep Decarbonization Pathways Project

The Deep Decarbonization Pathways Project (DDPP), an initiative of the Sustainable Development Solutions Network (SDSN) and the Institute for Sustainable Development and International Relations (IDDRI), aims to demonstrate how countries can transform their energy systems by 2050 in order to achieve a low-carbon economy and significantly reduce the global risk of catastrophic climate change. Built upon a rigorous accounting of national circumstances, the DDPP defines transparent pathways supporting the decarbonization of energy systems while respecting the specifics of national political economy and the fulfillment of domestic development priorities. The project currently comprises 16 Country Research Teams, composed of leading research institutions from countries representing about 70% of global GHG emissions and at very different stages of development. These 16 countries are: Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, South Africa, South Korea, the United Kingdom, and the United States.

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The Sustainable Development Solutions Network (SDSN) was commissioned by UN Secretary-General Ban Ki-moon to mobilize scientific and technical expertise from academia, civil society, and the private sector to support of practical problem solving for sustainable development at local, national, and global scales. The SDSN operates national and regional networks of knowledge institutions, solution-focused thematic groups, and is building SDSNedu, an online university for sustainable development.

November 2015

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Key findings

Deep decarbonization technological pathways in Mexico towards 2050 are feasible, under certain assumptions:

- Accelerated increase in energy efficiency uptake across all sectors
- Rapid development and deployment of CCS, zero emission vehicles, energy storage technologies and smart transmission and distribution (*smart grids*)
- System flexibility to promote, adopt and combine diverse options over the timeframe of decarbonization

Completing this transformation in only 35 years will demand a system-wide approach to short, medium and long-term planning of the energy systems nationwide. Therefore, a comprehensive vision is required by 2020.

- Policy decisions and investments in the next 5-10 years will directly affect 2050 conditions, as the lifetime of many key technologies is greater than 20 years and at least two replacement cycles are required to completely displace legacy assets.
- Actions carried out in one sector have implications on others: for example, significant growth in electric vehicles will increase demand for power generation.

Sectorial pathway analysis has revealed common needs in the planning process in order to allow the rapid and deep transformation that is required. To ensure that the 2025-2050 period can be fully dedicated to the roll-out of any credible decarbonization pathway, the 2015-2025 period must provide two fundamental enablers: an integral vision of energy systems decarbonization to provide a roadmap for change, and from this, robust sector planning based on detailed barrier and gap analyses to drive a broad program for action, combining institutional, policy, and resourcing measures. These ideas are summarized at a high level in the figure below, and described in greater detail in each of the sectorial analyses of Section 3.

Introductory remarks

Sector-based CO_2 emissions scenarios to 2050 have been generated in order to explore the changes required in Mexico's energy systems to achieve emissions reductions consistent with the internationally agreed 2°C goal. To develop these scenarios or "pathways," tools and methodologies were used that are shared between the 16 countries contributing to the Deep-Decarbonization Pathways Project (DDPP). These 16 countries are responsible for more than 70% of global GHG emissions.

The DDPP is a collaborative initiative, convened under the auspices of the Sustainable Development Solutions Network (SDSN) of the United Nations and the Institute for Sustainable Development and International Relations (IDDRI) of France, to explore how individual countries can transition to low-carbon economies by mid-century.

As the first study of this type in Mexico, the aim is not to provide a comprehensive analysis or a detailed simulation of a broad range of scenarios. Instead, the intention has been to create preliminary deep-decarbonization routes, to determine whether there are general conclusions that can be drawn at an aggregate level, as well as to identify areas that should be the focus for further analysis.

In keeping with Mexico's stated policy aims, this work has sought economic development that is low in carbon, rather than unconditional decarbonization. Although the amount of investment needed for the transition will affect the rate of adoption of technology and the costs to society of such change, not all interventions incur costs. Investment in greater energy efficiency will improve the country's productivity and it is highly profitable. Even some capital-intensive actions have attractive benefits. For example, increasing the share of renewables in the energy mix reduces recurring expenses on fuels with volatile prices, enhancing national energy security.

The relative prices of technologies will play a major role in the choice of future clean technologies to be adopted. However, the natural, human and industrial resources of each nation will also heavily influence decisions, seeking to optimize local economic growth, income, job creation and the indicators considered relevant under each national circumstance. The present study takes many of these elements into consideration in the modeling of the Mexican energy system and the deep-decarbonization routes developed, combining inputs from existing literature and modeling exercises with the informed opinions of colleagues and national and international experts.

This DDPP effort does not explore the specific dynamics of technological evolution. Instead, it opts for a *backcasting* approach in which the decarbonization goal is assumed to be reached by 2050, and the elements that need to be in place to make that happen are modeled in a manner that links present conditions to this future vision. The availability of low-carbon technologies at competitive prices is taken as a given by all analysis teams, thus integration of the 16 country-specific decarbonization scenarios will help identify the most crucial technologies globally.

An example of this is the capacity to capture and store CO_2 emissions from fossil fuel burning in power plants. Many DDPP analysis teams rely on this particular technology to lower the carbon footprint of electricity generation by 2050.

Results drawn at this stage suffice to highlight concrete recommendations to focus further collaborative efforts of research and development, to increase the performance and reduce the costs of key decarbonization technologies. Failure to accelerate such development efforts increases the risk of not achieving the target. We hope the present report will be a useful input for future analysis regarding the acceleration of technology innovation deployment and financing with a view to achieving deep decarbonization in Mexico while providing scope for incremental economic growth.

In spite of its limitations, this study yields results that could enrich the energy planning discussions that Mexico, along with all other UNFCCC signatories, will have to undertake with an ambitious economy-wide approach, sometime between the conclusion of COP-21 and the beginning of 2020. It is in this spirit that the present report is written.

Background and objectives of the deep decarbonization pathways project in Mexico

Total GHG emissions in Mexico reached 694 $MtCO_2e$ in 2010, approximately 60% of these emissions originate in the combustion of fossil fuels for energy uses (424 Mton). The main sources of GHG emissions are transportation (23% in 2010) and electricity generation (17%).

Total energy consumption increased at an annual rate of 2.5% between 1990 and 2010 to reach close to 200 million tons of oil equivalent (toe) by the end of that period. More than a fifth of that energy is dedicated to passenger transportation alone.

In the future, today's medium-size cities are expected to grow and historic trends show that urban centers expand in extensive patterns that increase energy consumption.

If current trends are maintained through 2050, energy-related CO_2 emissions could reach around 900 Mton and energy consumption could peak at 12 exajoules.

With population and GDP per capita projected to increase in the future, it is crucial to design a deep-decarbonization strategy to help guide decision-making before new infrastructure is built. The DDPP project in Mexico has focused on four main objectives:

- To explore the technical feasibility of reducing Mexico´s GHG emissions to 50% below 2000 levels by 2050, in accordance with the target set by the General Climate Change Law of 2012 and in a manner consistent with the 2°C objective of the UNFCCC
- To discuss the nature, scale and timing of the changes required to achieve this transformation, as well as possible challenges and opportunities
- To provide inputs and insights for future benchmarking work that will be required to evaluate the consistency of policy pathways with the achievement of a 2050 deep decarbonization in a credible and cost-effective manner
- To identify the requirements for further, more detailed deep-decarbonization analyses to inform future policy and investment decisions

Methodological approach

The deep-decarbonization scenario described herein was modeled as a CO_2 emissions path resulting from the accelerated evolution of the energy systems in Mexico through three main strategies or pillars: energy efficiency, electrification and fuel shift of energy end-uses across sectors, and low-carbon electricity.

Improving energy efficiency helps to simultaneously reduce GHG emissions and energy expenditure, delivering attractive economic benefits from energy savings directly to consumers. Ambitious energy-efficiency measures serve as the first step toward deep decarbonization. Additionally, carbon-neutral sources of energy are rolled out aggressively for electricity generation toward 2050, along with massive electrification across sectors. Finally, low-carbon alternatives fill in the gaps where renewables have already reached their full potential or seem difficult to adopt. An example of this is the transition from fossil fuels with high-carbon content (coke, residual fuel oil, etc.) to pipeline gas, biomass, biofuels, and carbon capture and storage (CCS) technologies.

The level of ambition of national deep-decarbonization pathways was set, by mutual agreement of the DDPP country teams, as a modeling target of 1.7 tons of CO_2 per capita per year by 2050. Based on population projections, by 2050 an annual level of CO_2 emissions is calculated as a target to help guide the analysis. In the case of Mexico that arbitrary target is 250 $MtCO_2$ a year in 2050.

Energy production and consumption in Mexico in the period 2010-2050 was modeled as an energy balance between four sectors: transport (passenger and freight); electricity generation; industry; and buildings (residential and commercial). To keep comparability of results within the DDPP research consortium, only energy-related CO_2 emissions have been considered.

A backcast interpolation of key indicators per sector was generated as a simulation of the future changes in energy use and production toward less emission-intensive alternatives according to the deep-decarbonization pillars:

- Energy efficiency
- Electrification and fuel shift
- Low-carbon electricity

Several combinations with different levels of implementation of the pillars per sector were produced to investigate the interplay between strategies.

These alternative-energy scenarios were the object of further analysis with the participation of expert opinions to refine modeling assumptions of current trends, identified potential strategies, and the feasibility of transitioning to low-carbon alternatives.

The result is a *central* deep-decarbonization pathways scenario of energy systems in Mexico. It illustrates the magnitude of the transformations required to enable a transition to a low-carbon economy, taking into account socio-economic conditions, development aspirations, infrastructure stocks, resource endowments, and other relevant factors.

Continuing the backcast analysis, the required timeline for changes to take place as a function of the expected turnover of the present asset base can be determined. This is very valuable information to identify preliminary time horizons for investment and policy interventions consistent with a transition to a low-carbon economy by 2050.

Sector results

The central deep-decarbonization scenario results in a substantial reduction of CO_2 emissions from 2010 to 2050, reaching 250 $MtCO_2$ within the sectors considered in this study at the end of the period. The aggregated effects of the changes modeled lead to highly significant reductions in both, the energy intensity of GDP (-59%) and in the CO_2 intensity of the final energy consumed (-66%).

The transition to a green economy requires that energy systems maintain a trend of steady and rapid decarbonization throughout the coming decades. The substitution of fuels with high carbon content for fossil alternatives with a lower CO_2 intensity (e.g. the change of fuel oil or diesel to natural gas without CCS) does not emerge as a recommended strategy for deep decarbonization as it yields insufficient reductions in GHG emissions at high investment costs, increasing the risk of producing burdensome stranded assets in the future or locking in emissions that exceed the target.

As has been previously seen in Mexico, large-scale transformations of the energy system are feasible when driven by consistent price signals over a period of decades, for example, the fuel switch for electricity generation from residual fuel oil to natural gas, between 1990 and 2015.

Therefore, to promote the technological transition toward low-carbon alternatives, such as CCS, electric vehicles, or renewables, strong and consistent price signals over long time periods may be required.

Transport

Transportation is the largest source of emissions in Mexico. Growth of emissions from this sector has been notable in recent decades, and it is estimated to continue at a high rate as GDP per capita rises.

The first decarbonization pillar can be implemented in two ways:

- Reduce overall demand for transportation by designing and building more compact and better connected cities, as well as advancing practices like work-at-home.
- Reduce energy consumption to satisfy an increasing demand for transportation by expanding the use of public transport systems, thereby reducing the share of travel in light-duty private vehicles with low occupancy.

The energy savings derived from accelerating energy efficiency gains in the light-duty vehicle fleet are overshadowed by those resulting from the modal shift to mass transport systems and are not sufficient to accomplish the deep-decarbonization goals alone -- unless demand is slashed, restraining future economic development.

Given the large scale of infrastructure required in both urban retrofit and new capital investments, as well as the behavioral change needed from commuters, an intensive transport infrastructure expansion program in conjunction with new urban design approaches must start before 2025 in order to reach deep-decarbonization targets.

The second pillar, referring to electrification of transport systems, can be implemented through different technological pathways. There could be a massive migration to electric vehicles with a strengthened battery industry and electric feed infrastructure, or alternative routes through other technologies, like hydrogen or fuel cells, that act as vectors to feed energy from other sources into vehicles, allowing them to operate with zero direct emissions.

Although the estimated average lifetime of a vehicle in Mexico, 15 to 25 years, seems short enough to allow for more than one fleet turnover by mid-century, the analysis shows that zero-emissions vehicles must permeate the market at a rapid pace, starting between 2025 and 2030, to reach the deep-decarbonization targets in a credible manner.

The third pillar, decarbonization of electricity generated, although typically addressed as an issue for the power sector only, will be influenced by the technological choices made for transportation. With the deployment of a large stock of batteries and charging points for zero-emissions vehicles, the electric grid could substantially increase its capacity to store energy and manage demand, contributing to the evolution of the whole system and playing a role within future smart grids.

Deep decarbonization of freight transport is also based on a modal shift of a share of demand to electric railroads. Furthermore, a better understanding of the logistics and distribution patterns of goods throughout the country is needed to identify the most significant actions to optimize energy consumption and reduce GHG emissions.

Electricity generation

Deep decarbonization of the power sector is essential, not only for the large source of GHG emissions it represents today, but also for the central role it will play in a future low-carbon economy.

Enforcing the first pillar in other sectors to increase energy efficiency is very important as it results in a substantial reduction of electricity demand. The benefits (energy and economic savings) from these interventions must be clearly quantified before planning and building future electricity generation infrastructure. Failing to secure them would render electrification of transport, buildings and industry a much harder and more expensive task to accomplish. The potential technological pathways that could be followed to accelerate energy efficiency are discussed in each sector section. Nevertheless, the power sector will be responsible for ensuring that the network and governance of electricity transmission and distribution are suitable for the dynamic and efficient electricity market required, optimizing energy used and saved (*negawatts*) and adopting international best practices.

The second pillar, electrification in other sectors, will significantly increase future generation demand This will require ambitious plans to design, finance, and build networks, plants, and other required assets. Mexico´s power sector will be transformed over the next 25 years.

The third pillar, decoupling CO_2 emissions from electricity generation is projected through two interventions:

- Massive installation of renewable generation capacity
- Retrofit of natural gas combined-cycle plants with CCS technologies

The combination of these two interventions will define capacity installation from 2020, if not before. An important decision point will be reached around 2025 on the commercial viability of CCS technologies for massive adoption. There is a critical period of less than a decade to discuss serious investment to develop CO_2 capture, transport, and storage capabilities, in the context of global collaboration efforts to reduce their cost. The central deep-decarbonization scenario projected is unattainable if this is not accomplished before 2025. The importance of CCS is magnified by the expected increase in domestic natural gas production derived from the recent reforms to the country's energy sector. Without CCS as a viable option the prolonged use of fossil fuels is not compatible with a decarbonization pathway, and an aggressive program to further develop and expand zero-carbon power generation must be in place by 2025, including additional boosts to renewable and nuclear capacities.

Industry

The industrial sector will have an opportunity to make an important contribution. The first wave of actions is relevant to the first pillar. As mentioned before, stimulating energy efficiency to reduce demand will be a key part of industry decarbonization, especially in the numerous medium- and low-energy-intensity fragmented activities, where many small and medium-size enterprises do not operate at high efficiency standards. In order to achieve this, coordination between technical training, financing schemes to aid technology uptake, and other instruments to align incentives for improving resource productivity will be essential. The benefits will mainly accrue to the businesses that act, since investments will tend to have positive rates of return.

The second and third pillars will manifest in various ways. Companies, especially those with a large energy footprint, must play a proactive role in the electrification process and in the installation of carbon-neutral generation and energy storage capacity. The opening of the electricity market presents a huge business opportunity, and it will be necessary to ensure that both the structure and incentives of the new markets allow for private investment to be directed toward low-carbon alternatives. Industry-wide (from the smallest to the largest companies and facilities) good opportunities for distributed electricity generation will arise. To fully take advantage of this potential, a flexible and robust electric system (i.e., with advanced data collection and demand management) is a prerequisite.

Decarbonization of CO_2-intensive industrial activities (namely mining and iron, steel, and cement manufacturing) is achieved with the help of capture and storage of combustion and process emissions. The same considerations made in the Electricity Generation section, regarding the efforts to advance CCS technologies and practices, are valid for deployment in these industrial operations. Enhanced innovation from this sector might accelerate the development of key technologies and markets in time to profit from the transition to deep-decarbonization. Hence, efforts directed toward these goals must have a compelling strategy for private sector long-term involvement.

Regarding the oil and gas sector, as future energy needs are progressively satisfied from clean sources, global demand will shrink. The rate at which this will happen is difficult to assess at present, as are the full effects of such a transformation. However, in Mexico conventional sources of oil and gas are quickly diminishing, and new non-conventional sources will heavily increase the energy footprint of oil and gas produced.

Buildings

Mexico's relatively mild weather keeps energy requirements in households low, and GHG emissions from buildings (residential and commercial sectors) have not been increasing at high rates. As GDP and energy expenditure per capita rise, steps must be taken to ensure energy consumption in buildings does not emulate North American patterns.

Deep decarbonization in buildings refers mainly to an accelerated adoption of best practices in energy efficiency (1st pillar) and the electrification of final energy uses (2nd pillar). As average household and commercial equipment is cheaper than the industrial counterpart, the technological transition required in buildings is apparently easier, but uninformed decision-making and misaligned economic incentives remain challenging barriers. We identify the need for an enabling market with three characteristics to overcome such barriers:

- A redesigned subsidy structure to convey the right messages to all energy consumers
- Well-regulated competition between ESCOs to capture most of the distributed potential energy savings and generation opportunities
- A mass-scale household appliance adoption program to assist the large part of the population that cannot afford the transition by their own means

Fast-tracking energy efficiency progress in all energy end uses in buildings has direct immediate positive impacts on families' cash flow, and it is useful to promote energy and economic security.

Possible future work

To better inform policy making, this study should be complemented by in-depth subsequent analyses at a disaggregated level, which would benefit from being carried out simultaneously.

On the one hand, greater detail on the potential evolution pathways of the asset base would help strengthen the preliminary deep-decarbonization pathways developed in this work, leading to clearer and more robust timelines, as well as fleshing out specific implementation issues and dependencies prior to detailed planning and commissioning.

On the other hand, dedicated micro- and macro-economic analyses would help identify the main potential impacts and investment needs, as well as the most cost-efficient pathways for deep-decarbonization in Mexico. These analyses may consider two complementary approaches: a bottom-up cost-benefit evaluation based on the evolution of the detailed asset base, and a top-down evaluation to explore potential impacts of implementing a deep-decarbonization trajectory on key macroeconomic indicators such as investment, energy prices, job creation and income distribution.

The information generated by these studies will be necessary to develop and implement a detailed and compelling national vision for deep decarbonization, including concrete national and international policy measures and instruments, that fully decouple Mexico´s energy systems from CO_2 emissions by mid-century.

Finally, future analysis should track progress made by Mexico versus the recommendations of this report.

1 Background to Deep-Decarbonization in Mexico

The Fifth Assessment Report from the IPCC emphasizes the risks of continuing on a trend under which average global temperatures may rise by 4°C or more, compared with the Earth's temperature in the pre-industrial age. Consistently, governments have recognized the need of limiting global mean warming to only 2°C within the present century.

Under the Cancun agreement, all major countries have adopted 2020 GHG emissions reduction targets. These targets, however, are insufficient to achieve a plausible trajectory consistent with the 2°C target.

Achieving this goal implies that global net emissions of greenhouse gases (GHG) must approach zero by the second half of the century. This will demand a profound transformation of energy systems by mid-century with steep reductions in carbon intensity in all sectors of the economy. This transition is referred to as **deep decarbonization** and it is the only way to achieve the important reductions in GHG emissions required. Meeting the challenges of deep decarbonization requires unprecedented problem solving on all fronts: technological development and diffusion, infrastructure building, evolution of financing mechanisms and regulation, advanced policy frameworks, synergistic institutional arrangements, innovative business models, consumer behavior analysis and understanding, etc.

As a first step of this process, the development of consistent and transparent deep decarbonization technological pathways towards 2050 is crucial. These pathways will help highlight national and global implications for R&D, infrastructure investments flow, regulation, tax systems, pricing policies, and trade rules required to enable decoupling of energy and GHG emissions. At COP-21, to be held in Paris at the end of 2015, there will be a chance to reach an international agreement on GHG reductions. Outputs from the Deep-Decarbonization Pathways Project (DDPP) could help inform national decision makers and the international community of the opportunities associated with a timely adoption of deep-decarbonization pathways. Promoting a "cooperative problem-solving approach" on how to deeply decarbonize energy systems nationally and regionally can also be useful to enrich the ongoing discussions on the subject.

The Deep-Decarbonization Pathways Project (DDPP) is a collaborative initiative, convened under the auspices of the Sustainable Development Solutions Network (SDSN) and the Institute for Sustainable Development and International Relations (IDDRI), to explore how individual countries can transition to low-carbon economies by 2050.

Research and analysis is conducted by 16 country teams comprised of more than 30 research institutions from Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, South Africa, South Korea, United Kingdom, and USA. Collectively these countries account for over 70% of global greenhouse gas emissions.

Additionally, DDPP has partnerships with other international organizations, research institutions, and business associations that provide critical expertise and support to the initiative.

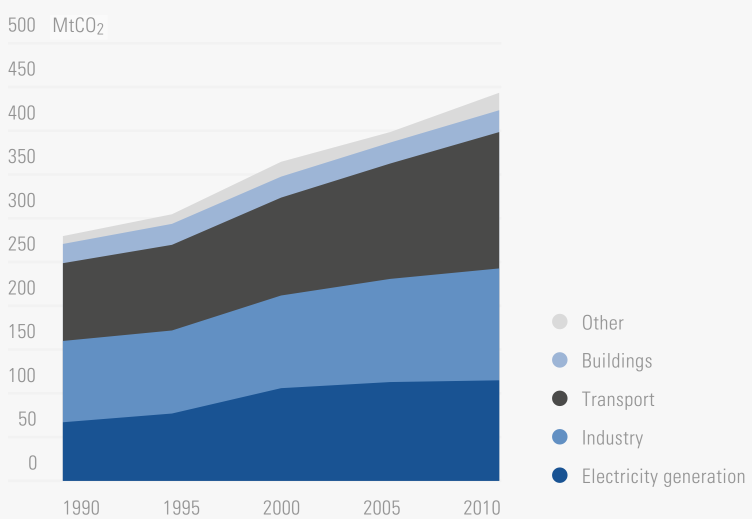
1.1 Mexico´s current emissions

GHG emissions in Mexico are rising due to an increasing consumption of fossil fuels. As the population slowly stabilizes (projected to be around 150 million by 2050)[1] and economic growth continues, it is crucial to design a deep-decarbonization strategy before new infrastructure is built.

Proven reserves of oil in Mexico are estimated to be around 13,000 million barrels of oil equivalent (boe), and natural gas reserves are estimated at 15,300 million cubic feet.[2] Present annual production averages 920 million barrels of crude oil and 2,400 billion cubic feet of natural gas, and recent regulatory changes in the energy sector could help increase production up to 45% and 60%, respectively, by 2050 compared with 2010 levels.[3]

Urban population reached 72% in 2010, and it is expected to be close to 83% by 2030. Around 98% of households have access to electricity to date, but in many rural areas wood is still used as the main fuel for heating and cooking.

Figure 1.1. Energy-related CO_2 emissions in Mexico by sector, historic



Following recent trends, most of future economic growth could be driven by an increase in tertiary activities (services), which could account for 70% of national GDP by 2050 (62% of total GDP in 2010). As activities in this sector tend to be less intensive both in energy and in CO_2, this shift is expected to help decrease GHG intensity in the long term. Presently, energy-intensive industry accounts for 10% of total GDP. This estimate takes into account the production of oil and gas, a traditional source of income for Mexico.

Total primary energy supply reached close to 200 million tons of oil equivalent (toe) in 2010 including all consumption by final users (transport, industry, buildings, and agriculture), as well as consumption for transformation of energy and transmission losses.[4] The distribution of final energy use was spread over the following fuels: gasoline (32%), electricity (16%), diesel (16%), natural gas (11%), LPG (10%), and wood (5%). Approximately 30% of all energy presently used in Mexico is dedicated to transportation, and close to 70% of that energy is demanded by passenger transport alone. The increased demand for mobility, satisfied by a large market of private vehicles with a low-occupancy rate, has been the main driver for gasoline consumption to exceed 1.5 EJ since 2010.

These figures are reflected in the rise in vehicle ownership, which doubled from 2000 to 2010 to approximately 207 vehicles per thousand inhabitants, and in GHG emissions from the transport sector that increased at an annual rate of 2.9% between 1990 and 2010.

1 Comisión Nacional de Población (CONAPO), at: http://www.conapo.gob.mx

2 Data reported for January 2015. SENER, 2015, at: http://egob2.energia.gob.mx/SNIH/Reportes/

3 Estimate based on official figures by 2028 in Prospectiva de Petróleo y Petrolíferos 2014-2028, SENER.

4 Balance Nacional de Energía, Sistema de Información Energética, SENER, 2015.

As GDP per capita slowly increases in the future, today's medium-sized cities are expected to grow. Historic trends show that urban centers expand in extensive patterns that increase energy consumption and increase pressure on land use. Smart urban development has been identified as a key way to transition toward more efficient and sustainable green growth schemes in Mexico.

Total GHG emissions in Mexico reached 694 $MtCO_2e$ in 2010. Around 60% of these correspond to CO_2 emissions stemming from the combustion of fossil fuels for energy uses (424 Mton). The largest single source of GHG emissions was transportation (23% of all GHG emissions in 2010) and electricity generation (17%) (Figure 1.1).

1.2 Reference scenario

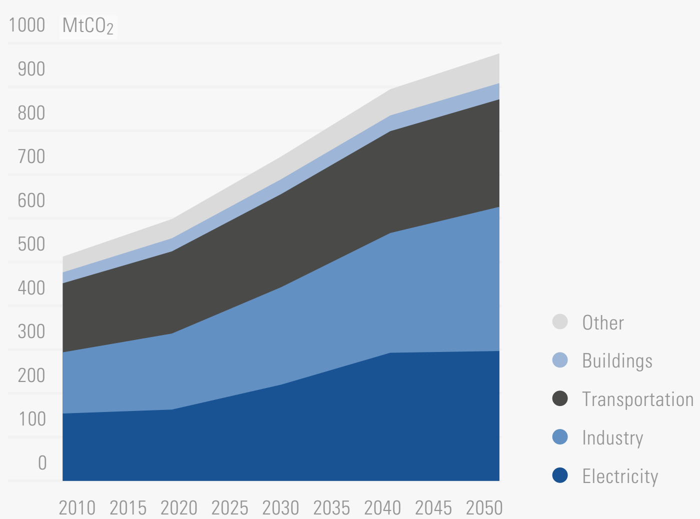
The reference scenario described in the present study is based on historical trends and well-informed assumptions of future activity for the main drivers of CO_2 emissions. Some of the defining factors include growth of population, GDP, and energy efficiency, alongside a slow reduction in the CO_2 emission factors of the energy carriers in a gradual migration towards low-carbon fuels. This scenario does not match officially reported GHG emissions in 2010 because it is calculated in a different manner. However, it is an accurate representation of energy fluxes within the Mexican economy and serves as a realistic basis for future projections.

Under this scenario, the resulting energy-related CO_2 emissions reach just above 900 Mton by 2050 (Figure 1.2). That figure increases to nearly 980 Mton if CO_2 process and fugitive emissions from the industry sector are also taken into account.[5]

All information used in the analysis is publicly available and in many cases was obtained from official sources. Modeling parameters were calibrated according to information from the National GHG Emissions Inventory (INEGEI) 1990-2012,[6] the Energy Information System of the Ministry of Energy (SIE, SENER) and the National Institute of Statistics & Geography (INEGI). An aggregate model was created to simulate the energy balance across sectors in Mexico and to reflect present trends in energy consumption and production, economic growth, and carbon footprint.

Further analysis was carried out in some sectors (notably in industry, oil and gas production, and electricity generation) to better understand the potential benefit of mitigation strategies within them. For this, additional sources of information were employed: the National Energy Prospective by SENER, estimations by the International Energy Agency (IEA), studies

Figure 1.2. Energy-related CO_2 emissions by sector, reference scenario



5 At the present stage of this study, only CO_2 emissions are analyzed. However, mention sould be made of the predominance of methane emissions among fugitive emissions in Mexico.

6 INECC & SEMARNAT, First Biennial Update Report to the UNFCCC, Mexico, 2015.

from the public and private sectors, and valuable feedback from experts from INECC, SENER, the National Commission for Nuclear Security (CNSNS), among others.

Although no economic analysis was specifically developed in this first stage of decarbonization analysis, the present report draws on the results on economic modeling of alternate decarbonization pathways, produced by INECC in collaboration with international partners (AFD, France and DEA, Denmark).

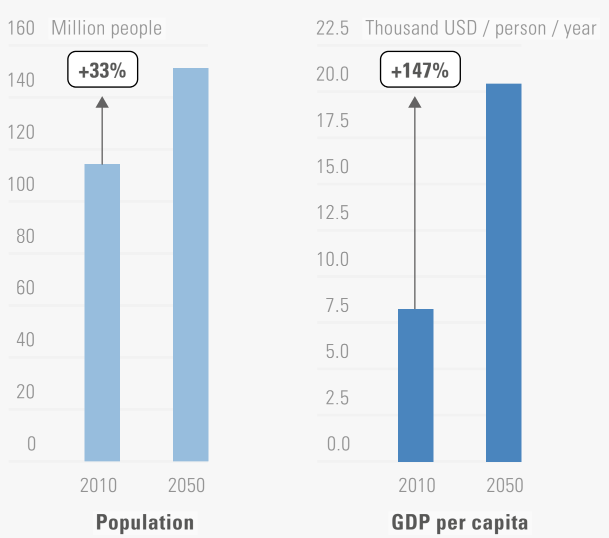
In the following sections, the most relevant assumptions made to model realistic future energy scenarios for Mexico are described by sector.

National characteristics

The population in Mexico is expected to increase 33% by 2050 to reach over 150 million people. Growth in the first part of that period will be quicker than at the end of it, according to official estimates.[7]

GDP in this exercise is modeled to increase at a constant annual rate of 3%, as a representation of long-term sustained economic growth. The assumption on future economic growth is in the high range of recent official estimates for 2015 and 2016 (from 2% to 3.2%).[8] This rate is greater than population growth, and results in an increase of 147% of GDP per capita from 2010 to 2050 (Figure 1.3).

Figure 1.3. Macroeconomic indicators in Mexico



The economic structure of the country is evolving toward a greater participation of the tertiary sector (services). In 2010 tertiary activities (including the public sector) accounted for 62% of total GDP, while secondary and primary activities (industry) represented 35% of GDP. By 2050, services could increase their participation to 70%, and industrial activities could reduce theirs to 30% of GDP.

This evolution will have profound effects on society, the economy, and the environment that are not simple to predict accurately. In general, services are less intensive in energy and carbon than industry, hence a reduction in the overall environmental impact of the economy is broadly expected.

In the reference scenario developed in this study, the share of industrial activity within the economy is reduced to reflect this future structural change. Due to this transformation, and to the constant increase in energy efficiency across sectors, the CO_2 intensity of the economy would decline 40% from the value estimated in 2010 (52 tCO_2/USD).

Passenger transport

Transportation is the largest single source of GHG emissions in Mexico, and if current patterns of vehicle ownership and public transport infrastructure are maintained, emissions could rise steeply along with energy consumption.

7 Comisión Nacional de Población (CONAPO), at: http://www.conapo.gob.mx

8 Recent news at: http://eleconomista.com.mx/finanzas-publicas/2015/05/21/mexico-no-crecera-mas-32-2015-segun-hacienda, with information from the Ministry of Treasury (SHCP) and the Bank of Mexico (Banxico).

According to experts consulted,[9] the demand for transportation will increase from the present level of 0.9 trillion passenger-kilometers to 1.4 trillion passenger-kilometers by 2050, a total increase of 56% in the period.

It is estimated that in 2010, 66% of the travel was made in lightweight vehicles, such as cars and taxis; 28% in buses; and the remaining 6% in other forms of transportation (planes, urban-trains, and motorcycles). The average number of passengers in vehicles was estimated at around 1.4 per car in that year, and the number of vehicles was estimated at 207 vehicles per 1,000 people.

If current trends continue, favoring the use of light vehicles with ever fewer people on board, the energy expenditure for passenger transportation and the CO_2 emissions derived could each increase by 25% by 2050. The already meaningful amount of energy consumed at present (around 1.5 exajoules) could reach 1.9 exajoules, equivalent to more than 300 million barrels of oil every year, and CO_2 emissions could increase by over 130 million tons a year.

Freight transport

The limited information available in reference to freight transport required assumptions to be made regarding the annual demand in 2010, which was calibrated with known GHG emissions data at 0.45 trillion ton-kilometers. In this particular exercise it is assumed that 92% of this demand is satisfied by road trucks, and that both air and water freight transport cover the rest. All present freight trucks are modeled to consume diesel, as accurate information is still missing to fully characterize this sector.

Diesel consumption for freight transport increased at an average rate of 3% every year from 2000 to 2010. By 2050, we estimate that the total demand for transportation of goods can increase 200% with respect to the 2010 value, to around 1.35 trillion ton-km. This is broadly consistent with projected growth of industrial output and with recent trends observed in fuel consumption, however, more detailed information is needed to gain a deeper understanding on transportation patterns in the country.

If current trends of energy expenditure are maintained, they could escalate to over 1.5 exajoules by 2050, an increase of almost 120% of today's level. If the same fuels are kept in use to satisfy the future energy requirements, the CO_2 emissions derived could increase proportionally to around 115 Mton annually.

Electricity generation

Electricity generated in Mexico totals 270 TWh a year. By 2050 it is calculated that total demand for electricity could be three times what it is today. The reference scenario models a gradual reduction of losses in transmission and distribution of power to only 8% of all electricity produced by 2050. Under such conditions, the annual generation of electricity could reach around 770 TWh. The future structure of this sector is subject to great uncertainty due to the changes energy regulation is undergoing that open up the market for investment other than the government's. Power generation by private producers rose from 1% in 2002 to more than 5% by 2012, and that share should increase significantly by 2050.

At present, electricity is mainly generated from natural gas (50%), fuel oil (17%), hydro (15%), and coal (11%). Nuclear and geothermal generation have traditionally played a smaller role, and each of them supply close to 4% of all electricity. Other renewables like solar and wind have yet to reach production to an appreciable level. The estimated emission factor of the present matrix is 0.57 kg of CO_2 per kWh produced.

The reference scenario simulates a slow transition from heavy oil derivatives, like residual

9 Instituto Nacional de Ecología y Cambio Climático, INECC.

fuel oil and petroleum coke to natural gas. This change has been occurring since the 1990s and has mainly been driven by a greater efficiency of electricity production through combined-cycle technology, which employs natural gas preferentially. By 2050 this would result in a fossil-based power system with an average emission factor of 0.4 $kgCO_2$/kWh, which is only 30% less intensive in CO_2 than the present system.

Industry

In the DDPP context, the industry sector includes all activities in the secondary and primary sectors of the economy. Thus, activities like mining (including oil and gas), fishing, and agriculture are also considered in this category. The resulting participation of all industry as part of the GDP is reduced from 38% to 31% from 2010 to 2050. The projected CO_2 emissions of the whole industry sector reach 400 Mton by 2050 in the reference scenario, including fugitive and process emissions. That represents an increase of 125% from 2010 levels.

Given the variation of intensity of the different activities within the industrial sector, it was divided into groups of similar activities to model more accurately the energy consumption trends and the carbon footprint of each group. Only three specific industries were treated separately because of their characteristically high intensity in energy: mining, cement manufacturing, and iron and steel.

Mining:

Mining includes all activates related to the extraction of materials from the ground in land and offshore operations. Perhaps the most relevant industrial branch in Mexico, it accounts for over a fifth of all industrial GDP. The production of crude oil and natural gas accounts for more than 80% of all mining output (+220 million tons a year in 2010), although that percentage has been decreasing in recent decades.

In this exercise, the physical output of mining activities other than oil and gas production is expected to increase at the same average annual rate as industry as a whole (2.5%). By 2050, this amounts to more than double the output in 2010, approximately 100 million tons. Under the reference scenario, oil and gas production rises from 180 million tons a year in 2010 to 265 million tons in 2050, mainly by following the official projections of natural gas production increasing 50% by 2024, and extrapolating beyond that date using a moderate growth rate, to a 67% increase by 2050. These estimates are subject to a significant uncertainty for two main reasons:

- Oil and gas production are very sensitive to international prices, which have a high variability
- Mexico is undergoing a major transformation of its energy sector, with new players beginning to participate, and it is difficult to foresee where all changes will lead.

The energy intensity of the future mining operations is another source of high uncertainty. Selection of oil and gas production projects is also very sensitive to expected prices, which is highly dependent on the energy intensity of each project. As shallow light oil reserves decline, nonconventional sources and heavier mixtures of oil will be produced, increasing the energy required to extract and process them. To take into account the effects of new nonconventional production of oil and gas, the reference scenario considers that energy intensity increases 2.5 times to reach around 4.4 GJ/ton by 2050. This is not inconsistent with expert opinion and public production plans.

Also due to the predominance of oil and gas production within mining, the fuel mix used is highly dependent on natural gas; it supplies 76% of all energy requirements, while electricity contributes 12% of that demand. Under a reference scenario, those shares are estimated to remain essentially the same (73% and 15%, respectively).

Iron and Steel:

This category also includes the production and manufacturing of other metallic products, such as aluminum and copper, but iron and steel represent more than 95% of total annual output. In 2010 this amounted to 13 million tons, and it is estimated that by 2050 it could reach 25 million tons a year.

The iron and steel industry is very intensive in the use of energy. The value estimated for 2010 is 15.3 GJ per ton of product, and that value is expected to gradually decrease 12% to around 13.5 GJ/ton by 2050, mostly driven by progressive technological advances.

The fuels most employed in this subsector are natural gas (53%), coking coal (31%), and electricity (12%). Based on recent trends, the shares of these fuels would remain unchanged by 2050, with the percentage of electricity declining marginally to 10%.

Cement manufacturing:

Cement production was estimated at 33 million tons per year in 2010, and in the reference scenario it is projected to reach around 76 million tons per year by 2050. This increase is similar as that projected for the iron and steel industry and is based on recently observed trends.

The average energy intensity of the cement subsector is 3.4 GJ/ton and this could increase to 3.8 GJ/ton under a reference scenario where best practices are not adopted. The fuels most used are petroleum coke (64%), electricity (26%), coal, and natural gas (each 4%). This energy matrix results in a CO_2 emissions factor of 95 g CO_2 per MJ of energy employed in this subsector. Although recent trends show that the share of electricity is gradually increasing, the reliance on petroleum coke could keep the emission factors unaltered by 2050.

Other manufacturing:

This category groups all activities related to the manufacturing of goods, from raw materials like petroleum-refining products or chemicals, to end products like beverages, cars, and clothing. These activities represent almost 40% of the industrial GDP and consume two thirds of all energy used in industry.

As new processes are developed to supply a growing demand for new products, this subsector could increase its participation within industry to 42% by 2050. Technological development and adoption have a noticeable effect in the energy consumption in this category due to the variety of activities it involves. A recent report found that while productivity has grown in large modern enterprises, it has fallen in small traditional firms in the last decade or so.[10] These trends in productivity could be reflected in the energy consumption patterns, suggesting that there is an important potential for improvement in the numerous smaller enterprises.

Activities of the oil and gas industry like refining, natural gas processing, and petrochemical have large energy requirements that are highly sensitive to the quality and characteristics of crude oil and gas that are fed into their processes as raw materials. As non-conventional sources of oil increase their share in the national production portfolio, refining operations might need as much as 50% more energy per barrel of oil processed in the future.

Under the reference scenario, energy intensity is assumed to decrease 21% across all manufacturing from the present 12.6 MJ/USD to 10 MJ/USD by 2050. However, due to the large increase in activity projected in the future, the total energy consumption of this group of activities could reach 4 EJ by 2050, 125% more than at present.

10 McKinsey Global Institute. 2014. A tale of two Mexico's: Growth and prosperity in a two-speed economy.

Other Industry:

The final subsector of industry includes primary activities like agriculture, fishing, and forestry, as well as construction and utilities. This group accounts for 35% of industrial GDP and is projected to maintain its participation in the future. The estimated average energy intensity is 1.6 MJ/USD, and it could rise to 1.9 MJ/USD by 2050 if current trends continue. Two fuels represent 97% of all energy consumed: diesel (58%) and electricity (39%).

Although this is not a large source of CO_2 emissions (22 $MtCO_2$ in 2010), it is an important source of other GHG like CH4 and N2O from agricultural activities. Additionally, it is deeply related to food security and poverty eradication, hence its role within the context of an integral low-carbon development strategy should be emphasized.

Residential

There were around 28 million households in Mexico in 2010. The amount of households in 2050 (47 million) was projected as a function of the total population and the average occupancy of households. This last indicator shows a decreasing trend from 1990, and it is assumed to continue decreasing from 4.1 people per household in 2010 to 3.2 people per household by 2050.

Another relevant indicator to calculate CO_2 emissions from the residential sector is the average size of each household. This was derived from a projection of the historical trends in the average residential space per capita from 15 m^2 in 2010 to 25 m^2 per person in each household by 2050. The evolution of these indicators does not imply a greater size in households of the future, but rather reflects the current transformation of family structures and the increasing share of urban population at a national level.

Information on energy consumption in the residential sector in 2010 was taken from SENER to calibrate the model with both energy and emissions official inventories. The unit energy consumed in households was modeled to gradually reduce from 455 MJ/m^2 in 2010 to 360 MJ/m^2. This represents a reduction of 21%.

Commercial

Information on the total surface dedicated to commercial activities is not available. An estimate of 0.5 billion square meters was taken as a starting point in 2010 to be increased linearly to reach 1.3 billion sq. meters by 2050.

Similarly to the residential sector, the unit energy consumption per square meter in the commercial sector was assumed to decrease steadily from 250 MJ/m^2 in 2010 to 210 MJ/m^2 in 2050. These figures were calibrated with information from energy and GHG emissions inventories.

1.3 Mexico´s climate commitments and the global 2°C goal

The General Climate Change Law of Mexico sets a target of no more than 300 $MtCO_2e$ for all national GHG emissions by 2050.[11] This objective is broadly consistent with limiting an increase in global surface temperature to only 2°C, and it will require a deep-decarbonization strategy to be accomplished.

The present document reports the first attempt to analytically determine the nature of the available options and the most significant challenges to hasten the transition to a low-carbon economy in Mexico.

We hope that the deep-decarbonization pathways presented here help enrich the ongoing domestic discussions on low-carbon development and the future energy security in Mexico.

11 Own estimate based on information from INECC.

1.4 Objectives of DDPP in Mexico

The ultimate goal of the Deep-Decarbonization Pathways Project is to help countries prepare and implement long-term policies that allow country-specific deep decarbonization by mid-century. In order to accomplish this, the team in Mexico has devised four objectives:

- To explore the technical feasibility of reducing Mexico´s GHG emissions to 50% below 2000 levels by 2050, in accordance with the target set by the General Climate Change Law of 2012 and in a manner consistent with the 2°C objective of the UNFCCC
- To discuss the nature, scale, and timing of the changes required to achieve this transformation, as well as possible challenges and opportunities
- To provide inputs and insights for future benchmarking work that will be required to evaluate the consistency of policy pathways with the achievement of a 2050 deep decarbonization in a credible and cost-effective manner
- To identify the requirements for further, more detailed deep-decarbonization analyses to inform future policy and investment decisions

2 Methodological approach to develop a Deep-Decarbonization Pathway for Mexico

This first stage of the DDPP work has centered on the technical feasibility of deep decarbonization of nationwide energy systems. In a manner consistent with the global DDPP approach, the focus is on CO_2 emissions stemming from the combustion of fossil fuels for energy uses across sectors of Mexico's economy.

Energy production, transformation and consumption in Mexico in the period 2010-2050 were modeled as an energy balance between four sectors: transport (passenger and freight), electricity generation, industry, and buildings (residential and commercial).

The exploration of the technical feasibility of deep-decarbonization pathways is consistent with the national context and with realistic assumptions on local resources and alternatives.

2.1 Three pillars for deep-decarbonization

The deep-decarbonization scenarios described herein were modeled as a CO_2 emissions paths resulting from the accelerated evolution of the energy systems in Mexico through three main strategies or pillars: energy efficiency, electrification and fuel shift of energy end uses across sectors, and low-carbon electricity.

Energy efficiency:

Accelerating energy-efficiency-improvement trends helps to simultaneously reduce emissions and energy expenditure. The benefits associated with an increased efficiency in energy consumption across sectors are manifold: from mitigation of climate change and health benefits for population, to increased energy security and attractive economic savings derived from energy consumption reduction. Ambitious energy-efficiency targets serve as the first step toward deep decarbonization. The main reasons to maximize potential efficiency gains and to accelerate its capture are:

- Energy and economic benefits impact final users directly and immediately
- Future energy infrastructure must be planned taking into account all possible efficiency gains

to avoid capacity over installation of capital-intensive plants

As energy efficiency is increased, it is important that price signals evolve adequately, to reduce the risk of rebound effects that might curtail the positive impact of energy savings.

Electrification and fuel switching:

This mitigation strategy seeks to minimize the carbon footprint of the energy used for human activities. There are two parts to it.

- Firstly, **zero-carbon energy** carriers are adopted aggressively and in full potential toward 2050. This includes massive electrification of end uses of energy across all sectors and a simultaneous increase in the share of renewable sources of electricity.
- Secondly, **low-carbon alternatives** fill in the gaps where renewables have already reached full potential or seem difficult to adopt. An example of this is the transition to pipeline gas, biomass, biofuels and CCS technologies.

There is also a structural change that is likely to happen eventually that would have a potentially deep impact on GHG emissions. The energy production and consumption paradigm could migrate from current centralized schemes to a more distributed dynamic network of consumers, producers, and storage of energy. In a system of this type, implementation of renewable-energy technologies and energy-efficiency standards could happen at a much quicker pace than in a system where energy is only provided from large centralized plants. Although the full effects of such a transformation are not taken into account in this study, the rate of adoption of renewables in the deep-decarbonization scenario is consistent with two characteristics of the new system: increased dynamism and technological maturity.

Low-carbon electricity:

As electricity is more widely used across all activities that require energy, cleaner sources of primary energy are needed to feed the energy-transformation chain, in order to expand clean electricity supplies at the national level. Failing to increase the share of non-fossil electricity sources could result in even larger GHG emissions should the electrification rate reach the central deep-decarbonization scenario levels.

A large share of intermittent renewables in the energy-production matrix will require extensive installation of energy storage capacity to minimize the use of fossil-fueled back-up generation capacity in the future.

2.2 Tools: Dashboard and Calculator

This project was carried out integrating the best information publicly available with feedback from national experts working in related efforts, such as the 2050 Energy and Emissions Calculator model for Mexico (developed in collaboration with DECC-UK)[12] and Mexico´s Intended Nationally Determined Contributions, submitted to the UNFCCC in March 2015.

The structure chosen to build and evaluate preliminary prospective energy scenarios was the *CO_2 emissions calculator,* developed as a spreadsheet platform by the US team and made available to other DDPP teams. The common format agreed for reporting the resulting indicators of deep-decarbonization exercises is known as the *dashboard*, and it expands the sector-based comparative architecture of the collaborative DDPP effort.

The level of ambition of national deep-decarbonization pathways was set, by mutual agreement of the DDPP countries' teams, as a mode-

12 2050 Energy and Emissions Calculator, DECC, UK, in: https://www.gov.uk/international-outreach-work-of-the-2050-calculator#calculator-overview

ling target of 1.7 ton of CO_2 per capita per year by 2050. This value is consistent with limiting the increase of the global temperature to 2°C.

Based on population projections for 2050, each country's team calculated an annual level of CO_2 emissions as a target to help guide the analysis. In the case of Mexico that arbitrary target is 255 $MtCO_2$ a year in 2050.

A backcast interpolation of key indicators per sector was generated as a simulation of the future changes in energy use and production toward less emission-intensive alternatives according to the deep-decarbonization pillars. Several combinations with different levels of implementation of the pillars per sector were produced to investigate interplay between strategies.

All scenarios model the period from 2010 to 2050. The activity levels in 2010 are consistent with official information, while the future activity assumptions are coherent with a vision of development as well as with current domestic trends and international best practices. All scenarios yield in the vicinity of 250 million tons of CO_2 emissions a year by 2050.

These alternative-energy scenarios were subject to further analysis with the participation of experts to refine modeling assumptions of current trends, identified potentialities, and the feasibility of transition to low-carbon alternatives.

The result is a *central* deep-decarbonization pathways scenario of energy systems in Mexico that was built from different sources by experts and that compiles results from various studies on climate-change mitigation.

This scenario is illustrative of the magnitude of the transformations required to enable a transition to a low-carbon economy, taking into account socio-economic conditions, development aspirations, infrastructure stocks, resource endowments, and other relevant factors.

Continuing the backcast analysis, the required timeline for changes to take place as a function of the expected turnover of present infrastructure can be determined. This is very valuable information to identify preliminary time horizons for investment and policy interventions that are consistent with a transition to a low-carbon economy by 2050.

It is important to emphasize that a number of factors make it impossible to anticipate what specific technology choices will be made in Mexico. For one, the country is undergoing a major reform of its energy sector, which will affect regulation, planning, and the increasing presence of private-sector providers. Therefore, energy scenarios discussed herein do not represent any government policy nor are they an official document of planning or intent. They merely seek to explore possible interplays between technologies and their feasibility considerations.

3 Results of the Deep-Decarbonization Pathway analysis for Mexico

The central deep-decarbonization scenario results in a substantial reduction in CO_2 emissions from 2010 to 2050 (-51%, Figure 3.1). The total CO_2 emissions reach 250 $MtCO_2$ by 2050, including fugitive and process emissions. The aggregated effects of the changes modeled are reflected as a notable reduction, from 2010 to 2050, in both the energy intensity of GDP (-59%) and in the CO_2 intensity of energy consumed (-66%).

One of the main features of this scenario is a marked increase of energy efficiency across all sectors. Final energy consumption is 35% less than in the reference trajectory, and it only increases 34% compared with 2010. Even as GDP per capita rises, along with all sectoral activity, the total amount of energy consumed would barely surpass 8 exajoules by 2050.

The other characteristic is a transformation of primary energy systems from a heavy dependence on oil to pipeline gas and renewables (Figure 3.2). This increased dependence on natural gas depends on the timely introduction of CCS technologies. An alternative scenario (described later in this paper) was developed to evaluate alternatives to natural gas if CCS is not developed in time or in scale.

The share of final energy that is consumed as electricity increases from 15% in 2010 to 40% by 2050. Simultaneously, the CO_2 footprint of electricity declines from 570 g of CO_2 per kWh produced to only 19 g of CO_2/kWh – less than a 20th of the current value! Although the amount of electricity generated in this scenario by 2050 is 3.5 times higher than in 2010, the CO_2 emissions from the power

Figure 3.1. Energy-related CO_2 emissions by sector, DDPP central scenario

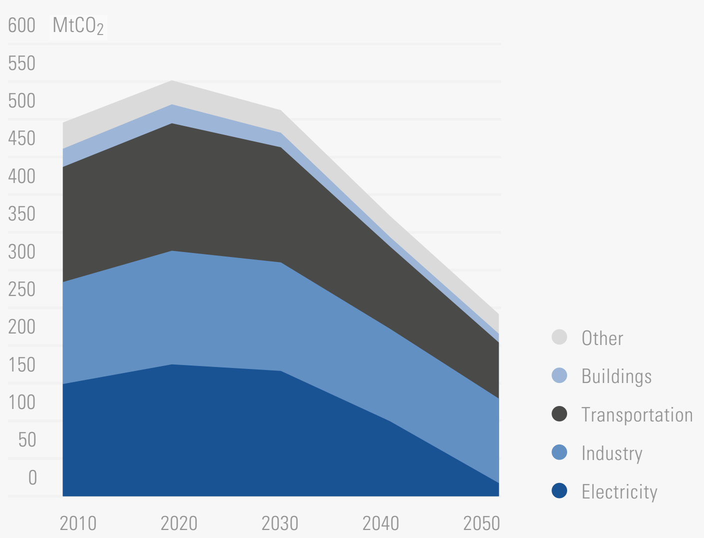
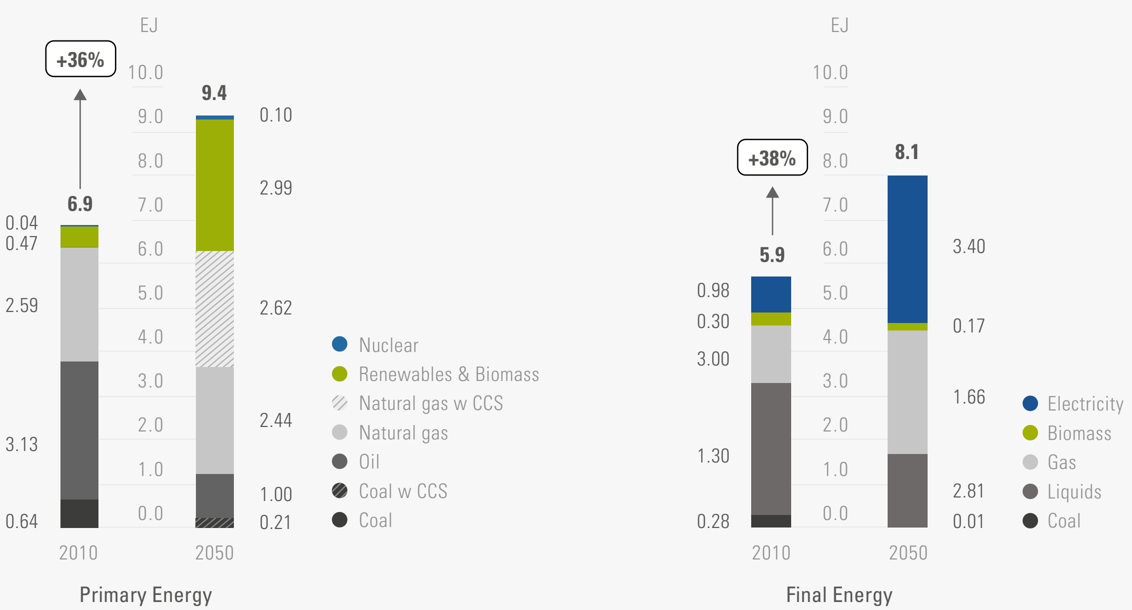


Figure 3.2. Aggregated energy indicators of deep decarbonization



sector are close to a tenth of their present value. As natural gas, biofuels, solar thermal energy, and biomass are used in buildings, industry, and transport systems to substitute the use of coal, residual fuel oil, and diesel, non-electricity energy also reduces its average CO_2 emission factor by a third.

The transition to a green economy requires that energy systems maintain a trend of steady and rapid decarbonization throughout the following decades. The substitution of fuels with high carbon content for fossil alternatives with a lower CO_2 intensity (e.g. the change of diesel to natural gas) is an ineffectual long-term decarbonization strategy for it only yields marginal reductions in GHG emissions at high investment costs, increasing the risk of producing burdensome stranded assets in the future.

The resulting transformation of efficiency, relating primary energy sources with the final use of energy, remains the same throughout the period, mainly because at this stage little is known about the future improvement in performance of renewable power sources, and deep decarbonization projections do not take it into account. As renewable technologies develop, undoubtedly providing better efficiency in energy transformation than at present, primary energy requirements by 2050 could be fewer than those estimated in this exercise.

3.1 Sector results of the deep-decarbonization central scenario

Although there is a range of alternative technological pathways, the transformation requires basic milestones to be aligned with the pillars of the decarbonization:

- Efficiency
- Clean electricity
- Electrification
- Mass transport (behavior + infrastructure)

High-level timing considerations

The central scenario – which reaches deep decarbonization by 2050 – assumes that such milestones follow from massive investment programs (5 times larger than at present in renewable-power capacity, for example), which should start in earnest between 2020 and 2025. Delaying action increases the pace and costs at which decarbonization must take place in the second half of our 35-year window. Such a delay could be seen to diminish the credibility of the overall deep-decarbonization effort.

Such up-front investment is required partly because the 35 year window for the transition only provides a small number of asset turnover cycles, depending on the type of asset involved; vehicles, domestic appliances, and power generation plants have very different lifetimes. The particular technology stocks already present determine the pace of the transition.

If a fundamental transformation cannot begin by 2025, it will not be possible to meet decarbonization targets without abandoning "traditional" investments as stranded assets by 2030. There is not enough time to adopt transitional technologies based on fossil technologies. Continuing investment in high-carbon infrastructure creates an inertia that will make the 2050 target more difficult to reach, require expensive retrofits, and put investments at risk of early retirement.[13] The sunk costs associated could become a great burden in a world of high-carbon taxation.

In economic terms, it is much more rational to prevent these assets from receiving investment. Environmentally speaking, locking in fossil-based technologies would seriously compromise international efforts to cut GHG emissions.

13 Williams, Haley, Kahrl, Moore, Jones, Torn, McJeon (2014). Pathways to deep decarbonization in the United States. The U.S. report of the Deep-Decarbonization Pathways Project of the Sustainable Development Solutions Network and the Institute for Sustainable Development and International Relations.

It is a major challenge for the present and the following administrations to create important and credible commitments that send clear signals to the market about the importance of the transformation at hand.

In the coming years, a shared 30+ years integral vision of national energy security could be defined, looking into critical aspects such as future energy production; storage and supply; urbanization dynamics; mobility and mass transport development; industrial structure evolution; technological development and energy efficiency across sectors; transportation of goods; and freight corridors.

From this strategic vision an institutional framework, which is conducive to the appropriate national planning and large-scale investments, can be created. Regulatory instruments that can be employed to implement decarbonization pathways range from mandatory efficiency standards to progressive price signals on carbon and energy.

Clear investment programs of the required scale can then be put forward, scheduling intermediate goals for enabling capacity (expanded transmission, charging points for electric vehicles, rail infrastructure, etc.) as well as final goals on implementation and operation of all initiatives. Transparent mechanisms for renewable-capacity auctions and contracting regimes to ensure future finance will be key to producing the market certainty needed for the continuing commitment of the private sector and the general population in long-term decarbonization.

With this timeline in mind, developing such a coordinated vision before 2020 is recommended to boost the credibility and positive momentum of long-term decarbonization within Mexico; roll-out of concrete initiatives must begin by 2025-2030 at the latest. A close monitoring of progress and alternatives available at each stage of implementation will be valuable to guarantee programmatic goals are met.

Steps must be taken now in order to allow for future decarbonization to take place, instead of perpetuating the status quo which will inhibit progress. The window of opportunity to create the necessary conditions for deep decarbonization, including a sensible strategy to make it affordable, is narrowing quickly.

Two crucial technology decision points

All programs and plans established should keep a degree of flexibility to allow for new technologies, schemes, and dynamics to be developed and integrated in the future, as well as to help ensure that the best decisions are taken at each time. From the analysis we can identify at least two important decision points referring to crucial technologies: zero-emissions vehicles and capture and storage of post-combustion CO_2.

As international efforts to accelerate development of these key technologies are implemented, a strict schedule must be followed in which an evaluation must be done of the relative advantages of these technologies against other alternatives. A decision must be made around 2025 regarding the massive implementation of the most cost-effective option with the best overall benefits.

Passenger transport

Transportation is the largest source of emissions in Mexico. Growth of emissions from this sector has been notable in recent decades, and it is estimated to continue at a high rate as GDP per capita rises. Given the great amount of energy dedicated to transport people and a growing demand (expected to increase 56% by 2050), deep reductions in CO_2 emissions require convergent strategies:

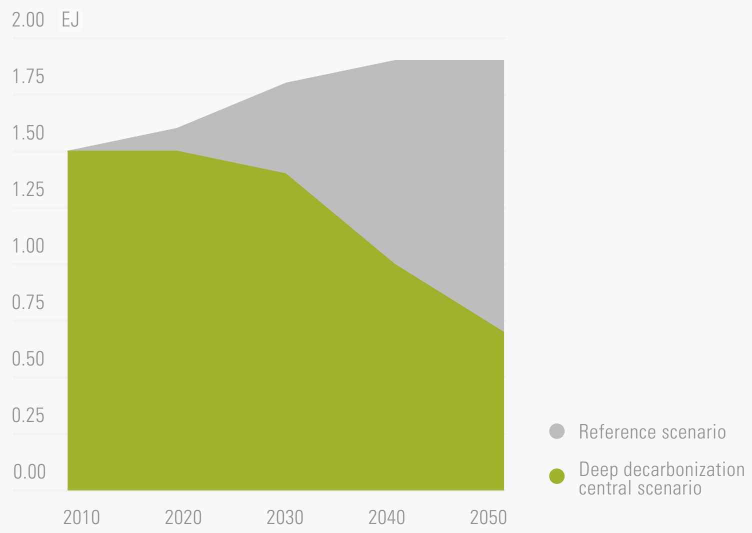
- Modal shift toward mass-transport systems to increase the amount of people transported per unit of energy. While 66% of travel demand is by lightweight vehicles at present, it should reduced to less than 50% in order to produce attractive energy savings and emissions reductions. In the deep-decarbonization scenario it is estimated that buses, urban rails, inter-urban rails, and airplanes supply most of the kilometers traveled by 2050 (jointly 53%).

- High efficiency in all transport to further reduce the energy footprint. Mileage of remaining gasoline vehicle increases 150% from an estimated average of 9.3 to 23.1 km/L between 2010 and 2050. This is 1.6 times what was estimated in the reference scenario, and it is consistent with the adoption of the best global practices in vehicle efficiency. Buses decrease 25% energy consumption per kilometer traveled from 2010 to 2050.
- Electrification and fuel switch to lower the emissions intensity of energy consumed. Low-carbon electricity provides energy for 45% of cars, 20% of buses, 50% of inter-urban rails, and all urban rails by 2050. Airplanes introduce 15% of biofuels in their fuel mix, and ethanol is added to substitute 5% of gasoline consumed by cars.

The resulting energy demand for transportation of people in the deep-decarbonization pathway is a third of that projected in the reference scenario by 2050, and half of what is consumed today (Figure 3.3). Final CO_2 emissions from this sector by 2050 are 34 $MtCO_2e$, a third of today's levels.

Given the large scale of infrastructure required in both urban retrofit and new capital investments, as well as the behavioral change needed from commuters, an intensive transport infrastructure expansion program in conjunction with new urban design approaches must start before 2025 in order to reach deep-decarbonization targets. To enable the transition, a shared long-term vision on future urban dynamics coupled with efficient and convenient mobility should be advanced in the near future (Figure 3.4).

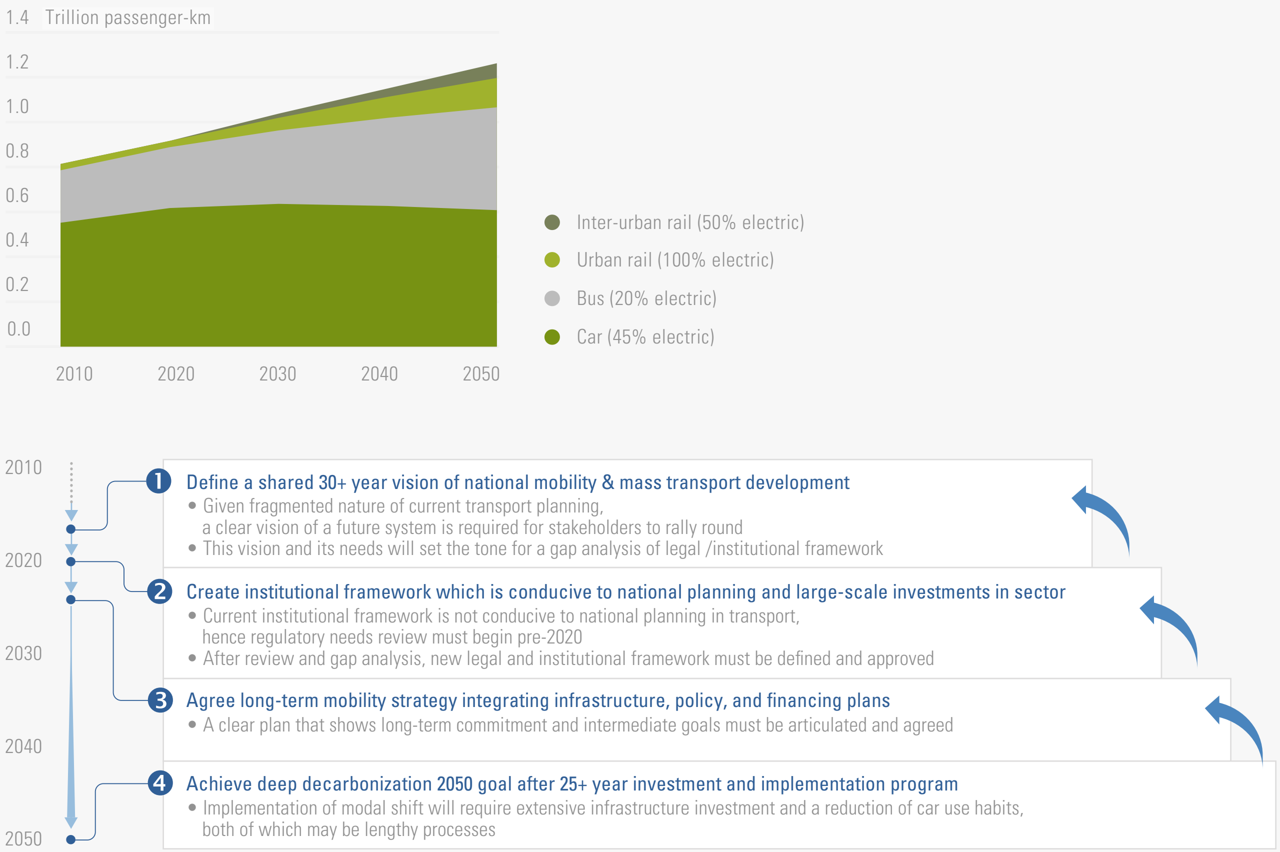
Figure 3.3. Passenger transport energy pathways



In the central deep-decarbonization scenario, the remaining fleet of light-duty vehicles migrates to 45% electric by 2050. At present there is great uncertainty over the timely (ca. 2025) development of electric vehicles and other technologies. In order to reach deep-decarbonization targets, any technology with zero direct emissions must be massively adopted starting in 2025 (Figure 3.5). F7

If the general mode of transportation does not change in the magnitude exemplified here, alternative decarbonization strategies will need to be considered, with their own implications and difficulties. For example, it could become necessary to dramatically improve agricultural productivity to guarantee the massive sustainable production of biofuels. Coincidentally, if only electrification of the vehicle fleet is considered without implementing massive transport systems, the demand of electricity by 2050 would be much higher, and it would need additional zero-carbon sources of energy, like nuclear, to be commissioned.

Figure 3.4. Passenger road transport modal shift



Freight transport

Deep decarbonization of freight transport is also based on a modal shift of 25% of all demand to electric railroads. This is coherent with other assumptions modeled in the decarbonization scenario, as it makes sense to use railroad infrastructure already built for passenger transport in freight corridors. Remaining road freight transport is assumed to shift to 45% biofuels (biodiesel and ethanol) and 30% liquefied natural gas (Figure 3.6a). This leaves only 25% of trucks and 20% of trains still running on diesel by 2050.

Increase of final energy of freight transport in the deep-decarbonization central scenario between 2010 and 2050 is limited to 70%, although it satisfies a demand three times higher by the end of that period (Figure 3.6b). Resulting CO_2 emissions are 20% lower in 2050 than in 2010.

The extent and main features of decarbonization estimated for this sector are preliminary at this stage. A better understanding of the patterns of distribution of goods throughout the country is needed to identify the most noteworthy actions to optimize energy consumption and reduce GHG emissions. This discussion should be framed within the context of the long-term national vision on energy security and sustainability mentioned before.

Figure 3.5. Light-duty vehicle fleet composition

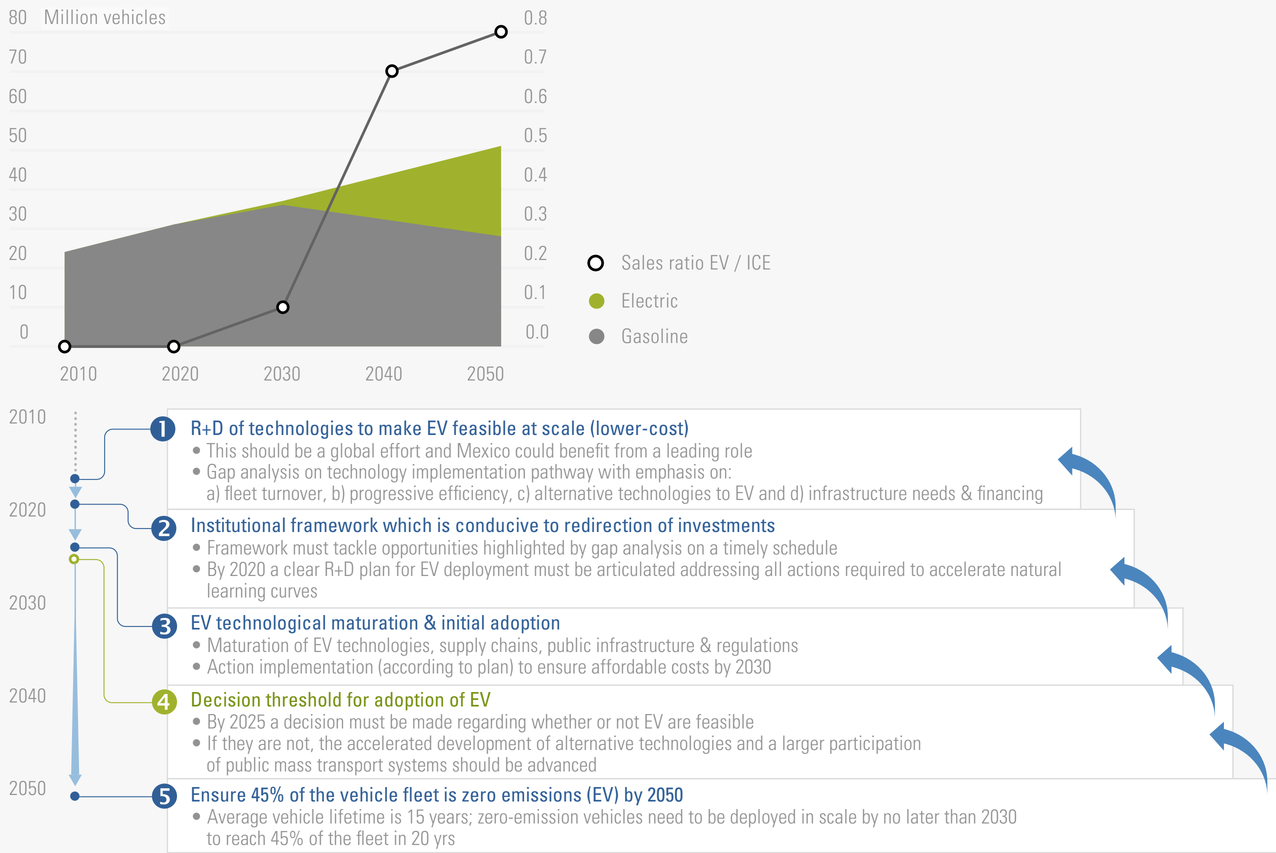
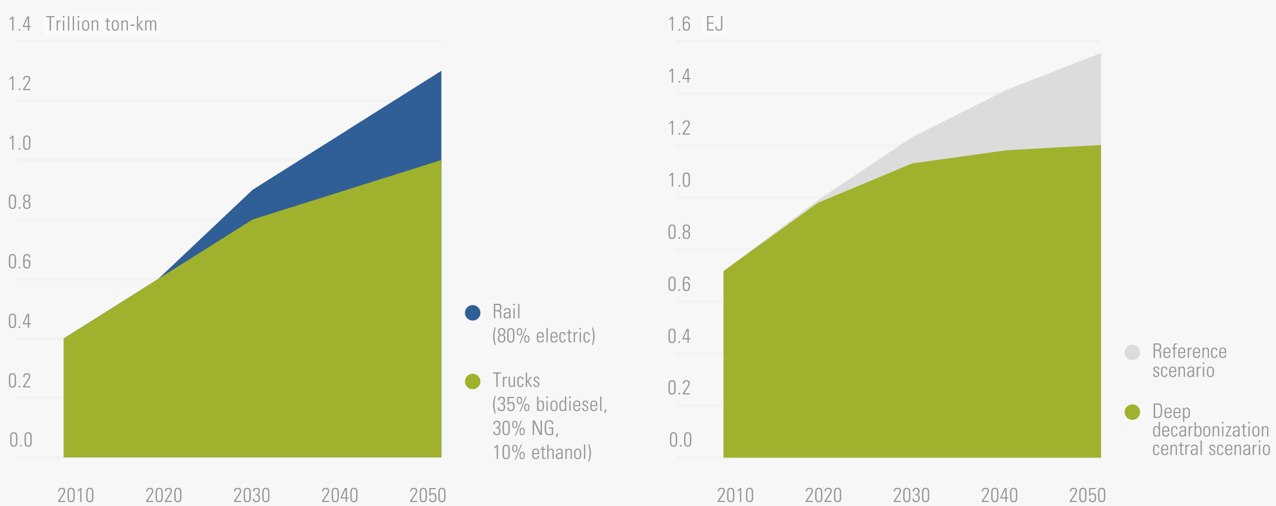


Figure 3.6. Road freight transport mode and energy pathways



Electricity generation

Decoupling CO_2 emissions from electricity generation, along with a greater use of electricity in all energy sectors in Mexico, is the primary deep-decarbonization strategy explored in this exercise. It is fundamental that every effort to increase electrification is accompanied by simultaneous actions to lower the CO_2 intensity per kilowatt distributed in the grid.

Under the deep-decarbonization scenario, future electricity supplies reach above 940 TWh by 2050, which represents 23% more than the reference scenario. To significantly reduce CO_2 emissions while satisfying this power demand, the central scenario explores two premises:

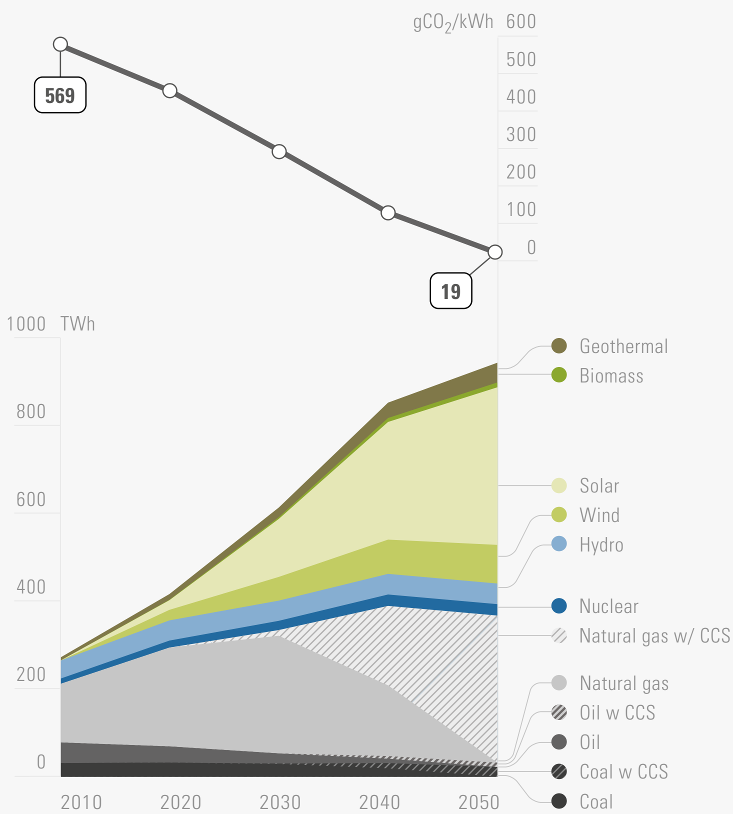
- All potential renewable sources of electricity identified to date are explored and used to generate electricity by 2050.[14]
- The predominant role of natural gas is possible until 2050 only if carbon capture and sequestration is carried out in all plants that use it.

The resulting CO_2 intensity of the electricity produced decreases from 570 g of CO_2 per each KWh produced in 2010 to 19 gCO_2/KWh by 2050 (Figure 3.7). This aggressive evolution of electricity's carbon footprint is essential to deep-decarbonization efforts.

To produce the amount of clean electricity on the scale required by 2050, the decarbonization scenario projects an accelerated diffusion of renewables into the national electricity generation matrix from 2020 (Figure 3.8). This will require investment in infrastructure for both producing and storing electricity. All future plans must consider grid robustness and final electricity costs, as new sources of electricity, new producers, and new technologies come into the market.

The central scenario of deep decarbonization in Mexico assumes that CCS technologies are implemented at scale from 2030 for all fossil-based electricity generation (Figure 3.9). Given the present uncertainty on the future development and cost associated with CCS, a decision point will be reached by 2025, when it will be necessary to evaluate all the existing options, including the readiness of CCS by 2030 and the potential alternatives for decarbonizing electricity production by 2050. It is vital that a plan for CCS development and future assessments of viability is executed in the near future to explore all alternatives available with enough time and information.

Figure 3.7. Evolution of electricity generation



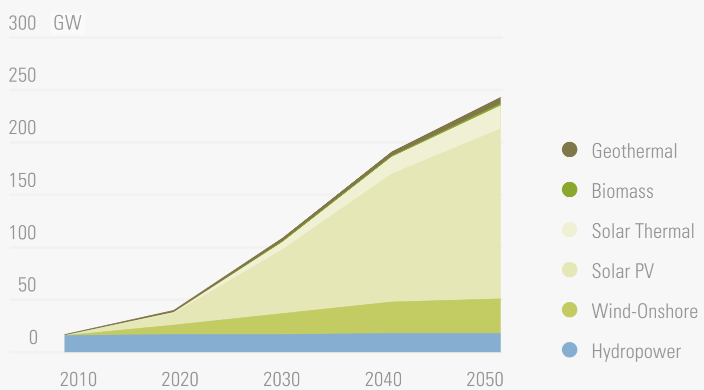
14 To the date of writing, solar power potential in Mexico is presumed larger than primary national energy requirements. Estimation of future solar generation was based on assumptions on potential deployment rates. Estimates based on information from SENER: http://inere.energia.gob.mx/publica/version3.5/

Although the retrofitting of a massive installed capacity of combined-cycle natural gas generators from 2030 to 2050 seems like an overwhelming endeavor, Mexico already has experience in large-scale transformations of the power system. The transition from traditional thermoelectric plants fed with residual fuel oil to gas turbines (many of them retrofitted with a combined cycle) took exactly 20 years, from the mid-nineties to date. The main driver of that transition was the long-term lower cost and higher efficiency of natural gas-based combined-cycle technology relative to thermoelectric plants.
To promote the technological transition toward low-carbon alternatives, such as CCS or renewables, strong price signals are required consistently for the next 30 years.

Industry

The industrial sector is assumed to slowly reduce its share within the whole economy. Still, as population and GDP per capita grow, an increasing demand of goods and infrastructure will require greater industrial output. In all scenarios analyzed, national GDP is projected to grow at a rate of 3% every year and industrial GDP would do so at a rate of 2.5%, from 2010 to 2050. The composition of the industrial sector is assumed to remain basically constant throughout the period projected. An important exception is made in the

Figure 3.8. Evolution of renewable electricity generation capacity



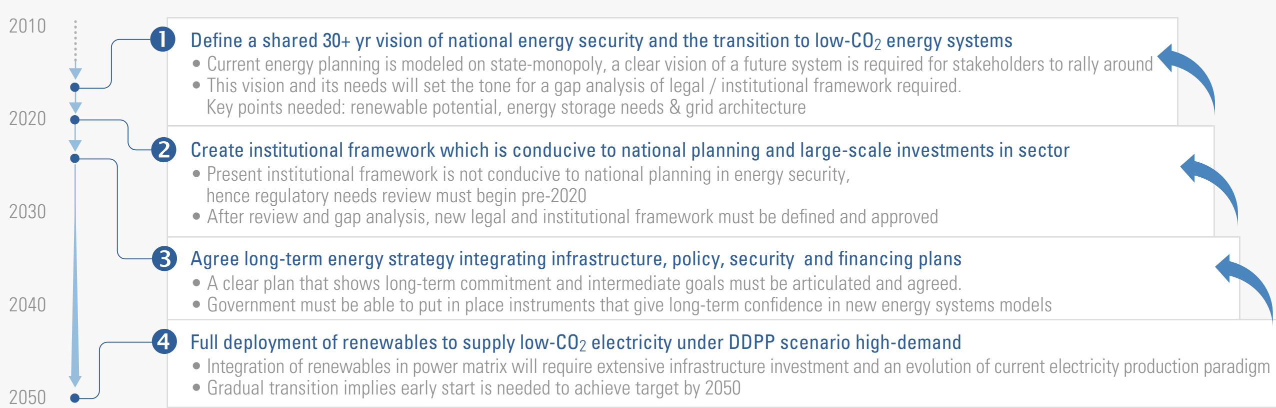
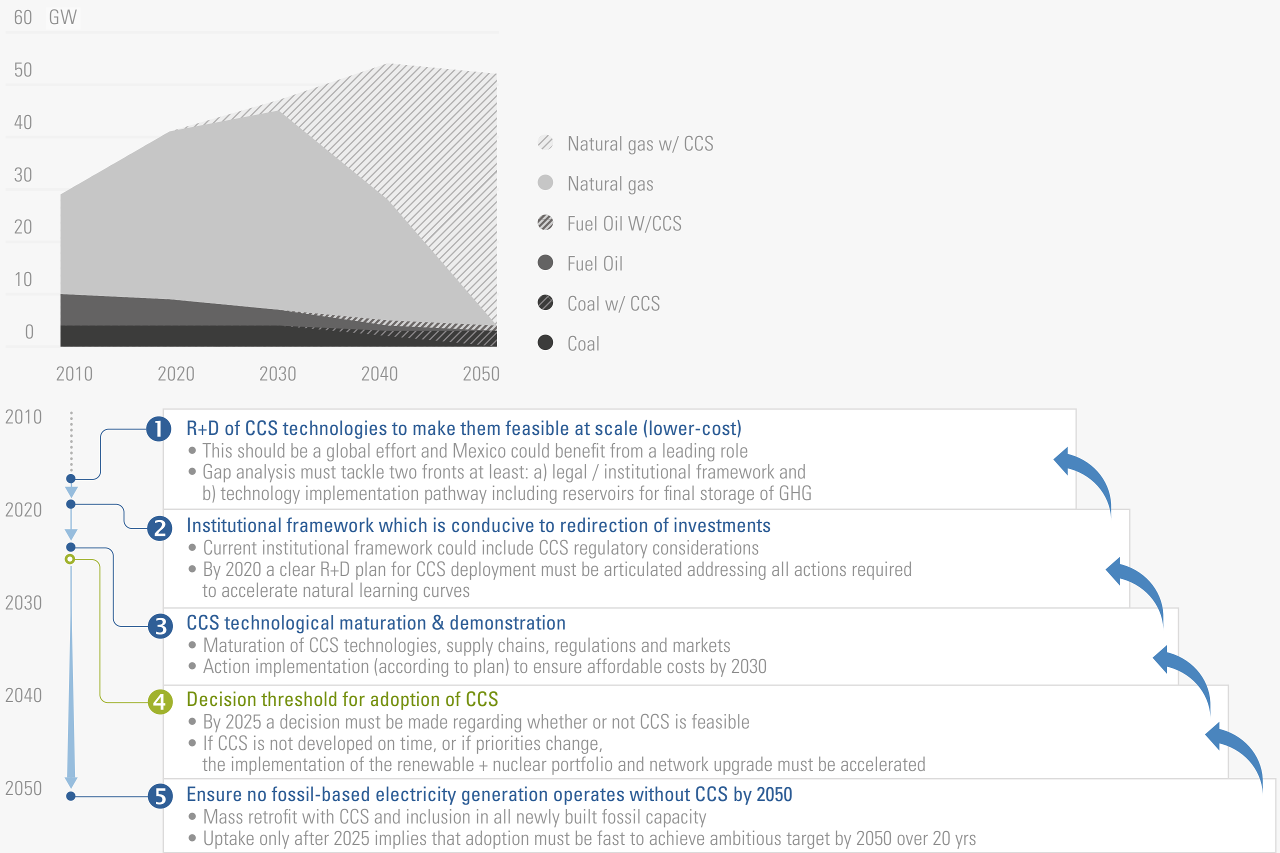


Figure 3.9. Evolution of fossil-based electricity generation capacity



mining subsector, where different perspectives on oil and gas production are adopted in the reference and the deep-decarbonization scenarios. Oil and gas production has reduced its participation within industrial GDP from 25% in 1995 to 18% in 2010. As countries and regions progressively meet future energy needs from non-fossil sources, oil and gas production will shrink. The rate at which this will happen is difficult to assess at present, as are the effects of such a transformation. For example, energy savings are expected to arise from industrial activity that diverges from fossil fuel mining, as conventional sources deplete and higher energy consumption is needed to tap into new non-conventional sources.

The deep-decarbonization central scenario assumes a larger production of natural gas, to supply expanded electricity demand; and a smaller output of crude oil, to reflect a shrinking demand in a global context undergoing decarbonization. Overall mining production increases 40% from 2010 to 2050, and projected energy intensity is only 50% higher than at present.[15]

15 DDPP central scenario assumes that domestic crude oil production by 2050 is 15% lower than in 2010. This assumption is based on estimations by the IEA on oil demand reduction under a "2 degree scenario." (IEA, ETP, 2014).

Stimulating energy efficiency is a valuable decarbonization strategy in all the scenarios modeled. By 2050 cement manufacturing and iron and steel production each reduce by one-third the energy consumed per ton produced in 2010. All other manufacturing, from cars to oil refining, is projected to reduce average energy intensity more than 40% in the same period. This generic manufacturing category includes a large population of low-energy fragmented activities with outdated production schemes that could dramatically benefit from the adoption of best global practices. Other industrial activities, like agriculture and construction, are assumed to marginally decrease energy intensity (trends show that it has been increasing in recent years).

The ambitious energy-efficiency improvement projected by the central deep-decarbonization scenario will necessitate that a dedicated program is enforced to synchronize technical training, financing schemes to aid technology uptake, business models to capture benefits from fragmented activities, and instruments to align incentives toward improving efficiency and productivity (Figure 3.10).

Electrification of end uses is estimated to be deepest in manufacturing (from 24% of all energy consumed in 2010 to 50% in 2050) and other industrial activities (from 39% to 60%). Increasing the

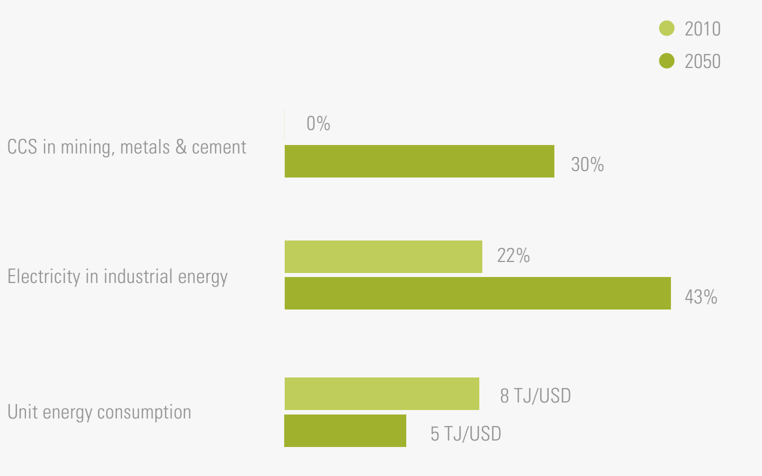
Figure 3.10. Energy efficiency increase in industry vs reference scenario

share of electricity plays a modest role in cement production (30% in 2050 from 26% in 2010), mining (20% in 2050 from 12%), and iron and steel (15% from 12%). As the electricity market opens to new private investment, large companies could benefit from promoting a larger share of electricity in their final energy consumption coupled with a direct supply of non-carbon electricity (for example through solar or wind capacity) and expanded electricity storage capability.

In the central deep-decarbonization scenario, it is assumed that carbon capture and sequestration (CCS) of post-combustion CO_2 becomes a mature and available technology between 2025 and 2035. If this turns out to be accurate, consumption of fossil fuels might not need to be halted as abruptly as will be required if such solution is not on the menu for decarbonizing energy systems. Mining, cement, and iron and steel are modeled to use CCS technologies in 30% of the natural gas consumed by 2050.

Under the deep-decarbonization central scenario, CO_2 emissions from energy uses in industry are 17% lower by 2050 than in 2010, totaling 116 $MtCO_2e$.

Figure 3.11. Aggregate key energy indicators in industry



Further potential for GHG emissions reductions in industrial activities might be identified with a deeper understanding at two levels:

- At a macro level to evaluate possible evolution pathways of the overall structure of the manufacturing industry toward a less energy-intensive portfolio of products, and
- At a detailed level in each of the energy-intensive branches (mining, cement, oil & gas, petrochemical, chemical, etc.) to explore improvements in their full-cycle, from the basic science and process redesign to the end-product distribution and its alternatives to the public (i.e. switch to less energy-intensive materials).

Buildings

Mexico's relatively mild weather keeps energy requirements in households low, and GHG emissions from buildings (residential and commercial sectors) have not been increasing at high rates. However, as GDP and energy expenditures per capita rise, steps must be taken to ensure household energy consumption does not emulate North American patterns.

The resulting CO_2 emissions from residential and commercial sectors are half of today's by 2050 in all deep-decarbonization scenarios developed in this study. The deep-decarbonization pathway accomplishes this mainly by electrification of final energy uses and the accelerated improvement of energy efficiency.

The rate of efficiency increase projected in this exercise is quite rapid due to four main reasons:

- Home devices have relatively short lifetimes and replacement rates. With the right incentives, final users would perceive the benefits of keeping up with latest efficiency standards.
- All economic benefits from saving energy have a positive impact directly on final users.
- Under present federal subsidy structure, energy savings could become meaningful and there is no reason to delay action in this regard.

- The potential energy savings would represent an attractive business opportunity in an open energy market of increasing maturity.

Strengthening and expanding existing institutional energy-efficiency efforts within the framework of a national integral long-term vision of energy security is a priority that should be undertaken before 2020 (Figure 3.12).

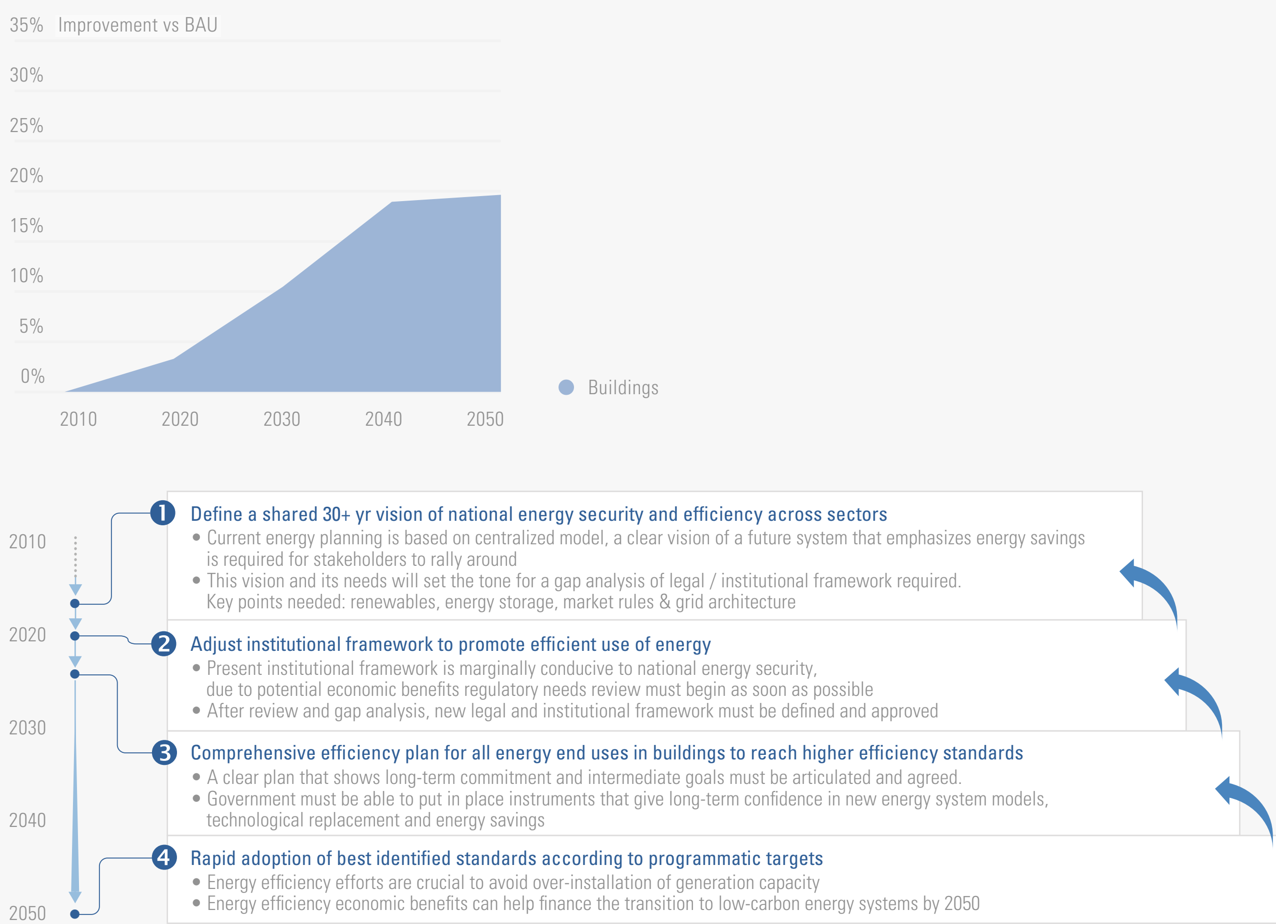
Interventions that could help speed the transition might include, but are not restricted to:

- A redesigned subsidy structure to convey the right messages to all energy consumers
- A well regulated competition between ESCOs to capture most of the distributed potential energy savings and generation opportunities
- A mass-scale household appliance exchange program to assist the large part of the population that cannot afford the transition by their own means

3.2 No-CCS alternative scenario

The accumulated amount of CO_2 captured by CCS in industry and electricity generation from 2010 to 2050 in the central deep-decarbonization scenario totals 2 billion tons (Figure 3.14).

Figure 3.12. Energy efficiency increase in buildings vs reference scenario



These emissions will have to be stored, probably underground, as CCS is implemented. Energy officials in Mexico have estimated a preliminary storage potential of 200 Giga tonnes[16]. All CO_2 emissions captured through 2050 in Mexico under the deep-decarbonization central scenario represent only 1% of this potential capacity.
Uncertainty about future CCS viability remains, it seems, not on the national storage capacity, but on its future costs and risks of leakage and other negative environmental impacts.

Fig 3.13. Aggregate key energy indicators in buildings

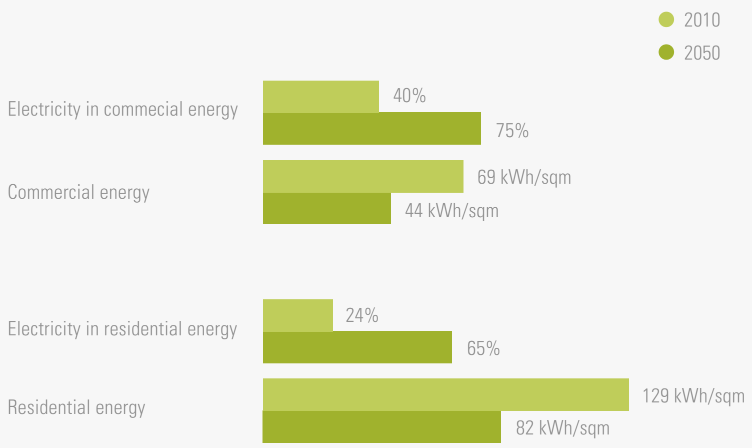
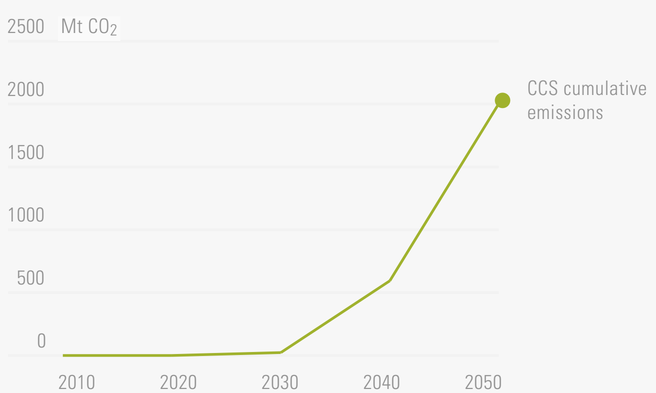


Figure 3.14. Underground capacity needed for CCS



Given the high dependence that the central deep-decarbonization scenario has on CCS, it is worth exploring alternatives to reach the same levels of decarbonization by 2050 in a pathway that does not include CCS at all.
Without CCS as a viable option, decarbonization targets can be reached. However, the prolonged use of fossil fuels is not compatible with this pathway, and an aggressive program to develop and expand zero-carbon power generation must be in place by 2025, including renewable and nuclear capacities.
Stepping up the transition of the industrial manufacturing sectors toward a less energy-intensive matrix of products could help implementation of deep-decarbonization pillars (energy efficiency, electrification) and would reduce future reliance of the whole industrial sector on fossil fuels and CCS.

Power generation:
To compensate for the reduction in electricity generation from fossil sources (mainly natural gas), electricity generation from alternative zero-carbon sources must be increased by 2050: nuclear (+165 TWh than in the Central scenario), biomass (+57 TWh), solar thermal (+37 TWh), wind off-shore (+37 TWh), wind on-shore (+22 TWh), hydro (+15 TWh), and other renewables (+10 TWh).
Solar photovoltaic and geothermal sources are assumed to have reached their maximum potential in the central deep-decarbonization scenario; in this alternative scenario they remain the same and no additional potential is allocated to them. The resulting total installed capacity is 11% larger in the No-CCS alternative scenario due to a greater share of renewables with lower capacity factors. This can be reduced with a larger share of nuclear power within the matrix.

16 Atlas de Almacenamiento Geológico de CO_2 en México, SENER-CFE, 2012, at: http://co2.energia.gob.mx/co2/atlas.html

In this alternative scenario, all investment in fossil technologies (like combined-cycle natural gas plants) installed after 2020 becomes at risk of early retirement to meet deep decarbonization targets. If CCS is not available by 2025, serious investment must be directed toward non-fossil power.

Industry:

In order to partially compensate for the lack of CCS in industry, the alternative deep-decarbonization scenario reduces even further the energy intensity of the industrial sector. Instead of a 36% reduction, as in the central scenario, the reduction is of 38% from 2010 levels in the No-CCS option. Notably, most of the additional energy intensity reduction is modeled for the three subsectors most relevant to CCS deployment: mining, cement, and iron & steel.

Additionally, to meet deep-decarbonization objectives, a greater share of electricity is required in some subsectors: iron and steel (18% by 2050 vs. 15% in the central scenario), manufacturing (55% by 2050 vs. 50% in the central scenario). And a larger share of biomass consumption is also projected as part of the energy fuel mix supplying iron and steel operations.

3.3 Remarks on technological lock-in

A recently published paper warns of the dangers of carbon technological lock-in: "Once certain investments are made, institutions are created, and development pathways are chosen, the behaviors (and carbon emissions) associated with them are more or less 'locked in,' and shifting to a new pathway becomes ever more difficult and expensive."[17]

As the preliminary results from this study show, steps must be taken in the present to allow for future decarbonization to take place. Capital-intensive assets have a long lifetime, and a clear and realistic pathway for the future is needed to aid decision-making at various scales.

Delayed or unpersuasive action would not only constrain the transition towards a green economy, but it would also increase the future costs and risks.

The window of opportunity to create the necessary conditions for deep decarbonization, including a sensible strategy to make it affordable, is closing quickly.

4 Areas of possible future work

To better inform policy making, this study should be complemented by in-depth subsequent analyses at a disaggregated level, which would benefit from being carried out simultaneously.

On the one hand, greater detail on the potential evolution pathways of the asset base would help strengthen the preliminary deep-decarbonization pathways developed in this work, leading to clearer and more robust timelines, as well as fleshing out specific implementation issues and dependencies prior to detailed planning and commissioning.

On the other hand, dedicated micro- and macro-economic analyses would help identify the main potential impacts and investment needs, as well as the most cost-efficient pathways for deep-decarbonization in Mexico. These analyses may consider two complementary

17 Erickson et al. Leaving room for 'green growth': identifying near-term actions to avoid long-term carbon lock-in, Policy Brief, Stockholm Environment Institute, 2015.

approaches: a bottom-up cost-benefit evaluation based on the evolution of the detailed asset base, and a top-down evaluation to explore potential impacts of implementing a deep-decarbonization trajectory on key macroeconomic indicators such as investment, energy prices, job creation and income distribution.

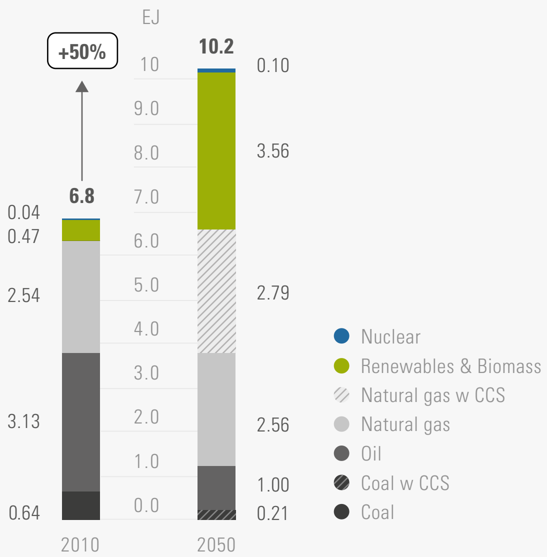
The information generated by these studies will be necessary to develop and implement a detailed and compelling national vision for deep decarbonization, including concrete national and international policy measures and instruments, to fully decouple Mexico´s energy systems from CO_2 emissions by mid-century.

Standardized DDPP graphics for Mexico scenarios

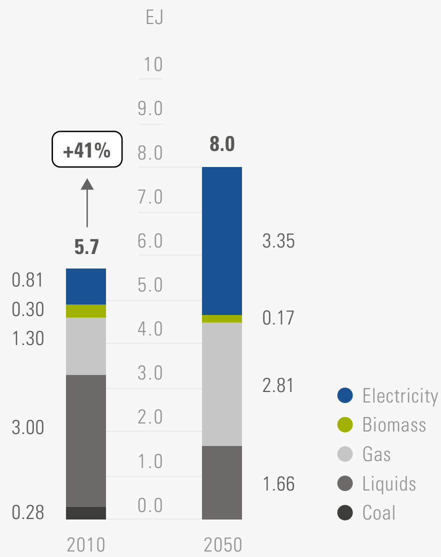
MX – Central
MX – No CCS
MX – Limited CCS

MX - Central

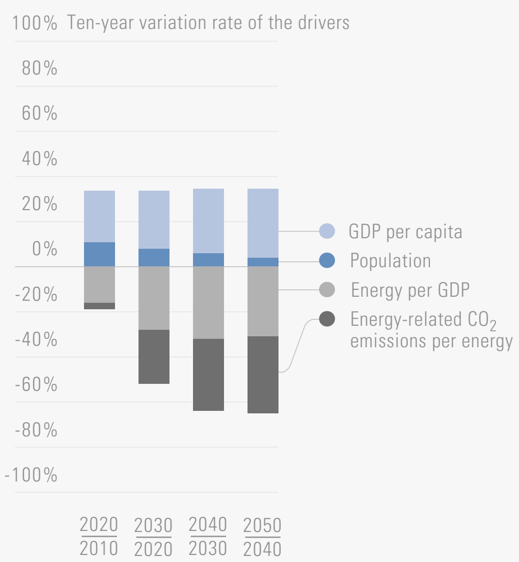
Energy Pathways, Primary Energy by source



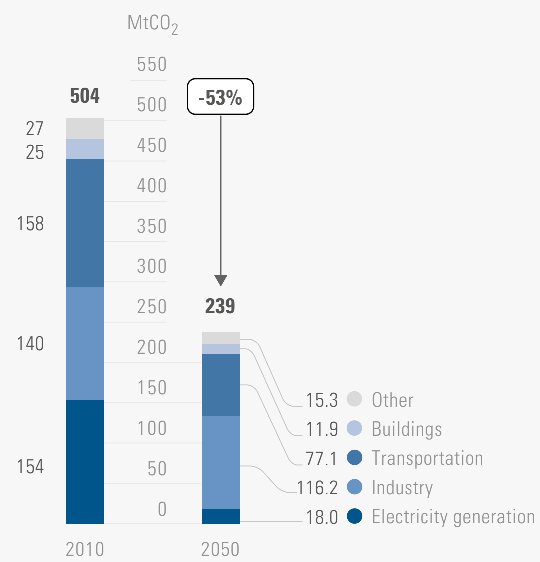
Energy Pathways, Final Energy by source



Energy-related CO_2 Emissions Drivers, 2010 to 2050



Energy-related CO_2 Emissions Pathway, by Sector

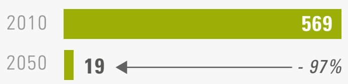


The Pillars of Decarbonization

Energy efficiency

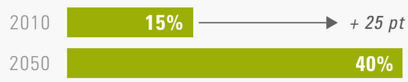
Energy Intensity of GDP, MJ/$

Decarbonization of electricity



Electricity Emissions Intensity, gCO_2/kWh

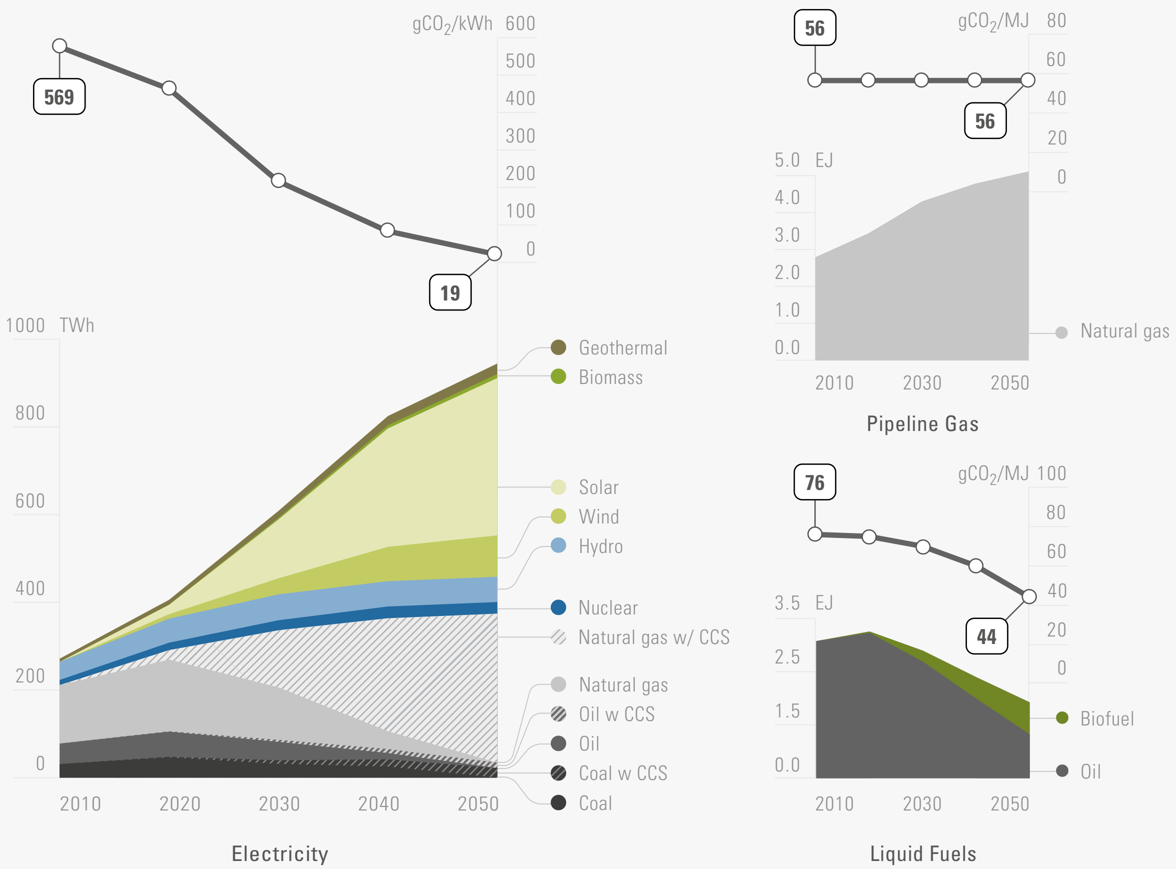
Electrification of end-uses



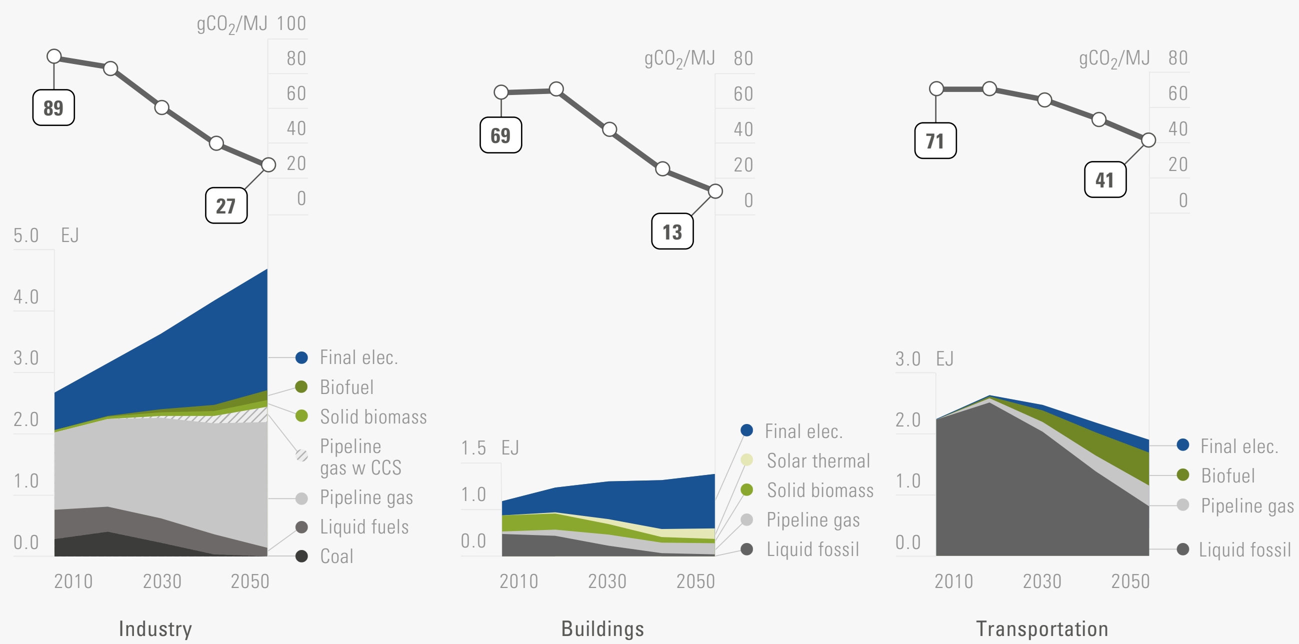
Share of electricity in total final energy, %

Carbon intensity

Energy Supply Pathways, by Resource

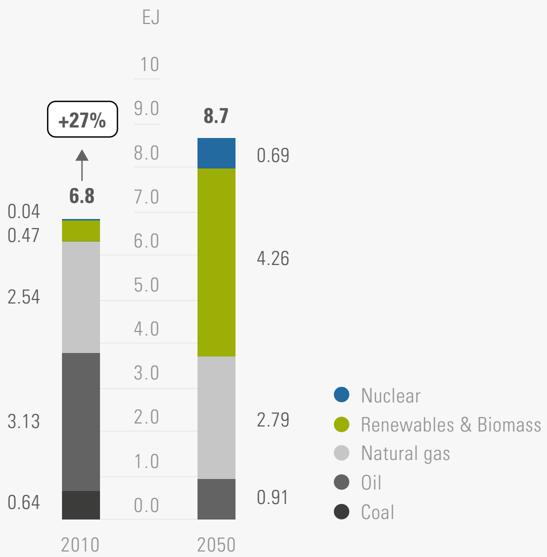


Energy Use Pathways for Each Sector, by Fuel, 2010 – 2050

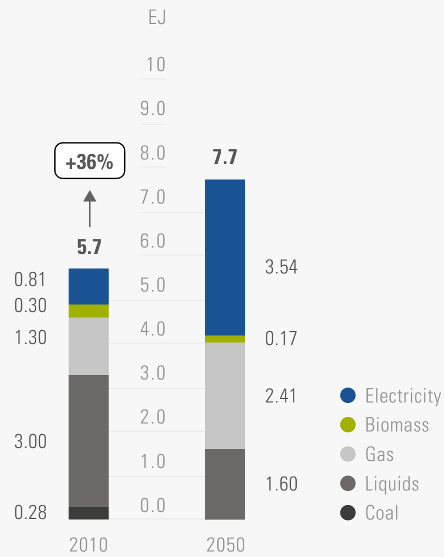


MX - No CCS

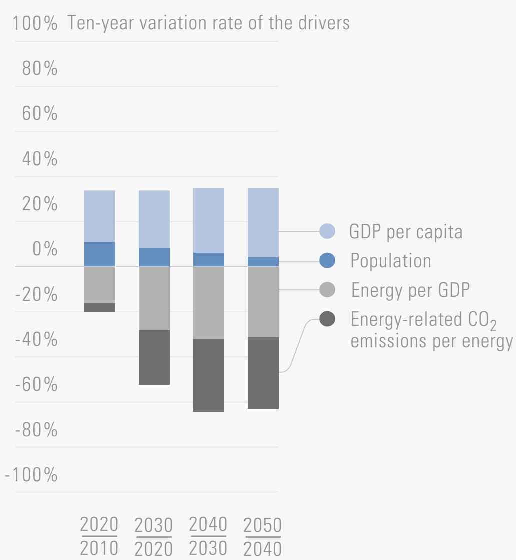
Energy Pathways, Primary Energy by source



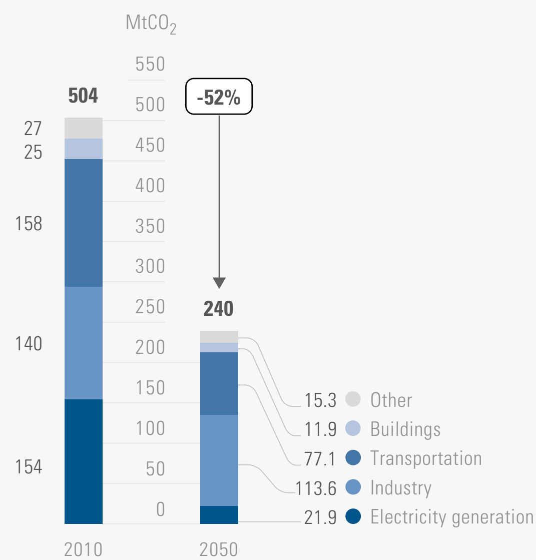
Energy Pathways, Final Energy by source



Energy-related CO_2 Emissions Drivers, 2010 to 2050

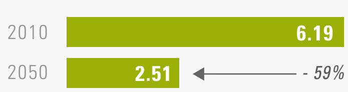


Energy-related CO_2 Emissions Pathway, by Sector



The Pillars of Decarbonization

Energy efficiency

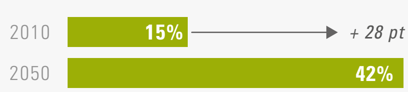


Energy Intensity of GDP, MJ/$

Decarbonization of electricity

Electricity Emissions Intensity, gCO_2/kWh

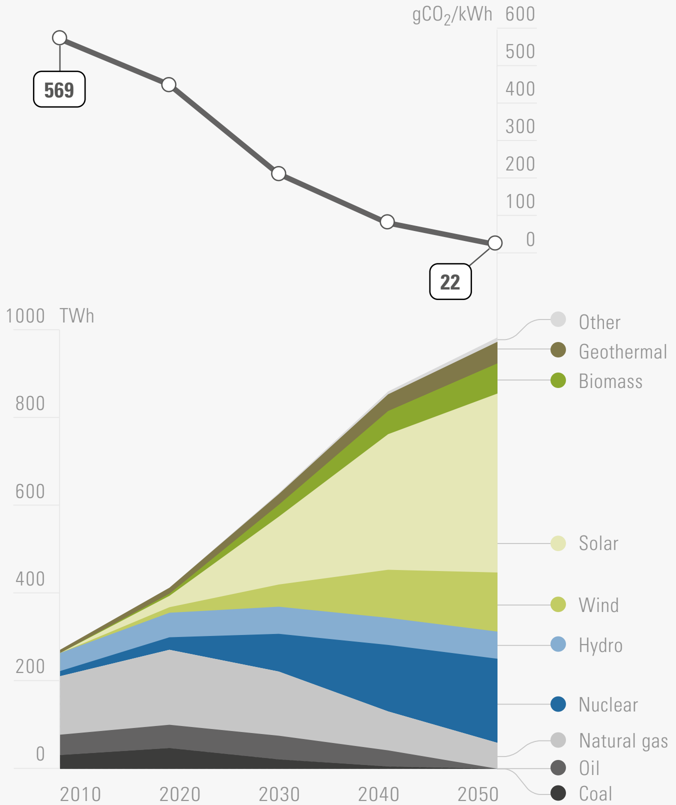
Electrification of end-uses



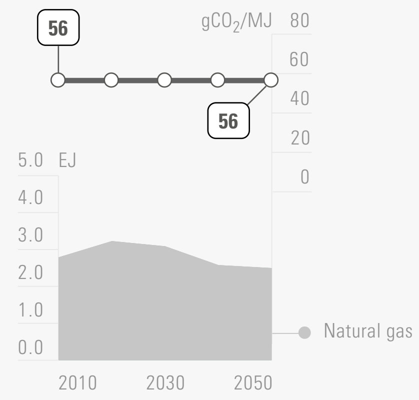
Share of electricity in total final energy, %

Carbon intensity

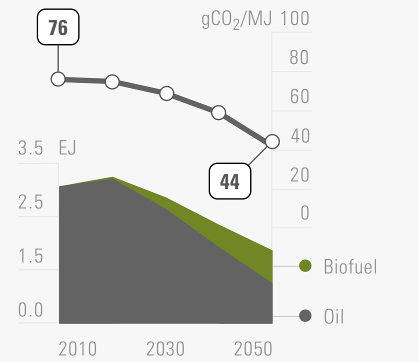
Energy Supply Pathways, by Resource



Electricity

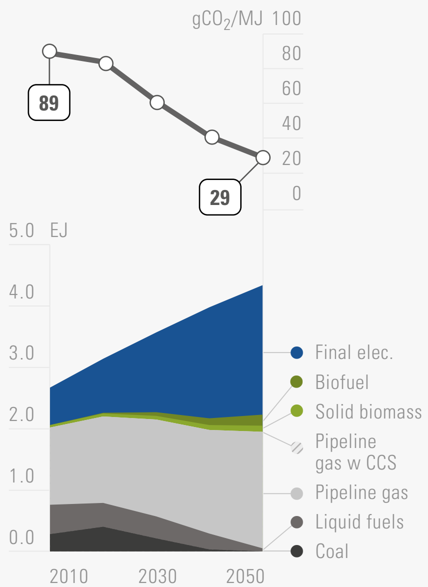


Pipeline Gas

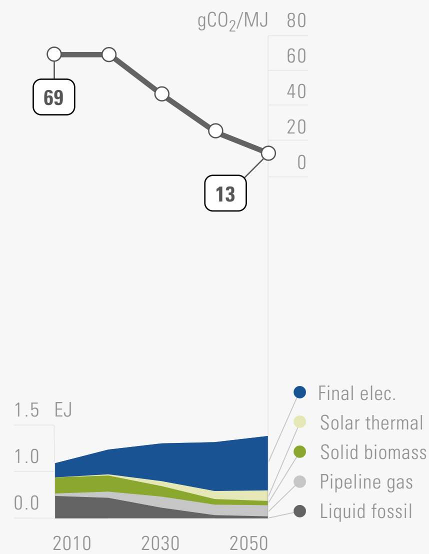


Liquid Fuels

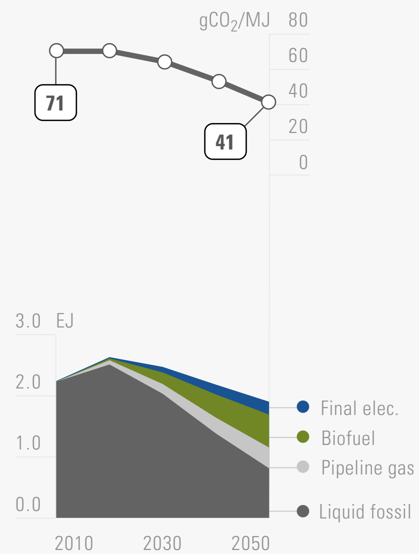
Energy Use Pathways for Each Sector, by Fuel, 2010 – 2050



Industry



Buildings



Transportation