Decarbonization challenges and opportunities for the light manufacturing industry in Mexico

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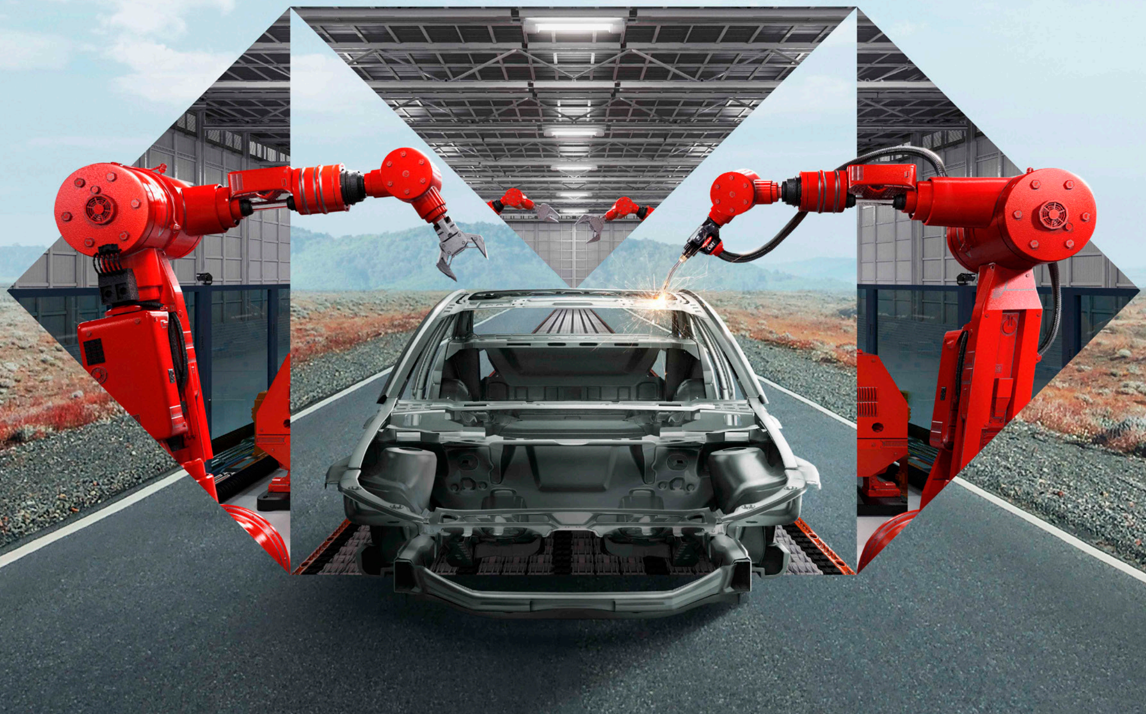

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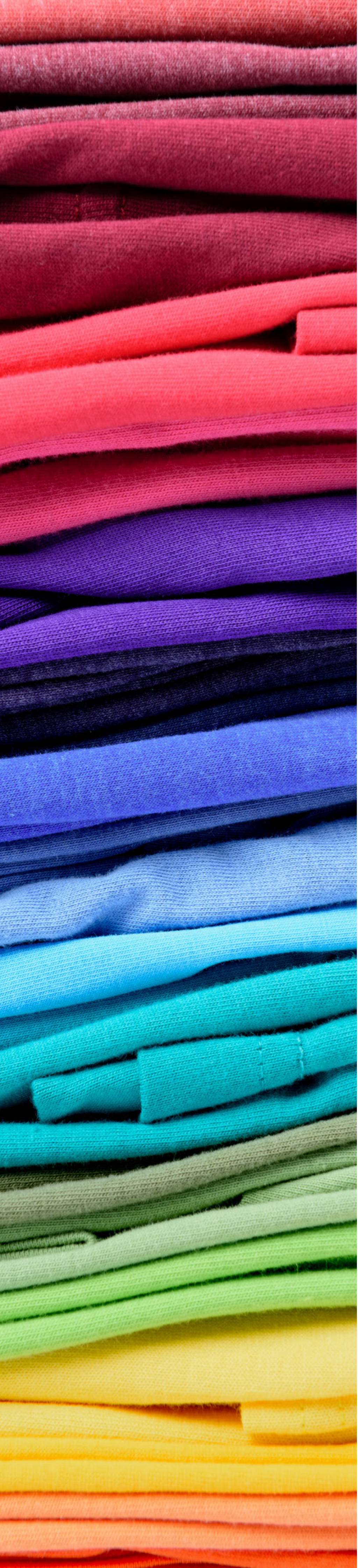

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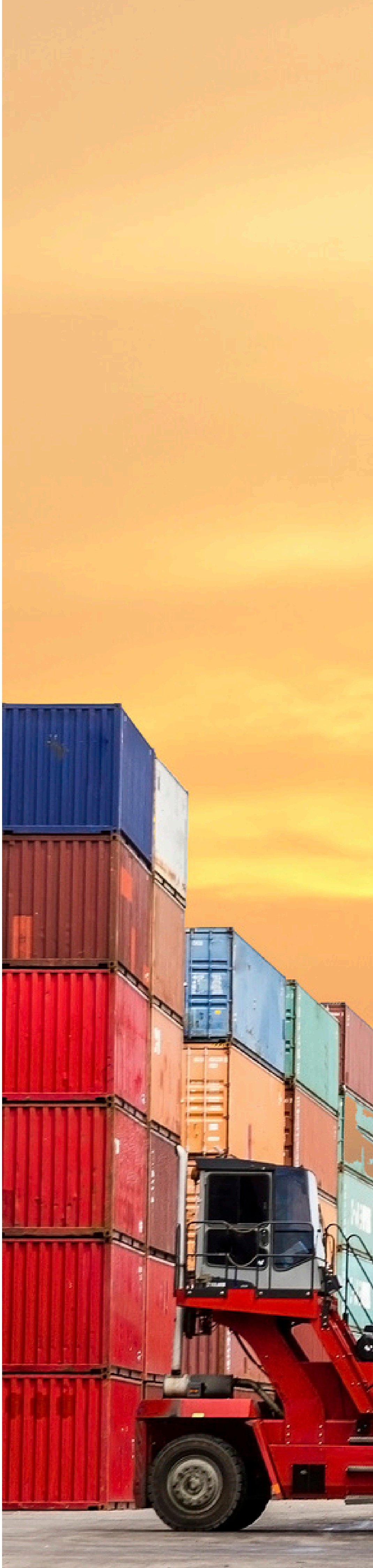
Executive summary

The Light Manufacturing Industry (LMI) is a branch of the manufacturing sector that produces relatively high-value items per unit weight, such as clothes and consumer electronics, through processes that use moderate amounts of energy and partially processed materials. The LMI has the potential to initiate rapid, substantial, and potentially self-propelling waves of rising output, employment, productivity, and exports that can push countries on a path of structural change.

In the case of the Mexican economy, LMI plays a strategic role. It accounts for 13.9% of GDP, 80% of manufacturing production, and 65% of exports. Either directly or indirectly, it employs over 3.8 million people, representing 91% of total jobs in manufacturing industries. In 2019 alone, LMI attracted 13.7 billion USD of foreign direct investment.

The sector is highly concentrated. Nearly 60% of LMI's GDP contribution comes from three manufacturing sub-sectors: transport equipment (23%), food industry (25%), and computer equipment (11%). Other LMI subsectors include textiles, wood, pulp and paper, printing, leather, furniture, and other unclassified subsectors.



Highlights

- The purpose of this report is to understand the opportunities and challenges faced by the light manufacturing industry in Mexico when attempting to advance its decarbonization strategies. This report aims to represent a useful diagnosis for stakeholders and policymakers to identify and implement cost-effective greenhouse gas (GHG) mitigation solutions in the light manufacturing sector to achieve Mexico's climate targets.
- In Mexico, by 2018, the LMI contributed roughly with 13.9% of the national Gross Domestic Product (GDP), 80% of total manufacturing production and 65% of total exports. The sector employs more than 3.8 million people and attracts USD 13.7 billion of foreign direct investment annually (FDI) (INEGI, 2019).
- Energy use in the light manufacturing sector grew at the same rate as the economy, 3.7% between 2010 and 2015, a slowdown compared to growth rates before 2005. In general, light manufacturing operations consume less energy per value generated, having reduced their energy intensity by 21.6% between 1995 and 2015,
- The mix of energy sources used by the LMI has shifted over time, with electricity growing from a 30% share in 1990 to 65% in 2018. The electrification trend of the sector may come as good news in terms of GHG emissions, as electric power generation can potentially decarbonize in full.
- LMI has seen a 3% annual growth in GHG emissions for the 2010-2015 period, reaching a share of 7% of total emissions. The industry will be the sector with the second-largest contribution to Mexico's GHG emissions by 2050 (20% of total emissions) if no mitigation actions are taken.
- The proposed decarbonization pathway includes energy efficiency, full electrification, and process optimization for all LMI operations, followed by a strict decarbonization effort of the whole value chain and the promotion of circular economy principles. Policies that have a strong abatement potential and represent a net revenue to implementing companies include industry efficiency standards, renewable energy generation, and a carbon tax.

LMI's energy requirements are relatively high, with it demanding almost 20% of the national energy generated in Mexico, ether in the form of electricity, natural gas, and liquid hydrocarbons. Energy demand in the sector is still growing, at an annual rate of 2.3%,mainly due to the expansion of activities, even though it has reduced its energy intensity by over 20% since 2000, through fuel shifting, energy efficiency improvements, and a growing share of less energy-intensive activities.

Electricity represents 65% of the sector's energy use. If full electrification was achieved, the sector would be in a position to significantly abate its greenhouse gas (GHG) emissions, as electric power generation can potentially decarbonize fully.

In Mexico, GHG emissions from light manufacturing operations contribute 7% of national total emissions. LMI GHG emissions are projected to grow 3% annually from now up until 2050, if no additional mitigation actions are taken. It is expected that the industry sector as a whole will become the second-largest contributor to Mexico's GHG emissions by mid-century, with 20% of total emissions.

Mexico has committed to reduce significantly its GHG emissions by 2030, by 22% below business as usual (BAU) unilaterally, and as much as 36% if a set of conditions are met. The light manufacturing industry is compelled to follow suit, putting in place a pathway to reduce emissions through a comprehensive approach, which can be summarized as an Avoid-Shift-Improve framework, as illustrated below:

- Avoid material and energy waste in all processes, through a strict application of energy efficiency, continuous improvement, and operational excellence principles. By eliminating waste, there should be an increase in profit margins; some savings should be reinvested in the following steps.
- Shift the use of fossil fuels by electrifying sector operations in full. Additional electric power demand should be met with renewable sources either by self-generation, purchasing contracts, or the grid. By moving emission sources out of site, on-site operations are safer, healthier, and can potentially be improved further.

- Improve processes through machinery/technozogy upgrades, monitoring and control, energy management systems, and heat recovery.
- Subsequently, follow a strict decarbonization effort of the value chain in full while promoting and building capacities for a circular economy.

The single policies with the greatest emissions abatement potential, and which entail net profits for the implementing companies are industry efficiency standards, renewable energy generation, and a carbon tax. Besides, corporate strategies and management practices can contribute significantly to achieve decarbonization.

Savings in energy consumption are a key driver to invest in renewable sources and develop energy management systems. Nowadays, the cost of electricity can reach 35% of the total production costs of LMI. Standards and regulations that limit energy consumption in equipment, devices, and commercial systems have been the most cost-effective policy to reduce energy use in the LMI.

Economic instruments implemented so far in Mexico are insufficient to achieve significant GHG emissions reductions. The emissions trading system has just started as a pilot program in 2020, and the carbon tax applied to fossil fuels is currently under 3 USD per tCO_2e, which is a meager rate contrasted with the 40-80 USD per tCO_2e suggested by the World Bank to stay consistent with achieving the temperature goal set at the Paris Agreement, of maximum 2oC above pre-industrial levels.

Corporate reporting, environmental standards, sustainability rankings, and global initiatives, such as Science Based Targets, We Mean Business Coalition, and RE100, are relevant frameworks to boost voluntary corporate commitments in the LMI. These initiatives need to permeate throughout the value chain to have a substantive effect in decarbonizing the sector.

In spite of the availability of feasible technologies and measure to advance decarbonization in the LMI, significant barriers hinder their implementation. Access to finance is one of the main ones. Presently, small and medium-sized companies represent 94.4% of total manufacturing companies, and they often have very limited access to public and private financial resources, which combined with their lack of participation in the global value chain, prevents

- Mexico has a broad range of policies and laws in place which can act as enablers of LMI decarbonization. These include its Nationally Determined Contribution (NDC), the General Law on Climate Change (LGCC), and the Energy Transition Law (LTE), with its respective GHG mitigation and clean energy penetration targets. Relevant instruments are also derived from them, such as the National Emissions Registry (RENE), the Carbon Tax, and the Emissions Trading Scheme (ETS).
- Mexico´s regulatory and standardization frameworks have been the most cost-effective policy. International standards, such as ISO 50001, and national programs, such as the National Program for Energy Management Systems (PRONASGEn), have been essential tools to manage energy efficiency and generate capacity.
- Corporate sustainability programs, rankings, coalitions, voluntary and compulsory reporting, and certifications were identified as fundamental drivers for capacity-building and reducing GHG emissions, along with savings derived from energy efficiency (EE) and better-priced renewable energy (RE). However, these need to permeate throughout the value chain in order to decarbonize the economy.
- Access to financial resources is one of the most significant challenges for Mexican companies, particularly for small and medium enterprises (SMEs), which represent 94.4% of total companies. Lack of access to public and private financial resources impedes companies from investing in RE and EE measures.
- A combination of financial products, fiscal instruments, and a regulatory framework that provides certainty to long term investments and contracts are required for LMI decarbonization. Enterprises and public entities need to continue investing in low hanging fruits, such as energy management systems and SMEs capacity building, looking to develop bankable projects.
- If decarbonization measures were implemented across all sectors, by 2050, the number of accumulated statistical lives saved from reduced exposure to criteria pollutants is projected to surpass 75,000. Actions in the LMI account for 5% of total particulate abatement, which would contribute to about 4,000 statistical deaths avoided by 2050.

them from investing in renewables or innovative energy systems and incorporating best management practices that would contribute to GHG abatement.

Another potential barrier lies with the technical and commercial risks associated with renewable energy projects, which are often estimated as being too high and with long periods of return on investment, preventing companies from investing in these technologies.

In order to have real chances, manufacturing and LMI decarbonization requires a combination of financial products, including credit, guarantees, bonds, and other financial vehicles, access to fiscal instruments, such as tax incentives and subsidies, and a regulatory framework that provides certainty to long term investments and contracts.

Recent changes to the energy policy in Mexico are halting private investment in renewables, jeopardizing the achievement of the emissions' peak target and the decoupling of carbon emissions from growth. Subsidies to fossil fuels, a decline in oil prices, and an increased domestic supply of fuel-oil might further thwart LMI and the power generation matrix potential decarbonization.

Mexico has played an active role in international climate change negotiations. Through climate policies, energy regulations, and a process of standardization, the country has been paving the way for a low carbon transition for industries, although implementation has fallen short. At the time of writing this report, Mexico was under the process of reviewing its nationally determined contribution (NDC) to the Paris Climate Agreement, planning to submit it by August 2020. It is widely expected that the country makes a stronger commitment, given the fact that the efforts made by countries so far are still far from getting us in a warming trajectory that is consistent with 2oC.

The LMI should be ready to advance through a decarbonization path, especially given the fact that it has the single largest share of electricity demand and one of the largest potentials for electrification. Among the GHG emission abatement measures available, the ones proposed in this report could contribute to around 48% reduction of LMI emissions. They are centered around energy efficiency standards (5% abatement) and electrification (3% abatement). The remaining 39% abatement is assigned to behavioral changes in demand and consumption associated with the application of a carbon tax that will incentivize decarbonization actions across the whole value chain.

The decarbonization measures proposed in this report could save around 75,000 lives by 2050, from associated reduced exposure to atmospheric pollution. Actions in the light manufacturing industry account for 5% of total particulate abatement, which would contribute to about 4,000 statistical deaths avoided by mid-century.

In the current context, with the COVID-19 pandemic posing enormous challenges for the economy and society in Mexico, new funds must build the foundation of a more resilient, sustainable, and prosperous future, in which the industry opts for greener ways of production. Increasing the availability of green credits, instruments, and incentives is paramount for a sustainable, low-carbon recovery.

1. Introduction

There is an international agreement on the critical need for action to tackle climate change. This action needs to happen in all economic activities to achieve the required abatement of greenhouse gas (GHG) emissions. The warning of the Intergovernmental Panel on Climate Change (IPCC) is clear: decarbonize the economy by 2050 or face a world above 1.5°C of average warming with regards to pre-industrial temperatures.

World leaders signed the Paris Agreement to avoid this scenario. Mexico ratified the Agreement and submitted its intended Nationally Determined Contribution (NDC) to the UNFCCC, becoming the first developing country to do so. In 2016, Mexico pledged an unconditional reduction of GHG emissions of 22% below a business as usual (BAU) baseline, which could increase to 36% if certain conditions were met, including a global agreement addressing International carbon pricing, carbon border adjustments, technical cooperation, low-cost financial resources, and technology transfer.

In this context, this report presents an analysis of what actions would be required to decarbonize the light manufacturing industry in Mexico and how the sector can contribute to the achievement of the national climate commitments. The analysis begins with a delimitation of what activities are considered, per this report, to be part of the sector, followed by a description of the Mexican context, which has enabled the growth of light manufacturing industries in recent decades. The second section comprises an assessment of the sector's relevance in terms of GHG emissions, looking at variables such as its energy intensity and fuel consumption. The third and fourth sections present a projection of the light manufacturing industry, both under current business-as-usual conditions and under an alternative decarbonization scenario with increased energy efficiency and electrification. The final section addresses enabling conditions and barriers to advance towards a decarbonization pathway.

This study complements the analysis of sectoral decarbonization pathways undertaken by WRI, Iniciativa Climática de México (ICM), and the Carbon Trust in 2019-2020, with funds provided by the UK Government. In this previous work, national and sectoral carbon budgets aligned with a 2°C maximum warming were estimated for transport, oil-and-gas, and electricity. The analysis presented here focuses on one additional sub-sector, covering a larger portion of the Mexican economy as well as of the potential GHG mitigation options and strategies. Its primary purpose is to understand the opportunities and challenges faced by the light manufacturing industry in Mexico when attempting to advance its decarbonization strategies. This report aims to represent a useful diagnosis for stakeholders and policymakers to identify and implement cost-effective GHG mitigation solutions in the light manufacturing sector to achieve Mexico's climate targets.

This study comes at an interesting point in time when Mexico is implementing substantive climate policy actions: an emissions registry, carbon taxes, fuel price liberalization, and an emissions trading scheme. It was developed amidst unprecedented health and economic crises, derived from the COVID-19 pandemic. With the pandemic triggering a global economic slowdown, leaders are already looking for ways to stabilize impacted industries and shore up their countries' economies. The approaches they take now to stimulate economic growth will have long-lasting effects. This report may help bring evidence on the benefits and cost-effectiveness related to choosing a low-carbon pathway towards economic development and recovery.

The assessment relies on literature review, data analysis, stakeholder consultations, and the application of a system-dynamics modeling tool developed by WRI Mexico partnering with Energy Innovation, a US-based think tank that specializes in the transformation of the energy sector and policy solutions towards decarbonization.

1.1. What we understand by Light Manufacturing Industry

The Light Manufacturing Industry (LMI) is the branch of the manufacturing sector that produces relatively high-value items per unit weight through processes that use moderate amounts of energy and partially processed materials, such as the manufacturing of clothes and consumer electronics. The LMI has the potential to initiate rapid, substantial, and potentially self-propelling waves of rising output, employment, productivity, and exports that can push countries on a path of structural change.

This report defines Light Manufacturing Industry (LMI) as in which fuel consumption is mainly electricity, natural gas, liquified petroleum gas, and other liquid hydrocarbons and does not involve chemical, extractive, transformation, or transportation processes. Its only process-related emissions are those derived from the use of specific materials or equipment (cooling, material propellent, paints and solvents, waste management). Sectors with heavy transformation activities (mining, cement aggregates, metals and steel, glass, and hydrocarbons) and the service industry (transportation, tourism, banking, trade, and other commercial sector activities) are excluded.

Due to the lack of a commonly-accepted definition of the LMI that specifies which subsectors may be included, this report uses the Annual Survey of the Manufacturing Industry (EAIM, Series 2013) developed by Mexico's National Institute of Statistics and Geography (INEGI), which lists the following subsectors[1] as part of LMI:

- Food industry
- Beverages and tobacco industry
- Textile production industry
- Clothing industry
- Tanning and finishing of leather
- Wood industry
- Printing and related industries
- Plastic and rubber industry
- Metallic products
- Machinery and equipment
- Computer equipment, communication, measurement and other electronic equipment, components, and accessories
- Accessories, electrical appliances, and electricity generation equipment
- Transportation equipment manufacturing
- Furniture, mattresses, and blinds
- Other industries[2]

Presentation, and dissemination of economic statistics, which reflect the structure of the manufacturing industry economy (EAIM, Methodologic Synthesis, 2013 Series).

[1] EAIM uses the North American Industrial Classification System (SCIAN Mexico) as a classifier of economic activities. EAIM's purpose is to provide a single, consistent, and updated framework for the collection, analysis.

[2] Following the EAIM the subsections excluded for this study (among manufacturing industries) are the manufacture of petroleum and coal products, chemical industry, manufacture of products based on non-metallic minerals, and basic metal industries.

2. Context

Over the last three decades, the Mexican economy has undergone significant structural changes, affecting its relationship with the rest of the world. The country shifted its economic development strategy from one that favored industrialization, for import substitution purposes, and was heavily oil-dependent, to one far more open and export-oriented, especially of manufactured goods (Williamson, 1990; Ten Kate, 1992). After joining the World Trade Organization (previously known as the General Agreement on Tariffs and Trade -GATT) in 1986 and subscribing to the North American Free Trade Agreement (NAFTA) in 1994, Mexico's trade and international capital flows increased significantly. Since then, Mexico has strategically promoted free trade by signing twelve free trade agreements with 46 countries, and 32 agreements for the reciprocal promotion and protection of investments.


TEXAS
Houston
Waco
Austin
San Antonio
Del Rio
Laredo
Corpus Christi
Bay City
Galveston
Brownsville
Matamoros
GULF OF MEXICO
Rio Grande
Tanque
SIERRA MADRE ORIENTAL
MEXICO
Monterrey
Ciudad Victoria
Tampico
Tuxpan
Gulf of Campeche
Veracruz
Puebla
Pachuca
Mexico City
Popocatepetl
17,887
Durango
Guadalajara
L. Chapala
Colima
Acapulco
Ometepec
Mazatlán
Acaponeta
Culiacán
Tres Marías Is.
Puerto Vallarta
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As a result of these trade policies, together with a set of domestic reforms, Mexico became one of the world's leading exporters of manufactured goods, in general, and of relatively sophisticated products (Blecker, 2016). In 2018, manufactured exports represented 81.26% of the total national exports and about three-quarters of these exports consisted of machinery and equipment broadly defined, including large volumes of automotive and electronic products, and small but growing amounts of aerospace equipment, biotechnology products, and information technology (World Bank, 2018).

The recently ratified trade agreement between the United States of America, Mexico, and Canada (USMCA), which updates the twenty-five-year-old NAFTA, sets a new context for the national manufacturing industry. The rules regarding trade and investment, as well as its environmental protection provisions, will require the domestic industry to improve its environmental performance even further. The agreement includes a comprehensive set of enforceable environmental obligations, incorporating measures to combat trafficking of wildlife, timber, and fish; strengthening law enforcement to combat such trafficking, and provisions to address pressing environmental issues, such as air and marine pollution.

Although USMCA is aligned with seven Multilateral Environmental Agreements (MEAs)[3], it does not make any reference to the United Nations Framework Convention on Climate Change (UNFCCC) or the Paris Agreement (IISD, 2020). Moreover, it does not include dispositions to promote energy efficiency or the use of clean energy in industrial processes and value chains within the North American market.

2.1. The contribution of the LMI to the national economy

The LMI plays a strategic economic role since it is characterized by initiating rapid, substantial, and potentially self-propelling waves of rising output, employment, productivity, and exports that can push countries on a path of structural change (Emrouznejad et al. 2016). In Mexico, by 2018, LMI contributed roughly with 13.9% of the national Gross Domestic Product (GDP), 80% of total manufacturing production and 65% of total exports. The sector employs more than 3.8 million people and attracts approximately USD 13.7 billion of foreign direct investment (FDI) annually (INEGI, 2019a).

The sector's contribution to the national economy has fluctuated slightly over time, in a range of 2.2 percentage points, with its lowest point being 11.5% in 2009, as a result of the severe impact of the global crisis and the resulting loss of jobs (Villareal, 2010). Its highest point was in 2002, with a contribution of 13.7% (See Figure 1). From 1995 to 2000, the sector's GDP increased considerably, at an average annual growth rate of 8% (see Figure 1); and its relative contribution to the national economy grew from 11.9% in 1995 to 13.7% in 2000. The increase is likely due to the entry into force of NAFTA and the dynamism it created for the industrial sector, especially its exporting segment. Between 2000 and 2009, LMI showed signs of slowing down, but it recovered later on, from 2004-2007. After the crisis of 2008 and since 2010, the sector seems to have accelerated, growing at an average annual rate of 4% until 2018, mainly due to an increase in international demand, particularly in the U.S., since Mexican light manufacturing GDP is closely related to the North American economy (Lenin Navarro et al., 2008).

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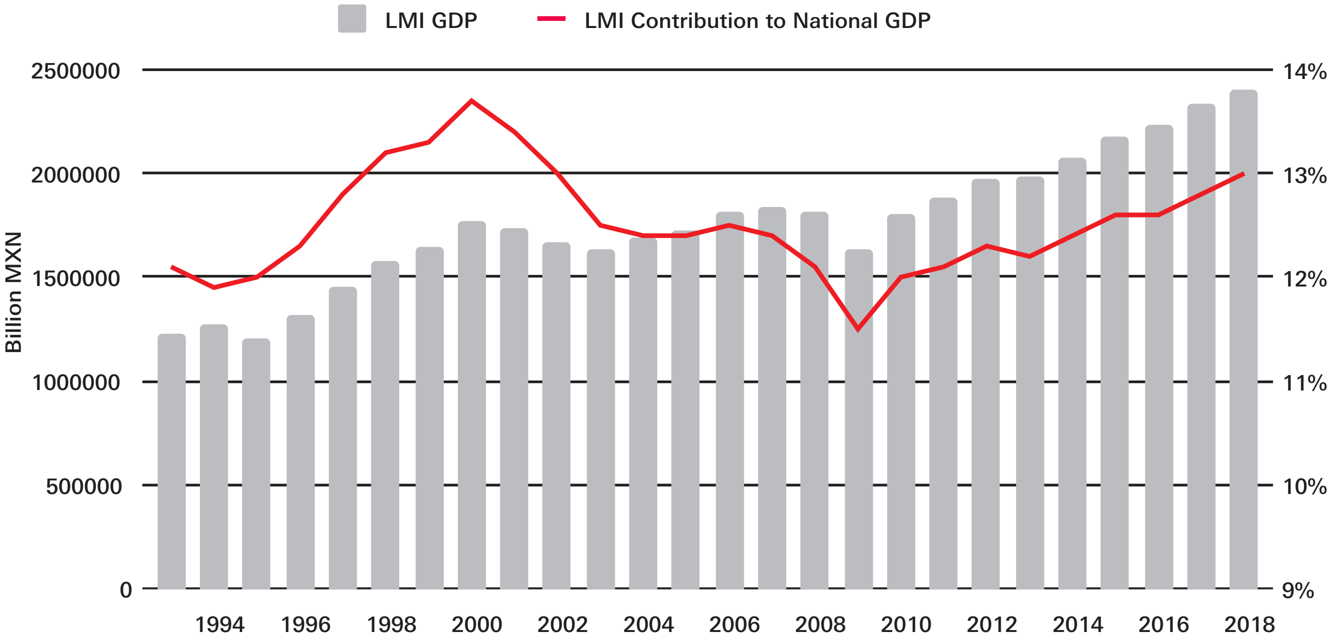
[3] These MEAs are the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES); Montreal Protocol on Substances that Deplete the Ozone Layer; International Convention to Prevent Pollution from Ships (MARPOL); Ramsar Convention on Wetlands; Convention on Antarctic Marine Living Resources; International Whaling Convention, and Inter-American Tropical Tuna Convention (USMCA, Chapter 24: Environment).

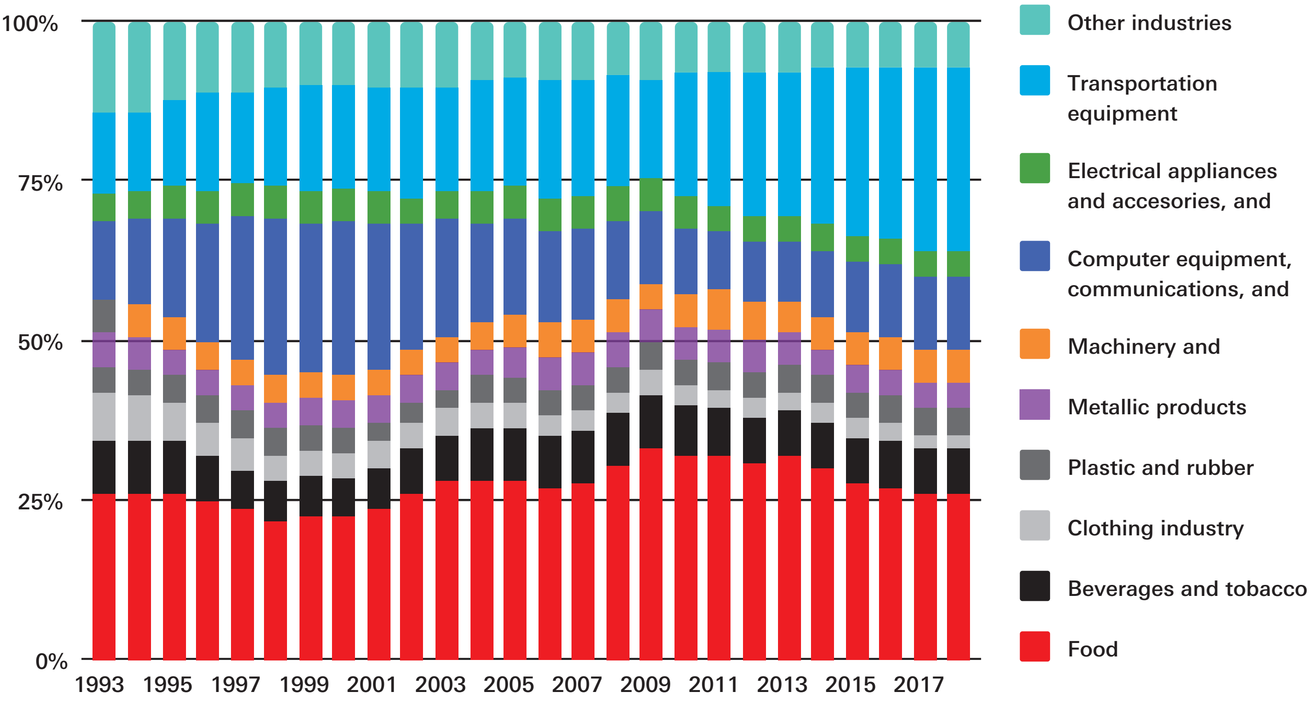
Figure 1 | **Light manufacturing industry GDP at constant prices (PPP 2013) and its contribution to national GDP (%)**



Source: National Accounts System, INEGI, 2019

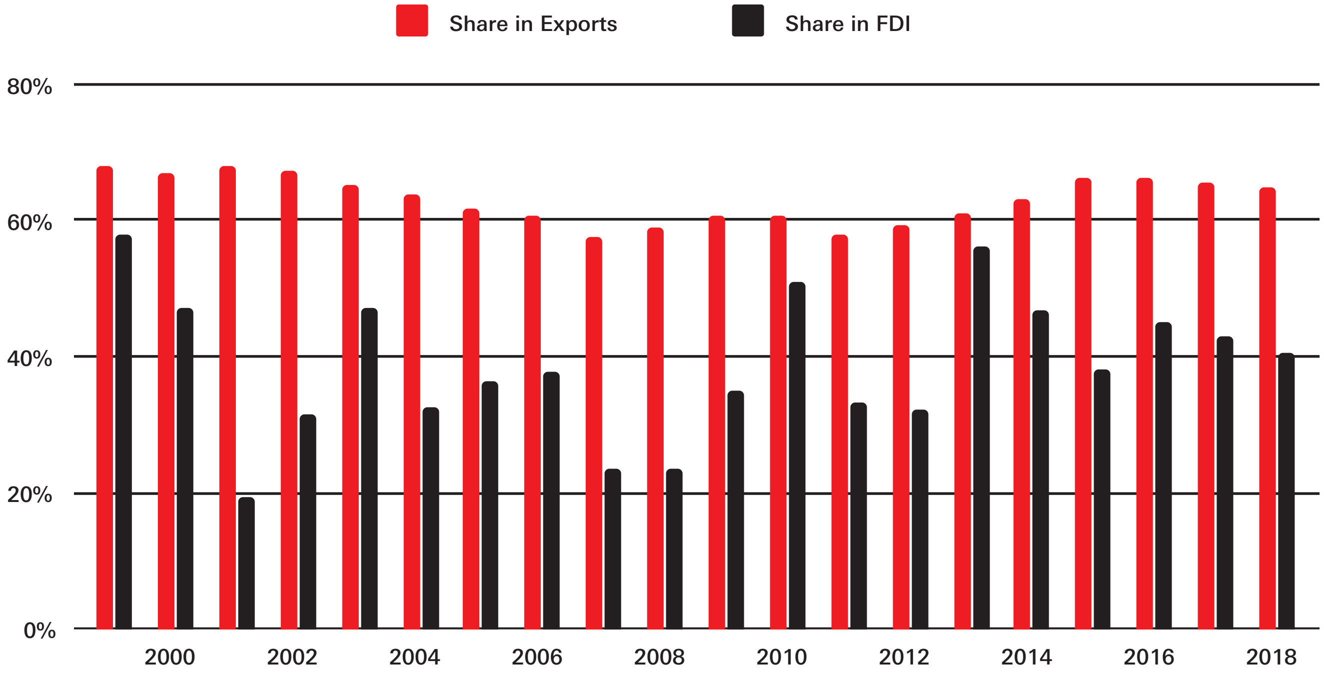
Figure 2 shows the breakdown of the subsector's contribution to the LMI. Nearly 60% of the contribution to GDP among the LMI is concentrated in 3 sub-sectors: manufacture of transport equipment with 23%, food industry with 25%, and computer equipment with 11% (INEGI, 2019a).

Figure 2 | **Light manufacturing GDP composition by sub-sectors**



Source: National Accounts System, INEGI, 2019

Figure 3 | Light manufacturing industry share in total national exports and in total FDI



Source: Central Bank of Mexico, 2020; Ministry of Economy, 2019

2.2. Exports and Foreign Direct Investment

Aided by NAFTA, Mexico became a manufacturing hub, deepening its integration into global value chains. The country's exports' share of GDP climbed from 19% in 1990 to 38% in 2017 (OCDE, 2019a). By 2018, light manufacturing goods accounted for 65% of total exports (see Figure 3), most of them for the United States market, despite intense competition from China. Between 1993 and 2018, this share has remained in a range of 57% to 67% of total exports. LMI's exports are highly correlated with economic activity in the United States; in periods of economic contraction, sales abroad shrink and in expansion times they tend to grow. The most important LMI export branches are transport equipment, computer equipment, machinery, and equipment manufacturing, representing an average share of 76% of light manufacturing exports during the last decade (Ministry of Economy, 2019).

Regarding FDI, the share of these investments in LMI has been around 39% in the last two decades, with some fluctuation. Between 2009-2017, this sub-sector represented approximately 12.2% of GDP and attracted an annual average of 41.75% of total FDI flows (see Figure 3). Most of these FDI flows to the Mexican LMI come from the US, except for two years: in 2010, when the Dutch company Heineken bought the brewery FEMSA, and in 2013, when the Belgian company Anheuser-Busch InBev acquired the brewery Modelo (Reuters, 2010). These transactions explain the peaks in FDI observed in those two years.

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4 Other industries include textile, wood, pulp and paper, printing and related industries, tanning and finishing of leather, furniture, mattresses and blinds, and other industries.

2.3. Employment and Productivity

By 2018, companies from the LMI provided direct employment to 3.9 million people, representing 91% of total jobs in manufacturing industries. The sub-sectors with the highest share of jobs are transport equipment, with a little over one million, food industry, with 831,000, computer equipment with 330,000, and the plastics and rubber industry, with 240,000. These four sub-sectors contribute with nearly 62% of total LMI jobs (INEGI, 2019a).

The manufacturing activities with greater dynamism in 2018 were transport equipment, with an annual growth of 7.7%; machinery and equipment, with 4.8%; computer, communication, measurement, and other electronic equipment, components and accessories with 4.4% growth; manufacture of accessories, electronic devices, and electrical generation equipment, with 3.7%; and the metal industries, with 2.9% (INEGI, 2019a).

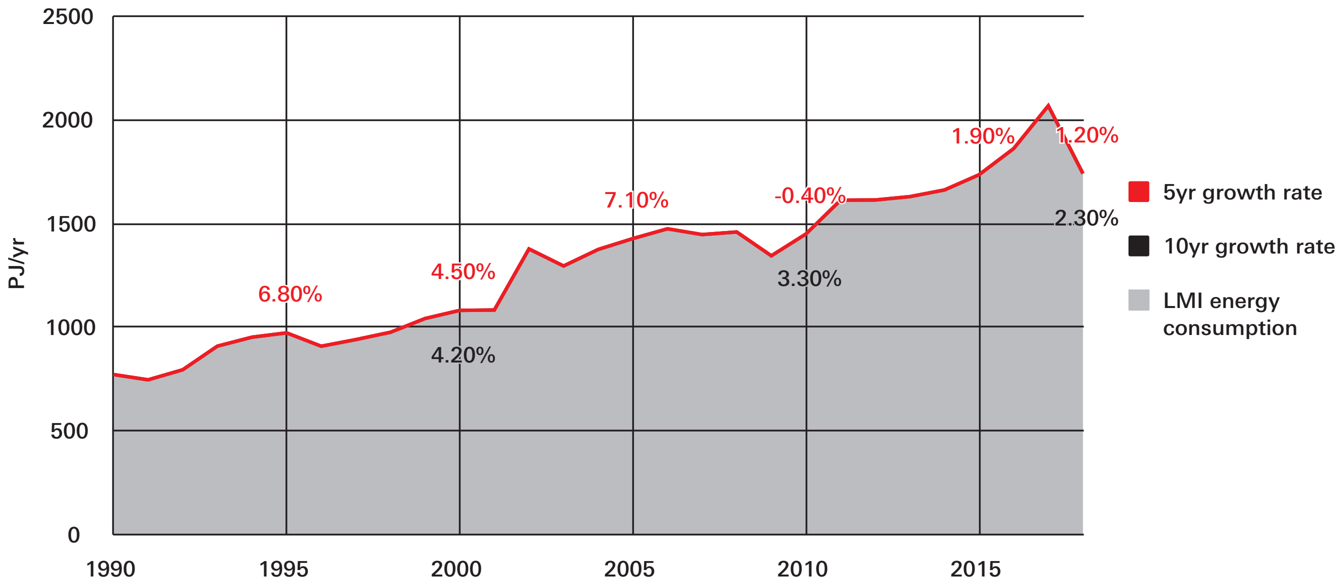
Regarding the composition of jobs by gender, it has remained constant in the last ten years, with males representing around 65% of total employed personnel in the LMI. The sub-sector with the highest percentage of women in 2018 was computer equipment, with 50.5%; the sub-sector with the lowest is metal products, with 17% (INEGI, 2018b).

Productivity is a critical factor that can be used to measure production efficiency. It is considered a vital source of economic growth and competitiveness and a fundamental statistical reference to assess economic performance (OCDE, 2017). Different methods exist to measure productivity; the most common one focuses on labor and it is usually expressed as GDP per hour worked. LMI’s[5] productivity index has increased by 20% throughout the last 15 years, while for the whole of the Mexican economy, this increase was only 4.1%. This performance reflects the dynamism of the LMI for the period considered. From 2013 on, however, LMI labor productivity has grown roughly at the same rate as the national economy, this is due to the relative stability of employment in absolute terms and to lower GDP growth (INEGI, 2020).

2.4. Energy use in the light manufacturing industry

LMI’s energy consumption is mainly based on hydrocarbons and electricity. Hydrocarbons like gasoline, diesel, fuel oil, liquid petroleum gas (LPG), and natural gas are mostly used for heat generation in steam boilers, ovens, and dryers (or powering internal combustion engines or turbines for electric power generation). Electricity is used for everything else: from powering assembly lines directly and powering machinery indirectly through electrically generated hydraulic or pneumatic power, to basic uses such as lighting and office equipment. Electric power usually comes from the grid, but in the case of larger operations, it can also be self-generated (from fossil or renewable sources) through a self-supply or some other private power-producing scheme, as shown on Figure 4.

Figure 4 | Light manufacturing industry energy consumption + CAGR



Source: National Energy Balance, SENER, 2019

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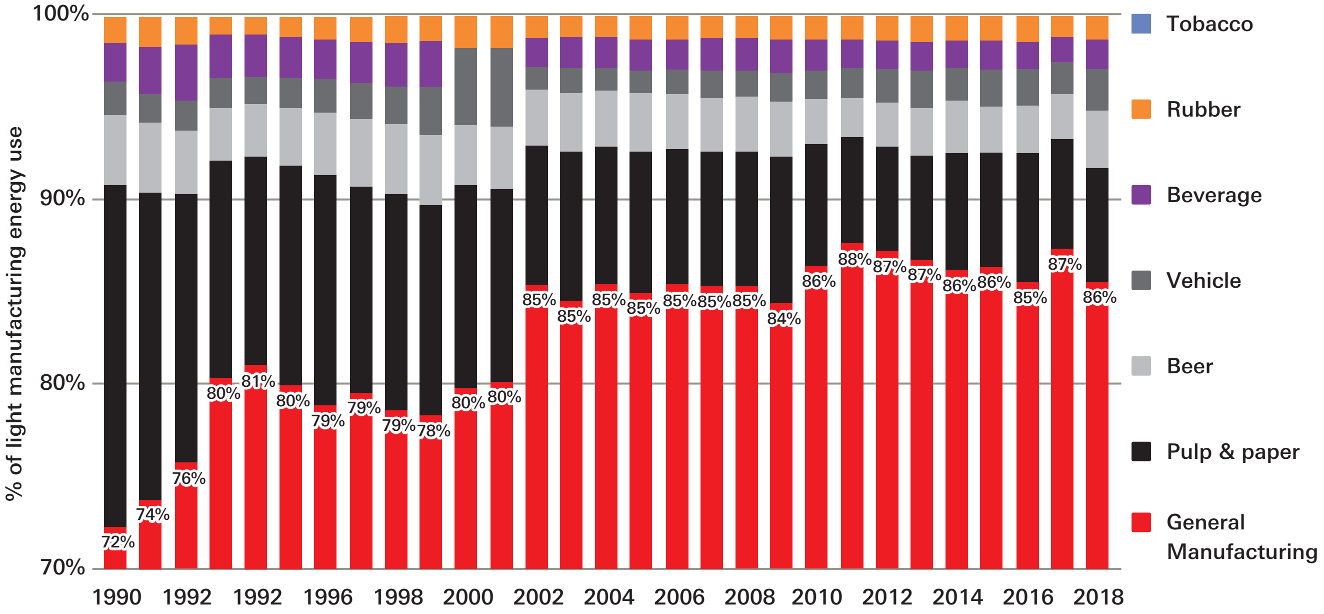
[5] The Labor Productivity Index is defined as the ratio between the index of the value of production at constant prices in a given period, and the index of hours worked or the index of total employed personnel in the same period. Data calculated for the LMI from the Global Labor Productivity Index of the Economy (INEGI) based on the total employed personnel (Base Index 2013 = 100).

Between 1990 and 2018, energy use in the LMI has grown at a compound annual rate (CAGR) of 2.9%. Intermittent growth of 6.8% was experienced between 1991-1995 and 7.1% from 2001-2005, alternating with a -0.4% recession in 2006-2010 and a 2.3% growth in the 2010-2018 period. This changing behavior reflects the combined effects of three separate dynamics: the economic growth/recession cycle of the Mexican industry, the net result of actions on energy efficiency and fuel shifting, and the mixing effect of a growing share of less energy-intensive (or more energy-efficient) activities over others that require more significant energy input, as shown in Figure 4. Sector composition has become more diverse, with general manufacturing increasing its share from 80% in 2000 to 85% in 2018; this is explained from faster growth in the other manufacturing category. Other sectors have not reduced their fuel consumption; they just have grown at a slower rate, potentially from energy efficiency and fuel switching (see Figure 5).

Figure 5 | Share of light manufacturing sub-sectors in energy use.



Source: National Energy Balance, SENER, 2019

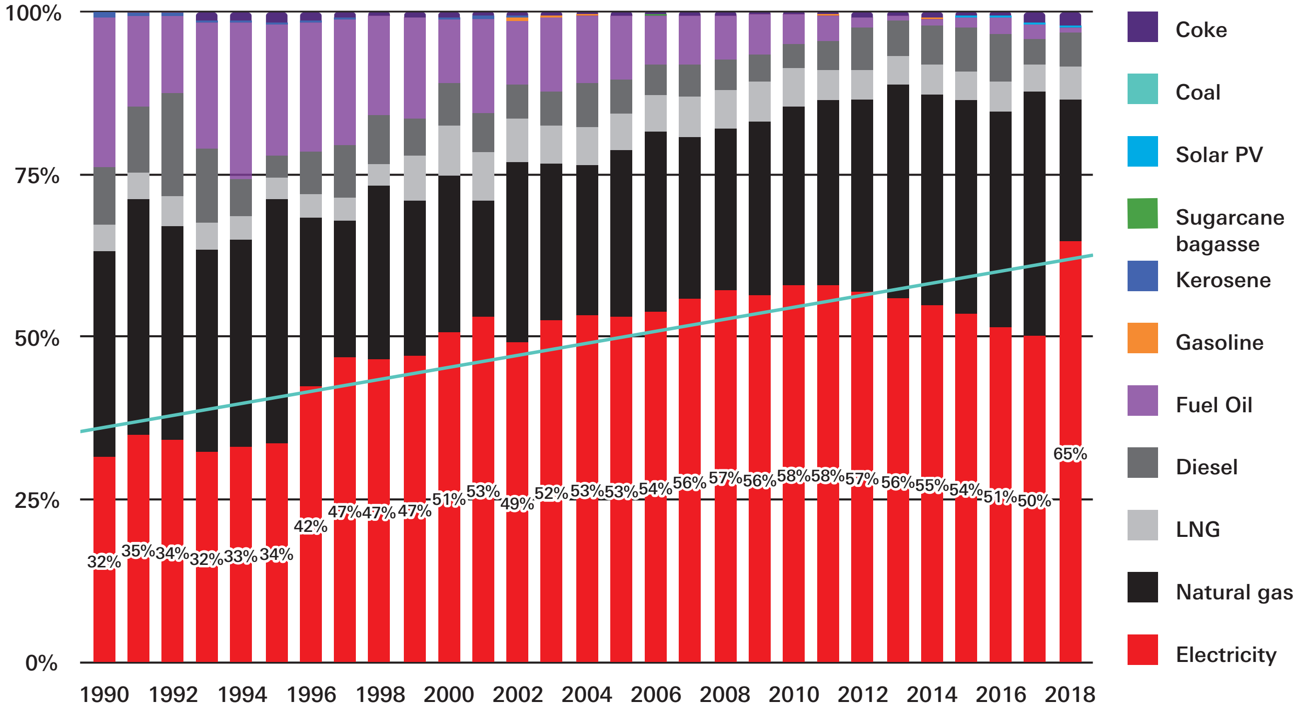
The mix of energy sources used by the LMI has also shifted drastically over time (see Figure 6), with electricity growing from a 30% share in 1990 to 50% by 2000 and up to 65% in 2018. This growth was achieved by replacing hydrocarbon use, whose contribution dropped from 37% in 1990 to just 11% in 2018. Natural gas kept its relative contribution, oscillating between a 28% share throughout 1990-2018, to a maximum of 37% in 2017, and a minimum of 22% in 2018 (SENER, 2019a). The electrification trend of the sector may come as good news in terms of GHG emissions, as electric power generation can potentially decarbonize in full, but can also mean higher emissions overall if power generation does not reduce its carbon intensity.

2.5. Energy intensity

Energy intensity quantifies how much economic benefit is provided per unit of energy used[6]. Energy use per capita only describes how much energy is being used and provides no details as to how that energy is helpful. Energy intensity can give clarity on what it is that results from the use of this energy, and widely varies from country to country depending on factors such as weather or prevailing economic activities, whereas in general wealthier countries use more energy per capita than less developed countries (CBC, 2015).

Mexican manufacturing has reduced its energy intensity consistently since 1995 (see Figure 7). Between 1995 and 2005, energy intensity for the LMI dropped 22%, reaching levels consistent with the national average, which also improved by 10% in the same period. This means that manufacturing activities have been generating equal economic value while consuming less energy (CEPAL, 2018)[7].

Figure 6 | Fuel share in the light manufacturing sector



Source: National Energy Balance, SENER, 2019

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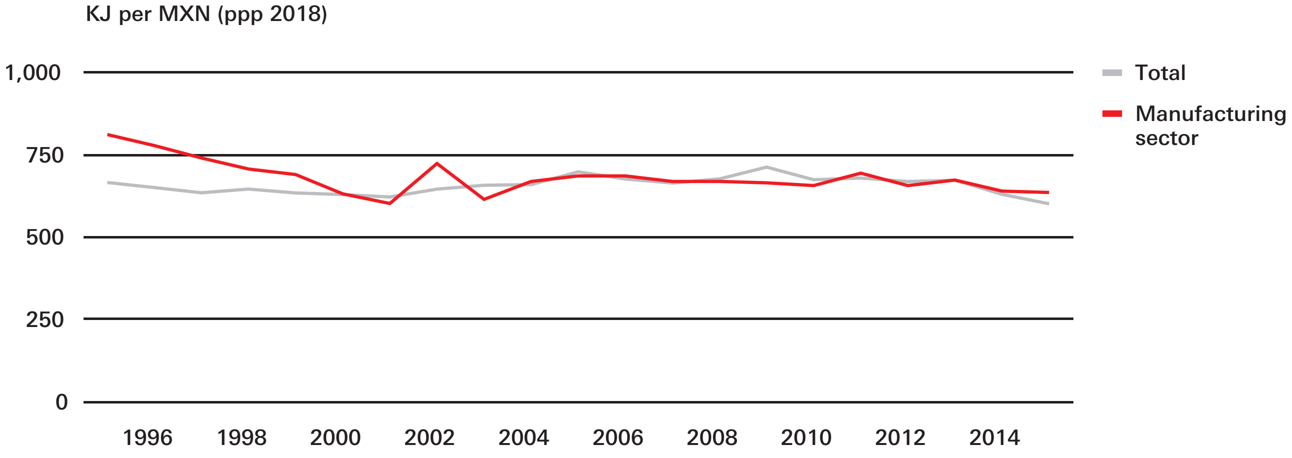
[6] Energy intensity (EI) is the ratio of energy use to GDP and indicates how effectively a certain economy is using its fuels. It is determined by dividing the total primary energy use (TPES, all of the fuels and flows that a country uses to get energy) over GDP and it is expressed in Megajoules per unit currency (MJ/$) (Wolfson, 2015).

[7] There are many reasons behind energy intensity variations among sectors, but the larger effect comes from resource scarcity and economics; as heavy industrial products become commodities and the world's economy becomes more globalized, their economic value is reduced while its energy demand remains unchanged. Global competition drives industrial efficiency, but the economic effect is larger than the energetic one.

Figure 7 | Manufacturing energy intensity per value added

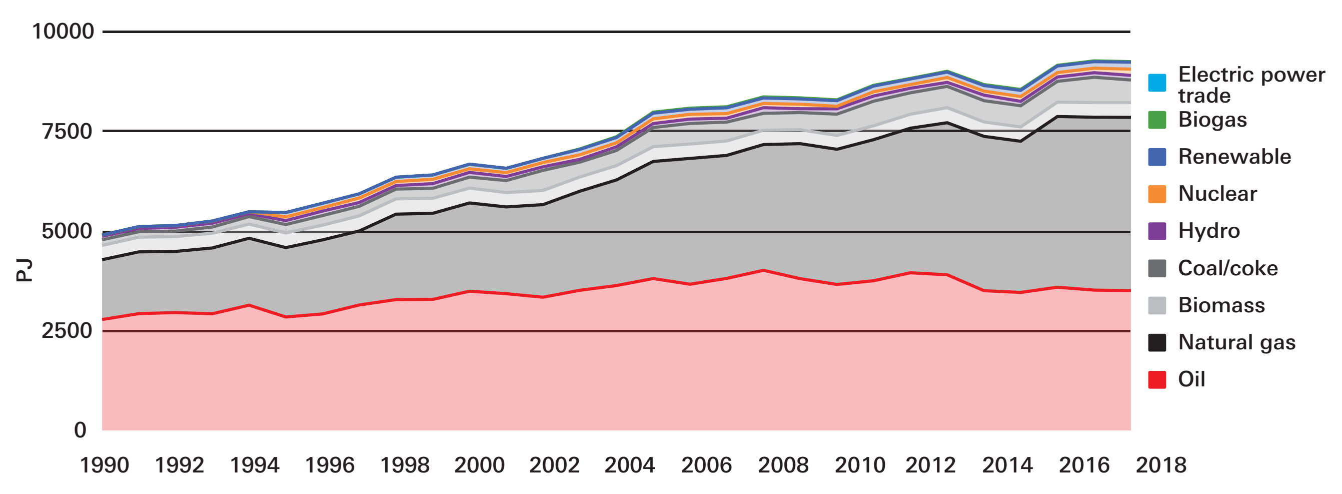


Source: SENER, 2020; ECLAC, 201819

Box 1 | mexico’s energy supply

Mexico’s total primary energy supply (TPES) [8] has shown consistent growth for decades, reaching 9,237 Petajoules (PJ)J in 2018, growing at an average annual rate of 1.15% between 2005 and 2018. In 2005, fossil fuels accounted for 91% of TPES, mostly consisting of oil (48%), natural gas (37%),and coal (6%). By 2018, fossil fuels still accounted for 91% of TPES, with crude oil (38%) substituted by natural gas (47%), and no reduction in coal/coke share (6%). Renewable energy accounted for 7.29% of TPES and nuclear power for 1.7%. Renewables include biofuels and waste(4%), geothermal, wind and solar (2%), and hydro (1.3%). Renewable and nuclear power generation has kept its share of TPES steady over the same period (SENER, 2020a).

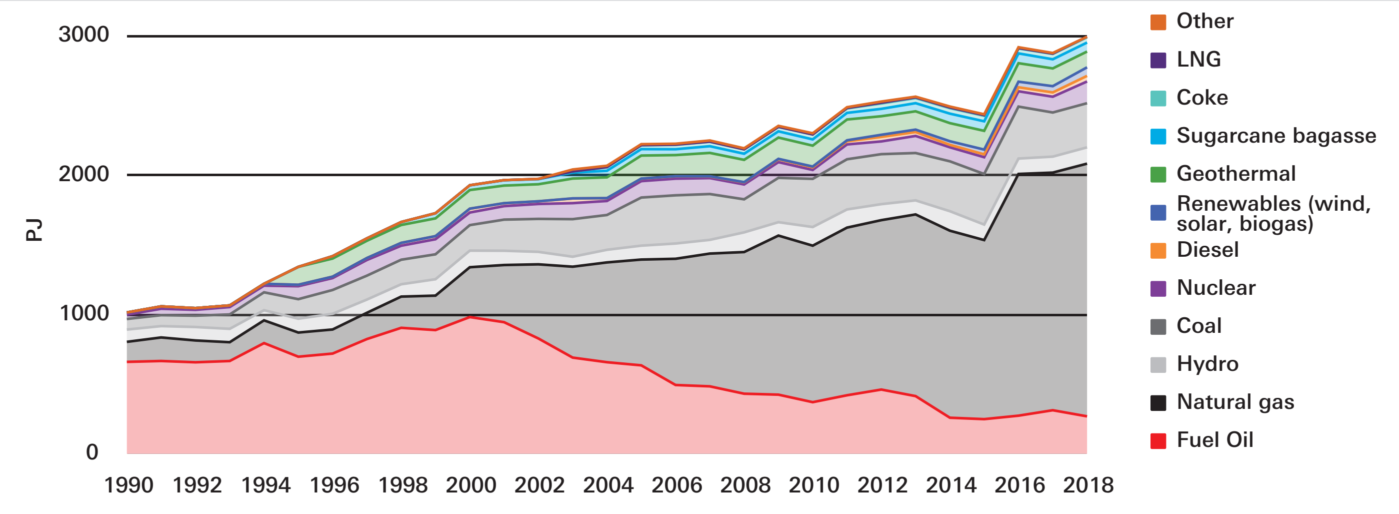
Total primary energy supply



Source: Energy Information System, SENER, 2020

Mexico’s electric power has grown at an annual rate of 2.32% in the 2005 - 2018 period, reaching 2,993PJ in 2018. Similarly to TPES, electric power generation has experienced a dramatic fuel shift, with fuel oil consumption dropping from 29% in 2005 to 9% in 2018, as it was replaced with natural gas, which now represents 60% of power generation, followed by coal (11%), nuclear (5%), hydro (4%). Renewable power (wind, solar, and biogas grew from 0% share in 2005 to 2.1% of power generation in 2018 (SENER, 2020a).

Electricity generation matrix



Source: Energy Information System, SENER, 2020

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[8] TPES is made up of production + imports - exports - international marine bunkers - international aviation bunkers ± stock changes. This equals the total supply of energy that is consumed domestically, either in transformation (for example refining) or in final use.

2.6. Current GHG emissions

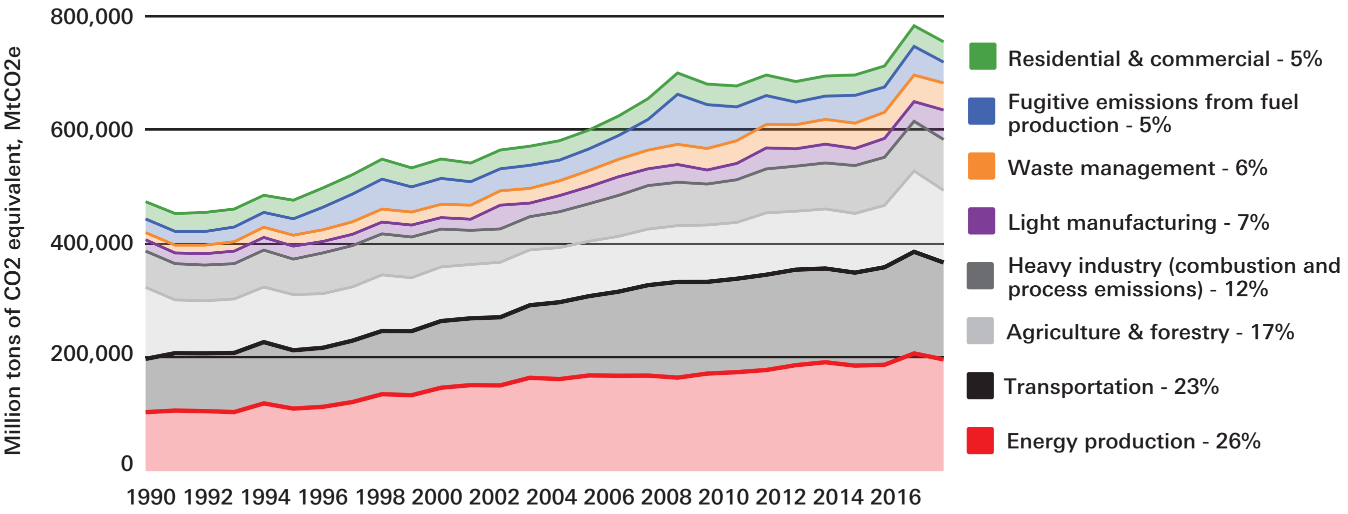
Mexico reports its GHG emissions in the National Greenhouse Gas Emissions Inventory (INEGyCEI) every four years, alongside the National Communication or the Biennial Update Report (BUR) to the UNFCCC, every two years. The latest inventory reports gross national GHG emissions for 2017 at 754.8 million tons of carbon dioxide equivalent (MtCO$_2$e)[9] (see Figure 8).

Gross GHG emissions grew at a 1.6% annual rate over the previous five-year period, this rate is the highest five-year growth since 2012, but it is still slower than that of the previous decade's five-year growth rates, which averaged 2.3%. 2017 emissions grew at a 1.2% annual rate over the previous ten-year period, a full percentage point below 2007's 2.2% ten-year growth rate (SENER, 2020b).

As shown in Figure 9, the LMI has seen a 3% annual growth in GHG emissions for the 2010-2015 period, reaching a share of 7% of total emissions, in big contrast with 4.5% of emissions in 2012. Light manufacturing ranks 5th in terms of its contribution to GHG emissions, after energy production, transportation, agriculture & forestry, and heavy industry (SEMARNAT, 2019).

Moreover, as shown in Figure 9, LMI's emissions come mainly from energy consumption associated with the processes being carried out. The sector's emissions reached 51.8 MtCO$_2$e in 2017, representing 52% of industrial energy use emissions (SEMARNAT, 2019)[10].

Figure 8 | **National GHG emissions by sector**



Source: National Greenhouse Gases and Compounds Inventory, INECC, 2019

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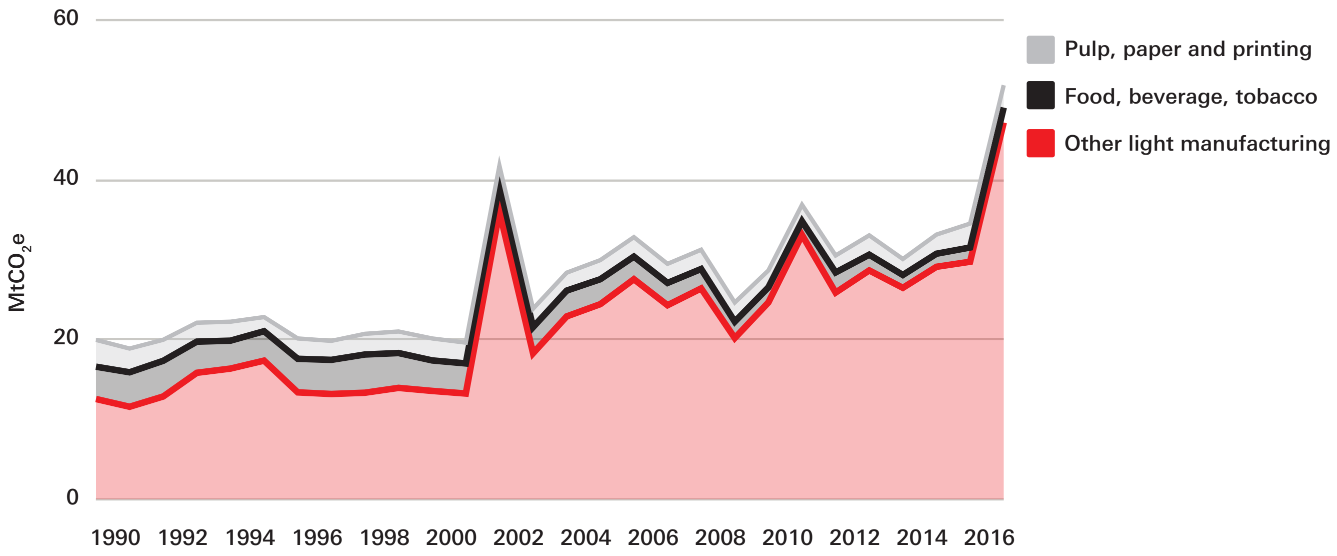
[9] MtCO$_2$e is the abbreviation for million tons of CO$_2$e. There are 7 GHG gases reported in the inventory, the six Kyoto gases plus black carbon. Total emissions are reported as CO$_2$e, short for carbon dioxide equivalent, a unit to report GHG emissions in a mass equivalent to the same level of warming potential if the gas was CO$_2$.

[10] Due to data limitations and the grouping of the national energy balance (SENER, 2019), light manufacturing energy use is not characterized in detail in the inventory and 90% of emissions fall into the "other manufacturing" grouping. This could also mean that data specific for this sector could be distorted by outliers that might be sent into the "other manufacturing" group.

Figure 9 | **Light manufacturing industry - GHG emissions, MtC0$_2$e**



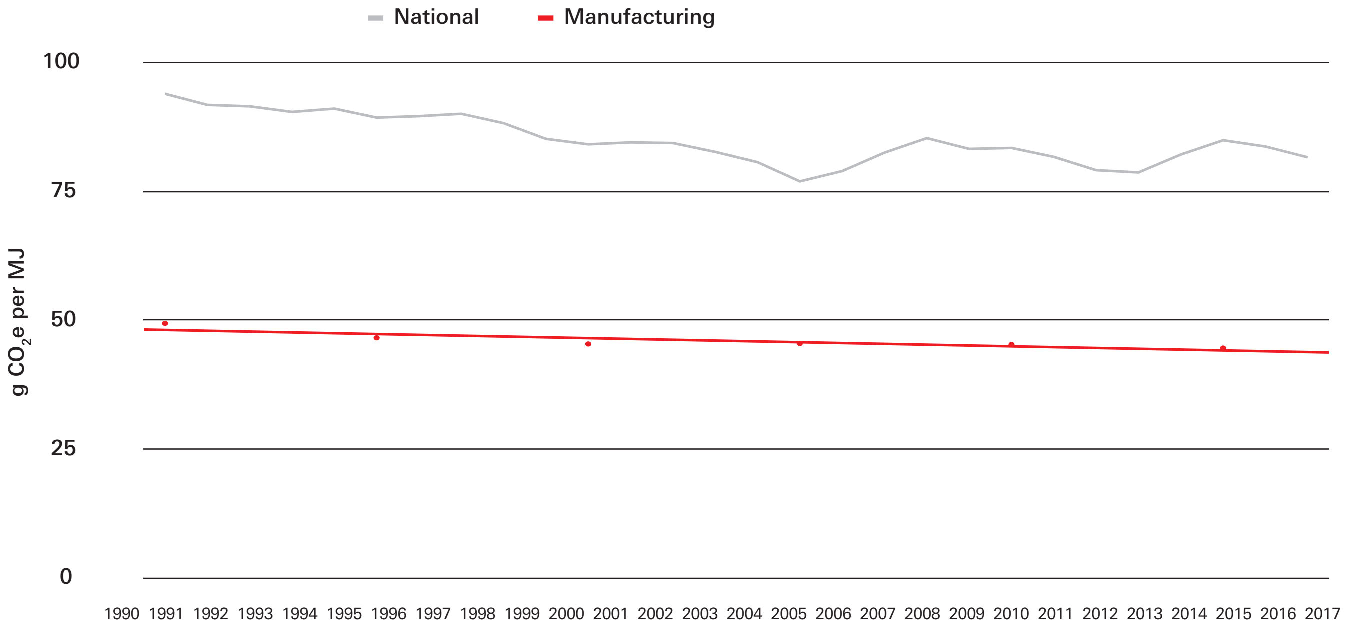
Source: National Greenhouse Gases and Compounds Inventory, INECC, 2019

2.7. Carbon intensity

Carbon intensity indicates how effectively an individual economy is controlling its emissions and using its fuels. It is determined as the coefficient between GHG emissions and TPES and expressed in CO$_2$e emissions per unit of energy (CO$_2$e/MJ).

Both national and manufacturing carbon intensities have steadily declined in Mexico (see Figure 10), boosted by fuel switching from fuel oil to natural gas. Yet, the rate of reduction is slow, and non-emitting fuel sources would be needed to effectively impact carbon emissions. This is one of the benefits of electrification; it helps transfer emissions to the energy sector, where decarbonization is happening at a much faster rate with the potential to decarbonize fully.

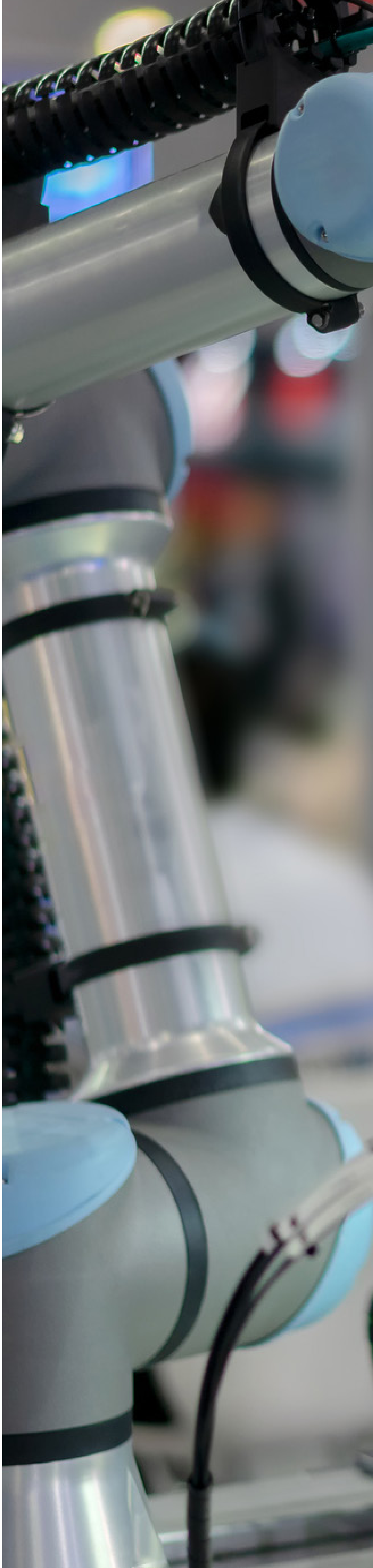
Figure 10 | **Carbon intensity for Mexico and the manufacturing sector, 1990-2017**



Source: Energy Information System, SENER, 2020; National Greenhouse Gases and Compounds Inventory, INECC, 2019

3. GHG emission projections

This section will introduce our modeling methodology and provide details on the projections of the LMI's GHG emissions, both under a Reference Case, reflecting current conditions (or business-as-usual scenario) and under an alternative decarbonization path with increased energy efficiency and electrification.



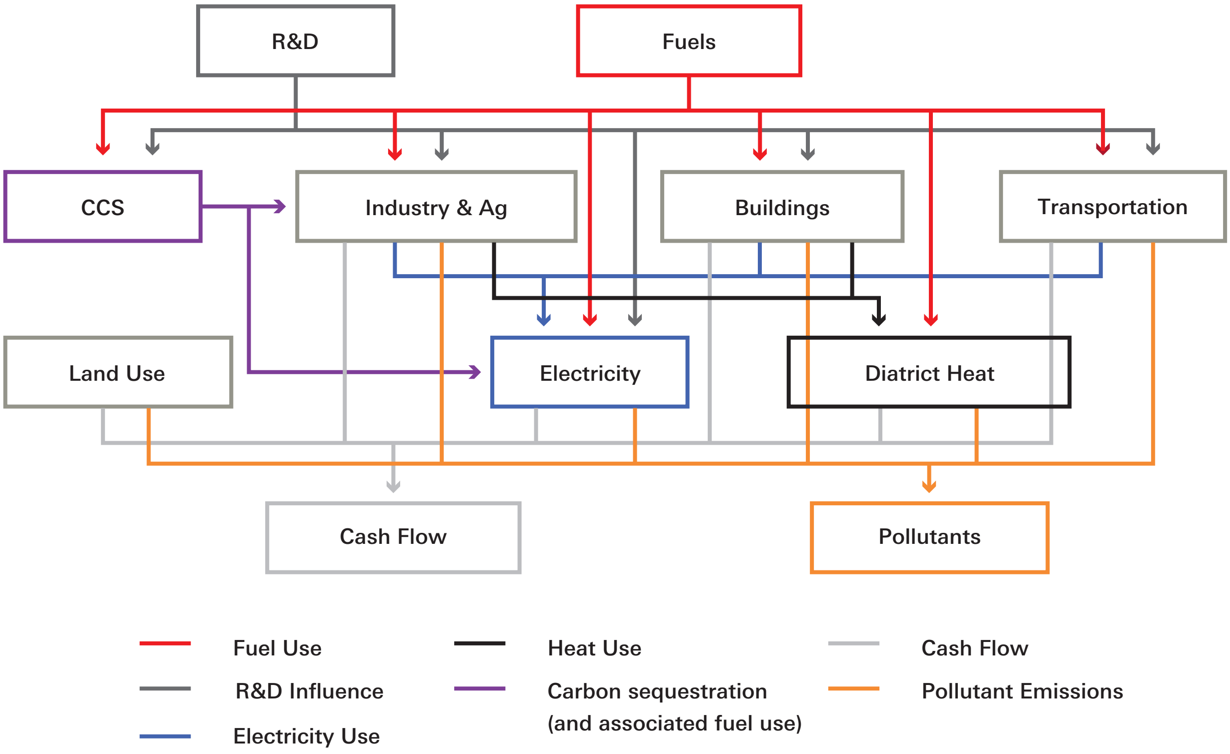
3.1. Projection methodology

Our research approach begins by identifying the potential measures that can be taken to avoid or reduce GHG emissions in the manufacturing sector and estimating their implementation cost. Using a model is particularly important in long-term analysis, since other approaches may produce solutions that make technical and economic sense in the short- and medium-term, but fall short in the long-term and can block the implementation of measures that allow greater abatement (lock-in) at later stages.

The EPS model

To support the elaboration of this comprehensive, economy-wide analysis, the Energy Policy Solutions (EPS) model was used. EPS is a powerful system dynamics computer model (see Box 2) that has a wide array of policy options available to reduce GHG emissions and helps analyze the effects of climate mitigation policies quantitatively. The main criteria for choosing this model was its ability to represent the entire economy and energy system for Mexico as it was capable of simulating a wide array of relevant policy options while accounting for interactions (see Figure 11). This is useful since policies enacted together often produce different results (such as more or fewer emissions abatement), than the sum of the effects of those policies adopted individually. Policies may also be specific to one sector or type of technology (for instance, light-duty vehicle fuel economy standards) or economy-wide (such as a carbon tax). Since the model assesses both, it may illustrate cases when, for instance, a market-driven approach, a direct regulatory approach, or a combination of the two can be used to advance the same goal.

Figure 11 | **EPS Model Structure**



Source: EL, 2020

The model produces the following outputs:

- Emissions of 12 different pollutants: carbon dioxide (CO_2), nitrogen oxides (NOx), sulfur-oxides (SOx), fine particulate matter (PM2.5), and eight others, aggregating GHGs according to their carbon dioxide equivalency (CO_2e).
- Direct cash flow impacts (costs or savings) for consumers, industry, and the government.
- Health benefits, due to avoided mortality from exposure to pollutants.
- Electricity generation capacity and output by technology and fuel.
- Energy consumption by technology and fuel.

Projections included in this study are all derived from a computer model, which makes a number of assumptions and simplifications. Similarly, model capabilities and results depend heavily on the quality of the input data. Although every care has been taken to validate data and calibrate model behavior, uncertainties are to be expect-ed. (see Technical Appendix).

3.2. Reference case scenario

The model uses a reference case, to establish the projected behavior if no actions were taken. This scenario is affected in response to policy settings applied by the model user. This business-as-usual scenario was built from official reports, such as the National GHG Emissions Inventory (INECC, 2018a), the National Forestry and Land use Inventory (CONAFOR, 2009), energy use data from the National Energy Balance (SENER, 2020a) prospective studies (SENER, 2018); and from recognized technical studies, such as the Poles Baseline Model (Danish Energy Agency, 2015) or the EPA Moves Mexico fleet projection (INECC, 2016b).

The model is designed to operate at a national scale and focuses on five sectors: transportation, electricity supply, buildings, industry (which includes oil and gas, agriculture, and waste management), and land use. The model reports outputs at annual intervals, from 2017 to 2050. The EPS allows the user to control multiple policies that impact energy use and emissions across the different sectors while allowing for customized implementation schedules for different policies, to better represent possible actions.

The model works with a reference case that represents Mexico's current emissions trajectory with no interference from additional policies and abatement actions and can be summarized as follows:

- Planning horizon, base year 2016, modeling horizon 2017 through 2050. Determined from prospective studies on energy demand (fuels and electricity), emission factors for all pollutants, and emissions from LULUCF. Mexico's official projections only cover 15 years, so trends were extended from the final available data values to project up to 2050.
- Scope, the model focuses on GHG emissions and associated criteria pollutants[11] and the financial costs and benefits of implementation (considers capital expenditures and operating costs).
- Scale, Mexico was modeled countrywide with no regional/political divisions, and national data was obtained from studies reporting a national total. The model includes every major sector of the economy.
- Units, GHG emissions are expressed in tCO_2e (or $MtCO_2e$ where indicated). Criteria pollutant emissions are expressed in thousand tonnes (metric tons). Costs are expressed in 2012 US dollars.[12]
- Assumptions: compatible data was used as much as possible from prospective studies covering the same planning horizon and using the same base assumptions of population, gross domestic product, fuel prices, cost of capital, and set of policies and standards. The energy projections consider Mexico's recent energy reform and energy transition legislation, the current carbon tax, and no carbon market.[13]

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[11] Black Carbon emissions are not included as a GHG and are only analyzed for their co-benefits since the model does not have enough level of detail about their potential GHG abatement contribution.

[12] The total cost of implementation was reported in 2016 US dollars, for easier comparison with other studies.

[13] The version used when developing EPS was presented with Mexico's NDCs and mid-century strategy (INECC, 2016a)

3.3. Projected GHG emissions and energy use

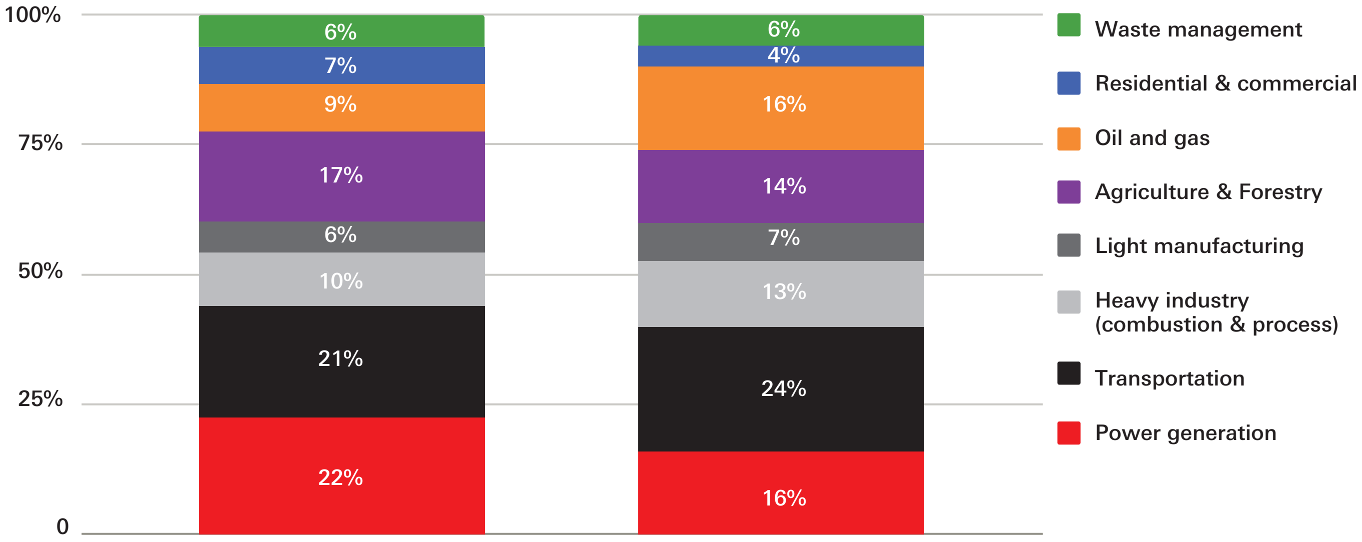
Once all data is gathered, the model is built and calibrated by comparing it against input data and existing projections. The resulting projection includes detail on the energy balance, emissions and cash flow throughout the planning horizon and establishes the Reference Case. Modeled policies will impact model behavior; their impact is determined through the difference of the resulting scenario against the reference case.

It is important to note that Mexico's official GHG emissions baseline and the EPS Mexico reference case do not represent the same thing. The baseline projects future GHG emissions without any climate change mitigation actions, while the reference case projects a trend from our current standing (base year 2016). The reference case uses an updated GHG inventory and new projections on energy demand and fuel consumption (energy prospective studies).

GHG emissions

GHG emissions were dominated by the electricity sector in 2017, with 22% of national emissions. Yet, prospective national studies already consider fuel switching and renewable penetration, so the sector evolves at a slower rate than the others and reduces its share to 16% of total emissions by 2050. The sector with the highest emissions by 2050 is the transport sector, which grows from a share of 21% in 2017 to 24% by 2050, mainly due to increased travel demand and continuous road fleet growth. The oil and gas sector shows the steepest growth, at 3.4% annually, going from 9% of total emissions in 2017 to 16% in 2050. The agriculture and waste management sectors show a growth similar to the total growth and retain a consistent share of emissions (13% and 6% respectively in 2050). The buildings and land-use sectors are the only ones that show a decrease in absolute emissions in the Reference Case. This derives from expected efficiencies in the buildings sector and a trend in improved forestry actions (see Figure 12).

Figure 12 | GHG Emissions by sector in the reference case



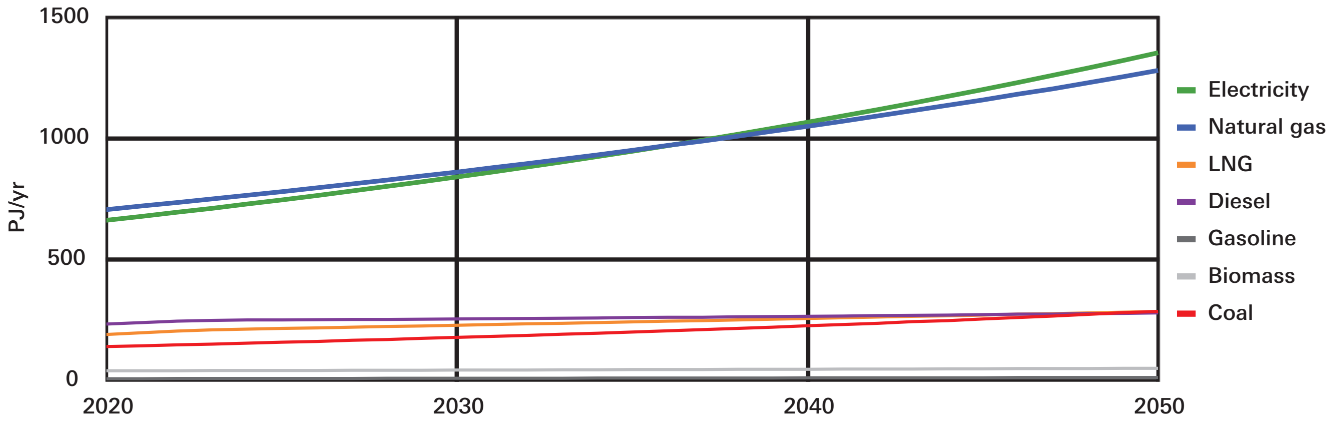
Source: EPS Mexico, WRI, 2018

The reference case projects energy consumption and GHG emissions throughout the planning horizon based on the supplied data. This results in varied behavior and relationship between sectors, as shown in Figure 12. Electricity generation grows at a moderate 0.8% annual rate, losing its rank as the top-emitting sector with 22% of emissions, sliding to third place with only 16% of total emissions by 2050. This is due to the heavy fuel-shifting from fuel oil to natural gas and some renewable energy penetration. Industry ranks second in emissions growth, with 2.4% annual growth, which comes from the historical growth in industrial activity. This brings industrial GHG emissions from 16% of the total emissions in 2017, to 20% by 2050, ranking second in total emissions by the end of the planning horizon.

Energy use

Energy use in the industrial sector as a whole increases at a 1.9% annual rate throughout the planning horizon, with electricity and coal showing a steeper 2.4% growth, consistent with business as usual trends. Electricity becomes the main source of energy for the sector, overtaking natural gas by 2038, and increasing its share from 32% of industrial energy use in 2017 to 38% by 2050. Coal also gains one percentage point in share, reaching 8% by 2050, while diesel exhibits the slowest growth with an annual rate of 0.6% going from 10.1% share in 2017 to 7.9% by 2050
(see Figure 13).

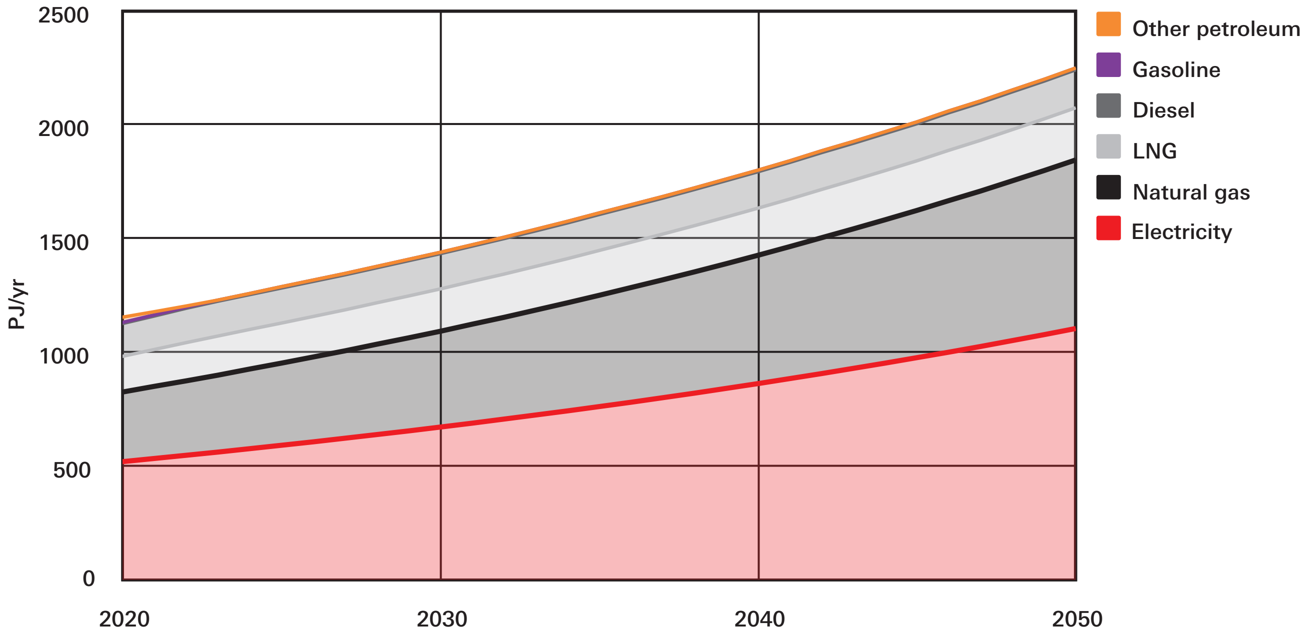
Figure 13 | Projected energy use in the industrial sector - reference case



Source: EPS Mexico, WRI, 2020

The LMI displays a similar projected behavior, with a steeper 2.2% annual growth rate throughout the period, driven by fast growth in both natural gas and electricity use. Natural gas grows 3% annually and increases its share from 26% in 2020 to 33% in 2050. Electricity grows 2.5% annually and remains the main source of energy for the LMI sector, growing from 45% share in 2020 to 49% by 2050. One of the proposed actions for emissions abatement is to electrify the sector's activity, shifting from natural gas and other fossil fuels to electric power.

Figure 14 | **Projected energy use in the light manufacturing sector - reference case**

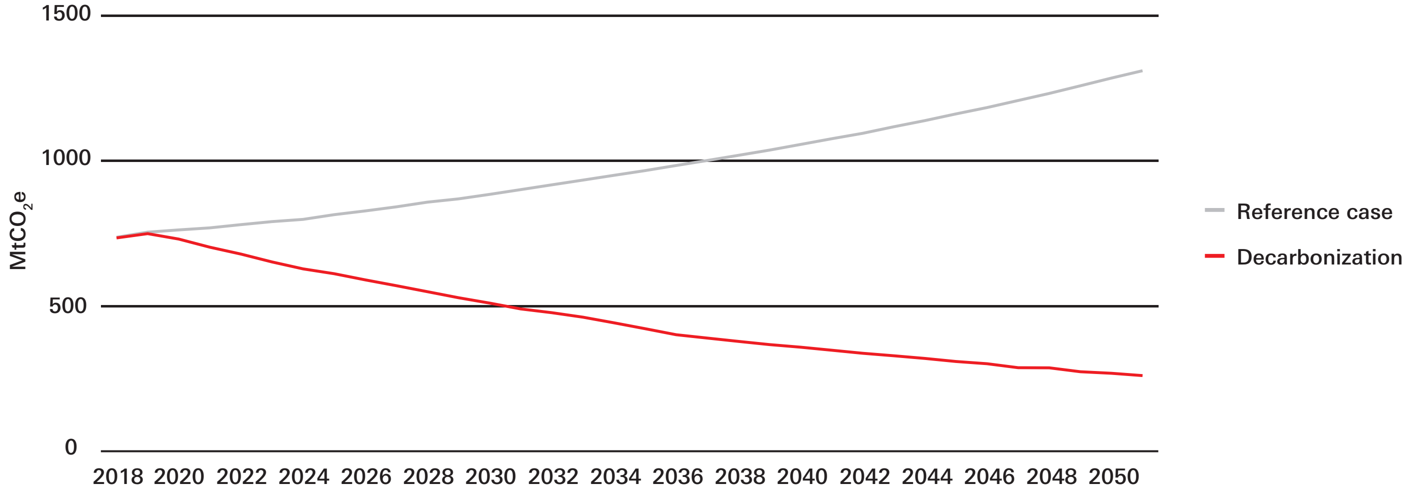


Source: EPS Mexico, WRI, 2020

3.4. Decarbonization effects

Through the combined effect of a host of decarbonization policies across all sectors, modeled GHG emissions decrease from 1,311 $MtCO_2e$ in the Reference Case to 262 $MtCO_2e$, which represents 1,049 $MtCO_2e$ abatement (80%) by 2050 (see Figure 15).

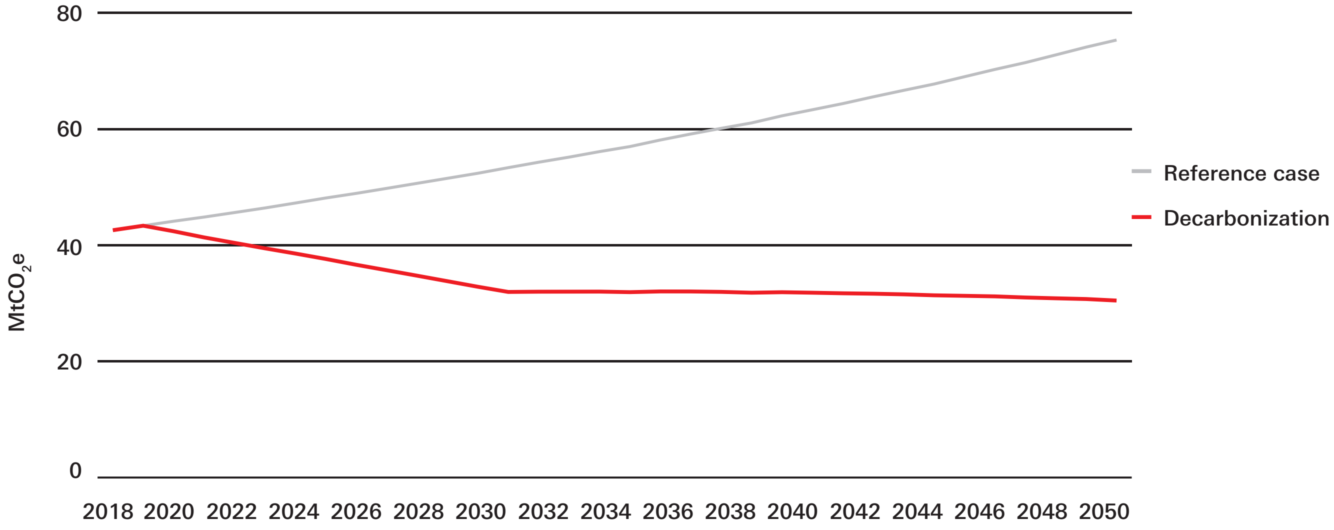
Figure 15 | Total GHG emissions, $C0_2e$



Source: EPS Mexico, WRI, 2018

Through energy efficiency, electrification, value chain integration, circular economy actions, and carbon pricing, LMI GHG emissions could be abated from 75 $MtCO_2e$ in the reference case, to 31 $MtCO_2e$ in 2050, which represents 45$MtCO_2e$ abatement (41%) (see Figure 16).

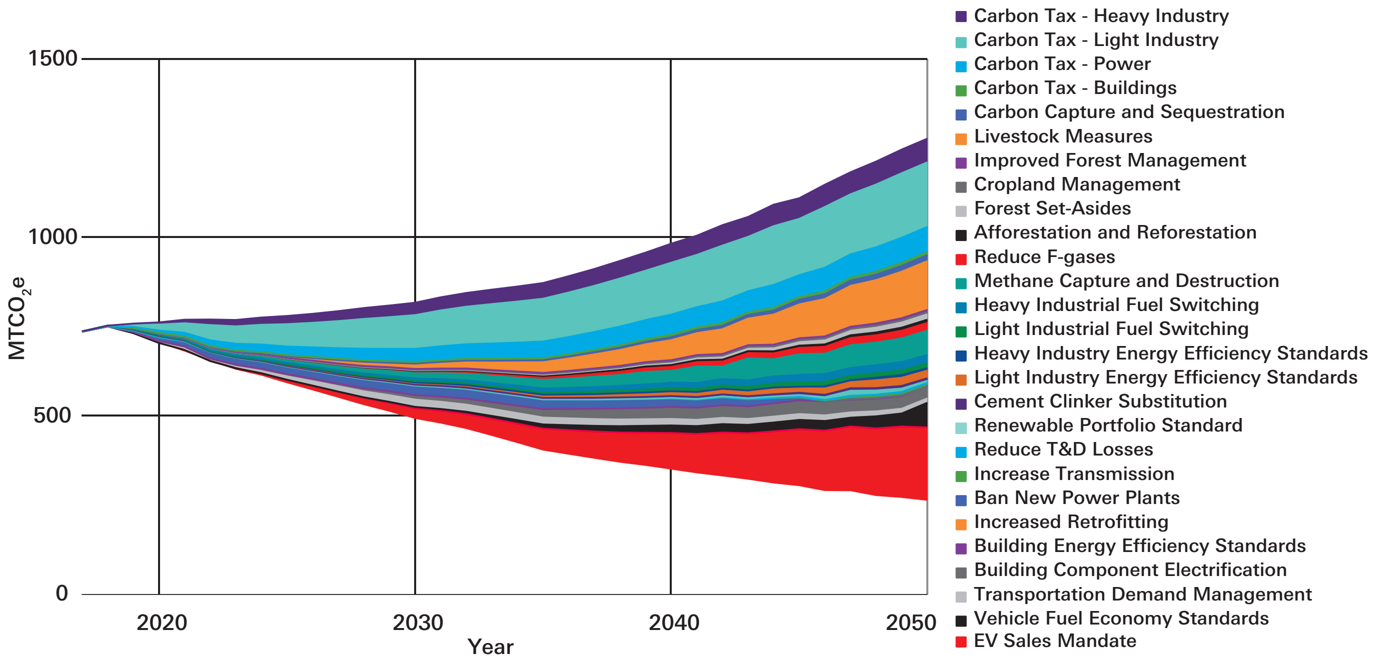
Figure 16 | LMI GHG emissions, $C0_2e$



Source: EPS Mexico, WRI, 2018

The achieved abatement effect of the individual decarbonization actions, as they impact the reference case for the national economy and the LMI sector in particular, is shown in Figures 17 and 18, respectively. The industrial sector reduces its emission, from 566.80 MtCO$_2$e in the reference case scenario, to 191.97 MtCO$_2$e in the decarbonization scenario, which represents a total of 374.84 MtCO$_2$e abatement (34%) by 2050.

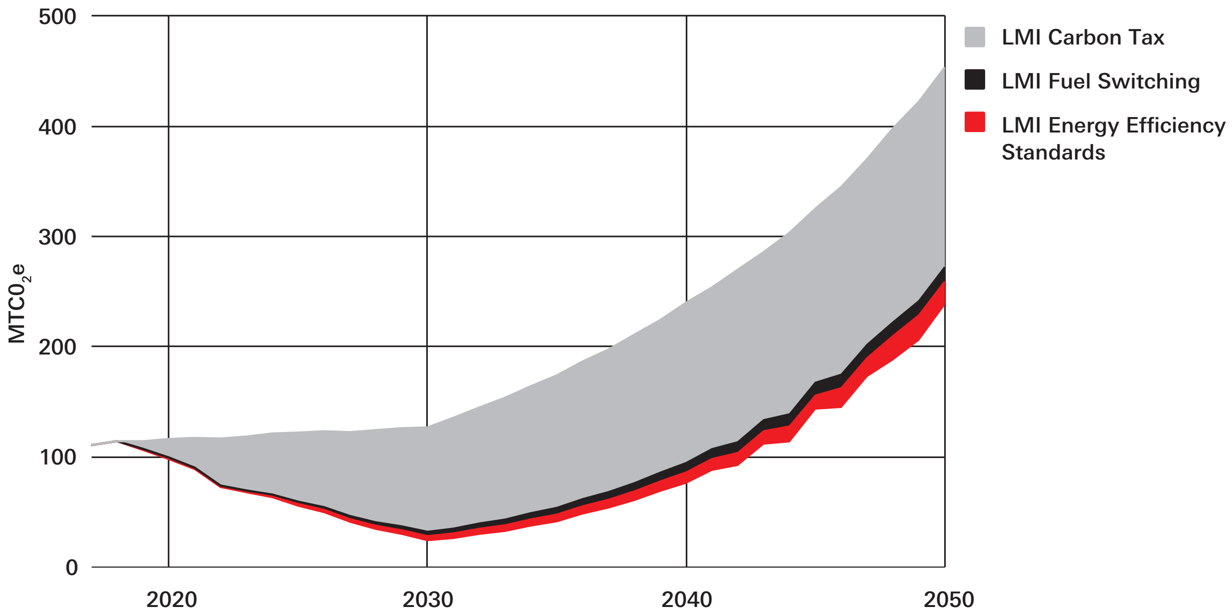
Figure 17 | Economywide decarbonization scenario wedge diagram



Source: EPS Mexico, WRI, 2018

Abatement measures in the LMI sector are centered around energy efficiency standards, with 18% GHG emissions abatement, and fuel switching, also with 18% abatement. The remaining 64% abatement is assigned to the behavioral changes in demand and consumption associated with the application of a strict carbon tax that will incentivize decarbonization actions across the whole value chain and foster the development of a circular economy.

Figure 18 | LMI Decarbonization wedge diagram



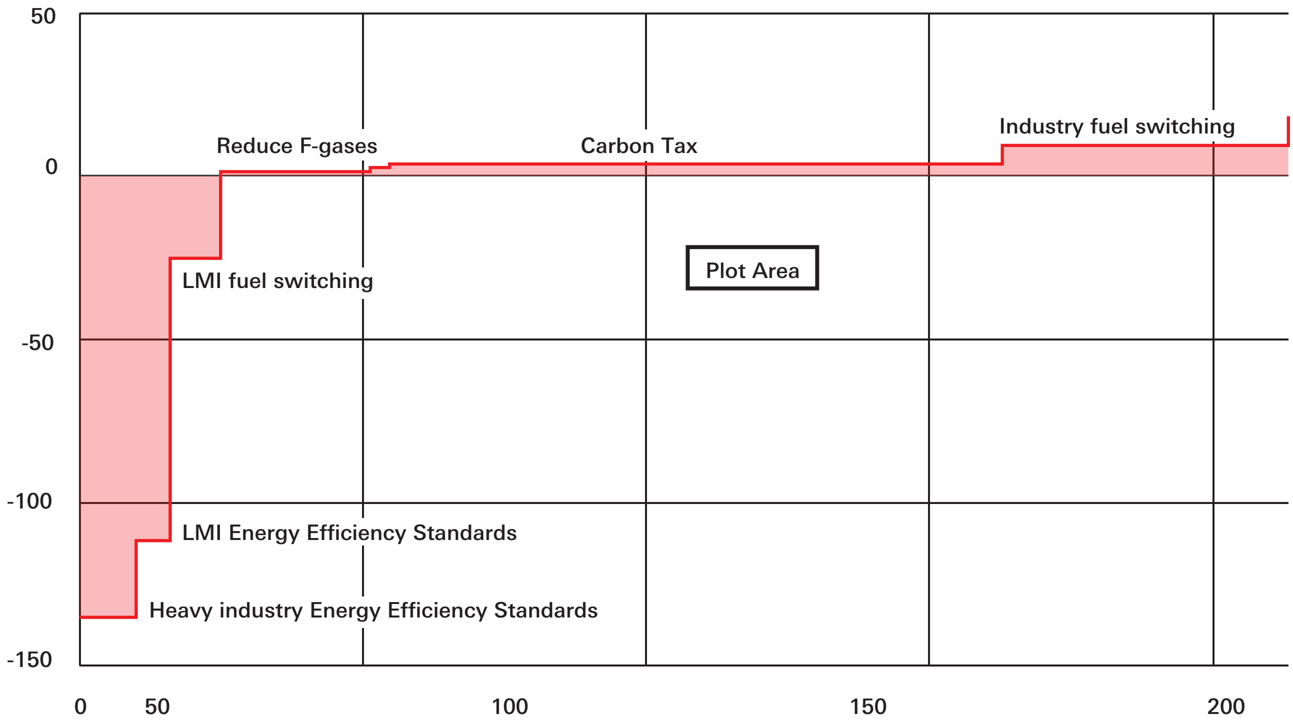
Source: EPS Mexico, WRI, 2018

Cost curve

The Marginal Abatement Cost Curve (MACC) reflects Present Net Values (NPV) of individual policy levers. MACC curves relate the NPV of the marginal abatement cost per ton of CO_2e emissions (shown in 2012 US Dollars, in the vertical axis) with each policy's abatement potential (shown in $MtCO_2e$, in the horizontal axis). The policies are ordered by increasing abatement cost; in other words, policies that represent net savings (shown negatively in the vertical axis) are the first ones from left to right. The magnitude of each policy's emissions abatement is illustrated by the width of its corresponding bar.

The MACC curve for the decarbonization scenario by 2050 is shown in Figure 19. Policies that have a strong abatement potential and entail a net revenue include industry efficiency standards, renewable energy generation, and a carbon tax. On the other hand, policies that represent a net cost (shown positive in the vertical axis) with a significant potential abatement are methane capture and destruction, and low-carbon fuel standards.

Figure 19 | **Decarbonization scenario marginal abatement cost curve. Industry decarbonization scenario**



Source: EPS Mexico, WRI, 2018

The actions proposed in the following chapter of this report can significantly reduce emissions in the manufacturing sector. Nevertheless, such actions alone would not achieve full decarbonization of the sector. Tackling remaining emissions will require further technological developments or changes in consumption patterns.

3.5. Health benefits

The implementation of decarbonization actions reduces not only GHG but also criteria pollutants, which affect human health and the environment at the local and regional level. Criteria pollutant emissions quantified by the EPS model include particulate matter (PM2.5 and PM10), organic carbon (OC), nitrogen oxides (NOx), sulfur oxides (SOx), carbon monoxide (CO), and volatile organic compounds (VOC). Since ground-level ozone (O3) is a secondary pollutant that forms in the atmosphere and is not directly emitted by any specific source, it is not considered in the model.

Criteria pollutant emissions have an impact on human health through increased mortality (registered deaths) and morbidity (incidence of non-fatal chronic or acute diseases). The effect on morbidity from individual criteria pollutant emissions is difficult to quantify. Therefore, our analysis only considers the effects on mortality. In Mexico, particulate air pollution ranks fifth as a health risk associated with premature deaths. In 2015, the mortality associated with diseases caused by criteria pollutants in Mexico was nearly 29,000 deaths (INECC, 2016c).

The implementation of the decarbonization scenario actions has an impact on criteria pollutant emissions and their concentration levels in the atmosphere. Particulate matter is the pollutant most related to mortality. Comparing the Reference Case and the Conditional Decarbonization Scenarios, PM10 emissions would be abated by 70% in 2030 and up to 93% by 2050; PM2.5 emissions would be abated around 40% and 50% for the same years with the implementation of selected policies (see Table 1).

Table 1 | Decarbonization scenario – Criteria pollutant emissions abatement in 2030 and 2050

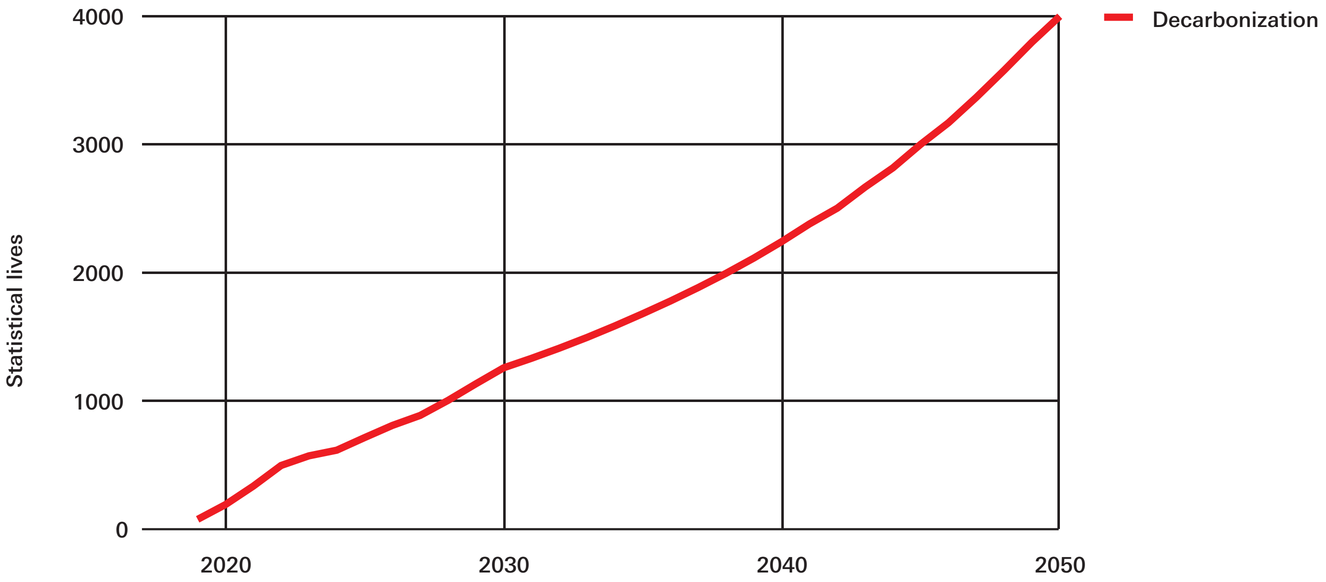
	Total Emissions Abatement		LMI Emissions Abatement	
Criteria Pollutant	**2030**	**2050**	**2030**	**2050**
PM2.5	56%	90%	53%	87%
PM10	71%	93%	57%	94%
VOC	38%	90%	43%	61%
NOx	28%	73%	46%	66%
SOx	56%	75%	40%	55%
CO	32%	89%	46%	67%

Note: PM2.5 = particulate matter under 2.5 micrometers in diameter.
PM10 = particulate matter under 10 micrometers in diameter.
NOx = nitrogen oxides. SOx = sulfur oxides. CO = carbon monoxide.
VOC = Volatile Organic Compounds.

Source: EPS Mexico, WRI, 2018

If the full decarbonization package was implemented economy wide, by 2030, the number of accumulated statistical lives saved from reduced exposure to criteria pollutants would be almost 34,500, and over 75,000 in 2050. Actions in the light manufacturing industry account for 5% of total particulate abatement, which would contribute to about 4,000 statistical deaths avoided by 2050 (see Figure 20)[14]. Policies to reduce emissions from particulate matter and other criteria pollutants would have to be enhanced to counter the 29,000 reported deaths associated with air pollution in 2015 alone.

Figure 20 | Accumulated statistical lives saved from reduced particulate emissions in the light manufacturing sector



Source: EPS Mexico, WRI, 2018; with data from CAME, 2017

[14] Data used to calculate the impact on mortality was taken from Mexico's Air Quality Improvement Program of the Megalopolis 2017-2030, published by SEMARNAT and INECC through the Environmental Commission of the Megalopolis (CAME, 2017).

4. Towards decarbonization

Industry will be the sector with the second-largest contribution to emissions by 2050 (20% of total emissions) if no mitigation actions are taken (EPS, 2020). LMI represents over half of Mexico's final industrial energy consumption. Yet, industrial energy consumption is not usually regarded as big a priority in decarbonization policy, whereas transportation or electricity generation are; this stems from a lack of familiarity with available opportunities and technologies or assumptions on how the industry is already adopting available and cost-effective means to reduce energy use.

Decarbonization efforts require careful consideration of industrial sector policies, to achieve synergies and maintain value. No single policy by itself can achieve the necessary emission reductions, but key types of policies used in combination would. These policies include education and technical assistance, financing, financial incentives, mandatory targets, and equipment standards. Often, investments in higher-quality equipment will not only reduce emissions but save energy and often pay for themselves, increasing companies' long-term competitiveness. Among the policies that both strengthen the economy and lower emissions, industrial efficiency policies are well suited to nearly all countries, especially those in need of ways to cut emissions while promoting competitiveness and long-term economic development.

There are multiple technological options available that can reduce energy use in industrial applications while saving money in the long run, often at lower costs than improvements in other sectors of the economy. Industrial energy efficiency measures can achieve a significant component of the global emission reductions necessary to hit the two-degree Celsius (2°C) target (Harvey, 2018).

The proposed decarbonization pathway for LMI in Mexico consists of a three-stage approach beginning with internal operations, followed by optimization of the value chain, in order to achieve a circular economy operation and minimal GHG emissions. This section will detail the required actions modeled for this decarbonization pathway.

4.1. Energy efficiency

Energy efficiency is job intensive. In the United States and Europe alone, more than 3.3 million people hold jobs in the energy efficiency industry, with the majority employed by small and medium-sized businesses. Investment through well-designed economic recovery programs can use the potential of energy efficiency to support the existing jobs, create new ones, and boost economic activity in key labor-intensive sectors such as manufacturing and construction. Energy efficiency delivers a range of longer-term benefits by enhancing competitiveness, improving energy affordability and lowering energy bills, decreasing reliance on energy imports, reducing greenhouse gas emissions, and freeing up funds to spend in other parts of the economy. Energy efficiency offers many win-win opportunities for labor-in-tensive projects that start quickly and are rooted in local supply chains such as construction and manufacturing. In the current context, putting such projects in stimulus programs can support existing workforces and create new jobs. Energy efficiency brings other major benefits: it improves the economic competitiveness of countries and businesses, makes energy more affordable for consumers, and reduces greenhouse gas emissions.

Energy efficiency actions should be the first step towards decarbonization in LMI, as they usually align with improved operations, better process control, proactive equipment maintenance, and technology improvements, and help achieve a leaner operation. It may include task automatization, digitalization, supply chain integration, and other benefits.

Technology upgrades and infrastructure projects across different parts of the economy can bring about rapid benefits. Appliance replacement programs, like **"replace your old one"** or **"cash for clunkers"**[15] initiatives, provide incentives from governments directly to consumers to replace old, poorly performing products with new, more efficient models. These programs, however, need to take care to avoid unwanted environmental effects and to avoid funding purchases that would have happened anyway.

4.2. Process electrification and renewable energy generation

In order to decarbonize the manufacturing sector, it will be necessary to transition to low- or no- emissions energy generation. Policies promoting fuel conversion can be mandatory (e.g., banning the use of coal or natural gas in certain industrial facilities), or market-based (e.g., taxing the use of coal or natural gas, or offering tax credits or incentives to use zero-carbon fuels) (see Table 2). Policies that price carbon emissions also create an incentive for facilities to switch away from burning fossil fuels.

Manufacturing facilities can evaluate on-site renewable generation, biofuels, and solar PV generation, which can be adapted to any size operations, with available technologies such as a biodigester, rooftop solar panels, or full-fledged solar farms. Existing regulation and long bureaucratic processes can present a challenge for sites to attempt on-site generation, but economics work out in most cases. Alternatively, sites can establish direct energy purchases of practically any amount from renewable energy generators, and in many cases, not only improve their environmental performance but also save money.

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[15] Some examples are https://cfe-recibos.com.mx/refrigeradores-cfe/ and https://www.cashforclunkers.org/

Box 2 | Hydrogen Fuel

Fuel-switching to hydrogen provides a possible path to further decarbonization, but this is only really possible as part of an integrated regional strategy whereby industries are clustered around a source of decarbonized hydrogen (produced through steam methane reforming, with CO_2 emissions captured). This can then be connected to carbon dioxide transportation and storage infrastructure. The question of cost remains; decarbonized hydrogen could be up to twice as expensive as natural gas. A doubling of energy costs could result in companies closing local facilities and moving abroad (so-called "carbon leakage"), so the government will need to support the price in some way as they are doing for biogas through the renewable heat incentive (RHI). Fortunately, most light manufacturing processes can be electrified, which is not the case for heavy industrial transformation operations, such as steel smelting from iron ore, which requires both high heat and a chemical reducing agent. In these cases, hydrogen can offer a way to meet industrial energy needs that are not amenable to electrification. Though industrial facilities would generally need new equipment to burn hydrogen, it is possible to transform hydrogen into other high-energy molecules that are compatible with existing industrial equipment (such as ammonia or methane) with modest energy losses. This could allow for a gradual transition to hydrogen, avoiding early equipment retirements or write-offs. Working in harmony with the industry's equipment replacement cycles and minimizing factory downtime will be important for facilitating the roll-out of this new technology.

Source: WSP, 2020. How, can Industry achieve zero carbon? https://www.wsp.com/en-GB/insights/how-can-industry-achieve-zero-carbon

Table 2 | Cost-effective energy measures to decarbonize the light manufacturing industry

Measure	Description
1. Industry energy efficiency standards	Industrial energy efficiency standards set minimum allow-able energy efficiency criteria for existing and newly con-structed plants, taking into account different types of raw materials, fuels, and capacities. Standards might include minimum efficiency criteria for specific pieces of equipment (e.g., motors or belts). Standards can also be based on production (e.g., energy use per ton of cement production). Energy performance standards should target enterprises that produce energy-intensive materials.
2. Waste heat recovery	The heat from high-temperature exhaust and water can be recovered and used in a variety of ways. It may be used to preheat loads (materials entering the system, such as com-bustion air or feed-water going into boilers) so that less fuel is needed to raise the temperature of these inputs once inside the system. Another application is to use the heat to drive an electric generator, producing electricity for use by the facility. A facility that uses waste heat to generate electricity is sometimes called combined heat and power or cogeneration facility. It is even possible to use waste heat for cooling purposes by adding an absorption chiller, a device that uses heat to drive a refrigeration cycle.
3. Cogeneration	Cogeneration and waste heat recovery policies aim to in-crease the share of on-site generation at industrial facilities that comes from combined heat and power (CHP) plants. CHP plants are much more efficient than conventional power plants because they capture and use the excess heat that is produced to generate steam. In many cases, this process heat can be recovered on-site and used in other manufacturing processes, replacing the need for purchased heat.

Measure	Description
4. Properly sized and variable speed motors	Motors are used for a variety of purposes in industrial facilities, such as moving materials, running assembly lines, and controlling equipment. The International Energy Agency reports that a full 40% of all electricity use is in motors and that a quarter of this at least can be saved, reducing global electricity demand by 10%. Several techniques can be used to reduce motor energy use. A motor, fan, or pump that is larger and more powerful than necessary wastes energy. Ensuring that overly large equipment is not purchased can reduce the purchase price of the motors while saving energy. Motors must be able to accommodate their peak loads, so designing the industrial process to lower the peak load on a single motor.
5. High High efficiency compressed air systems and alternatives	Compressed air is used in industrial facilities for tasks such as cooling, agitating, or mixing substances; operating pneumatic cylinders; inflating packages; cleaning parts; and removing debris. Compressed air systems inherently have low efficiency, and the best option is sometimes to replace the compressed air system with another mechanism to accomplish the same task. For instance, fans or blowers, motors, vacuum pumps, and brushes may be substituted for compressed air in some cases. When compressed air must be used, efficiency can be improved by frequently checking filters and clearing blockages; minimizing air leaks; using multiple, small compressors with sequencing controls rather than a larger compressor that always runs; and keeping the system at the lowest possible air pressure (using devices such as a booster or cylinder bore to increase air pressure locally for specific applications that require higher pressures).
6. High High efficiency, properly-sized, and condensing boilers	Boilers are used in industrial facilities to generate steam, which is used for a variety of purposes, such as to turn turbines or to heat kilns in cement plants. Apart from waste heat recovery (discussed earlier), a variety of steps may be taken to improve boiler efficiency. Process control technologies can monitor the exhaust stream and optimize the air/fuel mixture entering the boiler. Reduction of air leaks and excess air saves energy, as more of the energy goes into generating steam than heating the air. Ensuring boilers are not larger than needed, improving boiler insulation with modern materials, and regularly removing fouling or scaling on part surfaces all improve energy efficiency. Condensing boilers extract energy from the steam produced in combustion, thereby improving the efficiency of the system as a whole.
7. Building upgrades (lighting and HVAC systems)	Industrial firms can achieve energy savings by upgrading the lighting and heating, ventilation, and air conditioning (HVAC) systems of their buildings. Lighting efficiency can be improved by switching to more efficient types of bulbs (such as LEDs), using lighting control systems that illumi-nate areas only where light is needed and using more nat-ural light. HVAC efficiency can be improved via building or duct insulation and air sealing, upgrading to more efficient HVAC equipment, and using temperature setbacks during non-working hours.
8. Cog belts	Belts are used in industrial processes to transfer rotational motion between components. “Cog belts” (those with teeth molded into their inner diameters) are more efficient, run cooler, and last longer than traditional belts with a smooth lower surface.

Measure	Description
9. Smart monitoring and controls	Industrial facilities may use computer hardware, software, and sensors that monitor and optimize the energy use of building systems and industrial equipment. These systems can help plant operators quickly detect energy waste, such as when devices are consuming more energy than expect-ed, consuming energy while in standby mode, or in need of maintenance. Newer "smart" controls may use sophis-ticated learning algorithms, achieving even greater energy savings.
10. Energy management systems	In addition to smart monitoring and controls, industries may use energy management systems. An energy management system is not a particular technology but rather an internal governance system or processes that companies follow in order to "systematically track, analyze, and reduce energy demand." The most widely known guideline for energy management systems is ISO 50001, a set of requirements established by the International Organization for Standardization that in-clude an energy planning process establishing baseline en-ergy use, identifying energy performance indicators, setting objectives or targets, forming action plans, and conducting periodic measurement and internal audits.
11. Carbon pricing	The carbon tax increases fuel costs in general, the base cost of new power plants, and impacts industrial production levels based on changes in the base cost of capital equip-ment according to its carbon content. The decarbonization scenario includes the simulation of a carbon tax that grows linearly to reach \$90 USD/tCO_2e by 2050, applying to the oil and gas, power generation, trans-portation, industry, agriculture, and waste management sectors.

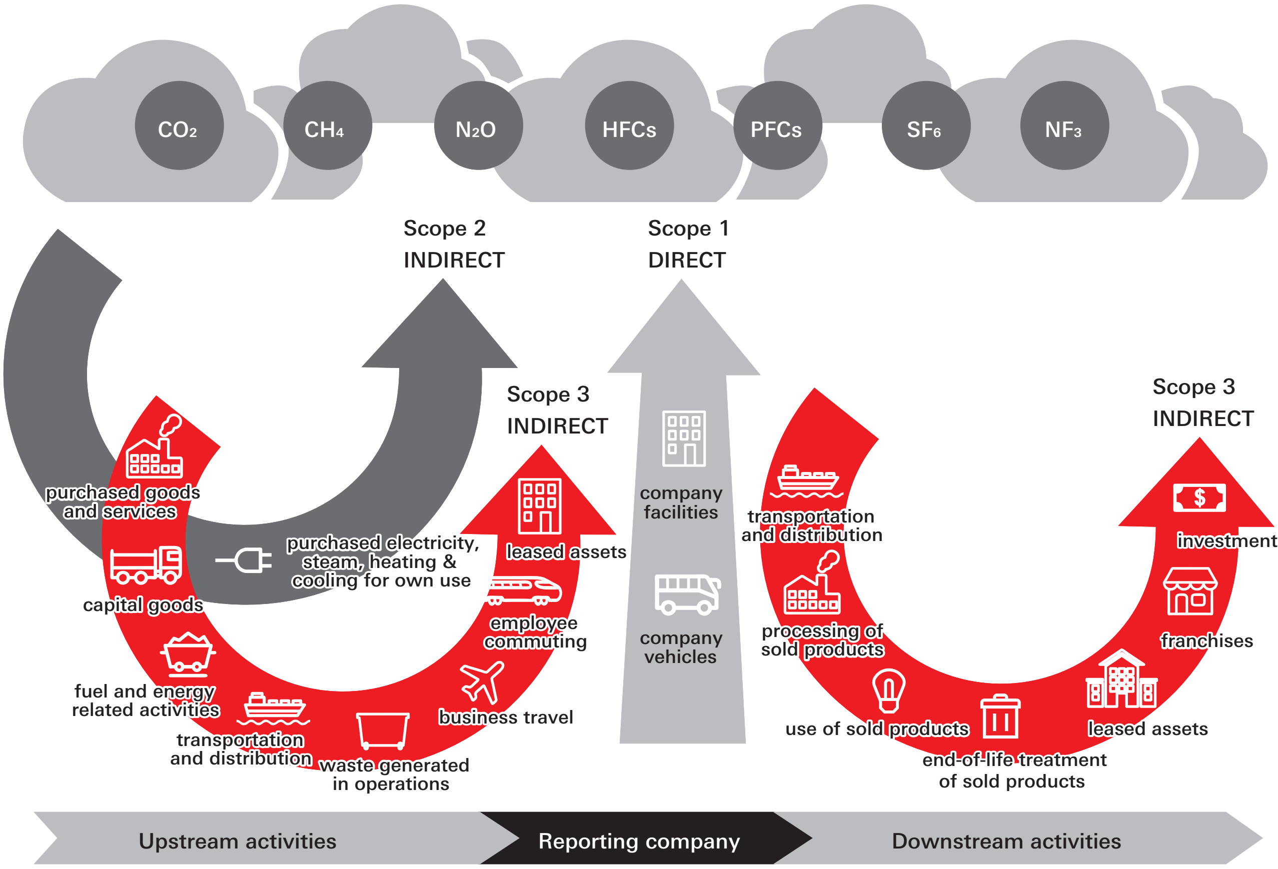
Source: Rissman, J. et.al., 2020

4.3. Value chain integration

In addition to the decarbonization of LMI's direct operations (scope 1 and 2), value chain integration (scope 3) provides significant opportunities to enable businesses to meet decarbonization targets. For many companies, the majority of GHG emissions and cost reduction opportunities are presented outside their own operations.

Figure 21 explains this scopes categorization, according to the GHG Protocol, in which Scope 1 refers to direct emissions from owned or controlled sources, Scope 2 to indirect emissions from the generation of purchased energy, and Scope 3 to indirect emissions that occur in the company's value chain, including upstream and downstream emissions (GHG Protocol, 2013).

Figure 21 | **GHG Protocol scopes and emissions across the value chain**



Source: GHG Protocol, 2013

All sectors are part of value chains that link raw materials through production to customers and consumers. Careful analysis of the supply chain can identify 'carbon hotspots' and inform research activities. Collaboration throughout the value chain can achieve and multiply, decarbonization opportunities and improvements in energy efficiency. For example, material efficiency explores opportunities to deliver the same quality of services for downstream industries with fewer material inputs (e.g., light-weighting in the iron and steel, ceramic and food packaging sectors), but requires engagement with the value chain to realize product or specification changes. Recycling presents an opportunity in the glass sector by increasing the use of recycled glass (cullet). Creating markets for low carbon products is another opportunity that could be realized through value chain collaboration. For example, creating markets for low carbon glass products would improve the business case for investing in additional environmental projects.

Material efficiency, longevity, and reuse

One of the most powerful ways of reducing industrial sector emissions is to reduce demand for materials, while still delivering equivalent or better final services and value to businesses and consumers. There are a variety of approaches that can achieve this outcome.

1. **Material efficiency** involves using smarter design to reduce the required amount of material. Many products are engineered to use more material than they need, sometimes to reduce manufacturing or construction complexity. For example, a building may require steel support beams of a variety of strengths, but assembling a building involving two dozen distinct types of steel beams increases construction complexity. Therefore, beams of only two or three types may be used, resulting in the use of larger and more massive beams than would be needed in various places within the building. Better systems to manage complexity can result in material savings. Computer-aided design and simulation software can similarly help to identify places where material can be reshaped to provide equivalent strength with less material use. Opportunities for material efficiency exist at each stage of any supply value chain, and include:
    - Vehicle light weighting and improved building design (product design and fabrication)
    - Extending building lifetimes through repair and refurbishment and reducing vehicle demand through mode-shifting (use-phase)
    - Increased metal manufacturing yields (material production stage)
    - Reuse (end-of-life).

2. **Additive manufacturing (3D printing)** is a relatively recent technique that enables material efficiency by placing material only where it is needed and eliminating waste material that results from subtractive manufacturing techniques (e.g., carving material away from a larger block).

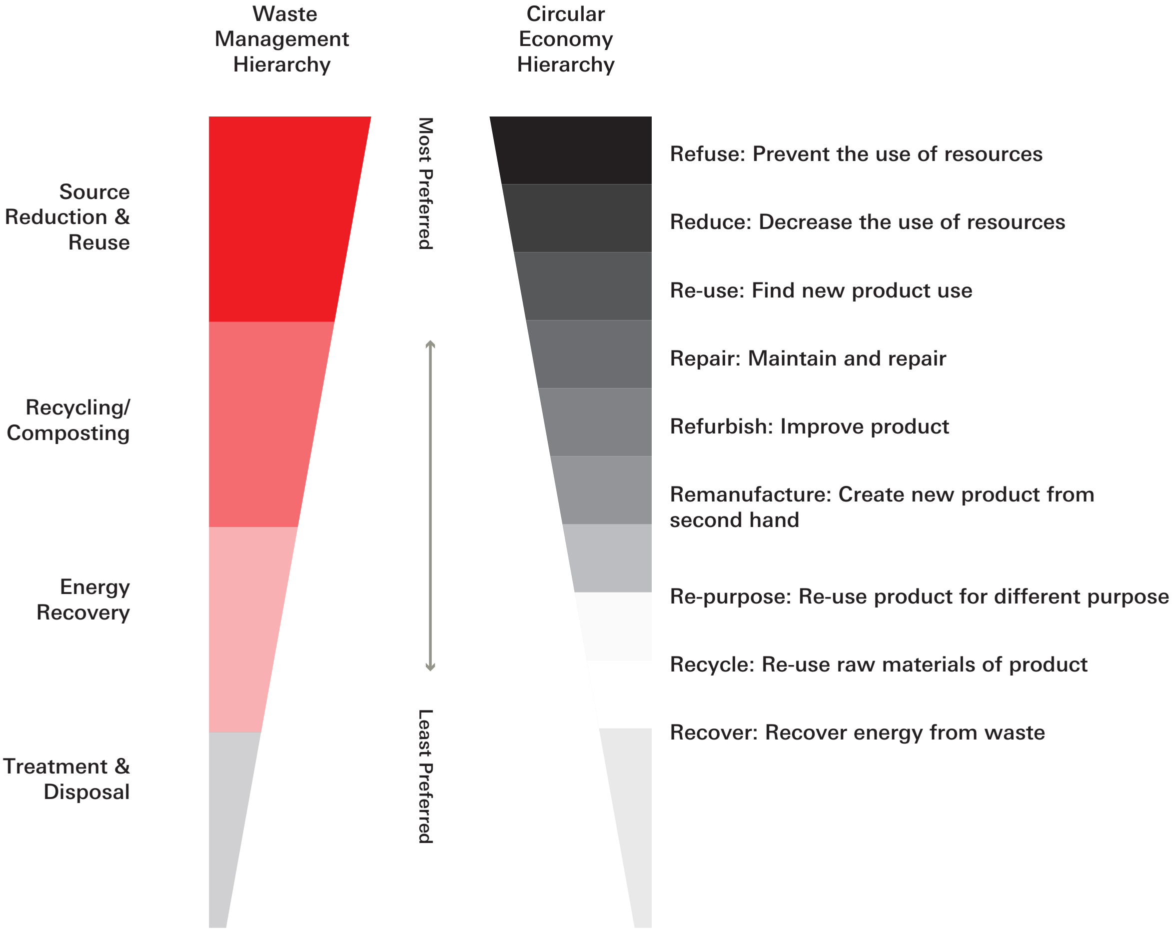
3. **Product longevity** means that products and buildings are designed and built to last longer before they need replacement. The longer the replacement cycle, the greater the material savings. Greater longevity may also mean the product is designed and built with a better quality, which can provide an improved experience for the end-user.

4. **Re-Use of products, components, or materials** is another technique for reducing the consumption of new materials. When a consumer no longer has a use for a product, if that product can be transferred to another consumer who wants it, a new product does not (yet) need to be manufactured, resulting in material savings. If the product is broken, it may not be possible to transfer the products as a whole to a different consumer, but it may be disassembled for parts (e.g. motors, pipes, wires, etc.) that can be used to repair similar products. If even the parts have no value (for example, obsolete electronic devices), materials may be able to be scavenged from the device via recycling. Manufacturers can make it easier to repair, disassemble, and recycle the materials in products through appropriate design and assembly techniques.

4.4. Circular economy

A "circular economy" is one that can be regenerative by design, retaining as much value as possible from products, parts, and materials, mitigate the climate impact of continually manufacturing new products and recoup the huge waste in the current take-make-waste consumer model (see Figure 22).

Figure 22 | **Circular economy hierarchy**



Source: 5 ways to unlock the value of the circular economy, WRI, 2019

The current waste management hierarchy, centered on public health and environmental protection, resulted in a focus on diverting waste from landfills and creating value through recycling and energy capture (e.g., waste to energy facilities). But this optimizes a bad situation without addressing its root cause. In fact, it is so efficient that we rarely think of waste as a loss.

Governments need to focus on developing and promoting circular economy principles, maximizing the utilization of materials by extending the life of products and extracting optimal value once they are discarded to turn them into new useful products. Under this new paradigm, all policies, including taxes, would be aligned to achieve the highest possible level of circularity, through lifecycle-based analysis (WRI, 2019).

Key levers of the circular economy

- Value-retention processes: Value retention processes extend products' life through reuse, repair, refurbishment, or remanufacturing. A recent report from the UN International Resources Panel found that these can reduce demand for raw materials by as much as 80-99% and decrease greenhouse gas emissions in some sectors by 79-99% (IRP, 2018).
- Material recovery and reuse: Recovering and reusing a spent product's materials can have significant decarbonization benefits. A recent study in Nordic economies concluded that by reusing aluminum, steel, and plastics, products could achieve lifecycle emissions reductions of up to 96%, 86%, and 37%, respectively, compared to the same products using raw materials (Hillman, 2015).
- Value: The supply chain is often overlooked, and its emissions can be up to four times higher than those of direct operations, but only a few of these companies actually engage their supply chains to reduce emissions (CDP, 2018).

An absolute reduction in emissions from the LMI will require the deployment of a broad set of mitigation options beyond energy efficiency, electrification and renewables, value chain integration, and circular economy measures. In the last two to three decades, there has been continued improvement in energy and process efficiency in the light manufacturing sector, driven by energy costs and a drive for productivity and value. In addition to the measures discussed above, other strategies such as emissions efficiency, including fuel and feedstock switching, and material use efficiency, including less scrap, new product design), recycling and re-use of materials and products, product service efficiency (e.g., car-sharing, maintaining buildings for longer, longer life for products), or demand reductions (e. g., fewer mobility services, less product demand) are required in parallel (IPCC, 2018).

5. Enabling conditions and barriers for the decarbonization of LMI

As described in previous sections, the energy consumption in the light manufacturing sector has been growing at a slower pace since 1995. This may be partly attributed to actions in energy efficiency improvement, fuel shifting, and the effect of a growing share of less energy-intensive technologies, such as LED lighting over CFLs. In general, light manufacturing operations consume less energy per value generated, having reduced their energy intensity by 21.6% between 1995 and 2015 (SENER, 2020a).

The mix of energy sources used by the LMI has also shifted drastically over time, with electricity growing from a 30% share in 1990 to 65% in 2018. The electrification trend of the sector may come as good news in terms of GHG emissions, as electric power generation can potentially decarbonize in full. In the case of Mexico, the latest numbers in the share of renewables in the power generation mix have remained at around 25% of installed generation capacity, regardless of growth. Yet, the government's latest numbers show a steep increase from 25% in the 2017 year to 31% in 2020 (Forbes, 2020), due to the energy reform[16]. The substitution of fossil fuels with electricity has reduced the carbon footprint of the LMI associated with its energy consumption.

In Mexico, GHG emissions from light manufacturing operations contribute 7% of national total emissions. LMI GHG emissions are projected to grow 3% annually from now up until 2050, if no additional mitigation actions are taken (SEMARNAT, 2019).

The next and last section of this study describes the enabling conditions for reducing energy consumption and increasing the share of renewables in the LMI as well as the main obstacles that hinder the path toward a decarbonized industry. It is based on desk research and a series of interviews with LMI representatives and energy sector stakeholders

5.1. The cost of energy; tariffs and subsidies to energy consumption

Although the price of electricity and fossil fuels varies for each industry (depending on the energy intensity of the processes and activities of each sector), it represents one of the most important production costs of the manufacturing sector in general. Particularly for LMI, electricity could represent around 35% of the production cost of paper and pulp, and 20% of apparel (PwC, 2019).

The volatility of energy prices, in consequence, has a direct impact on production planning and any company's competitiveness. Over the last decade, electricity rates for the industry have fluctuated considerably, up to +/- 30% (see Figure 23). Part of this volatility is linked to the prices of fuels (e.g., natural gas) that are used for the generation of power. Therefore, the volatility of prices cannot be fully mitigated, at least in the short and medium-term (PwC, 2019).

Before the Energy Reform of 2013, companies were only able to purchase electricity at the rates stipulated by the Federal Electricity Commission (CFE). Available options for companies wishing to procure their own energy were limited to Autoabastecimiento (self-supply), which basically consists of signing a power purchase agreement (PPA) with a third party where companies become partners in a special purpose vehicle -SPV- company or installing on-site generation below 500 kW. Today, the private sector has greater certainty on electricity prices and is also able to contract power purchases from qualified suppliers. The energy reform opened the door to a new wholesale electricity market based on renewables, where consumers are able to have access to clean energy at competitive prices; this will be discussed in the following sections.

A large number of interviewees consider the changes in the energy sector derived from the reform as favorable. However, they identify that the fluctuation in prices -in spite of its decrease after the reform and mainly derived from grid congestion-, the complexity of procedures to contract energy and the length of this type of processes represent a problem for companies and an obstacle in some cases to contract energy from renewable sources (for large sectors, this is also due to the complexity of the regulatory framework).

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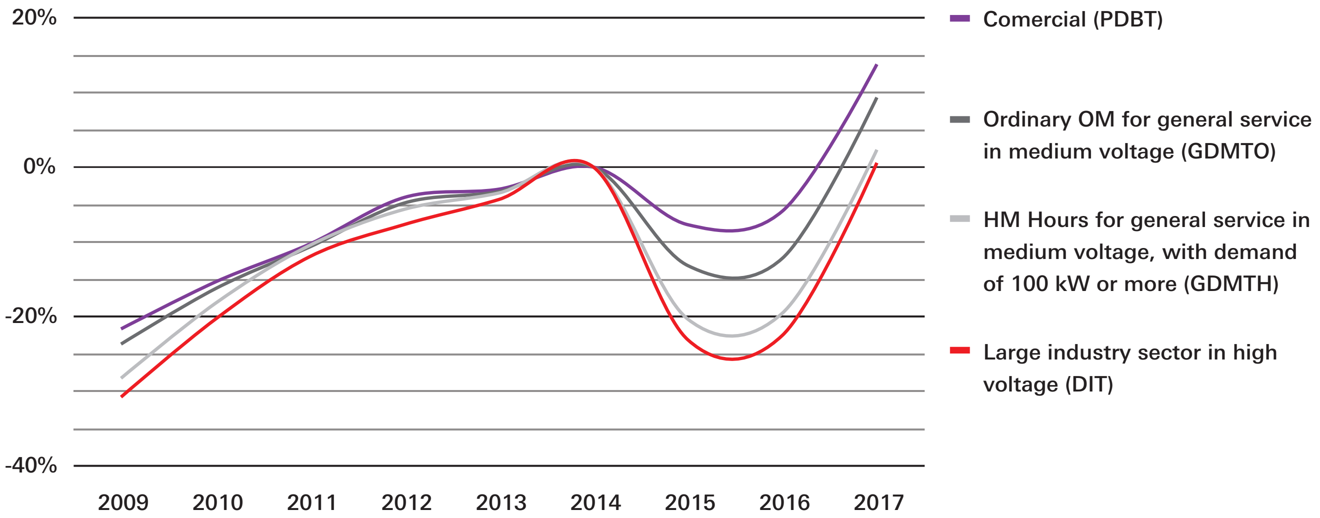
[16] According to SENER 2020, in Mexico, the renewable energy installed capacity is 31%, with geothermal contributing with 1.2%, nuclear 2.0%, solar 4.3%, wind 7.5% and, hydroelectric 16%. Forbes Mexico, available at: https://www.forbes.com.mx/economia-mexico-energia-renovable-sener/

Figure 23 | Variation in average prices of electricity by tariff (base year 2014)



Source: Energy Information System, SENER, 2020

The existence of inefficient fossil fuel subsidies in Mexico is also a barrier to technology innovation and decarbonization, although the issue has been gradually corrected. In 2016, Congress passed legislation to increase flexibility in the gasoline and diesel markets. In 2017, the Energy Regulatory Commission (CRE) was in charge of identifying the regions in the country to satisfy those new regulations. Furthermore, the energy reform responded to related commitments to eliminate inefficient fossil fuel subsidies by international groups of which Mexico is part, such as the G20 and the Asia–Pacific Economic Cooperation (APEC) (CONECC and GIZ, 2018).

On the other hand, measures promoting fossil fuel consumption, including subsidies, have been modified or established. These measures fall under four categories: **a)** tax incentives for fossil fuel exploration, development, or extraction; **b)** subsidies and tax benefits in fossil fuels used in the transportation sector; **c)** tax benefits for fossil fuel expenditure in the manufacturing, agriculture, and forestry sectors; and **d)** other fiscal benefits, including breaks and exceptions on carbon tax application[17].

Interviewees agreed that optimizing consumption and energy saving are the most important drivers for industrial transformation. Lower natural gas prices enabled the displacement of more carbon-intensive fuels, such as fuel oil and diesel, and competitive solar and wind prices increased the share of renewables in LMI electricity consumption.

The current dropping of international oil demand and oil prices, as well as the more stringent sulfur regulation enforced by the International Maritime Organization (IMO), might flood the internal market with dirty fuels (heavy oil and fuel oil primarily) putting the industry 10 years back in terms of clean fuel use.

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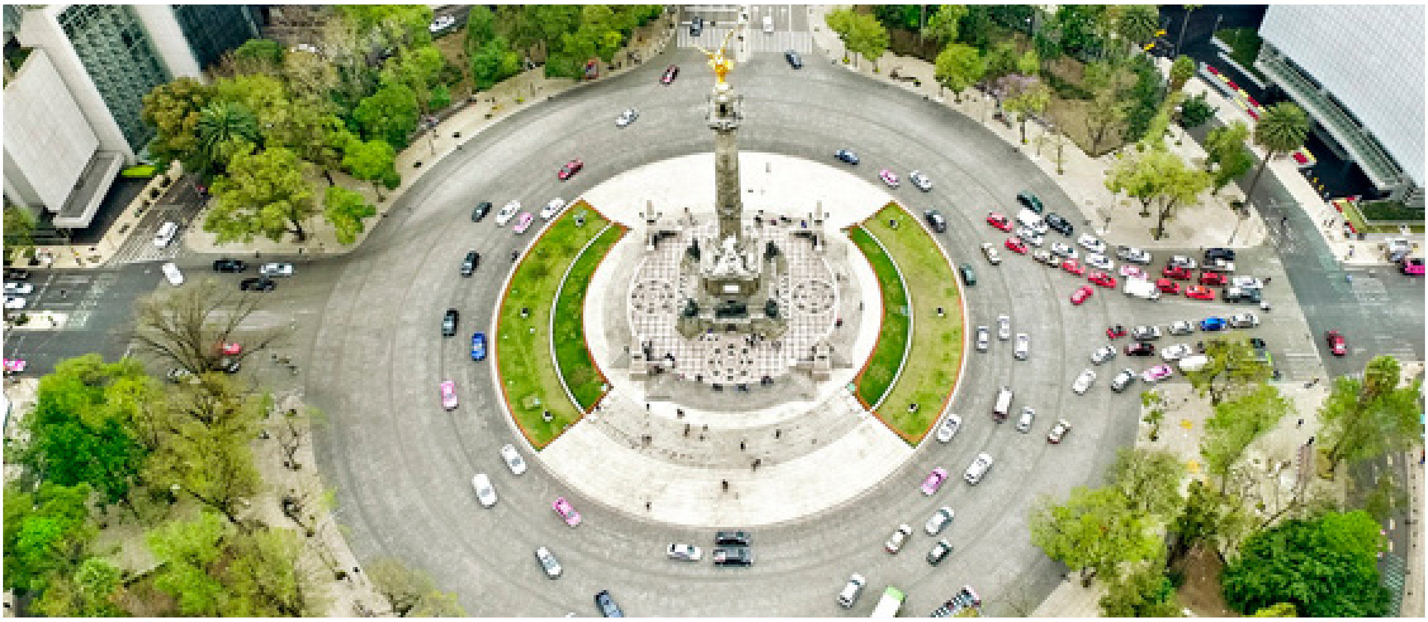
[17] Fossil fuels used in the industry sector are taxed in principle. However, a refund is available for the excise tax on diesel for most industrial end-use. Non-renewable waste and solid biofuels are not taxed.



5.2. Climate-related laws and national commitments

Mexico has played an active role in international climate change negotiations and pledges. The country was second (after the UK) to implement a comprehensive climate change legislation with the publication of the General Climate Change Law in 2012. In 2015, it became the first developing nation to submit its "Intended Nationally Determined Contribution" (iNDC) to the UNFCCC, which became its Nationally Determined Contribution (NDC) after the ratification of the Paris Agreement in 2016.

Although RENE's emissions threshold does not allow to track SMEs[18] and less carbon-intensive plants, this is a useful tool for mapping, evaluating, assessing trends, and establishing national emission reduction strategies. Furthermore, keeping an emissions registry allows companies and industries to identify their emission sources and thereby reduce their carbon footprint[19]. Information from the registry has also been used to identify the sectors and the overall cap for the emissions trading system, whose pilot phase initiated in 2020.

Engaging companies on climate action requires a combination of mandatory, economic, and voluntary instruments. All of them were established in the LGCC, but Mexico is still under the process of implementing the law's provisions.

General law on climate change

The General Law on Climate Change (LGCC) establishes an economy-wide target of reducing 30% GHG emissions by the year 2020 and 50% reduction by 2050, against a 2000 baseline. The National Strategy on Climate Change, the Special Program of Climate Change, and Mexico's Climate Change Mid-Century Strategy are the three climate change planning instruments that the country has developed to attain the LGCC´s GHG mitigation targets and to comply with its provisions. This Law, which positioned Mexico as a pioneer country regarding the development of a climate change institutional framework, assigns responsibilities and engagement mechanisms for different economic sectors, including industry, and tiers of government for reporting, reducing and monitoring GHG emission sources.

The LGCC established the National Emissions Registry (RENE), through which the industry reports its greenhouse gases and compounds (CyGEI) emissions. Industrial facilities that exceed 25,000 tCO_2e thresholds are required to report direct and indirect emissions (Scope 1 and Scope 2). Reporting includes the six Kyoto Protocol gases, plus black carbon and any additional GHGs identified by the IPCC and defined by the Secretariat of Environment and Natural Resources (SEMARNAT).

Carbon tax

In 2013, Mexico introduced a carbon tax, applied to fossil fuels, covering approximately 40% of total GHG emissions na-tionwide. It applies to producers or importers of fossil fuels, including oil products, coal, coke, and coal products across all sectors. Each fossil fuel has a different tax rate depending on the amount of carbon dioxide they contain. However, natural gas and jet fuel, initially contemplated in the proposed law, were exempted from this tax. This differentiated treatment of fuels supports the use of natural gas, making it appear as a carbon-free fuel compatible with decarbonization efforts, which it is not, although it is far cleaner than other fossil fuels such as fuel oil or coal. Coal to gas switching reduces emissions by 50% when producing electricity and by 33% when providing heat (IEA, 2020). However, this long-term decarbonization policy needs to be designed to eventually phase it out from the energy matrix.

Regarding the impact of the carbon tax on LMI emissions, for it to be significant, the price signal would need to be high enough for both companies and individuals to modify production and consumption patterns. In Mexico, at under 3 USD per tCO_2e, the rate is still too low for this to happen, especially contrasted with the 40-80 USD per tCO_2e suggested by the World Bank by 2020 to stay consistent with achieving the temperature goal of the Paris Agreement. The revenue collected in 2019 through this instrument was 5,153 million pesos (USD 313 million)[20] (Mexico2, 2019).

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[18] Which represents 94.4% of the total manufacturing industry in terms of the number of economic units and 46.4% in terms of employment (INEGI, 2016).

[19] With this objective, SEMARNAT has a calculator on its official site to estimate approximately the sum of the CyGEI emissions of the Establishment Subject to Reporting. Available at https://www.gob.mx/semarnat/acciones-y-programas/registro-nacional-de-emisiones-rene

[20] Average exchange rate December, 2019 at spot inter-bank market exchange rate.

Box 3 | Structure of energy taxation in mexico

As of the first of July 2018, the main taxes on energy use in Mexico are the following:

- The federal IEPS (Special Taxtax on Production and Services) is an excise tax that applies to automotive gasoline, automotive diesel, and their biofuel equivalents.
- The local IEPS applies to gasoline and diesel, and revenues are earmarked to states and municipalities.
- The carbon tax (Carbon content tax on fossil fuels) applies to fossil fuels (oil products, coal, coke, and coal products across all sectors), including when used to generate electricity, at rates of up to MXN 46.67 per tonne of CO_2. Natural gas is zero-rated under the CO_2 tax.

Source: OCDE (2019b), Taxing Energy Use 2019: Country Note – Mexico.

Energy transition law

The Energy Transition Law (LTE) was published in 2015. Its main objective is to regulate the sustainable use of energy and the obligations of the electricity industry regarding clean energies and the reduction of air pollutants, including GHG emissions, in a context of competitiveness (LTE, 2015). This instrument established the conditions to transit towards an open and competitive electric market underpinned under clean energies[21]. The LTE has been the most important mech-anism to set an enforceable roadmap with specific targets to gradually decarbonize the Mexican economy through its power sector and comply with the country’s climate change commitments.

The LTE establishes the Transition Strategy to Promote the Use of Cleaner Technologies and Fuels as a planning instru-ment. The document establishes medium- and long-term goals[22] for clean electricity generation: 35.1% of the total by 2024, 39.9% by 2033 and 50% in 2050. (SENER, 2020b). It is worth mentioning Mexico’s legal framework establishes different definitions for clean and renewable energy, and the goals are set for clean energy sources. As discussed in previous sections, Mexico’s installed capacity from clean sources represents 31%[23]. However, renewables represent 22% of the total generation, and solar and wind 7%.

The generation of instruments for distributed generation was a key milestone established by LTE, which allowed any person, company, or business to produce and sell its own electricity with a maximum of 500 kW of installed capacity. It also opened the door for qualified users (registered consumers with a demand of at least 1MW in a single consumption point or aggregated consumption from various facilities) to purchase electricity from qualified private suppliers. Today there are 23 qualified private suppliers operating and 364 registered qualified consumers in total (see Figure 24 and 25) with the manufacturing sector representing the largest share of qualified consumers (see Figure 26) (CENACE, 2020).

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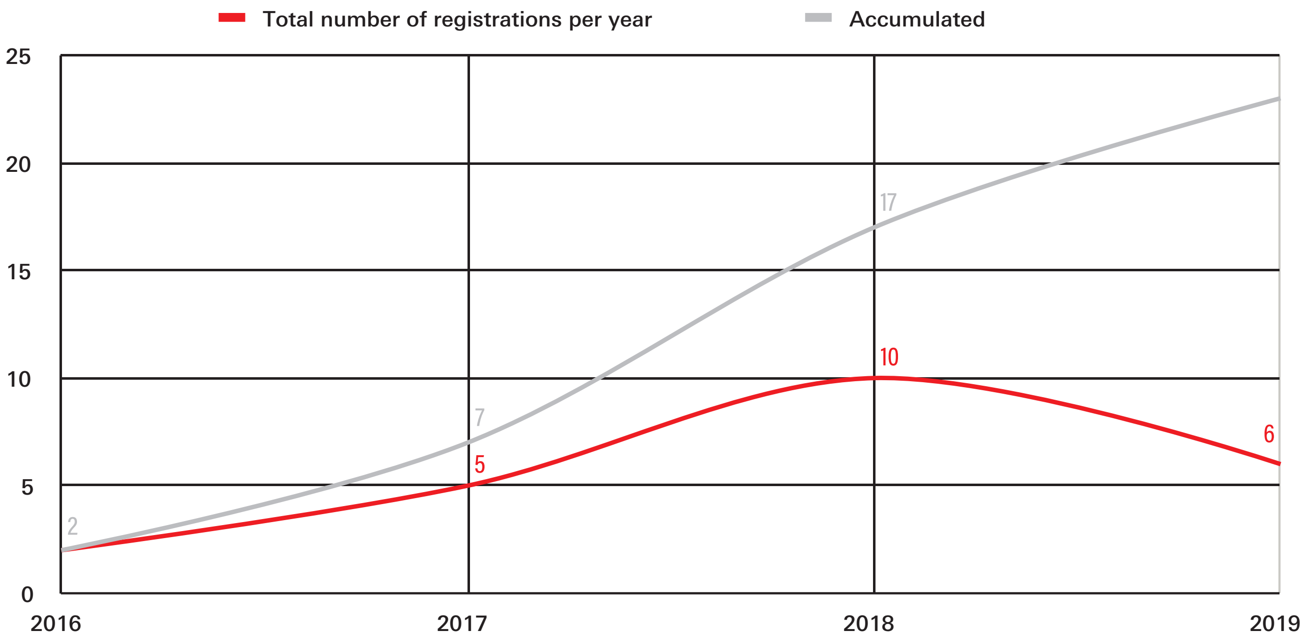
[21] According to this Law, goals have a different scope: clean energy is established as binding for the national electricity industry and in terms of a percentage of participation in total generation. The energy efficiency goal is indicative. EE’s goal parameter has not been established; CONUEE is responsible for defining the energy efficiency roadmap.

[22] The Electricity Industry Law defines clean energy as energy sources and electricity generation processes whose emissions do not exceed established thresholds. The following are considered as Clean Energies: wind, sun, ocean energy, geothermal energy, bioenergetic energy, energy generated by harnessing the calorific value of methane and other associated gases at waste disposal sites, energy generated by harnessing hydrogen through combustion or its use in fuel cells, hydroelectric energy, nuclear power, energy generated with the products of processing agricultural waste or urban solid waste, efficient cogeneration, energy generated by sugar mills, energy generated by thermal plants with geological capture and storage processes, or bio-sequestration of dioxide carbon, technologies considered low carbon according to international standards, and other technologies determined by SEMARNAT (Electricity Industry Law, 2014).

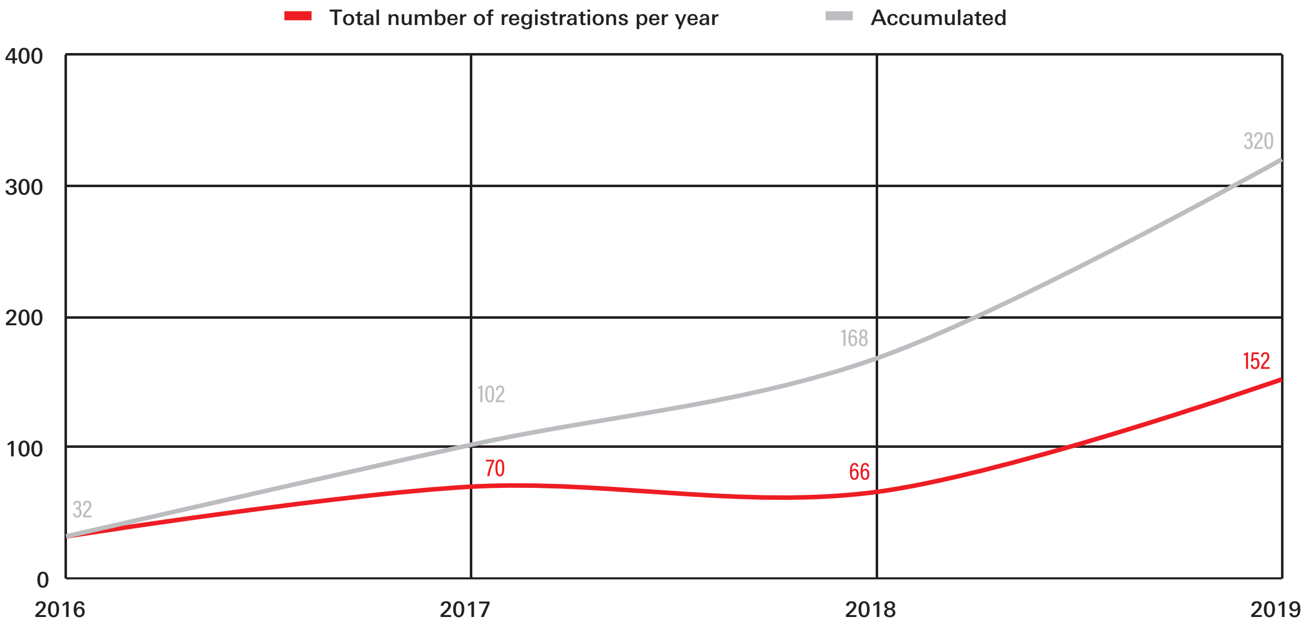
[23] The LTE regulates in terms of clean energy, not renewable energy, so its goals are established under this category. LTE defines clean energy as a group that includes renewables.

Figure 24 | Registered qualified suppliers



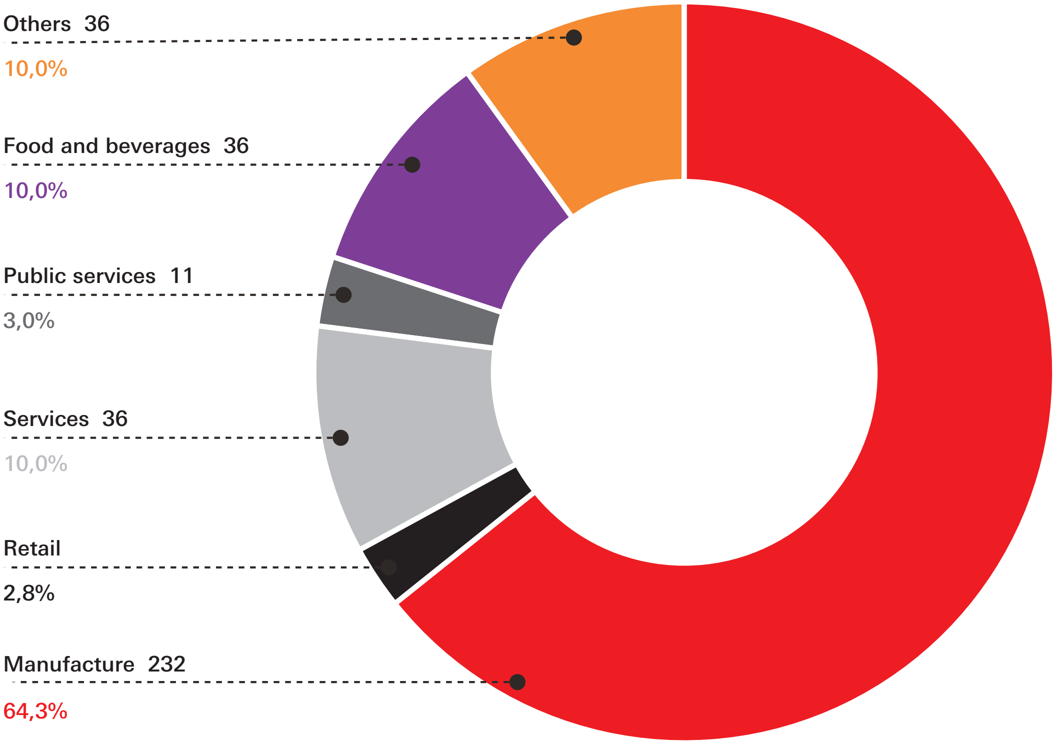
Source: Wholesale electricity market participants, CENACE, 2020

Figure 25 | Registered qualified consumers



Source: Wholesale electricity market participants, CENACE, 2020

Figure 26 | Number of qualified consumers by sector, 2020



Source: Wholesale electricity market participants, CENACE, 2020

By creating the figures of qualified users and suppliers, the LTE gave the manufacturing industry the opportunity to have further control of electricity costs, not only by reducing power consumption through EE measures but also by purchasing electricity from suppliers with the most competitive tariff or even generating part of all of the power they require. The majority of LMI large corporations included in this survey had a Power Purchase Agreement (PPA), which allowed them to buy most of their electricity consumption from renewable sources and to comply and track their Scope 2 GHG emissions.

However, the power market in Mexico is still incipient, covering only corporations with a high level of investment grade-debt (AAA or AA+) and with sufficient electricity demand and capacity to aggregate their power consumption from their different facilities. According to a PwC survey, just 16 of 100 surveyed Mexican companies had a PPA contract (PwC, 2019). In general, the results of the conducted interviews highlight the general lack of knowledge on the electricity market operation, mostly due to the complexity of the tariff composition25. While LMI companies listed on the Mexican Stock Market (BMV) are able to make better decisions in terms of suppliers and contracts and have a better understanding of the electricity market, most companies, including SME, are still making blind decisions when purchasing electricity.

Surveyed companies for this study considered a PPA with a renewable energy supplier as the most cost-effective vehicle to decarbonize their electricity consumption. Self-supply through solar and wind technology was not mentioned as a relevant option: the low return of investment ratio for small scale renewable projects, as well as the strong initial investment needed, act against the companies' cash flow. This, coupled with the current uncertainty of the renewables' market and the lack of attractive financial instruments tailored for different sizes of companies, causes self-supply projects to be off the table.

Even though LTE paved the way for a low carbon transition for industries, particularly for LMI that has the largest share of electricity demand and the highest potential of electrification of its industrial processes, there is still a long way to achieve its purpose.

National determined contribution to the paris climate agreement

In 2015, Mexico became the first developing country to submit its "Intended Nationally Determined Contribution" (iNDC) to the UNFCCC, which became its Nationally Determined Contribution (NDC) after the ratification of the Paris Agreement in 2016. Mexico's NDC set to unconditionally reduce GHG emissions by 22% below a business as usual (BAU) baseline and 36% if a number of conditions are met, including a global agreement addressing International carbon pricing, carbon border adjustments, technical cooperation, low-cost financial resources, and technology transfer. The NDC also establishes "a net emissions peak starting from 2026", a decoupling of GHG emissions from economic growth, and a decrease of the carbon intensity of around 40% between 2013 and 2030. It also sets sectoral GHG reduction targets of 18% for transport; 31% for power generation; 18% for residential and services; 14% for oil and gas; 8% for agriculture and livestock; 28% for waste and 5% for the industry.

At the time of writing this report, Mexico was under the process of revision of its NDC, planning to submit it to the UNFCCC Secretariat by August 2020. At COP 25 in Madrid, the Government declared its intentions to align its enhanced NDC to stay on track to limiting global warming below 2°C. However, current modifications to the energy policy in Mexico are halting investments in renewables[26], making it difficult to achieve the emissions peak target and decouple its carbon emissions from growth.

[26] The cancellation of energy auctions, the lack of definition on public policies regarding the future of clean energy and energy transition have reduced Mexico's competitiveness in investments for renewable energy. The country fell from 19th to 24th place in the ranking of most attractive countries for investments in renewable energy during the last semester of 2019 (EY, 2019).

5.3. Standards and programs for energy management systems

Even though Mexico is an oil-producing country, it has been recognized as a leader in the promotion of energy efficiency. In 1980, the first national program for national energy use was launched and, since the end of the decade, the National Commission for Energy Saving, known nowadays as CONUEE, started building a solid regulatory and standardization framework to sustain a wide range of energy efficiency measures undertaken by different economic sectors.

The development of standards and norms has been the most cost-effective policy. This entails technical specifications aimed at limiting energy consumption in equipment, devices, or commercial systems sold in the country. This standardization process has been accompanied by the creation of private infrastructure to assess (by test laboratories) and certified energy efficiency practices (CEPAL, 2018).

International standards, such as ISO 50001 Energy Management System (created in 2008 and modified in 2011), have been important tools for the industry sector in Mexico, as they provide guidance to manage energy efficiency in a permanent, systematic, and measurable manner and to make constant improvements. The interviewees from the food industry agreed that the National Program for Energy Management Systems (PRONASGEn), designed by CONUEE in collaboration with various international agencies[27] to facilitate the implementation of ISO 50001, was a key enabler for the creation of Energy Management Systems (SGEn) associated with industrial processes transformations oriented to improve energy performance. It is estimated that SGEn can improve energy performance by at least 10% based on low or no-cost operational improvements.

In regard to incentives for reducing GHG emissions, besides potential savings associated with energy efficiency and purchases of electricity from renewable sources, most of the companies interviewed mentioned corporate sustainability and climate policies, and certificates as fundamental drivers for decarbonization. Sectoral coalitions for each sector such as the Sustainable Apparel Coalition[28] with a suite of tools to measure and score a company and product sustainability performance, as well as global initiatives such as **We Mean Business Coalition[29], RE100[30], Carbon Disclosure Project (CDP)[31] and Science Based Targets Initiative[32]** through which companies are also stepping up to prioritize and disclose voluntary climate commitments.

Corporate reporting frameworks and sustainability rankings, including the Sustainable Price and Quotations Index in 2011 of BMV, are aligning large manufacturing industries towards decarbonization practices. However, energy efficiency standards and systems, as well as voluntary climate commitments, need to permeate throughout the value chain in order to have a substantive effect in decarbonizing the economy.

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[27] The National Program for Energy Management Systems 2013-2018 was designed in collaboration with the German Cooperation Agency (GIZ in German), the German Institute of Metrology (PTB in German), the United States Department of Energy (DOE), the Danish Energy Agency (ADE) and the North American Commission for Environmental Cooperation (CEC).

[28] The Coalition developed the Higg Index, a standardized value chain measurement suite of tools for all industry participants.

[29] A global nonprofit coalition composed of 1,283 companies that aim to catalyze business leadership to drive policy ambition and accelerate the transition to a zero-carbon economy. For further information: https://www.wemeanbusinesscoalition.org

[30] Renewable Energy 100 is a global corporate initiative led by the Climate Group in partnership with CDP, which brings together influential businesses committed to 100% renewable electricity. The initiative works to increase corporate demand for – and in turn supply of – renewable energy. For further information: http://there100.org

[31] A not-for-profit charity that runs the global disclosure system for investors, companies, cities, states and regions to manage their environmental impacts. Further information available at https://www.cdp.net/en

[32] A collaboration between CDP, the United Nations Global Compact (UNGC), World Resources Institute (WRI), and the World Wide Fund for Nature (WWF) and one of the We Mean Business Coalition commitments. The initiative showcases companies that set science-based targets through case studies, events and media to highlight the increased innovation, reduced regulatory uncertainty, strengthened investor confidence and improved profitability and competitiveness generated by a science-based target setting. Further information available at https://sciencebasedtargets.org

Box 4 | Science based targets initiative (SBT)

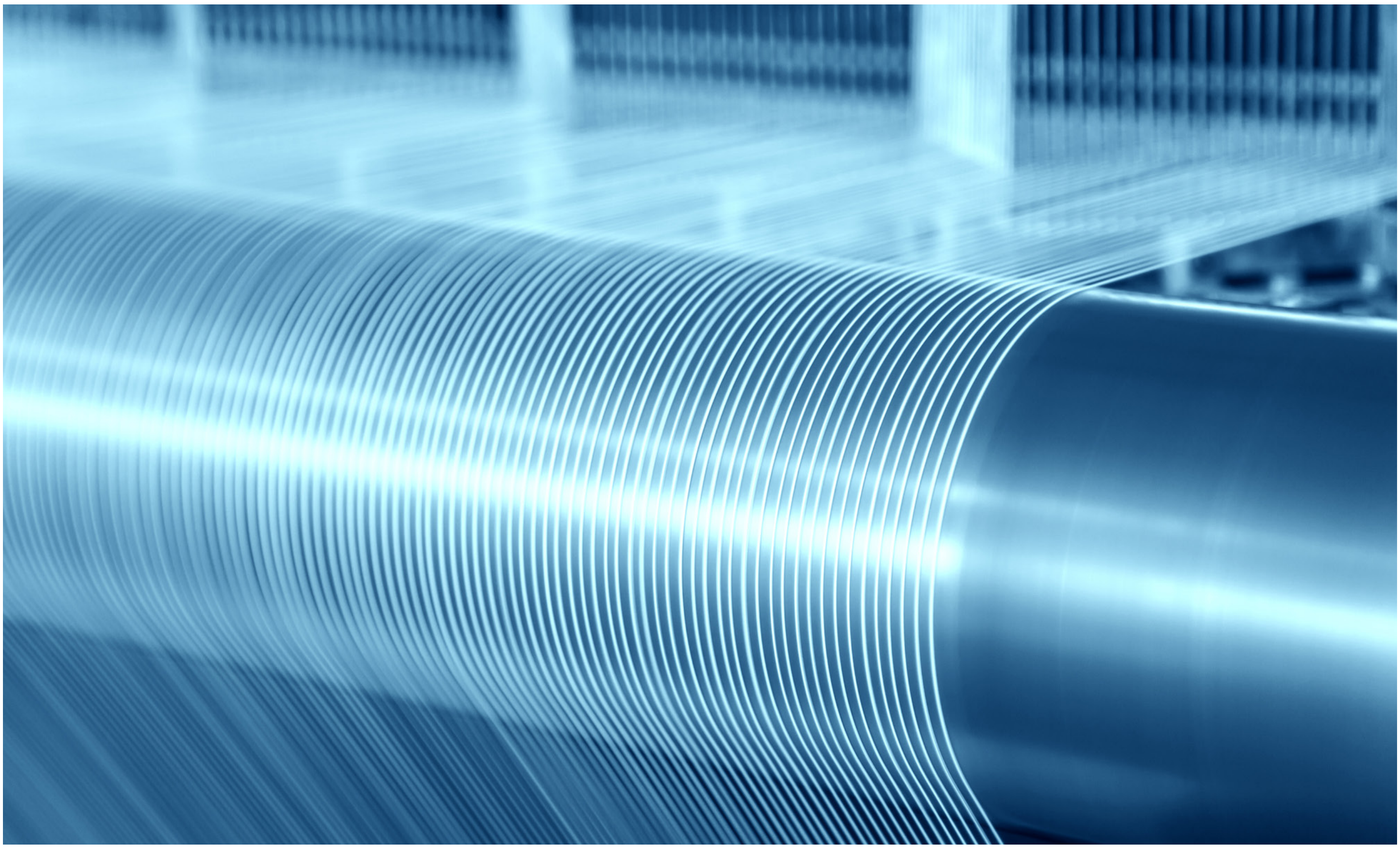
Sixty-six Parties to the UNFCCC, 10 regions, 102 cities, 93 companies, and 12 investors have committed through the Climate Ambition Alliance to increase ambition to achieve net-zero CO_2 emissions by 2050, demonstrating that climate action requires the participation of all economic sectors.

Science Based Targets, a global initiative jointly led by the World Resources Institute (WRI), the World Wildlife Fund (WWF), CDP and the United Nations Global Compact, provide companies with a clearly defined pathway to future-proof growth by specifying how much and how quickly they need to reduce their greenhouse gas emissions. As of May 2020, 892 companies have committed to science-based climate action, and 374 companies have had their targets approved.

SBTs tools and resources support companies in setting climate-based targets to meet the goals of the Paris Agreement of limiting global warming to well-below 2°C above pre-industrial levels and pursue efforts to limit warming to 1.5°C. The Initiative is constantly updating its guidelines and resources so companies can access to the latest information, some of the most useful for LMI are:

Source: **Science-based Target-Setting Manual** - A step-by-step guide to science-based target-setting for companies
New Route for SMEs - Sets specific target validation routes for small and medium-sized enterprises.

Source: https://sciencebasedtargets.org/

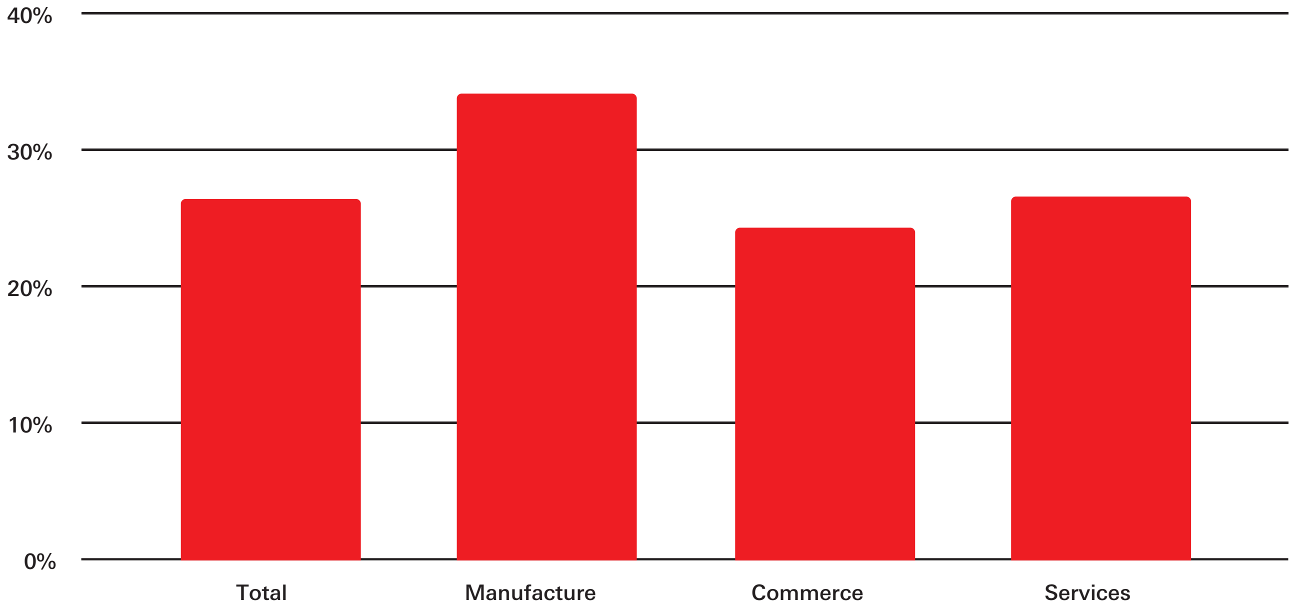


5.4. Financing

Access to financial resources is one of the greatest challenges that Mexican companies face, particularly for SMEs, who represent 94.4% of total manufacturing companies in terms of the number of economic units and 46.6% in terms of employment (INEGI, 2016). INEGI's latest survey on Productivity and Competitivity of SMEs (ENAPROCE) shows that 34% of total manufacturing companies are willing to take a bank credit under the 2018 financial bank's terms (see Figure 27) (INEGI, 2018a). The National Survey of Business Financing (ENAFIN), on the other hand, shows that only 51% of manufacturing companies have requested or had external financing since their creation, and only 26.3% of all man-ufacturing companies declare to have had access to loans or financing in 2018 (INEGI, 2018b) (see Figure 28).

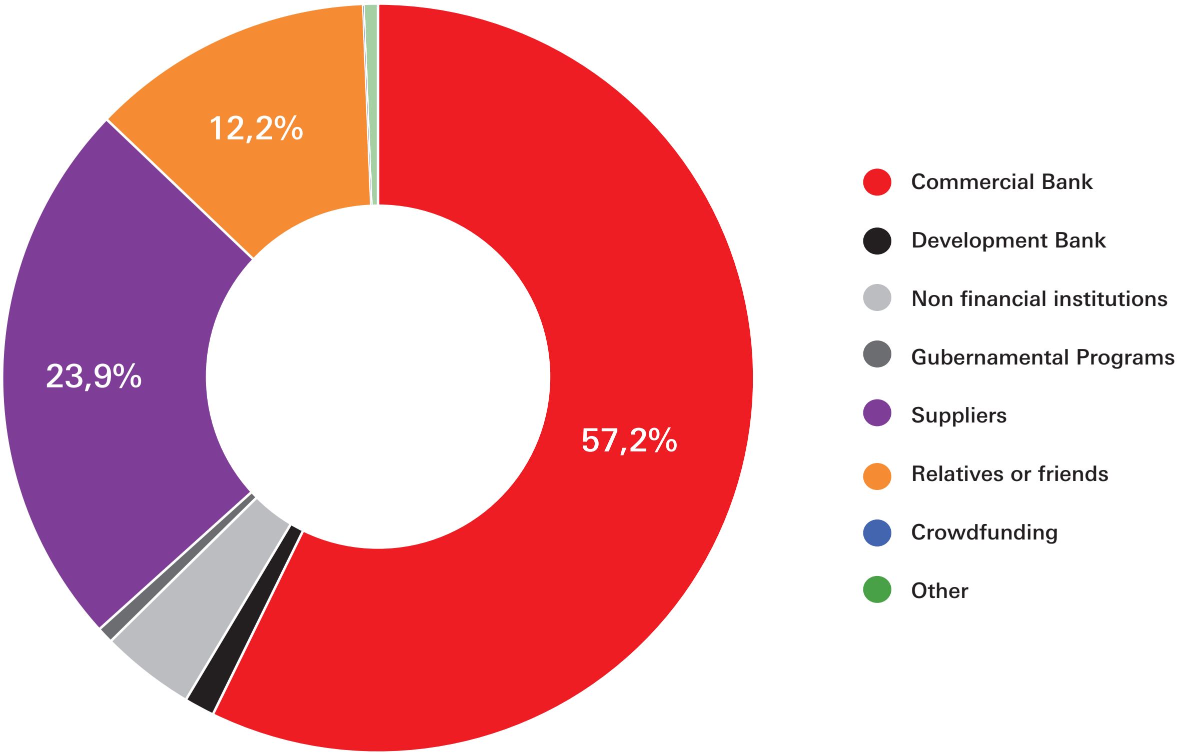
Most manufacturing companies (57%) are financed through commercial banking (see Figure 28), and only 16% of SMEs are aware of finance and promotion programs offered by institutions of the Federal Government.

Figure 27 | SMEs willing to accept a bank credit



Source: National Survey of Productivity and Competitivity of SMEs, INEGI, 2018INEGI, 2018

Figure 28 | Institution or source with which the manufacturing industry has had credit or financing during 2018



Source: ENAFIN, 2018

The lack of access to public and private financial resources faced by most of the manufacturing sector, combined with the absence of participation in the global value chain (95% of SMEs), deprive companies of the opportunity to invest in cleaner energy or innovative systems, and to incorporate best management practices that would contribute to GHG abatement.

Large companies and industrial chambers interviewed for this study mentioned that measures and projects to reduce energy consumption and shift to less carbon-intensive fuels were paid with their own resources. Apart from FIDE, interviewees did not know mechanisms, either at national or commercial banks, aiming at improving energy efficiency or promoting renewable energy. Moreover, in their view, the lack of fiscal incentives and targeted public policies, oriented to promote these types of investment, represents a relevant barrier for LMI decarbonization.

The main financial programs mentioned by SMEs were EcoCredit, a credit line to replace obsolete equipment with new technologies bought from FIDE-certified suppliers; a financing system carried out by the national development bank Nacional Financiera (NAFIN); and Financiamiento CSolar, also by NAFIN, which is a credit program for SMEs to purchase and install interconnected photovoltaic solar systems[33].

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33 In May 2020, EcoCredit and CSolar had a fixed interest rate of 14.5% and they financed up to 15 million pesos (USD 660,792 at current prices).

Box 5 | EcoMicro-Program Initiative

EcoMicro is a Technical Cooperation Program by the Inter-American Development Bank's IDB Lab, co-financed by Global Affairs Canada, IDB Lab, and Nordic Development Fund. EcoMicro partners with Financial Institutions to create Green Finance Products that build the resilience Micro, Small & Medium Enterprises (MSMEs) to Climate Change. This is an innovative approach to developing products that facilitate access to sustainable, low-cost energy or adaptation technologies for MSMEs. This includes designing products such as:

- Productive loans for those interested in becoming suppliers/retailers of renewable energy, energy efficiency, or adaptation products and/or services.
- Consumer loans that promote the increased adoption and use of these technologies.
- Financing for green entrepreneurs and MSME businesses.
- Providing micro-insurance for MSME asset protection, including crop insurance for smallholder farmers. Implementation of EcoMicro in Latin

America allows for great flexibility in the selection of Executing Agencies and their partners. Executing Agencies can include MSME cooperatives, FIs, microfinance networks, networks of cooperatives, technology providers who seek to provide credit to their customers or insurance companies. In Mexico, the first Eco-Micro program was developed by Financiera Te Creeemos in 2015, as part of the approved and financed programs of this initiative. Te Creemos developed green loans to promote access to solar water heaters, efficient refrigeration, and photovoltaic systems for 100 of their microenterprise clients. The successful uptake of the green loans led Te Creemos to change their entire business model to support the delivery of green products, having trained over 1,000 employees. The institution subsequently scaled up this effort to expand its green loan portfolio from USD 773,000USD $773,000, under the pilot project, to USD $9 million.

Source: IDB (2019)

Knowing the financial challenges of the smaller companies integrated into their supply chains, large companies mentioned starting the implementation of programs to increase their capacities on energy management systems and replace energy-consuming devices. This represents an opportunity for SMEs to implement EE measures and be part of global sustainable commitments.

Technical and commercial risks associated with renewable energy projects are often estimated as being too high and with long periods of return on investment, which prevents them from investing in these technologies and choosing PPA or co-generation instead. Although large LMI companies have greater financial capacity and commonly have sustainability programs addressing energy consumption and GHG emissions, when it comes to accessing renewable energy, they usually find difficulties, largely due to lengthy procedures and complex regulation.

Box 6 | Green Bonds

Green Bonds[34] are debt instruments, available for companies listed in the Mexican Stock Exchange (BMV). By February 2020, 19 green bonds have been issued and listed in Mexico, 12 of them directly related to energy efficiency or renewable energy (CCFC, 2019)[35]. However, until now, no LMI company has issued this type of debt instrument. Two interviewees showed interest in green bonds, but declared not having a program to carry out their issuing, despite the investment potential and recent rapid market growth that these instruments have had in Mexico.

The energy sector received more than half of the resources from green bonds in the first half of 2019 (Filkova, et al.et. al., 2019). Of these, renewable energies take the largest portion, prioritizing wind, solar, and hydroelectric projects (Gallegos, et al.et. al., 2018). The growth of the green bond market could help mobilize both private and public capital and channel future investments to projects that support the sustainable development of the LMI. Although Mexico has small participation in the global climate-aligned bond market, opportunities abound, since the instrument has shown an important growth potential with an increase in the total amount of bonds issued during the last three years. The local market is also being boosted by increasing demand for green bonds and the establishment of international principles (CCFV, 2019).

Manufacturing and LMI decarbonization require a combination of financial products, including credit, guarantees, bonds, and other financial vehicles, access to fiscal instruments, such as tax incentives and subsidies; and a regulatory framework that provides certainty to long term investments and contracts. The current institutional framework, nevertheless, contains some enabling conditions for LMI to implement energy efficiency improvements and renewable purchases. Enterprises and public entities, such as CONUEE, need to continue investing in promoting energy management systems and SMEs' capacity building oriented to develop bankable projects, supported with measurable energy data.

The COVID-19 pandemic has brought a severe economic and social crisis in Mexico. The total cost in human lives and the consequences of the economic slowdown derived from confinement measures and halt of economic activities are still uncertain. So far, Mexican authorities and the Bank of Mexico are taking action in order to insert liquidity into the economy to face the immediate recession. Initiatives such as the undertaken by the Inter-American Development Bank (IDB Invest) and the Mexican Business Council (CMN) for SMEs[36], are helping to overcome the recession. However, as the health crisis recedes, and the gradual revival and reopening of economic activities begin, the country will focus on relevant recovery packages. It is important to seize the opportunity and push for new funds to build the foundations for a more resilient, sustainable, and prosperous future in which the industry opts for greener and more sustainable ways of production.

Efforts from different actors such as commercial banking and the public and private initiative are needed to ensure long-term climate targets. These packages and loans also have the potential to tackle existing inequalities through decarbonization and green job generation working towards a sustainable economy. Overall, increasing the availability of green credits, instruments, and incentives is paramount for a sustainable, resilient, and just low-carbon recovery.

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[34] A Green Bond according to the CCFC is defined as a debt instrument, capital or hybrid, that complies with the "Green Bond Principles MX".

[35] Regarding its regulation in Mexico, the CCFC developed the Green Bond Principles MX which are based on the International Capital Markets Association (ICMA) Green Bond Principles (GBP) and international best practices.

[36] The IDB and the CMN announced a program in April 2020 to provide up to $12 billion in loans a year to SMEs aimed to help some 30,000 firms in the country to help deal with the coronavirus crisis. The accord sought to build a $3 billion program in reverse factoring lines of credit that would complement schemes that IDB Invest already runs in Mexico.

Box 7 | Post COVID-19 recovery packages

Support the accelerated uptake of efficient appliances, lighting, and digital devices
Governments can facilitate the scrapping of inefficient appliances by providing incentives to consumers. Financial incentives such as 'cash-for-clunker' scrappage payments or VAT reductions for household appliances, such as refrigerators and digital devices, foster job creation throughout the manufacturing, transport, and retail supply chains (IEA, 2020a; Motherway & Oppermann, 2020). Any such replacement policy would need to build upon well-established energy efficiency standards and labels and encourage purchases of high-efficiency high efficiency products. Green stimulus interventions can initiate large-scale replacements of street lighting in urban and rural areas, promoting an upgrade of public infrastructure, energy efficiency gains, and economic stimulus impacts. Considering the early replacement of inefficient appliances, direct support and investments can target state-of-the-art circular economy programs to allow for sustainable recycling.

Accelerated funding of R&D and pilot projects of low-carbon technologies
The slowdown of economic activity affects the production and operations of many heavy industry subsectors, such as steelmaking or cement production (Onstad, 2020; Tarasenko, 2020). Green stimulus interventions targeted at other sectors, such as the automobile industry, might indirectly re-stimulate demand, but private companies might face budget constraints for accelerated R&D and the roll-out of pilot projects for low-carbon technologies of industrial processes. Any interventions by policymakers should envision: Green stimulus interventions that can target the accelerated roll-out of large-scale demonstration projects of low-carbon industrial production technologies such as steelmaking using direct reduced iron with hydrogen and electrolysis (Fischedick & Schneidewind, 2020). Some steel making companies are setting up such first demonstration plants for hydrogen-based steelmaking (Ker, 2020; Pooler, 2020), which might come under pressure if corporate revenues were to drop for a prolonged period.

https://www.reuters.com/article/us-health-coronavirus-mexico-business/mexican-private-sector-idb-agree-12-billion-loan-scheme-idUSKCN2280Q5

"Do No Harm" examples of actions to avoid in the industry sector
While green stimulus interventions can support the industry in direct response to the COVID-19 pandemic, policymakers should follow the principle to 'do no harm' when deciding on any stimulus intervention. Examples include: The rollback of existing climate measures and regulation can jeopardize the limited progress some countries have achieved to promote low-carbon technologies (Dohmen, 2020). Similar to other sectors like energy or transport, any unconditional support or bailouts for industry companies without distinct climate safeguards disincentives the urgently required transition to low-carbon technologies, especially in hard-to-abate sectors such as steelmaking or cement.

Source: CAT, 2020, https://climateactiontracker.org/documents/706/CAT_2020-04-27_Briefing_COVID19_Apr2020.pdf

6. Conclusion

Understanding the magnitude of the challenge faced by the planet, it is worth emphasizing that for achieving a maximum 1.5 degree warming pathway, every part of the economy needs to decarbonize. Should any source of emissions delay action, others will need to compensate through further GHG reductions.

Decarbonization of the LMI in Mexico is a critical step in the achievement of this 1.5 degree path. Light manufacturing operations represent the largest component of Mexico’s industrial energy consumption, and Mexican industrial emissions will reach 20% of total emissions by 2050 if no mitigation actions are taken.

The LMI plays a strategic economic role since it is characterized by initiating rapid, substantial, and potentially self-propelling waves of rising output, employment, productivity, and exports that can push countries on a path of structural change.

The proposed decarbonization pathway includes energy efficiency, full electrification, and process optimization for all LMI operations, followed by a strict decarbonization effort of the full value chain and the promotion of circular economy principles. Energy efficiency actions should be the first step towards decarbonization in the LMI, as they usually align with improved operations, better process control, proactive equipment maintenance, and technology improvements, and help achieve a leaner operation. Based on the EPS model, it has been shown that policies that have a strong abatement potential and represent a net revenue include industry efficiency standards, renewable energy generation, and a carbon tax.

The electrification trend of the LMI sector may come as good news in terms of GHG and other air pollutant emissions abatement, as electric power generation can potentially decarbonize in full. Although Mexico has put in place a broad range of standards, policies, and laws to improve energy use and increase the share of renewables in electricity production and consumption, the LMI still faces important barriers.

While large LMI companies can make informed decisions in terms of suppliers and contracts and can explore purchasing and generating renewable power, most SMEs need a better understanding of the electricity market. Large companies are starting to integrate their full supply chain into their decarbonization efforts, which represents an opportunity for SMEs to implement EE and RE measures, which helps them achieve their sustainable development commitments and corporate strategies.

Mandatory and voluntary reporting mechanisms play a key role in generating inhouse capacity for measuring, monitoring, setting targets, and making informed decisions, as well as increasing ambition for sustainability performance through highly cost-effective measures. However, these need to permeate throughout the value chain in order to decarbonize the economy.

There is often a disconnect between corporate goals and manufacturing site needs. Even large companies that have undertaken energy audits and comply with environmental requirements struggle to implement the energy efficiency measures identified. Organizational factors are critical to close this gap. Companies need to adapt their strategy and tactics to make carbon reduction projects happen on-site, and train staff and bring in any external expertise they need as well. Without backing from leadership positions, even easy-win projects with immediate savings like sub-metering and LED lighting can struggle to get funding.

There are shortages or limited availability of a range of skills that can enable decarbonization and energy efficiency progress, among them:

- Operational and maintenance skills that can enable incremental improvements in energy efficiency;
- The ability to develop projects including articulating a viable business case;
- R&D skills, including for the development of successful links with equipment manufacturers, technical centers and academia;
- Technical and engineering skills relating to specific processes and technologies identified in the pathways analysis such as combustion, electrification, and engineering. and
- The ability to better engage with senior leaders so that they understand the challenges in terms of skills and how they can develop and deploy the skills needed to tackle the challenges ahead.

A combination of financial products, including credit, guarantees, and bonds; fiscal instruments, such as tax incentives and subsidies; and a regulatory framework that provides certainty to long term investments and contracts, are required for LMI decarbonization. Enterprises and public entities need to continue investing in low hanging fruits, looking to develop bankable projects. Moreover, technical and commercial risks associated with RE projects must also be overcome if a clean energy transition is to be carried out.

There is a niche of opportunity for development and commercial banks in creating, promoting, and delivering sustainable finance products, programs focused on EE projects, the shift to low-carbon power, and electrification. The financial returns and environmental benefits of these types of projects can also help attract other capital investors. A combination of private, public, and alternative financial sources can contribute to implement emissions abatement and climate impacts adaptation actions. Both the Energy Reform and the National Energy Strategy stress the importance of creating mechanisms and incentives to finance low carbon infrastructure. However, further progress is needed to improve the investment return/ profile of renewables, energy efficiency projects, and other low carbon infrastructure.

The COVID-19 pandemic poses enormous challenges for the economy and society in Mexico. It is important that new funds build the foundations of a more resilient, sustainable, and prosperous future in which the industry opts for greener ways of production. Increasing the availability of green credits, instruments, and incentives is paramount for a sustainable, low-carbon recovery. These packages and loans also have the potential to tackle existing inequalities through decarbonization and green job generation working towards a sustainable economy. Moreover, if a full decarbonization package was implemented nationally, by 2050, the number of accumulated lives saved from reduced exposure to criteria pollutants is projected to surpass 75,000 by 2050. Actions in the light manufacturing industry would account for 5% of total particulate abatement and would contribute to about 4,000 statistical deaths avoided by 2050.

This study focused on climate change mitigation action on the LMI in general. It sheds light on the pathway the sector needs to follow in order to decarbonize through energy efficiency, fuel switching (electrification), and optimization throughout its value chain. However, this pathway provides only an indication of the actions that may be required, given that the manufacturing sector is so diverse, and includes several activities and unit processes. A deeper understanding of the specific actions and policies required to remove barriers and drive LMI decarbonization across regions and sectors that include considerations for industry operations of all sizes and levels of support would be needed, in order to get to more specific recommendations.

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Annex I. EPS web tool and online documentation

Model structure and functionality
The EPS was developed by Energy Innovation LLC, as part of its Energy Policy Solutions project (EI, 2020), aiming to inform policymakers and regulators about which climate and energy policies will reduce GHG emissions most effectively and at the lowest cost. This study uses the latest version for Mexico (v.1.4.4), released in July 2018. The model is open-source and widely documented.

Projections included in this study are all derived from a computer model, which makes a number of assumptions and simplifications. Similarly, model capabilities and results depend heavily on the quality of the input data. Although every care has been taken to validate data and calibrate model behavior, uncertainties are to be expected. The numerical characterization of such uncertainty is not possible as almost all of the input data used in the EPS lack numerical uncertainty bounds. Even if such bounds had been available, it would have been difficult to carry them through the complex model calculations to establish uncertainty bounds on the final result. Nevertheless, the objective of this type of models is to inform on projected trends and the changes that can be affected in those trends, not specific numerical values. As such, EPS has proven useful in building climate change action packages and in the development of decarbonization pathways.

System dynamics modeling

A variety of approaches exist for representing the economy and the energy system in a computer simulation. The Energy Policy Simulator is based on a theoretical framework called "system dynamics." This approach views the processes of energy use and the economy as an open, ever-changing, nonequilibrium system. This may be contrasted with approaches such as computable general equilibrium models, which regard the economy as an equilibrium system subject to exogenous shocks, or disaggregated technology-based models, which focus on the potential efficiency gains or emissions reductions that could be achieved by upgrading specific types of equipment.

The use of a system dynamics model allows for stock carry-over between periods, making it possible to register changes in capacities, populations/fleets, and accumulated benefits, in comparison to a reference scenario; it also allows for a gradual change in parameters that does not require to recalculate a general parameter for a specific sector; this is useful in the industry sector to allow for progressive efficiency improvements.

Source: EI, 2020

The EPS model development included a web application with a high-level technical architecture that facilitates and simplifies model use and review. The web interface displays the most significant results of the model in easy to read and downloadable graphs that include: emissions, policy abatement wedge diagrams, marginal abatement cost curves for selected policies, financials, social benefits and specific results for each of the included sectors for each of the included scenarios. It also includes brief descriptions for each policy, extensive documentation on model calculations and architecture, and clarification on how to design each policy well.

The web application can be accessed at https://mexico.energypolicy.solutions

By creating a user account, the model allows to review preset scenarios and to construct personalized scenarios allowing the study of results from specific policies by modifying their implementation level and even allowing a customized implementation schedule.

Extensive on-line documentation on the web application use can be found at
https://us.energypolicy.solutions/docs/online-model-tutorial.html

Annex II. Companies and organizations interviewed

For the qualitative analysis of this report, 13 semi-structured interviews were conducted during one month, from April 21 to May 15, 2020.

In total, 8 companies that are an important sample of the LMI sector were interviewed from the following subsectors: 4 from food and drink, 2 from textile and 1 from telecommunications. An industrial chamber was also part of the interview process. These interviews include questions to know about companies' energy consumption, energy efficiency measures, energy diagnoses, renewable energy implementation, and their supply chains as well as incentives and barriers identified to establish decarbonization strategies in their operations.

In addition, four government and non-governmental organizations were interviewed:

- The National Commission for the Efficient Use of Energy (CONUEE) - Public sector
- The German Cooperation Agency (GIZ) – International Cooperation
- Private Sector Studies Commission for Sustainable Development (CESPEDES) – The environmental branch of the Business Coordinating Council (CCE)
- Mexico2 - A subsidiary company of the Mexican Stock Exchange Group


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