



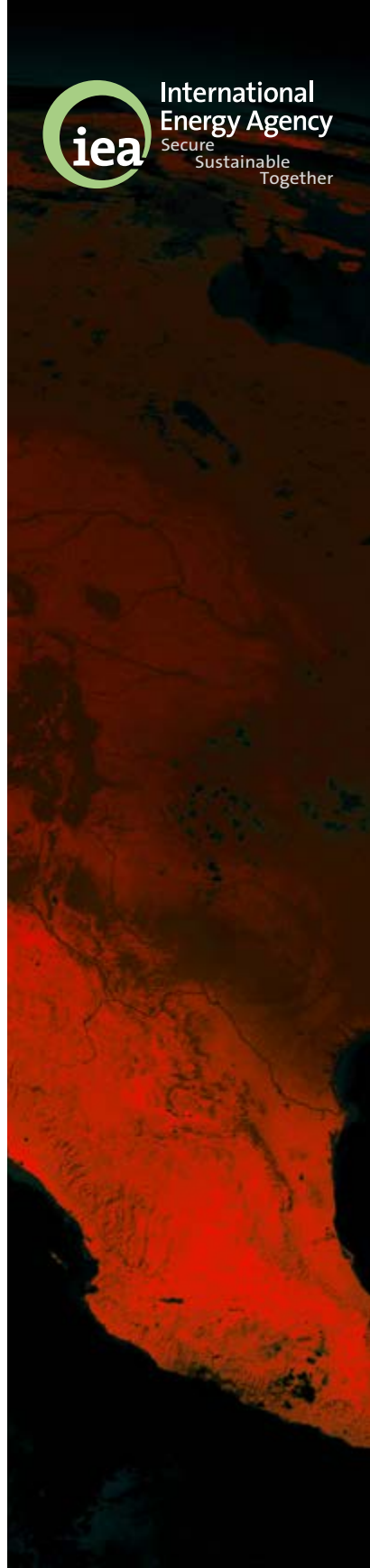
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Mexico Energy Outlook

World Energy Outlook Special Report

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Mexico is recasting its energy sector. The *Reforma Energética* and Mexico's strong leadership on environmental issues underpin the vision of a modern energy system that meets the needs of a growing and modernising economy. The scale of ambition is truly impressive. The effects will be felt in Mexico and beyond.

Mexico and the International Energy Agency have longstanding ties, as befits a country that has for decades been a major energy player. The pace and scope of our co-operation has grown in recent years, culminating in the request made by Mexico – presented at the IEA Ministerial Meeting in November 2015 – to join the Agency. Closer ties with the IEA will not only enable Mexico to tap IEA member country experience in tackling their own energy policy challenges, but also enable the IEA to absorb lessons learned and innovative solutions developed with the Reform in Mexico. The procedures and steps required for Mexico's accession are well underway and I hope that they will be completed in 2017. Membership would not only be a milestone for Mexico and the IEA, it would also open the door to greater engagement by the IEA across Latin America.

As highlighted in this *World Energy Outlook Special Report*, Mexico's Energy Reform has already made remarkable progress, in no small part thanks to the leadership and vision shown by Secretary Pedro Joaquín Coldwell. The transformation is not yet complete and there are many tasks that still lie ahead, but there are good reasons to expect that progress will continue. I am sure the economic and social benefits will be felt by many generations to come. I trust that this report will provide useful insights to all stakeholders in Mexico, including policy-makers, the energy industry, energy experts and the general public alike. I also hope that this report will help to raise awareness elsewhere in the energy world about the scale and importance of the profound changes underway in Mexico.

The findings in the report are those of the IEA alone, but the process has been a collaborative one in which the *World Energy Outlook* team has worked closely with the Government of Mexico, especially with SENER, as well as with industry and leading Mexican research organisations, and international experts. I would like to extend my sincere appreciation to all those that have provided their support throughout this study.

Dr. Fatih Birol
Executive Director
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Mexico's energy sector is in a period of profound change, catalysed by the comprehensive Energy Reform the government has enacted since 2013. The Reform was spurred by the recognition that key energy indicators were moving in the wrong direction, with the attendant risk of a widening gap between the performance of the oil, gas and power sectors and the needs and aspirations of a modern Mexico. The Reform recasts the structures that have governed the energy sector for over 80 years, and seeks to bring in new investment and technology across the hydrocarbons value chain by ending the monopoly of *Petróleos Mexicanos* (PEMEX) and by attracting new players into the power sector to ensure cost-efficient investment into both traditional and low-carbon sources of electricity. The changes reflect both the government's broader vision of modernising the Mexican economy, as well as its intention to show leadership on environmental issues – Mexico was among the first countries to submit a climate pledge in advance of the COP21 meeting in Paris and to embed its clean energy target in domestic legislation.

The Reform has been complicated by the period of lower international oil prices. Even though Mexico's economy as a whole has diversified away from reliance on the hydrocarbons sector, oil revenue still accounted for around one-third of fiscal revenue in 2014, and so the decline in prices had a significant impact on government finances (the share of oil in fiscal revenue fell by more than half in 2015) as well as those of the major state energy companies. Crude oil production fell further in 2015 and exports followed suit, all but eliminating an energy trade surplus that stood at \$25 billion as recently as 2011. However, lower prices have also had some upside: the increasing availability of relatively cheap natural gas imports from the United States has provided a welcome boost to Mexico's power sector. The government's determination to press ahead with the Reform has not diminished, as witnessed by successive and successful bid rounds for upstream oil and gas prospects, and competitive auctions for new electricity supply. The new projects promised in these bid rounds and auctions will need time to become operational, but the decisions and investments taken now are foundational for Mexico's energy future. The aim of this *World Energy Outlook (WEO)* Special Report is to assess the long-term impact of the changes brought by the Reform and to consider their potential ramifications for Mexico's economic development and environmental goals.

Time to turn the oil sector around

Mexico's projected crude oil output bottoms out at under 2 mb/d towards 2020 and then rises as the Reform efforts bear fruit, new projects – notably deepwater developments – start operation and higher oil prices improve profitability. By 2040, crude oil output returns to 2.4 mb/d, but adding in natural gas liquids and, by then, some tight oil takes total oil output in 2040 up to 3.4 mb/d. Mexico's long-standing position as one of the world's major producers and exporters has been weakened in recent years, with investment by PEMEX insufficient to arrest an output decline of more than 1 mb/d since 2004 (a loss of output greater even than Libya's over that period). The projected turnaround rests on three distinct pillars. In shallow water fields, which account for 70% of current production,

the task is to mitigate current declines through enhanced oil recovery techniques and the development of satellite fields around the main existing producing complexes, Cantarell and Ku-Maloob-Zaap. The main source of future growth, however, is anticipated to come from deepwater fields. This is a new frontier for Mexico where PEMEX has less experience and where other players are anticipated, alone or in partnership with PEMEX, to play a prominent role: deepwater fields account for almost half of Mexico's projected offshore oil output by 2040. The final pillar is onshore, with Mexico's tight oil potential and the huge, but hard-to-develop Chicontapac field. Investment is likewise critical to revitalise Mexico's downstream sector, which is beset by poor performance that has pushed up gasoline imports to around 50% of total demand. Upgrades to refinery units help to push up utilisation rates from a very low 60% today towards 90% by 2040, increasing refinery runs and reducing gasoline imports to a more modest one-third of consumption (while virtually eliminating the need for imported diesel).

Imports from the United States provide a very competitive source of natural gas for Mexico, although domestic production – including shale gas – picks up in latter part of the projection period to reach 60 bcm in 2040. The rising role of gas in Mexico's energy mix is facilitated by extensive infrastructure development, the ready availability of relatively cheap gas via new pipelines from the southern United States, and regulatory and pricing reforms that are targeting a liberalised gas market by 2018. Most of Mexico's current domestic output is associated with oil production and its anticipated recovery in the 2020s is closely linked to that of oil. A key determinant of non-associated gas development, including unconventional gas, is the point at which projects can compete with imported gas supply from the US: in our projections, a gradual rise in the US wholesale gas price steadily improves the commercial case for new upstream gas projects within Mexico, triggering larger-scale development from the late 2020s. The prospects for shale gas (a projected 15 bcm in 2040, although the estimated resource base could support considerably higher output) depend also on action to ensure public acceptance, with water availability and responsible water management key issues in the most promising areas.

A clean break with the past in the power sector

Further opening of the power sector to private participation helps Mexico mobilise the \$10 billion per year that it needs to meet an 85% increase in electricity demand to 2040: a more efficient power system brings a 14% decrease (in real terms) in industrial electricity prices to 2040, despite a projected increase in the natural gas price over the period. The unbundling of the *Comisión Federal de Electricidad* (CFE) and long-term auctions for energy, capacity and clean energy certificates provide new players with access to Mexico's power market on a competitive basis, as well as a cost-effective way to bring low-carbon generation into the mix. The first two auctions for new power supply, held in 2016, demonstrated strong private readiness to invest in new solar PV and wind generation, validating the innovative choice of market design. Investment in strengthening the grid and bringing down network losses, alongside a continued switch away from expensive oil-fired generation (which is all but complete by 2020), all help to keep the costs of electricity

supply in check, providing a boost to Mexico's industrial competitiveness. This also provides an opportunity to reduce the costs of subsidies for residential electricity consumers, which currently run at \$6 billion per year; we assume that these subsidies are removed gradually to 2035, in which case the cumulative subsidy bill would be around \$90 billion.

The new policy and market design also provides a substantial boost to Mexico's clean energy efforts: more than half of the 120 GW of new power generation capacity installed to 2040 is renewables-based. This halves the emissions intensity of power generation (from more than 450 g CO₂/kWh in 2014 to 220 g CO₂/kWh in 2040) and even produces an absolute decline in power sector emissions over the *Outlook* period. A distinctive feature of Mexico's Reform in the power sector is that clean energy has been integrated into the Reform package from the outset. This eases the achievement of a 35% share of electricity generation sourced from clean energy by 2024 (a target written into the Energy Transition Law), plays a large part in moving Mexico towards its climate pledge to reduce greenhouse gas emissions by at least 25% below business-as-usual by 2030, and also reduces emissions of other air pollutants.

Efficiency measures can put Mexico on a healthier path to growth

Energy demand in Mexico has grown by a quarter and electricity consumption by half since 2000, but per-capita energy use is still less than 40% of the OECD average, leaving strong potential for further growth. Opportunities for energy savings also exist, with the energy intensity of Mexico's economy higher than the OECD average and showing only a limited improvement since 2000. The energy mix is dominated by fossil fuels, particularly oil, which accounted for more than half of total demand in 2014, making Mexico one of the most oil-reliant major economies in the world. Transport is by some distance the largest end-use sector, accounting for almost 45% of final consumption. The vehicle fleet has grown from 14 million in 2000 to more than 30 million today, leading to traffic congestion that has taken a toll on urban air quality — all of Mexico's largest cities far exceed the World Health Organization's upper recommended limit for particulate matter concentrations.¹

In our main scenario, the economy doubles in size to 2040 but total primary energy demand grows only by around 20%: further growth is tempered by efficiency improvements and structural shifts in the economy that halve the energy intensity of Mexico's economy. Oil loses ground in the overall energy mix, its share declining to 42% in 2040 as that of gas continues to rise (reaching 38% by 2040) and low-carbon sources grow rapidly from a relatively low base. Among the main end-use sectors, robust growth in demand from industry, services and the residential sector is fuelled by gas and, particularly, by electricity, the latter accounting for almost half the increase in final energy consumption to 2040. Electricity demand grows at a pace more than three-times faster than the OECD

¹ See also "Energy and Air Pollution: World Energy Outlook Special Report 2016", available for free at: www.worldenergyoutlook.org/airpollution.

average, as rising incomes and living standards feed through into higher ownership levels of a range of electrical appliances, and demand for cooling increases three-fold. Efficiency improvements, motivated in large part by tighter standards and more stringent codes, play a prominent role in mitigating the rise of consumption. Yet the potential for further savings is substantial. For example, no fuel-economy standards have yet been announced for freight transport: heavy goods vehicles currently consume less than 15% of total transport energy demand but they are expected to account for more than half of the increase in transport fuel consumption to 2040.

A “No Reform Case” highlights what is at stake for Mexico’s energy sector

Mexico’s pre-Reform energy pathway was not a sustainable one: the cumulative gains in GDP from the Reform to 2040 are estimated at more than \$1 trillion, compared with a case in which the reforms do not take place. A “No Reform Case” posits an outlook for Mexico in which none of the major reforms since 2013 are enacted, so the state monopoly is maintained in oil and gas and there is no additional private participation or restructuring in the electricity sector. The historical relationship between oil revenue and PEMEX upstream spending was used to derive an alternative outlook for upstream investment in the No Reform Case, a constraint that severely limits Mexico’s capacity to fund expansion and enhanced recovery projects in legacy fields, and delays the start of technically challenging deep water and tight oil development projects. This results in oil production being some 1 mb/d lower by 2040 than in our main scenario. In the power sector, without the same efficiency gains made in networks and other parts of the system, the costs of electricity supply are higher, meaning higher prices for industry and an expanded subsidy bill for households (a cumulative \$135 billion to 2040) to avoid sharper rises in residential electricity tariffs. Without specific policies to increase the role of clean energy, lower deployment of renewables leaves Mexico well short of its clean energy targets. The repercussions extend beyond the energy sector and into the wider economy: the net impact is to leave Mexico’s economy 4% smaller in 2040 than in our main scenario.

Successful Energy Reform is essential to secure the investment in energy supply required in our main scenario, \$240 billion in the power sector and \$640 billion in the upstream, and an additional \$130 billion in energy efficiency. Mobilising cost-efficient investment at average levels of \$40 billion per year represents a constant challenge for Mexico’s policy. Significant tasks remain, notably to ensure that the new regulatory bodies have the authority and capacity to oversee the transition to competitive, efficient and transparent market operation, that the reformed “state productive enterprises” of PEMEX and CFE focus on their strengths, and that effective regulation can allow other players to compete with them on an equal footing. But the initial signs are positive, in terms of the overall direction and design of the Reform effort, the readiness on the part of the government to ensure that the terms for investment remain attractive, and the response of the private sector in the bid rounds and auctions.

Energy in Mexico today

To improve is to change

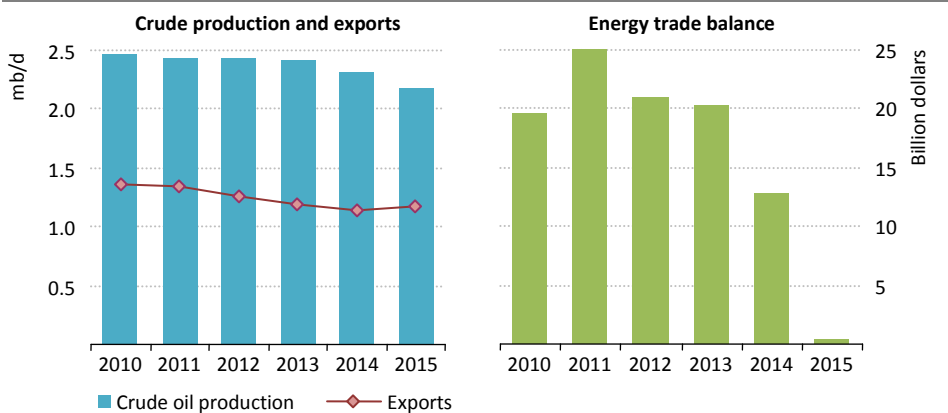
Highlights

- Mexico's Energy Reform (*Reforma Energética*), initiated in 2013, is transforming the country's oil, gas and electricity sectors. A new regulatory and institutional framework has brought an end to long-standing monopolies, opening competition in all aspects of oil and gas supply, and power generation. Private investors can now participate, alongside PEMEX and CFE, the two large state-owned enterprises, in a wide range of the energy industry value chain, attracting capital and technology to areas that are in need of renewal.
- Total energy demand in Mexico has grown by a quarter since 2000 and electricity consumption by half, but per-capita energy use is still less than 40% of the OECD average, leaving scope for further growth. The energy mix is dominated by oil and gas, with oil accounting for around half of the total – a share higher even than that in the highly oil-dependent Middle East.
- Oil has traditionally played a major role as a fuel for power generation, but it is rapidly losing ground to natural gas, whose cost advantage has been reinforced by the shale gas boom in the United States. Non-fossil fuelled generation, primarily from hydropower and nuclear, currently accounts for one-fifth of the total. Wind power has gained a foothold, with capacity of around 3 GW in 2015; but this remains far below its potential. The market for solar PV is nascent, but is expected to grow rapidly: the first two auctions for new long-term power supply, held in 2016, demonstrated private sector willingness to invest in new solar and wind capacity.
- Mexico's long-standing position as one of the world's major oil producers and exporters has weakened in recent years, with oil production declining by over 1 mb/d since 2004. This fall in output is linked to a shortfall in the funds available to PEMEX for capital expenditure to slow declines in mature fields or to develop new ones. A combination of limited refining capacities and rising demand means that Mexico is a net importer of oil products. Natural gas output has also been in decline (most of the production is associated with oil) and imports now meet almost 50% of gas demand.
- Sustainability and climate change considerations are prominent in Mexico's energy policy. Mexico was among the first nations to submit a climate pledge in the run-up to COP21, and was among the countries that pushed hardest for a climate change agreement in Paris. It has legislated to adopt a binding climate target: the second country in the world to do so. With institutional changes that help promote clean energy, Mexico is embarked on a course towards a considerably more sustainable and efficient energy system in the future.

1.1 Introduction

In a fast-changing energy world, Mexico is a leading proponent of change. After a long period in which a state-run and oil-dominated energy system gradually lost direction and momentum, Mexico’s energy sector has been shaken up by a bold *Reforma Energética* (Energy Reform), initiated in 2013 as part of a broader effort to modernise and diversify the country’s economy and increase the competitiveness of industry. A cornerstone of the Reform is the objective to open the energy sector to private and international investment by ending the monopolies of various state-affiliated enterprises.¹ The overall aim is to provide for a more sustainable, efficient, transparent and productive energy sector, to increase the benefits drawn from the country’s large hydrocarbon resource, while also encouraging low-carbon sources of growth (see section 1.3.2).

Figure 1.1 ▶ Crude oil production, exports and the energy trade balance in Mexico, 2010-2015



Key energy indicators in Mexico have been moving in the wrong direction

Note: mb/d = million barrels per day. Source: SENER.

Several considerations gave impetus to the Reform. The state-owned oil company, *Petróleos Mexicanos* (PEMEX), which had enjoyed a monopoly on upstream development, was not in a position to make the investments necessary to arrest declining oil production from ageing oil fields, resulting in a squeeze on the volumes available for export (a factor that, alongside the decline in the oil price, helps to explain the decrease in the energy trade balance from \$25 billion in 2011 to just \$325 million in 2015) (Figure 1.1). In the power sector, limited private sector participation in electricity generation and the monopoly position of the state utility, *Comisión Federal de Electricidad* (CFE) in the transmission, distribution and retail sectors, translated into inefficiencies across the system that have pushed up costs.

¹ In this report, we refer to the *Reforma Energética* as the Reform and the Energy Reform.

Meeting Mexico's rising energy demand in an efficient, secure, sustainable way depends on diligent effort to achieve the promise of the Reform. Bringing in new players, capital and technology requires careful design of the implementing measures and early creation, at the necessary scale, of the essential institutional structures. The intention of this special report is to provide a strategic input to this process by offering a coherent analytical framework against which Mexico's own policy choices can be tested.

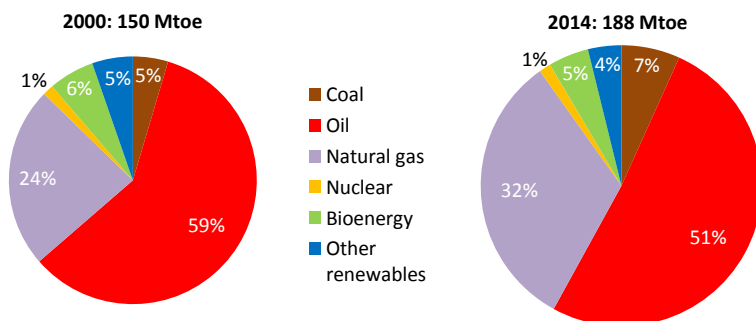
1.2 Key energy trends in Mexico

1.2.1 Energy demand

Primary energy demand

Primary energy demand in Mexico has increased by 25% since 2000, a rise that mostly matches the expansion of the economy, meaning that the energy intensity of Mexico's economy shifted only slightly over this period, from 0.180 tonnes of oil equivalent (toe) required for each \$1 000 of gross domestic product (GDP) in 2000 to 0.168 toe/\$1 000 in 2014. This pace of improvement is around one-third of that of the Organisation for Economic Co-operation and Development (OECD) average. The absolute level is also relatively high compared with an OECD average of 0.118 toe/\$1 000, reflecting the structure of the Mexican economy – where the high value added but low energy use services sectors plays a smaller role than elsewhere in the OECD – as well as the opportunities that remain to improve energy efficiency. Mexico is also different from the OECD group as a whole in that there is substantial potential for further growth in energy consumption: per-capita energy demand in Mexico is the lowest among OECD countries, less than 40% of the average. While aggregate energy use in the OECD is set to decline in the decades to 2040 (despite growing economic activity), Mexico's energy use is set to rise.

Figure 1.2 ▶ Primary energy demand by fuel



Gas is rapidly expanding its role, but oil remains the dominant force in Mexico's primary energy mix

Fossil fuels dominate the primary energy mix, with oil, natural gas and coal collectively accounting for around 90% of primary demand for the past two decades. Oil remains the dominant fuel, with demand currently at 96.4 million tonnes of oil equivalent (Mtoe). Over the last decade, there has been a shift from oil towards natural gas, primarily in power generation, which has decreased the share of oil in the primary energy mix from 59% in 2000 to 51% in 2014 (Figure 1.2): this is still one of the highest such indicators in the world, above even the 48% share of oil in the Middle East. Demand for natural gas has increased by more than 70% since 2000, with its share in the primary energy mix increasing from 24% in 2000 to 32% in 2014. Fuel switching in the power sector, rising industrial demand and, more recently, the import opportunity that opened up for Mexico by the shale gas boom in the United States (and facilitated by Mexico's policy of constructing new gas import pipelines) have accelerated the use of gas. The overall share of renewable energy has fallen slightly, to 8.5% of total primary energy, reflecting in part the declining use of solid biomass, mainly fuelwood used by poorer households.

Sectoral demand

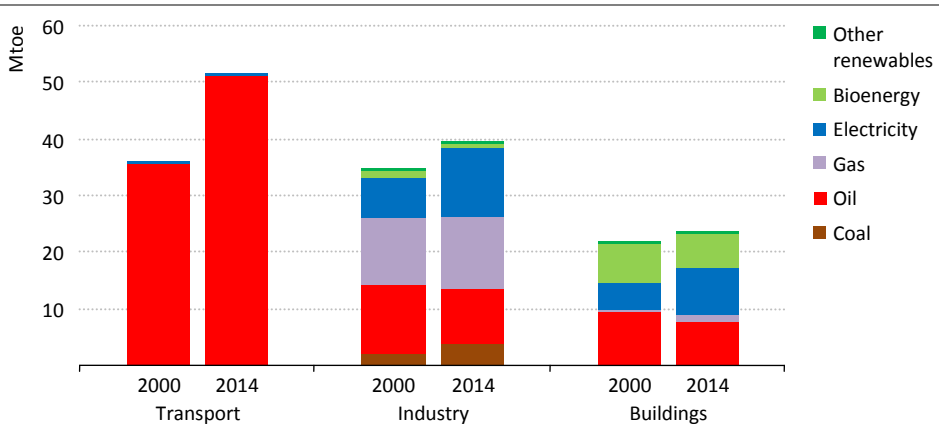
Energy demand for transport accounted for over 40% of total final consumption in 2014, significantly higher than the OECD average of 33%. The transport sector is the largest energy consumer of all end-use energy sectors in Mexico, well above industry (28%) and buildings (20%) (Figure 1.3). Energy demand for transport has been rising rapidly, at an average annual growth rate of 2.6% since 2000, as the passenger vehicle stock rose from around 9 million in 2000 to over 25 million in 2014, with rates of ownership more than doubling to over 200 vehicles per 1 000 people over the same period. Unsurprisingly, transport sector consumption is completely dominated by oil products, and the rise in demand has led to serious problems of traffic congestion and air pollution in the large cities. The policy response from the government has encompassed a range of measures (see section 1.3.4.), from tighter restrictions on the sulfur content of fuels to the “one-day-without-a-car” programme, which restricts private vehicles from circulating in Mexico City when air pollution exceeds specified levels.

Industrial energy demand² has increased by about 14% since 2000, while the contribution to GDP made by industry has grown by about 17% during the same period, meaning that industrial energy intensity, as measured by total industrial energy consumption/\$1 000 of value added by industry, has remained almost flat during the period. However, this results from the combination of two contrary trends: the continuous decline in energy intensity in the major energy-intensive industries, counterbalanced by a rise in energy intensity elsewhere. Energy-intensive industries, such as iron and steel, chemical, cement, and paper and pulp industries, accounted for 45% of industrial energy demand in 2014 and their energy intensity has declined continuously over the past twenty years. For example, the energy intensity of the iron and steel branch of the industry sector (calculated as energy consumption/tonne of steel produced) has fallen by 40%, while that of the chemical

² Industry energy demand includes blast furnace, coke ovens and petrochemical feedstocks.

industries (calculated as energy consumption/tonne of high value chemicals produced) declined by 60%. Intense global competition in commodity markets has obliged these industries to take energy-saving measures in order to compete, which has resulted in lower energy intensity.

Figure 1.3 ▶ Energy demand by fuel in selected end-use sectors



The oil-dominated transport sector is growing fast and has by far the largest share of final energy consumption in Mexico

Taking advantage of relatively low labour costs in Mexico, proximity to the large United States market and free trade agreements in the region, many large companies, notably car manufacturers and their component suppliers but also other manufacturing firms, have set up operations in Mexico. As a result, Mexico's industrial electricity consumption has increased significantly in recent years, rising by almost 70% since 2000. Electricity consumption in the central-west and north-east regions of Mexico, where many automakers, auto parts and appliance factories are located, accounts for almost half of the growth in national electricity consumption over the last ten years (SENER, 2016). Ensuring reliable electricity supply, at competitive rates, is vital to support the role of these manufacturing industries in the Mexican economy.

In the buildings sector, energy consumption has increased by just 10% since 2000. This relatively moderate growth is largely due to efficiency gains as solid biomass is displaced as a residential fuel by electricity and natural gas. Within the buildings sector, electricity demand has increased rapidly – by more than 80% since 2000 – and has become the main source of energy as the household ownership rate of appliances such as televisions and refrigerators has grown to more than 80%. Nonetheless, on a per-capita basis, electricity consumption in the residential sector is still only around one-quarter of the OECD average, highlighting the potential for additional growth as incomes rise further. This also underlines the importance of energy-saving measures in the sector: a number of programmes are underway (Box 1.1).

Box 1.1 ► “Good light” for households in Mexico

Tapping Mexico’s efficiency potential in the buildings sector is becoming an important policy priority, as rising incomes and urbanisation push up electricity consumption. Mexico has already implemented a variety of measures to foster efficiency in the buildings sectors, such as efficiency standards for lighting, appliances and insulation, although limited resources and capabilities, weak co-ordination between different levels of government and a lack of public awareness can result in indifferent enforcement of those measures. Energy efficiency standards for buildings, for example, have been developed at federal level, but local governments, which are responsible for incorporating them into local bylaws, enforcing and updating them, have limited capacity to do so.

There are, however, some positive examples of what can be undertaken, notably a massive programme for replacing inefficient light bulbs in households, known as *Ahórrate una Luz* (Save yourself a light). FIDE, a public-private fund promoting electricity savings, has launched this programme to give as many as 40 million ballasted compact fluorescent lamps (CFLs) to 8 million families in small Mexican towns (FIDE, 2016). The government expects to achieve annual savings in electricity bills and consumption of almost 2 400 gigawatt-hours (GWh), an amount corresponding to more than 3% of residential electricity consumption in 2014. As of November 2015, the programme has made steady progress towards its goal, providing 15.5 million CFLs to 3.1 million families. In addition, the government of Mexico has introduced a residential appliance replacement programme, whereby it provides subsidised loans to finance replacement of more than two million old refrigerators by more efficient ones. This is one example of a concerted effort to nurture a culture of energy saving in households.

1.2.2 Electricity

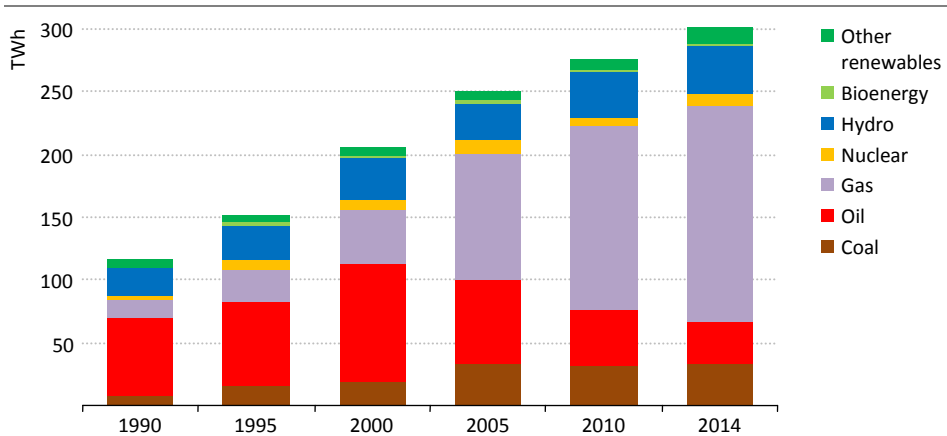
Electricity demand and supply

Electricity demand in Mexico has more than doubled over the last 20 years and in 2014 accounted for around 18% of total final energy consumption (a level consistent with the global average share, albeit slightly below the OECD average of 22%). More than 99% of the population has access to electricity, but per-capita consumption is relatively low. Among the end-use sectors, industry accounts for well over half (56%) of final electricity consumption, much higher than the average elsewhere in the OECD. However, growth in electricity demand in the buildings sector, which constitutes almost 40% of final electricity consumption, has been faster since 2000, the annual growth rate being more than 4%.

On the supply side, generation is dominated by natural gas, which has supplanted oil as the main fuel for power generation (Figure 1.4). As recently as 2000, oil accounted for almost half of total generation, but the high cost of oil-based generation and rising concerns about local air pollution have led successive administrations to promote diversification of the power mix. Already in the 1990s, policies allowing the private sector to invest in power generation as well as in natural gas transmission, distribution and storage were introduced

to encourage gas use in power generation. This resulted in 25 permits being issued for Independent Power Producer (IPP) projects for gas-fired power plants and more than 40 private companies becoming active in gas and electricity projects, the first such significant private sector participation in Mexico's electricity sector. Since 2014, IPPs generate around 30% of Mexico's electricity supply (SENER, 2016). Gas consumption for power generation has almost tripled since 2000 (while oil use has more than halved) and the share of gas-fired power generation overtook that of oil in 2003.

Figure 1.4 ▶ Electricity generation by fuel



Electricity generation in Mexico has more than doubled since 1990 and diversified away from a costly reliance on oil

Notes: TWh = terawatt-hours. Other renewables include geothermal, solar PV and wind.

As of 2015, Mexico had around 19 gigawatts (GW) of non-fossil fuel generation capacity (of a total installed capacity of 70 GW), providing around one-fifth of total generation. The largest share from non-fossil fuels comes from hydropower, followed by nuclear and wind. The main source of non-hydro renewables for power generation traditionally had been geothermal, but in recent years the contribution of wind power has grown rapidly. Renewable energy generation technologies are likely to see rapid expansion as the Reform opens investment opportunities to help meet Mexico's climate pledge and clean power targets (See section 1.3.2).

Transmission and distribution

During the past decade, the transmission and distribution (T&D) network in Mexico expanded by 2.6% on average annually. Technical losses, due to the poor state of the current network in parts of the country, are at 6% of generation in 2015. Together with non-technical losses of 7.9% due to theft, non-payment or inadequate billing arrangements, this means that 14% of the electricity fed into the T&D network is not paid for by users. This far exceeds the OECD average figure of 6.6%. The government has set the target of reducing T&D losses to 8% in 2024 and has initiated relevant programmes,

including introducing smart grid technology, replacing metering equipment, ensuring efficient billing and bringing communities with illegal connections into the formal distribution system. Since 2014, the electricity market reform has allowed private sector players to participate in public tenders to construct T&D lines and gives CFE the option of offering contracts to private sector companies to manage distribution areas.

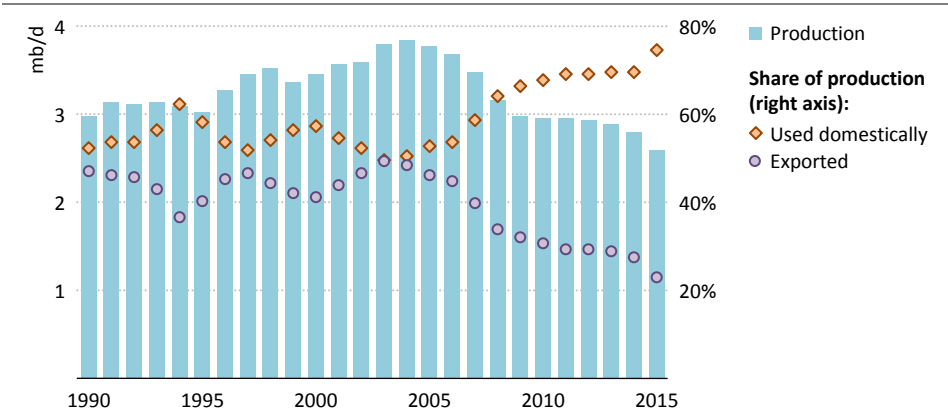
Currently there are 13 international connections between Mexico and neighbouring countries, of which 11 connections are with United States and 2 with Central America. The connections with United States consist of five for emergency purposes and six for routine exports and imports. Exports from Mexico to the United States (1 700 GWh in 2015) and imports from the United States to Mexico (1 630 GWh) are equivalent to only 4% of the volumes exchanged between the United States and Canada.

1.2.3 Energy resources, production and trade

Oil and oil products

Mexico is the eleventh-largest oil producer in the world, but has been confronted in recent years by a combination of declining oil production and rising demand. Oil production (crude and natural gas liquids) stood at 2.6 million barrels per day (mb/d) in 2015, well below the high point of 3.8 mb/d in 2004 (Figure 1.5). Overall production has been dragged down by declines at mature fields (notably the offshore Cantarell field that produced more than 2 mb/d in 2004, but where output has since fallen by over 80%) and by failure to develop sufficient new resources to compensate for these declines. The problem is not one of resource availability; Mexico has significant remaining resources, including those in deepwater and unconventional oil and gas. However, the pre-reform model that made PEMEX the sole player in oil and gas upstream development, coupled with government reliance on hydrocarbon revenue for other spending priorities, deprived the upstream of the investment and technology that it needed.

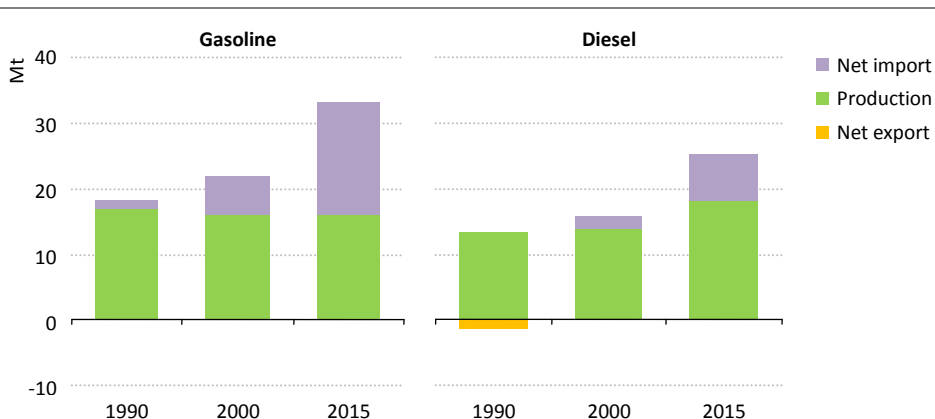
Figure 1.5 ▶ Oil production and exports, 1990-2015



Less than 25% of oil production is now exported, because of output declines and rising domestic needs

The falling trajectory of oil production and the steady rise in demand in the domestic market have squeezed the volumes of crude oil available for export: shipments fell to 1.2 mb/d in 2015 from a peak of 1.9 mb/d in 2004. Mexico's dependence on imports of refined products has also risen substantially: since 2000, net imports of gasoline and diesel have almost tripled, most of which are furnished by refineries in the United States (Figure 1.6).

Figure 1.6 ▶ Production and trade of gasoline and diesel



Rising demand for transport fuels in Mexico has been met mainly by an increase in imports from the United States

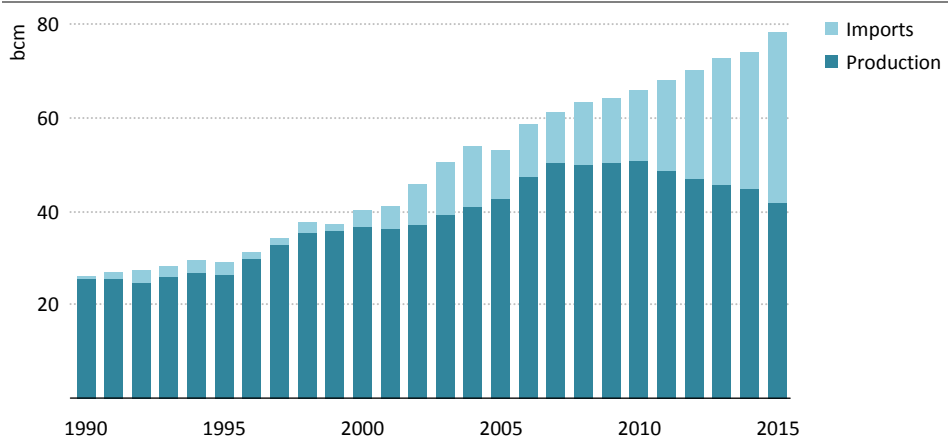
Mexico's own refinery capacity has not kept pace with the increase in domestic product demand and, in addition, some of the existing capacity is not well adapted to process Mexico's increasingly heavy crude slate. The six PEMEX refineries (with a joint capacity of 1.6 mb/d) were all built prior to 1980 and a shortage of investment capital – alongside the prohibition on private investment in oil – has stymied attempts to expand or modernise the refining sector. A partial fix for some of Mexico's refinery limitations has taken the form of joint ventures with US refiners, such as the Deer Park Shell-PEMEX refinery at the Houston Shipping Channel in Texas, which processes heavy Maya crude imported from Mexico and exports products back to the Mexican market. Over the longer term, investment in modern refinery capacity – by PEMEX and others – will be needed to avoid a further surge in product imports.

Natural gas

Around three-quarters of Mexico's natural gas production comes from associated gas and this means that gas output, like oil, has been on a declining trend in recent years. Production in 2015 was 42 billion cubic metres (bcm), down 18% from the peak in 2010 (Figure 1.7). As in the case of oil, the country's resources are sufficient to support significantly higher output of both conventional and unconventional gas. The US Department of Energy/Energy Information Administration has assessed Mexico's shale gas

potential as the sixth-largest in the world. However, the incentive to develop Mexico’s gas resources at scale has been weakened by the ready availability of gas for import, at very competitive prices, from southern US states. Gas imports from the United States have been increasing at an average annual rate of 26% over the past five years and now meet around 40% of Mexico’s natural gas demand.

Figure 1.7 ▶ Production and imports of natural gas



Gas imports to Mexico have risen sharply to compensate for declining output and to benefit from the US shale gas boom

Today there are 17 cross-border natural gas pipelines between United States and Mexico, with total transport capacity of around 50 bcm per year. Further expansion is at hand: some 20 gas pipeline construction projects are in various stages of realisation, with four projects already in the construction phase and expected to be completed in 2016 (CFE, 2016). The government of Mexico has estimated that, by 2019, gas import pipeline capacity from the United States will increase to around 100 bcm, roughly twice the current level. Mexico also has three liquefied natural gas (LNG) regasification terminals, two of which are connected to the main gas grid. Around 30% of imported gas was sourced in 2014 under long-term contracts, mainly from Qatar, Nigeria and Peru. Additional pipeline imports from the United States are expected to displace this LNG from the Mexican market, with occasional LNG cargoes being used mainly to balance any shortages in supply from pipeline imports and domestic production.

Renewable energy resources

Mexico has abundant renewable energy resources, that – with the exception of hydropower – it has barely started to tap. Hydropower capacity, now at 12.5 GW, has been a long-standing part of Mexico’s power generation mix, but arid conditions across much of the country leave relatively little scope for further expansion. By contrast, reliance on wind, geothermal and solar photovoltaic (PV) has been limited thus far, but the potential for growth is enormous and policies are increasingly supportive. The Energy Transition Law,

published in 2015, together with the Electricity Law, provides the legal framework for accelerated deployment of power generation from clean energy, which it defines as renewable sources, nuclear, high-efficiency cogeneration, waste-based generation and thermal power plants with carbon capture and storage. Two electricity auctions were held in 2016, one in March and one in September. The two auctions awarded long-term contracts for around 4.9 GW of new capacity. The outcomes indicate a possible new direction for Mexico's power mix: in both auctions, solar PV and wind accounted for almost all the energy contracts awarded.

Mexico's solar power potential is based on average daily irradiation of around 5.5 kilowatt-hours per square metre (kWh/m²) (SENER, 2012), roughly double the levels seen in Germany. While supportive policies in Germany have led to installed capacity reaching 38 GW by the end of 2015, the comparable figure for Mexico was less than 1% of this total. Efforts to develop wind power in Mexico are picking up pace; almost 3 GW of capacity are already in place and there is potential for further development across large swathes of northern and southern Mexico.

With around 900 MW of operating capacity, Mexico is the fifth-largest producer of geothermal energy in the world (after United States, Philippines, Indonesia and New Zealand). Geothermal generation capacity has been nearly flat over the last decade, but this could change in the coming years. In 2014, the Geothermal Energy Law was approved, providing a legal framework for further geothermal energy development which allows private sector participation. In July 2015, the Ministry of Energy (SENER) provided concessions to develop 13 geothermal sites to CFE, which could increase installed geothermal capacity by 450 megawatts (MW) (SENER, 2015). The prospect of these projects being fully realised are dampened by the stiff competition geothermal faces from increasingly competitive wind and solar power.

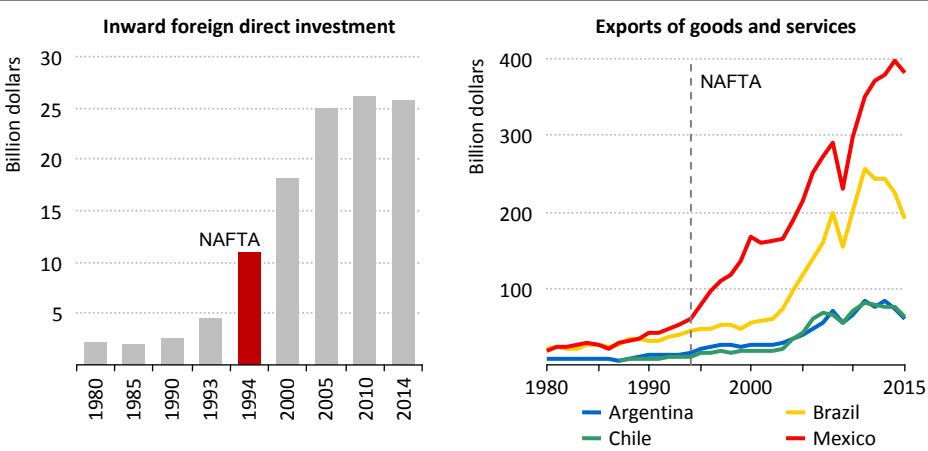
1.3 Factors affecting Mexico's energy development

1.3.1 Economy and demographics

Mexico's economy has grown by around 90% since 1990, following a profound reorganisation in the 1980s that transformed it from an inward-looking system focussed on local manufacturing, primarily with the aim of substituting imports, to a liberalised one open to foreign trade, investment and private sector participation. The signature of the North American Free Trade Agreement (NAFTA)³ with the United States and Canada in 1994 provided a second impetus that effectively shifted Mexico's economy into its modern incarnation (Figure 1.8). Non-oil exports, notably from the manufacturing sector, now account for more than 90% of export revenue (INEGI, 2014). As of 2014, Mexico was the second-largest destination for US exports (after Canada) and the third-largest exporter to the United States (after China and Canada).

³ Apart from eliminating import tariffs for several sectors, NAFTA extended protections for investors and set the mechanism for settlement of disputes.

Figure 1.8 ▶ Exports and inward foreign direct investment in Mexico and selected countries, 1980-2014



The conclusion of NAFTA in 1994 was an inflection point for Mexico's exports and inward foreign direct investment

Sources: IMF; United Nations Conference on Trade and Development.

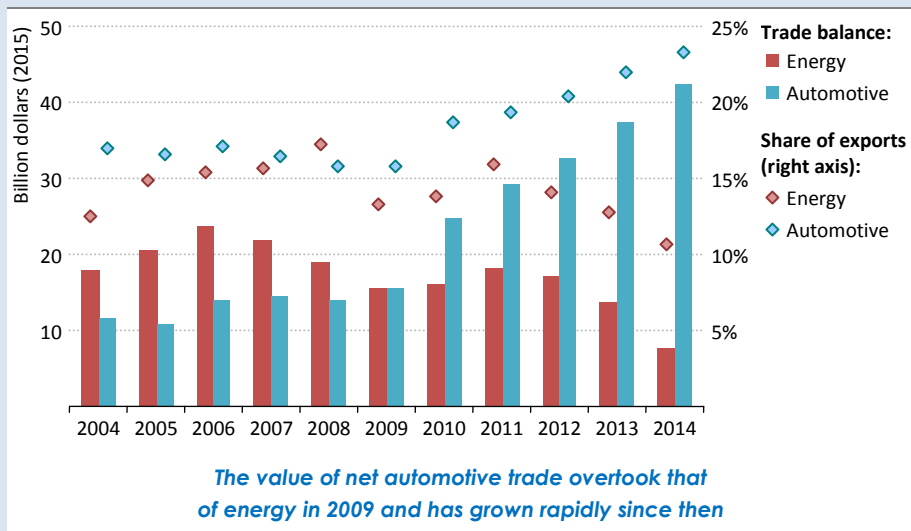
The success of the manufacturing sector rests on several factors. At the inception of the NAFTA, relatively cheap labour costs and a large neighbouring market in the US stimulated production of low value products (such as textiles). By 2000, increasing competition from China pushed Mexico into manufacturing higher value-added products such as computers, appliances, automotive parts and assembled cars (Box 1.2). Overall, Mexico's manufacturing sector has become a prime destination for inflows of foreign direct investment (FDI), which amounted to around \$30 billion in 2013. This represents around two-thirds of total FDI inflows in Mexico, far above the amount going into mineral industries (including upstream oil and gas). Manufacturing industries employ more than 5 million people, almost a quarter of total employment in 2014.

Compared with other major hydrocarbon producers, Mexico now has a much more diversified economy, making it less vulnerable to fluctuations in the oil price. This is the case also for public finance, though oil-related revenue remains an important pillar of the country's fiscal balance. Over the ten years to 2014, oil-related revenue typically accounted for between one-third and 40% of total government income (Banco de México, 2015). As a result, the fall in oil revenue since 2014 has forced fiscal consolidation and budget cuts: 2016 spending was slashed by more than Mexican pesos (MXN) 132 billion (0.7% of GDP) – much of this in the form of reductions in PEMEX's budget for capital spending. Yet the fiscal impact was softened considerably by the Reform, which since 2013 has raised revenue from non-oil sectors of the economy: non-oil tax revenue rose by around 30% in 2015, compared with the previous year (Banco de México, 2016).

Box 1.2 ▶ In Mexico's trade, cars have overtaken energy

The boom in Mexico's industrial exports has been underpinned by a meteoric rise in automobile manufacturing. The automotive sector has grown by around 12% per year since 2004 (INEGI, 2014), attracting some of the world's largest automakers and allowing Mexico to take a larger share of global automotive foreign direct investment than China in 2013 (FDi Markets, 2015). This wave of investment has turned Mexico into the world's seventh-largest manufacturer of cars and light trucks, producing more than 3 million in 2014, and the world's fourth-largest exporter, after Germany, Japan and South Korea (PROMEXICO, 2016). It has a long way to go before coming close to the level of US annual car production, which is above 11 million, but it has already overtaken Japan to become the second-largest supplier of vehicles to the US market, after Canada. Along the way, automobiles have become a more important source of export revenue than energy (Figure 1.9). As of 2014, the value of the net exports of automobile products stood at more than \$40 billion, a figure almost four-times higher than in 2005 and well ahead of the value of net exports of energy (excluding electricity), which decreased by 60% over the same period.

Figure 1.9 ▶ Trade in energy and automotive sectors, 2004-2014



Sources: World Trade Organization; IEA analysis.

Another measure that has afforded Mexico some protection against oil market volatility has been a price hedging strategy that serves as a partial check against boom-and-bust cycles. Hedging is a costly strategy that does not always bring returns; but the effect in 2015 – in return for a hedge cost in options premiums of some \$770 million – was to guarantee a price considerably higher than the market rate (around \$75/barrel versus a

market rate of less than \$50/barrel) for a share of Mexico's output. The pay out of more than \$6 billion surpassed the previous record, from 2009, when Mexico received around \$5 billion after prices plunged with the global economic crisis.

Reduced reliance on oil revenue does not mean insulation from broader global economic trends. As an economy with close trade and financial ties to the rest of the world, Mexico is exposed to the effects of any weakness in global growth or change in investor sentiment towards emerging markets. Reform in the energy sector is part of a wider set of structural reforms designed to bolster long-term growth. One challenge for Mexico is to increase its presence in industrial value chains by manufacturing more component parts within the country: currently Mexico imports around two-thirds of the intermediate products (often formed through energy-intensive processes) used in manufactured products that are subsequently exported (De La Cruz, et al., 2011). The ability of Mexico to do this rests on the ability of its firms to compete with suppliers in the United States; this, in turn, will depend heavily on the reliability and affordability of energy supply.

A strong economic and fiscal policy framework is essential to meet the needs of a growing population, which has expanded by almost 34 million since 1990 to reach 120 million. Over half of the population is under the age of 30, a young and growing labour force which provides a widening consumer and tax base. But there are challenges, including the need for the economy to create around 4 000 new jobs each day to absorb new entrants to the labour market. All the population growth has occurred in cities, often putting severe strain on the provision of infrastructure and services, as well as accentuating the problems of water stress and air quality.

1.3.2 Reform agenda and institutional framework

For much of the past eight decades, Mexico's energy sector has been constituted in the same way with state-owned companies enjoying monopolies throughout the value chain: PEMEX for upstream, midstream and downstream oil and gas; and the *Comisión Federal de Electricidad* (CFE) for power generation, T&D and retail sales. (Limited private sector participation in power generation was first allowed in 1992 through independent power projects, which were obliged to sell their electricity to CFE under long-term contracts or to sell to captive industrial customers). Reform of the energy sector has been a long-standing ambition of successive governments in Mexico. An attempt in 2008 failed because of the difficulty of making changes to three articles of the constitution (Articles 25, 27 and 28), which restricted private sector participation in oil and gas activities, and in the electricity sector.

Two enabling factors converged to allow new attempts at reform in late-2013. First, the two main political parties, the Institutional Revolutionary Party (PRI) and the National Action Party (PAN), came to an agreement that provided political backing to the agenda; and second, there was widespread recognition that PEMEX was not in a position to make the investments necessary to arrest declining production from existing fields, did not have

the technical capacity to bring new production online from deepwater and shale resources and could not provide the refinery capacity necessary to meet the country's oil product needs. Underpinning the argument for reform was a context of slow economic growth and the realisation that inefficiencies in the power sector were driving costs higher than necessary, harming the competitiveness of the manufacturing sector.

The Energy Reform package⁴ initiated in 2013 established new structures for the oil, gas and electricity industries in Mexico (Figure 1.10). Among other important changes, the Reform brought an end to the existing order in the energy sector, turning PEMEX and CFE into “state productive enterprises” whose portfolios of responsibilities (which previously included issues such as the country's energy security) have been pared back to focus on value creation. Crucially, the Reform law also ended the state monopoly on oil and gas production (though it maintains the inalienable national ownership of hydrocarbon resources) and on electricity retail sales. These changes have drastically altered the hue of policy and policymaking in Mexico, and therefore the outlook for energy prospects.

Key aspects of the constitutional amendments and the nine new secondary laws (and twelve newly amended ones) that have been passed are:

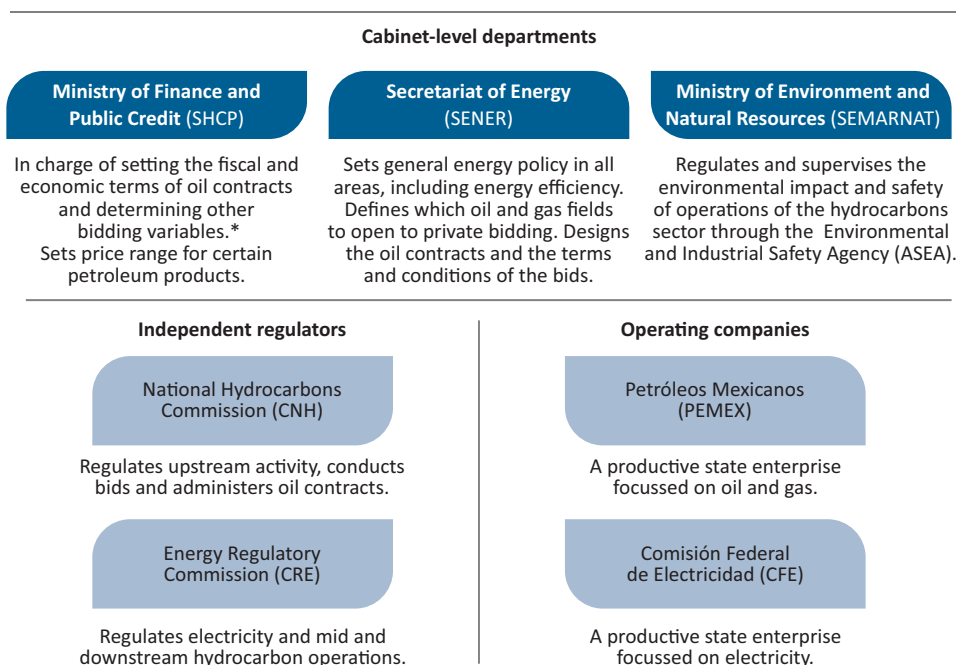
- **Electricity Law:** Creates a competitive electricity market by disaggregating the vertical structure of CFE, which since 1992 had controlled the generation market, been responsible for the operation of the national grid and exercised a monopoly over T&D. The law establishes a new regulatory regime that distributes policy, regulatory and market-control functions to SENER, the *Comisión Reguladora de Energía* (CRE) and to a newly decentralised agency *Centro Nacional de Control de Energía* (CENACE) respectively.
- **Hydrocarbons Law and Hydrocarbons Revenue Law:** Authorises and regulates the participation of the private sector in upstream activities, through the introduction of four contract types: licence contracts, production-sharing contracts, profit-sharing contracts and service agreements. The laws assign responsibilities for regulation to the *Comisión Nacional de Hidrocarburos* (CNH) and establish an independent operator, *Centro Nacional de Control de Gas Natural* (CENEGAS) for the gas pipeline network. The Hydrocarbons Law also gives SENER the authority to grant permits for: petroleum treatment and refining; processing of natural gas; import and export of crude oil, natural gas and petroleum products; and activities that were previously held exclusively by PEMEX.
- **PEMEX Law:** Codifies PEMEX's new responsibilities as a “state productive enterprise”, including its obligations to pay dividends to the newly established “Petroleum Fund for Stabilization and Development”. The law specifies a dividend of at least 30% of revenues in 2016, decreasing to 15% by 2020 and falling to 0% by 2026, by which time the Ministry of Finance and Public Credit (SHCP) will determine the dividend. The law also permits PEMEX to enter into partnerships with private companies at any point in

⁴ This report refers to the constitutional amendments and the related laws as the Reform package.

the hydrocarbon value chain and to bid for exploration and extraction blocks in tenders held by the state.

- **CFE Law:** Codifies CFE’s new responsibilities as a "state productive enterprise", including its obligation to pay dividends to the federal government and introduces a corporate governance structure that includes the creation of a board of directors with, for the first time, four independent directors.
- The establishment of the **Mexican Petroleum Fund for Stabilization and Development**, under the management of the central bank and a board comprising the ministers of finance and energy, the chairman of the central bank and four independent members nominated by the president and ratified by the senate. All royalties and resource rents from the oil and gas sector will be held in this fund. The right to withdraw from this fund to finance the government budget is capped at 4.3% of GDP.

Figure 1.10 ▶ **Main institutions influencing energy policy in Mexico**



The Reform introduced fundamental changes to energy governance in Mexico

*These include parameters such as proposals for a programme of work, which is a factor in determining the winning bidder.

Energy governance has been transformed with the Reform. A number of responsibilities that were the domain of state-owned monopolies have been transferred to independent regulatory bodies. These include the CNH and the CRE. The Reform is part of a broader vision by the government to pursue energy policies that reconcile energy security

imperatives with sustainability and efficiency considerations, and a general recognition of the need to shift to a low-carbon growth model. This underpins the National Energy Strategy (2014-2027); the Energy Transition Law (passed in December 2015) and the far-reaching climate pledge submitted in advance of the Paris COP21. The main features of Mexico's vision include:

- A commitment to increase the share of clean energy sources⁵ in power generation from 21% today to 25% by 2018, 30% by 2021 and 35% in 2024.
- A commitment to reduce greenhouse-gas emissions (GHGs) by 22% and black carbon emissions by 51% by 2030, relative to a business-as-usual scenario.

The speed at which the Reform has been implemented, as well as its extent, has surpassed the expectations of many stakeholders. It will nonetheless take time for the new institutional arrangements and responsibilities to settle, for the designated productive state enterprises to organise for their new roles, and for private and international investors to navigate their entry to the market. The full restructuring of vertically and horizontally integrated companies whose remit has been drastically altered poses particular challenges. CFE, for example, has been legally unbundled to separate network activities from power generation and now has a number of individual subsidiaries, some of which compete with each other and with private players on the wholesale market. Ensuring that CFE's restructuring is consistent with the market-oriented principles underpinning the Reform requires that effective "Chinese walls" are put in place between the subsidiaries, a process that needs to be closely controlled by the regulator. This, and other newly formed entities that will handle responsibilities bequeathed to them from the old monopolies will need to be appropriately staffed to handle their tasks to ensure that bottlenecks do not form that could delay investments. As regards upstream oil and gas investments, SENER has proven adept at reacting to successive bidding rounds by altering the terms offered to better reflect the needs of both the state and private investors. However, the successful establishment of joint ventures between PEMEX and private companies for offshore oil production will require close co-operation between many other agencies too, including CNH, SHCP and PEMEX itself. Enhanced co-ordination, as well as a continuation of a policy of reacting to signals from successive bid rounds will maximise the chances of Mexico reaching its stated targets.⁶

1.3.3 Energy prices and subsidies

Energy price liberalisation has followed two diverging tracks in Mexico, with pricing for gasoline, diesel, natural gas and LPG increasingly reflecting market realities, while the price for electricity remains below cost for residential consumers. The move towards liberalisation of gasoline and diesel pricing has been gradual: reduction of subsidies started

⁵ Clean energy resources in this regard include renewables, nuclear, high-efficiency cogeneration, waste-based generation and thermal power plants with carbon capture and storage.

⁶ An in-depth review of Mexico's energy policies currently is being conducted by the IEA. The report and its recommendations are due to be published in early 2017.

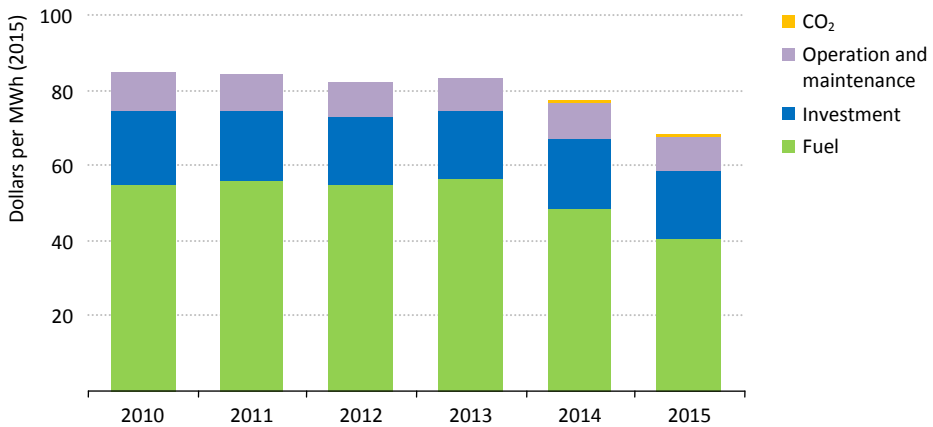
in 2008, when the government introduced weekly increases to prices, largely to alleviate the financial burden on the state (gasoline subsidies alone are estimated by SENER to have cost the state over \$20 billion in 2008). Such increases persisted until end-2014, by which time gasoline and diesel sales were generating positive earnings for the state totalling \$1.2 billion (MXN 16.5 billion) in 2014 and \$1.9 billion (MXN 30.3 billion) in 2015.

Gasoline and diesel market liberalisation feature heavily in the Energy Reform package currently being implemented. In April 2016, permits were issued for the first time allowing private companies to import gasoline and diesel, effectively ending PEMEX's monopoly over trading, storage, transportation, distribution and retailing of oil products. SHCP has proposed plans to introduce market-based pricing for gasoline and diesel in 2017. Until then, the SHCP has been tasked with setting a pricing range for products that takes into consideration the evolution of international prices and local inflation.

The price of natural gas sold by PEMEX is currently regulated by CRE, which sets prices that take into consideration the distance from the US border (for gas imported by pipeline). The Reform aims to move to a more fully market-based pricing for natural gas by end-2017, through the development of a competitive gas market in which private entities compete with the former monopoly to transport and market gas (see Chapter 2.3.3).⁷ Reform of liquefied petroleum gas (LPG) pricing has been slower, reflecting its status as a “basic consumption good” relied upon by poorer segments of society. A price cap policy has effectively been in place since 2000 (a national maximum average price is set monthly). This practice will be continued until end-2016, after which LPG prices will be liberalised.

Residential electricity tariffs in Mexico do not adequately reflect the cost of electricity supply with CFE (until recently the state-controlled monopoly) absorbing much of the loss. Two factors, lower imported natural gas prices and the increasing switch from fuel-oil to natural gas in power generation, have helped reduce the average cost of supply by almost 20% since 2013 (Figure 1.11). Part of this reduction in cost has been used to reduce subsidisation, with the remainder spread to reduce average tariffs to consumers by around 10%. The Reform has partially transferred the subsidy burden from CFE to the treasury, introducing it as an explicit item in the national budget. This will increase oversight and inject impetus into finding ways of reducing the cost of the subsidy scheme in the future. Reducing electricity costs was one of the main goals of the Energy Reform, to be achieved by the profound restructuring of the sector so as to capture efficiency improvements and lower costs through competition, as well as alleviating the cost burden of subsidies on the state (or CFE). An examination of the current cost structure shows that in certain areas, significant savings could still be made. For example, bringing down technical and non-technical losses, which are currently significantly higher than elsewhere in the OECD, would reduce the need for investment in additional generation capacity, while improvements in operational efficiency in the newly unbundled CFE could significantly reduce the retailing component of the cost structure.

⁷ *Política Pública para la Implementación del Mercado de Gas Natural* (The Gas Market Implementation Policy) was published in July 2016 by SENER, outlining short- and medium-term targets for the move towards a competitive natural gas market.

Figure 1.11 ▶ Composition of wholesale electricity costs in Mexico

Fuel switching to gas, and falling oil and natural gas prices have led to large reductions in wholesale power costs in Mexico

1.3.4 Social and environmental aspects

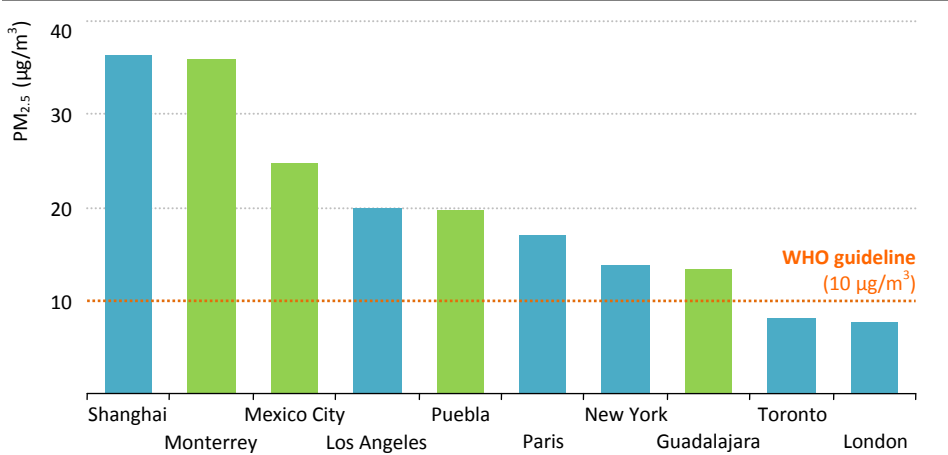
Local air pollution

High urbanisation rates, a rapid increase in demand for mobility and the dominance of liquid fuel in power generation have meant that local air pollution is a significant issue in cities across Mexico. A number of Mexico's largest cities have annual average particulate levels (PM)⁸ that far exceed the World Health Organization's (WHO) upper limit of 10 micrometres per cubic metre ($\mu\text{g}/\text{m}^3$), with Mexico City and Monterrey both more than twice this level (Figure 1.12). This can be explained, in part, by the fact that three-of-the-five-largest cities in Mexico, including Mexico City, are situated at an elevation above 2 000 metres. At this altitude, atmospheric oxygen levels can be up to one-quarter lower than at sea level, causing the incomplete combustion of fuels. This leads to higher PM and carbon monoxide emissions from cars and trucks, and partially accounts for the fact that Mexico's transport sector has a PM emissions factor that is double that of the OECD average. The government is well aware of the problem and, in its climate pledge to COP21, it highlighted air quality as a main driver for its targets. It set one of the most aggressive targets for reducing black carbon emissions (a particularly harmful component of fine PM), pledging to reduce such emissions by 51% by 2030, compared with a business-as-usual scenario.

⁸ Particulate matter is a mix of solid/liquid organic and inorganic substances that may be a primary or secondary pollutant. PM is linked to major detrimental health impacts for which size is an important factor: coarse particles are between 2.5 and 10 micrometres (μg) in diameter and fine particles are smaller than 2.5 μg . The adverse health impacts of PM₁₀ are less severe than those of the fine particles (PM_{2.5}).

In response to a growing air pollution problem that has been taking an increasing toll on public health, the government has introduced a large number of policies and controls. The General Law of Ecological Balance and Environmental Protection (LGEEPA) is the overarching legal framework for air quality improvement. It assigns responsibility for implementing programmes to reduce emissions to the federal government. In practice, local authorities design their air quality programmes and submit them to the Ministry of Environment (SEMARNAT). The primary policy, PROAIRE, currently covers 13 metropolitan regions – the country’s major urban centres. The detailed programme for each depends on the region in which it was designed, but each programme contains three components: monitoring of pollutants; annual vehicle emissions testing (with cars that fall below a certain standard being allowed to operate only four-out-of-five work days); and a contingency plan for days of particularly high pollution that can introduce a rotating ban on private car use and mandate the cessation of some manufacturing activity. These programmes have had a significant impact: in Mexico City, sulfur oxides (SO_x) and nitrogen oxides (NO_x) emissions are nearly three-times lower today than they were in 1992 (Ireland, 2014).

Figure 1.12 ▸ **PM_{2.5} levels in selected cities**



Many cities in Mexico have PM_{2.5} pollution levels well above WHO norms

Source: World Health Organization.

Land and indigenous rights

Land ownership and its use for private enterprise have historically been contentious in Mexico. Following the Mexican revolution in 1910, over half of the national territory was designated communal land and was made available to peasants and indigenous communities. Efforts at reform in the 1990s passed private title to the lands to those that had previously lived and worked on them, including provision for the new owners to lease or sell their plots, but did not drastically change the composition of ownership, as many

have chosen to retain their titles. More than 5.6 million people still live and work on 31 500 “social properties” across the country. The 2014 Hydrocarbons Law introduces measures that seek to ensure local acceptance for projects before they are started: it compels the SENER to conduct a study that takes account of the social, political, environmental and cultural specificities of a proposed area, and to ensure that consultations with indigenous populations are conducted according to the Indigenous and Tribal Peoples Convention (International Labour Organization, 1989). The law does not permit land owners (whether private or social) to refuse to either sell, exchange, rent or lease their land to energy companies that are planning projects on the land. Land owners can negotiate compensation and royalty fees (in the case of upstream oil projects, temporary occupation can be agreed under terms offering 0.5% to 2% of profits), but have no right of ultimate refusal. As well as the possibility of growing resistance to these provisions, the difficulty of proving titles to boundaries that were established nearly 100 years ago (despite the proper titling of the majority of the “social” land) raises the risk of prolonged disagreement and delays to projects.

Issues of land rights are not restricted to oil and gas projects, but can also affect renewable energy power generation projects. The current auction process does not require firms bidding for clean energy supply contracts to have obtained all the necessary permits that would allow their projects to proceed. This is the case in the Yucatan Peninsula, where most of the solar capacity was awarded in the first electricity auction in March 2016 and where there are significant historical sites and indigenous communities. Engagement with local communities is indispensable to a positive outcome: in Oaxaca, an area with considerable wind resources (but also with an important tradition of active social and indigenous movements), a project to install 132 wind turbines, with a total capacity of 396 MW, has encountered repeated challenges despite an eight month preliminary consultation period (the first of its kind).

Water

Nearly two-thirds of Mexico is categorised as arid or semi-arid. The least water-stressed areas hold a relatively small share of the country’s population and make only a limited contribution to economic output. Northern and central Mexico, which together hold 77% of the population and contribute 85% of GDP, hold only 32% of the country’s renewable water resources.⁹ Annual water demand of around 80 bcm is significantly greater than Mexico’s sustainable supply of around 67 billion cubic metres, with the deficit met through unsustainable withdrawals. The issue is multifaceted. In Mexico City, for example, demand for water has doubled every twenty years, at a rate exceeding that of population growth, suggesting that losses, increased connections to the water supply network and increased per-capita consumption (associated with increased affluence) all play a part. To meet demand, Mexico City has to withdraw water from ever more distant sources, often over 100 km away (Valdez, et al., 2016). This imposes a considerable energy cost on the system:

⁹ This refers to surface and groundwater resources generated via the hydrological cycle.

at 4.5 kilowatt-hours per cubic metre (kWh/m³), water transported from a distance uses almost 20-times the amount of energy as that withdrawn from aquifers below the city. Put another way, despite contributing only 18% to supply, imported water consumes almost two-thirds of the electricity associated with the supply of water through the municipal network. The over-exploitation of underground aquifers under Mexico City is also contributing to the city's gradual subsidence (considered to be one of the most severe cases in the world). Among the impacts is that sub-surface pipes are being damaged, contributing to increased losses. Water stress could be a significant constraint on the exploitation of energy resources in Mexico, particularly of unconventional gas in the north. Some of the most promising resources are thought to be an extension of the Eagle Ford formation, which stretches into Coahuila state, Mexico's second-driest, which has a water stress index of 77% (meaning that 77% of the renewable water resources in the area are already allocated).

Climate change

Mexico is judged to be highly vulnerable to the negative impacts of climate change, particularly to the impacts of rising sea levels, increases in average temperatures and the increased frequency of severe weather events such as cyclones, hurricanes and droughts (90% of the country suffered drought in 2011). The greater vulnerability of low-income segments of the population to disasters, combined with increased exposure to climate risks, means that 319 municipalities (13% of the country) are considered "highly vulnerable" to climate change. More than two-thirds of Mexico's population have been impacted by a natural disaster in their lifetime. The National Climate Change Strategy recognises that 46% of PEMEX's infrastructure and over 30% of CFE's transmission lines are vulnerable to the impacts of climate change.

Mexico's CO₂ emissions profile is heavily skewed towards transport, which accounted for 35% of the total in 2014, and the power sector (32%). The ongoing effort to switch from oil- to gas-fired generation has reduced the carbon intensity of the sector by 23% since 2000 and further improvements are expected. The oil and gas sector is a significant emitter of methane, a potent greenhouse gas.

Although a country with a large endowment of oil and gas resources, Mexico has also been among the world leaders in integrating climate change objectives into policymaking. It was the second country in the world to pass a Climate Change Law (in 2012) which stipulates that the country should cut greenhouse-gas emissions by 30% by 2020 (rising to 50% in 2050) compared with levels in 2000, preferably by means of cost-effective actions that create co-benefits for the population. Mexico's climate pledge, submitted in advance of COP21 in 2015, further strengthens the commitment to reduce GHG emissions and follow a low-carbon and resilient path (See section 1.3.2.). It includes goals to reduce the emissions of short-lived climate forcers and contaminants, which have a direct impact on air quality and human health. GHG emissions would need to peak by 2026 in the mitigation scenario and start decreasing from then, with the emissions intensity of the economy needing to be reduced by 40% (compared with 2013 levels) by 2030.

A large part of the expected emissions reductions are dependent on actions in the energy sector, including increasing the share of clean energy in power generation to 35% by 2024 and 40% by 2035 and controlling methane leaks in the upstream hydrocarbon sector. In this regard, Mexico made a standing commitment during the 2016 North American Leaders' Summit to reduce its methane emissions by 40-45% relative to 2012 levels by 2025. Studies by ICF have shown that Mexico could significantly reduce its methane emissions from the oil and gas sector by targeting four known areas: offshore venting, leaking oil tanks, uncontrolled condensate tanks and reciprocating compressor seals (ICF International, 2015). Abatement in these areas is also shown to be cost effective; 54% of the onshore and offshore emissions reductions can be achieved at a net total cost of Mexican pesos 0.43 per million cubic feet (MXN/mcf) (\$0.03/mcf) of methane reduced or for less than MXN 0.01/mcf of gas produced nationwide. This requires a capital investment of an estimated MXN 1.6 billion (\$106 million). However, the cost of methane abatement projects remains uncertain, and PEMEX's strained budget may make allocation of capital towards such projects challenging, particularly in the short term.

A carbon tax was placed on fuels in 2014, with the price set according to the carbon content of each fuel. The current price range is \$0.33 per tonne of CO₂ (tCO₂) to \$2.66/tCO₂.¹⁰ There is also broad recognition of the opportunities that energy efficiency measures offer in reaching Mexico's targets, including through improving the sustainability of buildings, harmonising the standards for vehicles and equipment traded through NAFTA, and promoting sustainable transport.

1.3.5 Investment

Investment in energy supply in Mexico over the last 15 years has averaged, in our estimation, around \$30 billion per year, with oil and gas investments accounting for 80% of the total. This skew towards oil and gas projects means that investment is highly sensitive to oil price fluctuations. Despite accounting for the vast majority of supply investment, spending on upstream oil and gas projects is widely considered to have fallen well short of what is required, as illustrated by the 900 thousand barrels per day (kb/d) decrease in oil production since 2000 (see section 1.2.3.). The majority of the investment burden fell on PEMEX, whose own budget has been hit by falling production and prices, setting in motion a self-perpetuating cycle of low investment, low revenue and low production (Box 1.3). Reversing this trend is one of the primary motivations for the Energy Reform.

Under a "Round Zero" held in 2014, before the start of the open licensing rounds, PEMEX requested and was allocated a substantial part of Mexico's hydrocarbon resource, mainly in shallow water and onshore areas where it has existing operations, but also including some deepwater and unconventional acreage. The remainder (and any part of PEMEX's allocation that it chooses to develop jointly) is open in principle to other companies. The Reform legislation opens five ways in which private investors can take part in the development of

¹⁰ Using an exchange rate of MXN 18.77 to 1 US dollar.

Mexico's oil and gas resources, in all cases after pre-qualification and taking part in a bidding process, conducted by CNH, except that service contracts can be agreed directly with PEMEX.

- Licence contracts: allow a company to book ownership of oil or gas assets (for financial purposes) at the wellhead after it has paid its tax dues, with the company paying a signing bonus, payments during exploration and royalties on production.
- Production-sharing contracts: allow a company to recover costs and a share of the operating profit, received as a portion of the oil or gas extracted.
- Profit-sharing contracts: allow a company to recover costs and a share of the profit, after it has marketed and sold the resource.
- Service contracts: a company is paid for specified project activities on behalf of PEMEX or the state.
- Farm-outs/migrations: allow a company to enter into a joint venture agreement with PEMEX in a project that has already seen exploration and production efforts.

In 2015, three phases of bidding under a "Round One" auction successfully awarded rights to 30 fields to a mix of local and international investors. Encouragingly, the Round One phases have been progressively more successful, reflecting the willingness of the authorities to listen to feedback from the private sector regarding the terms which will encourage investment. A critically important fourth phase, set to offer ten promising deepwater exploration areas, is due in December 2016. There has been a step-change in the amount of offshore seismic survey work conducted in Mexico since 2014, a tangible demonstration of private and international interest in the country's resource potential. Alongside the plans for conventional oil and gas, the government has also announced its intention to develop Mexico's unconventional resources. The bidding schedule for unconventional acreage has been subject to revision, but there is a strong intention to auction promising shale blocks.

Mexico's intention of attracting foreign and private capital into the energy sector is not confined to the oil and gas sector. The power sector is undergoing two transformations. The first is to bring about the reduction of oil-based generation in the short term (due to be completed by end-2017). The second is to ensure that future growth corresponds with the government's climate and environmental objectives, through the promotion of clean energy. In its efforts to attract the necessary investment in generation, the Reform has introduced various market instruments that aim to provide at least a measure of the long-term certainty sought by investors, including price signals and setting a value for clean energy. The measures taken include:

- Formation of a generation capacity market, designed to ensure capacity adequacy through remuneration of the fixed costs that are not recovered on the energy market.
- Establishment of Clean Energy Certificates as an integral part of the electricity market design. These aim to ensure the development of clean electricity generation by providing a source of income for clean energy electricity producers, to supplement revenue from selling electricity and capacity.

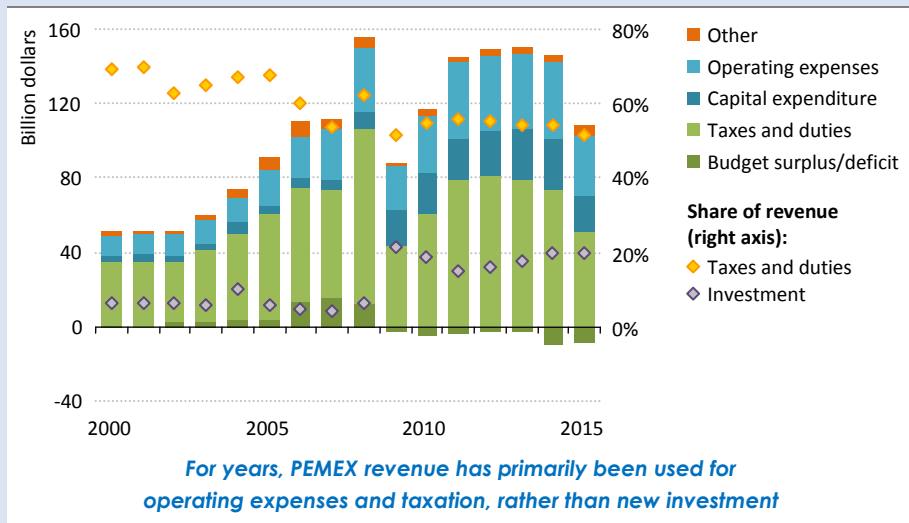
- Provision for long-term contracts and auctions, locking in prices for generators of clean energy (for a period of 15 year), capacity (15 years) and Clean Energy Certificates (20 years).

As noted, Mexico has already attracted investment into its newly liberalised power sector. Two electricity auctions held in 2016 have awarded contracts for around 4.9 GW of generation capacity to private investors (including several global players). The associated investment is expected to reach \$6.6 billion by 2018, equivalent to almost three-times the average annual investment in power generation since 2000.

Box 1.3 ► PEMEX in transition

One of the aims of the Reform process is to transform the national oil company, PEMEX, into a “state productive enterprise” that would increasingly be subject to standard market and commercial disciplines. This transition was initially envisaged at a time of triple-digit oil prices: it has become both more urgent, and much more complex, in a lower price environment. PEMEX faces considerable financial challenges, reporting a full-year net income loss of \$25 billion in 2015, and is looking at opportunities to reduce its spending by deferring some projects (including expensive deepwater projects) and cutting overheads and workforce. Despite assistance from the government, including a \$4.2 billion aid package in April 2016 and reductions in its tax obligations, the decline in the company’s oil production is adding to the pressure on its finances.

Figure 1.13 ► PEMEX revenue and expenditure, 2000-2015



Note: Other includes finance costs, other operations, products for resale and other capital transfers from government.

Sources: PEMEX; IEA analysis.

Despite the difficult market conditions, some improvement has been achieved in recent years. The legacy of under-investment has been tackled with increases in capital spending between 2010 and 2014. The share of revenue going to taxes has fallen from around 70% in the early 2000s to about 50% currently. PEMEX is also intensifying efforts to make operational savings, although this is the area that remains most resistant to change. The overall Energy Reform process will increase the competitive pressure on PEMEX, but also open up new opportunities. The company will gradually migrate towards a more standard tax and corporate structure. It also now has the possibility to create joint ventures with companies able to offer capital, specialised technologies or operational expertise, or to farm out selected fields.

1.4 Projecting future developments

The projections in our *Mexico Energy Outlook* (the results of which are set out in Chapter 2) look out to 2040 and are derived from the overall methodological approach used in the *World Energy Outlook-2016*.¹¹ The central scenario in this *Outlook* is the **New Policies Scenario**. It takes into account existing policies and measures as well as Mexico's announced policy intentions. It therefore incorporates both existing progress and future intentions expressed in Mexico's Energy Reform programme, as well as other targets for the future, e.g. those related to clean energy and GHG emissions reductions. Where policy intentions are not backed by clearly defined implementing measures, then our assessment of possible regulatory, market, infrastructure and financing constraints determines how far and how fast these intentions are met.

We also refer to two additional scenarios modelled in *WEO-2016* and one case developed specifically for this report. The **Current Policies Scenario** depicts a path for Mexico shorn of all policy intentions that, as of mid-2016, had yet to be expressed in specific implementing measures. No allowance is made for changes in policies or measures beyond this point, regardless of announced intentions. The Current Policies Scenario can therefore be considered as the "default setting" for Mexico's energy system, with little or no change compared with what has already been agreed and settled. Its results provide a benchmark against which the impact of "new" policies can be measured. The **450 Scenario** describes a world in which countries take concerted action to limit the rise in global average temperatures to less than 2 degrees Celsius; at global level it sees an early peak and subsequent decline in global energy-related CO₂. The additional case, specific to this analysis, is the **No Reform Case**. This is an illustrative counter-factual case that deliberately seeks to portray what might have happened to Mexico in the absence of the Energy Reform announced in 2013. This case retains the pre-reform positions of PEMEX and CFE in Mexico's energy system and limits the extent to which new investment and technology can

¹¹ Chapter 1 of *WEO-2016*, which describes the scope of the analytical work and the underlying assumptions and price trajectories used, is available online at www.worldenergyoutlook.org (from 16 November 2016).

be attracted to these sectors. It provides an alternative baseline against which the impacts of the entire Reform process can be assessed and measured.

The data used in this modelling work was primarily sourced from IEA databases of energy and economic statistics, which were supplemented by data from governments, international organisations, energy companies, consulting companies and financial institutions. Data provided directly by SENER and other Mexican institutions have been invaluable. The starting year for the most of the projections is 2014, as reliable energy data were available only up to 2014 at the time of the modelling. However, where more recent data are available even on preliminary basis, they have been incorporated.

Economic growth

As in most other countries, economic growth is the principal driver of energy demand in Mexico. The GDP of Mexico has increased by more than 30% since 2000, reaching \$2.2 trillion in 2014 (expressed in year-2015 dollars and in terms of purchasing power parity [PPP]). Mexico has enjoyed stable economic growth since 2000, with annual GDP growth averaging 2.1%, higher than the OECD average of 1.6%. In our projections, GDP growth assumptions are the same as in the main *WEO-2016* scenarios (New Policies Scenario, Current Policies Scenario, 450 Scenario) and are based primarily on International Monetary Fund (IMF) projections. GDP is assumed to grow by 3.1% over the period from 2015 to 2040, with prospects for growth and improvements in productivity (Table 1.1). By 2040, the size of the economy more than doubles to \$4.8 trillion (year-2015 dollars, PPP terms). Average per-capita income rises from \$18 000 to \$32 000 by 2040.

Table 1.1 ► GDP assumptions in Mexico*

	GDP*		CAAGR**	Per-capita GDP		CAAGR**
	(\$2015 billion, PPP)			(\$2015, PPP)		
	2014	2040	2014-40	2014	2040	2014-40
Mexico	2 172	4 774	3.1%	18 127	31 665	2.2%
OECD	50 293	81 374	1.9%	39 525	58 372	1.5%
World	110 370	265 292	3.4%	15 213	28 987	2.5%

*Calculated based on GDP expressed in PPP terms. **Compound average annual growth rate.

The GDP assumptions used for Mexico reflect a methodology that is used uniformly across all countries in the *WEO-2016* analysis. They do, though, result in a compound annual average rate of growth that is lower than that used to generate SENER's central case for Mexico's energy development. We therefore conducted a sensitivity analysis for our energy projections in an **Enhanced Growth Case**, presented in Chapter 2, which uses a higher assumption of GDP. The No Reform Case, by contrast, has a slightly lower GDP outlook than that used in the main *WEO-2016* analysis: compound annual average growth of 2.9% to 2040 compared with 3.1% in New Policies Scenario. This differential was calculated by coupling the results of the IEA's World Energy Model with the OECD's computable general equilibrium model, ENV-LINKAGES.

Demographic trends

Demographic change is another important driver of energy demand and the pattern of energy use. Our assumed population growth rates are based on the medium-variant of the latest UN projections (UNPD, 2015). The population of Mexico in 2014 is estimated to have been 120 million and grows to more than 150 million in 2040, an annual average rate of 0.9%, a growth rate more than twice as fast as the OECD average. The population of those living in urban areas grows at an annual average rate of 1.2% and by 2040, around 130 million people, corresponding to almost 85% of total population, live in urban areas in Mexico. The working age population, aged between 15 years and 64 years, continues to grow during our projection period.

Energy prices

In the New Policies Scenario, we assume that energy prices (except electricity) are determined on the basis of global market prices, reflecting the government's intention to liberalise energy markets as a part of the Energy Reform. For example, the prices of oil products such as gasoline and diesel, as well as LPG, are assumed to be deregulated in 2017. Natural gas prices are assumed to remain linked to prevailing import prices, in particular US market prices, with the relevant transmission cost added, and are not regulated in retail marketing. In the case of electricity tariffs, we assume in the New Policies Scenario a gradual phase out of subsidies by 2035, helped by cost reductions in the power sector that come as a result of efficiency gains related to the Reform, a progressive tariff structure and greater disclosure of existing subsidies in the government budget, which will help the government to rationalise them in the long run and meet international commitments made in the G20.¹² International energy prices are taken from the broader *WEO-2016* modelling (see Chapter 1 of *WEO-2016*).

Policies

As a part of broader reforms such as those relating to climate change and clean energy, Mexico has set targets and initiated policies affecting many energy policy areas. Some of the key energy targets and policies assumed in the New Policies Scenario are listed in Table 1.2.

¹² G20 leaders reaffirmed their commitment to rationalise and phase out inefficient fossil-fuel subsidies at a G20 meeting held in China in 2016.

Table 1.2 ▶ Selected key energy policies and targets in Mexico

Energy supply
<ul style="list-style-type: none"> ■ Constitutional amendments and subsequent legislation to attract investment and modernise the energy sector, which allows the private sector to participate in oil and gas upstream, mid and downstream sectors. ■ Exploration and production based on the Five-Year Plan and new contracting schemes.
Cross-cutting policies
<ul style="list-style-type: none"> ■ Reduce GHG emissions by 25% compared with business-as-usual by 2030. ■ The National Program for Sustainable Use of Energy to promote optimal use of energy and reduce energy intensity in all sectors, formulated on the basis of the Energy Transition Law. ■ Excise (carbon) taxes for oil products, such as gasoline, diesel and fuel-oil. ■ Prices of gasoline, diesel and LPG are liberalised in 2017.
Power sector
<ul style="list-style-type: none"> ■ Development of wholesale power market and establishment of CFE as a modified state enterprise, unbundled into power generation, T&D, load-serving entities and retail sectors to promote efficiency and competition. ■ Development of generation capacities and T&D networks based on the Development Program of the National Electric System 2016-2030. ■ Clean energy share of 25% in total electricity generation by 2018, 30% by 2021 and 35% by 2024. (Clean energy, defined by the Electricity Law, includes renewables, efficient cogeneration, nuclear and thermal power plants with carbon capture and storage). ■ Clean Energy Certificates which will provide additional revenues from selling electricity and development of wholesale market auctions. ■ Other incentives for clean energy, such as tax relief, soft loans and net metering schemes. ■ Enhanced efforts to strengthen the national grid and reduce T&D losses to 8% by 2024.
Transport
<ul style="list-style-type: none"> ■ National standard for fuel economy and carbon emissions standard for light-weight vehicles.
Industry
<ul style="list-style-type: none"> ■ Voluntary energy management systems in large industries and energy efficiency programmes for small- and medium-size enterprises. ■ National standard for motor efficiency.
Buildings
<ul style="list-style-type: none"> ■ National standards for energy efficiency for building envelope and building components, such as thermal insulation and appliances. ■ Development of an energy efficiency code for buildings to promote the adoption of relevant building codes by local governments. ■ Replacement programmes for inefficient lightings and appliances. ■ Soft loans to sustainable housing.

Energy Outlook in Mexico to 2040

A clean break with the past?

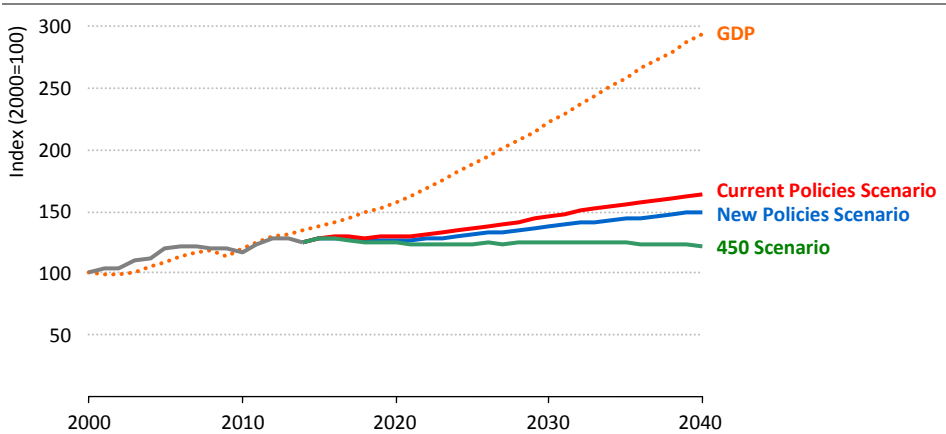
Highlights

- Mexico's economy expands to well over twice its current size in our projections to 2040, but total energy demand increases by only around 20%, highlighting a significant decoupling of energy demand from economic output. In the New Policies Scenario – our central scenario – almost all of the growth in demand is met by natural gas and renewables. The share of oil falls from 51% today to 42% in 2040: increased demand for transport and petrochemicals is offset by reduced use in power generation and the residential sector.
- Electricity demand grows robustly, by 85%. The largest growth comes from the buildings sector, but industry remains the largest consumer. The role of gas and low-carbon sources in lifting generation from 300 TWh to more than 500 TWh by 2040 heralds a sharp reduction in the greenhouse-gas emissions intensity of the power sector. Solar PV and wind account for around half of total investment in generation and half of generating capacity additions over the period, helping Mexico to achieve its long-term targets for electricity generation from clean power sources. CO₂ emissions from power generation are around 20% lower in 2040 than in 2014.
- In the end-use sectors, residential consumption of electricity almost doubles between 2014 and 2040. Rising incomes and living standards feed through into higher ownership levels of a range of appliances with demand for cooling increasing three-fold. Efficiency policies in buildings and industry are increasingly effective in tempering the rise in demand. The passenger vehicle stock grows by around half over the period to 2040, but improvements in fuel economy limit the impact on oil demand. The same is not true for road freight: trucks account for 13% of transport energy demand but, on the assumptions of our New Policies Scenario, generate more than half of the rise in transport energy demand to 2040.
- The outlook for developing Mexico's oil and gas resources has been re-shaped by the *Reforma Energética* (Energy Reform). The decline in total oil production bottoms out in 2018 at 2.3 mb/d, before climbing to 3.4 mb/d by 2040. Gas production follows a similar trajectory to oil, as much of the output is associated gas; but towards the end of the projection period, Mexico starts to see larger scale development of its considerable shale gas resources. Total gas production rises to 60 bcm, but Mexico remains a sizeable importer of gas from the United States throughout the period to 2040, benefiting from the availability of competitively priced imports. As Mexico's natural gas use increases, so does the importance of good interconnections and market operation, and gas storage to meet fluctuations in demand.

2.1 Pathways for Mexico’s energy development

In the New Policies Scenario, the central scenario presented in the *World Energy Outlook*, Mexico’s primary energy demand increases by around 20% in total between 2014 and 2040, the growth rate averaging 0.7% per year. In all of our global scenarios (the New Policies Scenario, Current Policies Scenario and 450 Scenario), energy demand growth decouples from economic growth (Figure 2.1), reflecting a structural shift in the economy that sees a growing prominence of the services sector and energy efficiency improvements over the projection period. Another trend common across the scenarios is robust growth of electricity demand. This surpasses the pace of growth in primary energy demand, with annual average growth ranging between 1.7% and 2.7% (Table 2.1). More than 99% of the population already has access to electricity, and an increasing population, rising incomes and a growing middle class, coupled with intensified urbanisation, underpins the increase in power demand.

Figure 2.1 ▶ **Primary energy demand and GDP in Mexico by scenario, 2000-2040** (indexed to 2000 level)



Mexico’s primary energy demand decouples from the anticipated rise in GDP

Energy demand in Mexico has historically been highly correlated to economic growth and, although this relationship is set to weaken in the future, gross domestic product (GDP) will remain an integral contributor to energy demand. As described in Chapter 1, our global GDP outlook in the New Policies Scenario is based on annual average economic growth of 3.1% between now and 2040. This falls within the range of the scenarios considered in the *Programa De Desarrollo Del Sistema Eléctrico Nacional* (PRODESEN), the Mexican national electricity system development plan, but is lower than the plan’s central scenario (which projects 4% economic growth per year for the period to 2029). For this reason, we have also considered an alternative trajectory for Mexico in an Enhanced Growth Case. In that case the economy grows at an annual average of 4% to 2029, before slowing somewhat thereafter. The same assumptions regarding policies and the *Reforma Energética* (Energy Reform) apply as in the New Policies Scenario.

Table 2.1 ▶ Mexico key indicators in selected scenarios

	2014	New Policies Scenario		Current Policies Scenario		450 Scenario	
		2025	2040	2025	2040	2025	2040
Primary energy demand (Mtoe)	188	196	225	204	246	186	184
Share of fossil fuels (%)	92	89	86	89	88	87	74
Final consumption (Mtoe)	118	134	156	139	169	128	132
Electricity demand (TWh)	248	326	459	338	490	296	380
Energy intensity of GDP (2014 = 100)	100	75	54	78	60	71	44
Carbon intensity of power (2014 = 100)	100	64	48	66	53	59	27

Note: Mtoe = million tonnes of oil equivalent; TWh = terawatt-hours.

In the Enhanced Growth Case, the rise in primary energy demand is 1% on average annually, a pace significantly faster than in the New Policies Scenario (0.7%), while the carbon intensity of the power sector remains comparable to that in the New Policies Scenario, as renewables grow strongly and Mexico successfully achieves its clean energy targets (Table 2.2). This highlights the importance of a reformed power system in facilitating the transition to a low-carbon economy. Electricity demand in the Enhanced Growth Case grows by 2.8% on average annually, a growth rate comparable to that projected in the PRODESEN.

Table 2.2 ▶ Mexico key indicators: New Policies Scenario and sensitivity cases

	2014	New Policies Scenario		Enhanced GDP Case		No Reform Case	
		2025	2040	2025	2040	2025	2040
Primary energy demand (Mtoe)	188	196	225	207	245	200	226
Share of fossil fuels (%)	92	89	86	89	86	91	87
Final consumption (Mtoe)	118	134	156	144	174	134	155
Electricity demand (TWh)	248	326	459	344	505	327	450
Energy intensity of GDP (2014 = 100)	100	75	54	72	52	77	57
Carbon intensity of power (2014 = 100)	100	64	48	63	48	77	57

The policy changes stemming from the Reform are at the core of the projections in the New Policies Scenario (and in the Enhanced Growth Case). But in order to illustrate the importance of the Reform on the energy sector and the economy as a whole, we consider a No Reform Case, discussed in Chapter 3. This extreme hypothesis traces an alternative trajectory for Mexico in which the reforms do not take place – even those already translated into adopted policy measures. For example, *Petróleos Mexicanos* (PEMEX) retains its monopoly position in the oil and gas sectors, and there are no changes to *Comisión Federal de Electricidad* (CFE)'s structure or role in the power sector. Our analysis

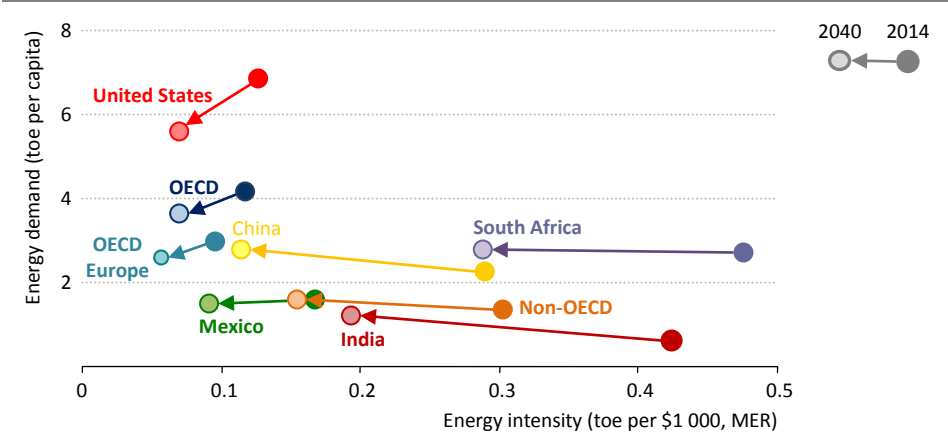
is coupled with a broader general equilibrium model for the economy, permitting our analysis of the outlook for oil, gas, electricity and other fuels to be accompanied by some wider reflections on the repercussions for growth in different parts of Mexico’s economy.

2.2 Outlook by sector in the New Policies Scenario

2.2.1 Overview

In the New Policies Scenario, Mexico follows the trend of the OECD in general in being successful in loosening the ties between economic growth and energy consumption (Figure 2.2): by 2040 energy intensity declines by around 50%. This trend reflects a shift in the structure of the economy, with the services sector accounting for an increasing share of value added and considerable energy efficiency gains in industrial activity. Over the same period, primary energy demand per capita remains broadly stable, reflecting two trends that counteract each other. Demand for per-capita energy services increases as incomes rise, but the power sector (in particular) uses less energy per unit of electricity supplied, as the electricity mix switches to more efficient sources of power generation and the network delivers power to end-users with fewer losses along the way.

Figure 2.2 ▶ Energy intensity and per-capita energy demand for selected countries, 2014 and 2040



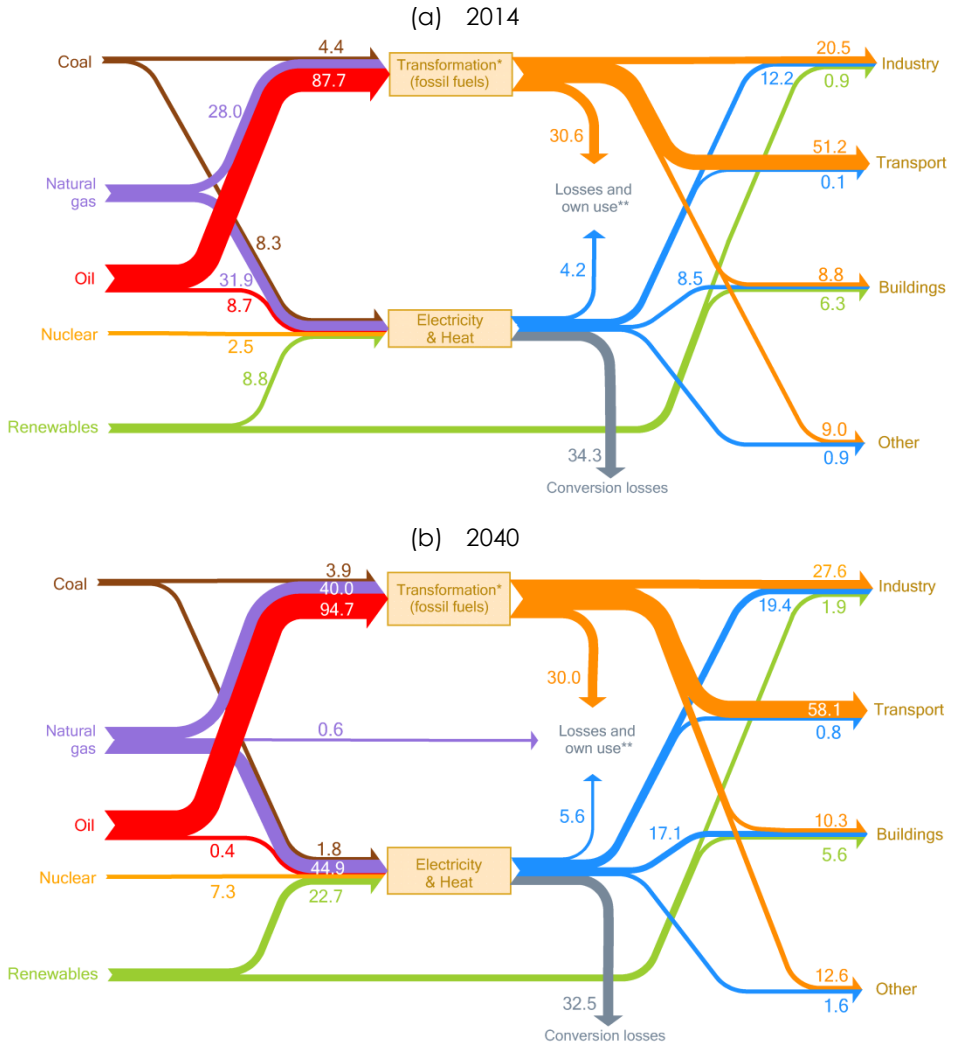
Improvements in the energy intensity of Mexico's GDP bring it in line with today's OECD average, while keeping per-capita demand flat

Note: toe = tonne of oil equivalent; MER = market exchange rate.

The features which characterised the evolution of the energy mix in Mexico over the past decade continue to be seen in our projection (Figure 2.3). Most notably, the shift continues from oil to natural gas, primarily in power generation, increasing the share of gas in total primary energy demand to 38% in 2040 (from 32% in 2014), while reducing the share of oil from 51% to 42%. Nonetheless, oil continues to be the principal source of energy in Mexico

over the projection period, with transport, the largest energy-using end-use sector, accounting for around 60% of oil consumption. Coal consumption decreases by 55% by 2040, as some coal-fired power plants are retired and only small coal-fired capacity additions are made.

Figure 2.3 ▶ Mexico domestic energy balance, 2014 and 2040 (Mtoe)



Mexico's domestic energy balance in the New Policies Scenario highlights the expansion and diversification of the system

* Transformation of fossil fuels (e.g. oil refining) into a form that can be used in the final consuming sectors.

** Includes fuel consumed in oil and gas production, transformation losses and own use, generation lost or consumed in the process of electricity production, and transmission and distribution losses.

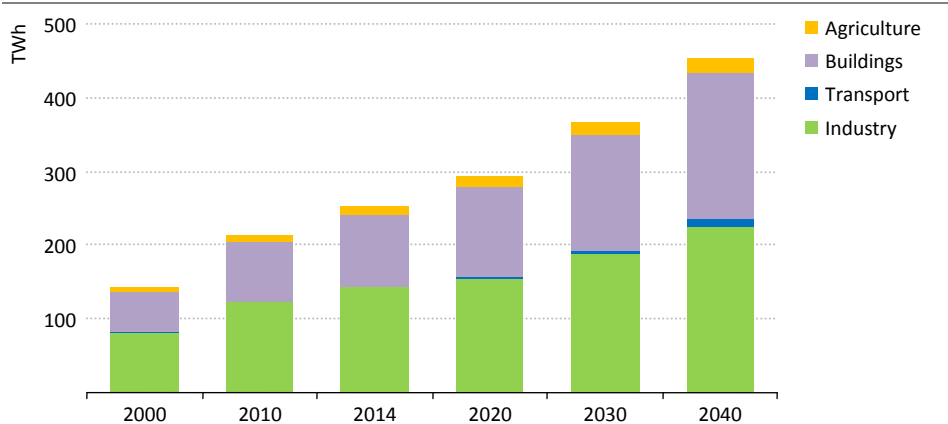
Renewable energy supply grows relatively fast, in line with Mexico’s commitment to utilise wind and solar to reduce the energy sector’s carbon footprint. The share of renewables in total primary energy demand increases from around 9% in 2014 to 14% in 2040. The share of bioenergy, used mainly in residential cooking and water heating, remains relatively stable over the projection period, as increased use in power generation and industry is offset by reduced use of solid biomass in households. Despite the rise in renewables, fossil fuels still remain the dominant source of energy, accounting for 83% of total primary energy demand in 2040.

2.2.2 Power sector

Electricity demand

Electricity demand in Mexico grows at an annual average rate of 2.4% between 2014 and 2040 in the New Policies Scenario, a pace that is more than three-times faster than the OECD average. Consequently, per-capita electricity demand also grows by around 50% from 2014 to 2040. Industry remains (just) the largest electricity-consuming sector, accounting for 50% of electricity demand in 2040, although this represents a decrease from over 56% in 2014 (Figure 2.4). Demand for electricity in non energy-intensive industries, composed of a range of entities including small- and medium-size enterprises (SMEs), accounts for 85% of the increase in industrial electricity demand between 2014 and 2040.

Figure 2.4 ▶ **Electricity demand by sector in Mexico in the New Policies Scenario**



Industry remains the largest electricity user in Mexico in the New Policies Scenario, although buildings sector demand rises more quickly

Note: TWh = terawatt-hours.

The largest growth in electricity consumption arises in the building sector (residential and services), which accounts for half of the total increase in final electricity consumption to 2040. The largest share of this increase comes from residential consumers, due to the

steady rise in the ownership and use of appliances: residential consumption for electrical appliances almost doubles between now and 2040. Demand for cooling in households grows particularly rapidly, more than tripling over our projection period, as ownership and use of air conditioners expands with rising incomes and living standards. Electricity consumption in the transport sector rapidly increases, reflecting the effects of government support schemes for electric vehicles. These measures include tax exemptions for such vehicles and the installation of special electricity meters with preferential tariffs. To further promote the adoption of electric vehicles, the government is planning to introduce a tax incentive for charging stations in the 2017 Economic Package (SENER, 2016a). Despite the strong rate of increase, transport accounts for only around 2% of electricity demand in 2040.

Electricity supply

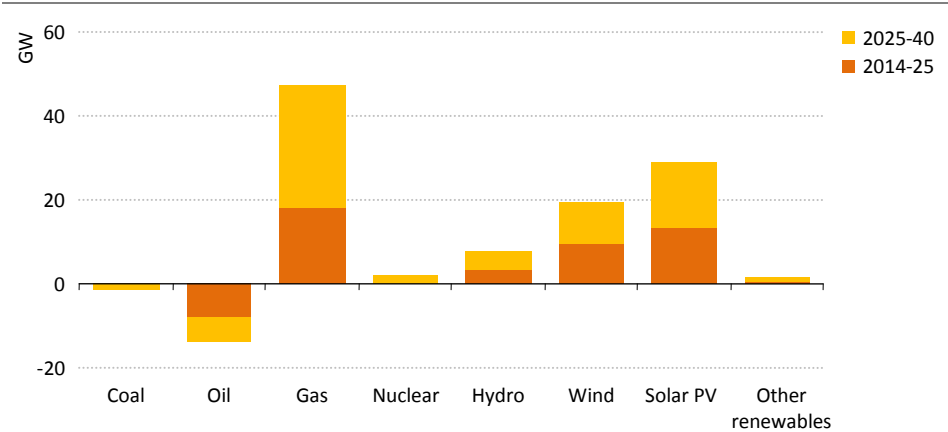
In the New Policies Scenario, installed electricity generation capacity more than doubles, from 70 gigawatts (GW) in 2015 to almost 160 GW in 2040. Gas-fired plants account for half of the increase, meaning that Mexico accounts for 15% of the increase in gas-fired power plants capacity in the OECD to 2040. This reflects the ongoing switch in the medium term from oil to gas in Mexico for power generation, enabled by the expanded availability of gas from the United States and the requirement for capacity additions to keep pace with demand (Figure 2.5). Oil-fired electricity generating capacity decreases from 17 GW in 2015 to 3 GW in 2040, when they are used primarily to meet short-term peaks, because of their relatively high operating cost. Coal-fired power capacity decreases by 1.5 GW by 2040, as a portion of existing capacity is retired.

The electricity generation mix in Mexico is progressively decarbonised over the period to 2040 (Figure 2.6). The share of renewables-based electricity generation capacity rises from 25% to 46%, under the impetus of government policy to increase the use of clean energy (see Chapter 3). In volumetric terms, renewables-based capacity increases from 17 GW in 2015 (most of which is hydropower) to a much more diverse portfolio of 74 GW in 2040. Among the different renewable technologies, solar photovoltaic (PV) capacity grows rapidly, from 0.2 GW in 2015 to almost 30 GW in 2040. Wind power also contributes to the rapid expansion of renewable electricity capacity, with an additional 19 GW by 2040. The rise in hydropower is much slower, at 7.6 GW by 2040.

The rapid expansion of solar PV and wind is not a product of specific technology choices by the government as the auction system under which they are introduced to the market is technology-neutral among clean energy technologies. Rather, it reflects the good fit for wind and solar with the market design introduced under Mexico's power sector reform, which has built-in mechanisms to increase the share of clean energy in the mix. The relatively low barriers to participation in pre-qualification for the long-term auctions have encouraged private investors to enter the renewables market in Mexico. However, the fact that these players are not obliged to demonstrate acquired land rights – they need to apply

for necessary permissions only after the announcement of the results of the auctions – does introduce risk that not all projects will be implemented as planned.

Figure 2.5 ▶ **Change in power generation capacity in Mexico in the New Policies Scenario**



Natural gas and renewables-based power leads capacity increases in Mexico in the New Policies Scenario to 2040

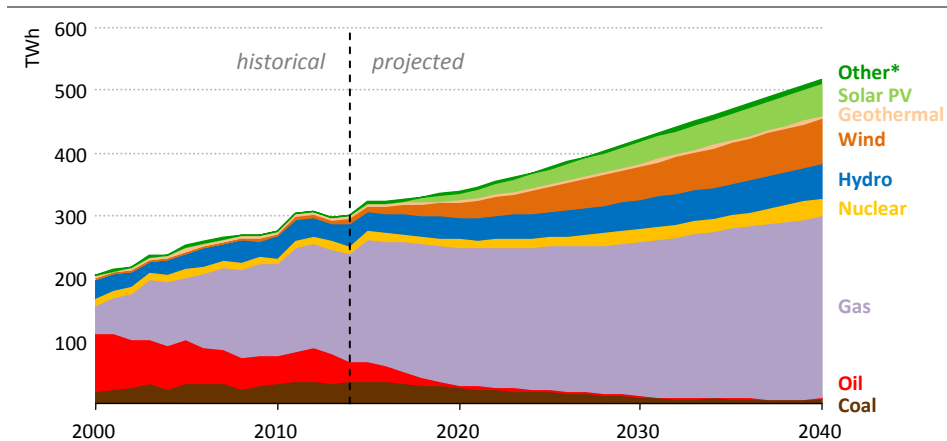
Note: Other renewables includes geothermal, bioenergy and concentrating solar power.

In PRODESEN, 4 GW of nuclear capacity is expected to be built by 2030, in addition to the existing 1.5 GW at the Laguna Verde site. However, the high capital requirements for nuclear power plants create some uncertainty concerning the realisation of this plan. Although the Reform has opened up the power sector to participation by the private sector, nuclear power generation remains the exclusive responsibility of the state. The Electricity Law includes nuclear as a form of clean energy, so the same mechanism of auctions for energy, capacity and clean energy certificates could be expected to support the introduction of new nuclear power projects. However, the level of prices revealed in the auctions in March and September 2016 would be too low to support new nuclear construction based on the experience of other OECD countries. Plus the duration of the long-term contracts on offer (15 years for energy and capacity, and 20 years for clean certificates) is likely to be too short to incentivise nuclear power projects. Even our cautious assessment of an additional 2 GW of nuclear capacity built by 2040 may require some additional mechanism of support or guarantee. In addition, greenfield nuclear power projects are likely to face considerable opposition from local communities. The current policy of consultation needs to be developed, together with effective waste disposal and nuclear safety policies.

Power generation in Mexico rises to more than 500 terawatt-hours (TWh) in 2040, at an annual average growth rate of 2.1%, three-times faster than the OECD average of 0.6%. As

renewables-based capacity grows, the generation mix in Mexico becomes increasingly diverse and less reliant on fossil fuels, and the share of fossil fuel-based power generation falls from 79% in 2014 to 58% in 2040. Gas remains the dominant source of power, accounting for around 60% of total electricity generation over the projection period, as additional capacity and import infrastructure become available. While the contribution of oil and coal fades, renewables play a much greater role, their share in total electricity generation more than doubling to 37% in 2040 and accounting for two-thirds of the rise in electricity generation to 2040. Wind and solar PV lead the growth in renewables-based power generation: the contribution of wind energy grows from 6.4 TWh in 2014 to 71 TWh in 2040, while that of solar PV jumps from 0.2 TWh in 2014 to 52 TWh in 2040. As discussed in more detail in Chapter 3, the electricity reform that opens the door to private investment in power generation is instrumental in the rapid transition of the power mix.

Figure 2.6 ▶ Electricity generation by source in the New Policies Scenario, 2000-2040



The power generation mix in Mexico becomes steadily more diverse and less carbon-intensive in the New Policies Scenario

*Other renewables include bioenergy and concentrating solar power.

Transmission and distribution

The electricity network in Mexico is divided into seven interconnected regional areas and three isolated areas (Baja California, Baja California Sur and Mulegé-Santa Rosalía). Different climatic conditions across Mexico produce differing demand profiles and peak demand periods, providing a powerful rationale for a well-interconnected network which can partially smooth the variations. The case for expansion and modernisation of the grid is strengthened by the rapid rise in electricity demand, the increased deployment of renewables and the current relatively high level of network losses.

Mexico plans to increase the length of the country's transmission lines to around 132 000 kilometres (km) transmission lines by 2030, up from 104 000 km in 2014 (SENER, 2016b). In our projection, which is consistent with the government programme, 46 000 km of new transmission lines are added by 2040 and around 70 000 km of ageing lines are replaced. Expansion of transmission lines has a positive impact on Mexico's ability to accommodate more renewables-based power in the electricity mix. For example, the Baja California region has strong wind, solar and geothermal power potential, with wind speeds reaching 12 metres per second (m/s) and daily solar radiation of up to 8.5 kilowatt-hours (kWh) (SENER, 2016b), but the region is isolated from the main power grid. Connecting the region to the main grid, as planned in PRODESEN, will allow Mexico to better exploit its significant renewable resources and optimise electricity supply over a larger area.

Distribution lines also need expansion and modernisation to accommodate rising residential demand and to reduce network losses. In the New Policies Scenario, the total length of distribution lines increases by one-third to 2040, from 770 000 km in 2014. The addition of new lines to meet increasing demand accounts for around 60% of the investment in the distribution systems. The government of Mexico is also making efforts to reduce non-technical losses, by measures such as reducing illegal connections and ensuring the effective operation of meters and billing systems. In the New Policies Scenario, such efforts serve to reduce transmission and distribution losses to 8.6% of net generation in 2040, a level closer to the OECD average today. Expansion and modernisation of the distribution network will also help Mexico to accommodate more distributed power generation, both of renewables and of efficient cogeneration plants with a capacity less than 0.5 MW, for which the government provides financial incentives to promote deployment.

2.2.3 End-use sectors

In the New Policies Scenario, the rise in final energy consumption by end-use sectors, underpinned by economic and population growth, and urbanisation, averages 1.1% annually to 2040. Growth is strongest in industry and buildings, although the transport sector continues to be the largest energy consuming sector (Table 2.3). The mix of energies consumed in end-use sectors reflects some of the trends seen in primary energy demand, with gas consumption increasing (mainly in industry and buildings) and the share of oil consumption decreasing. However, oil, mainly used for transport, is still the main source of energy demand in end-use sectors, accounting for more than 50% of total final energy consumption over the projection period (albeit down from 62% in 2014). The share of electricity in final energy demand increases substantially, from 18% in 2014 to 25% in 2040, as consumption in industry and buildings grows rapidly.

Table 2.3 ▶ Final energy consumption by sector in Mexico in the New Policies Scenario (Mtoe)

	2000	2014	2020	2030	2040	Shares		2014-2040	
						2014	2040	Change	CAAGR*
Industry	28	34	37	43	49	28%	31%	15	1.5%
Transport	36	51	53	57	59	43%	38%	8	0.5%
Buildings	21	24	26	29	33	20%	21%	10	1.3%
Other sectors**	10	10	12	14	15	8%	10%	5	1.6%
Total	95	118	128	143	156	100%	100%	38	1.1%
Industry, incl. transformation***	35	39	44	51	58	n.a.	n.a.	18	1.5%

*Compound average annual growth rate. ** Includes agriculture and non-energy use. *** Includes energy demand from blast furnaces and coke ovens (not part of final consumption) and petrochemical feedstocks. Note: n.a. = not applicable.

Industry¹

Energy demand in industry grows at an annual average rate of 1.5%, reaching 58 million tonnes of oil equivalent (Mtoe) by 2040, a level around 50% higher than in 2014. This makes industry the second-largest energy end-user, next to transport. Electricity consumption grows at an annual average rate of 1.8%, meeting one-third of industrial energy requirements in 2040. The increase in electricity consumption is spread across a wide range of businesses, including automotive and component manufacturers that use electricity as their major energy source, and SMEs, whose electricity consumption has grown at an annual average rate of 2.8% for the past decade (SENER, 2016c). Natural gas use also grows at an annual average rate of 1.9%, accounting for 35% of industrial energy consumption in 2040.

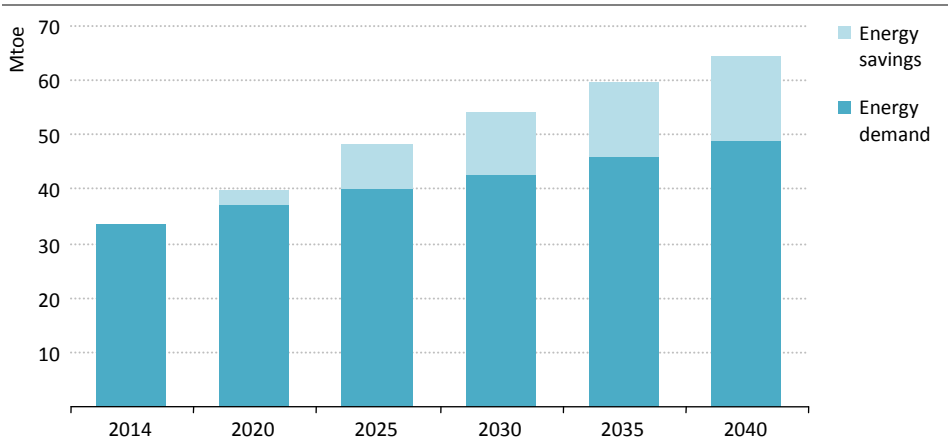
Energy-intensive industries² continue to account for around 40% of industrial energy consumption over the *Outlook* period. Around a quarter of the increase in industrial energy consumption between 2014 and 2040 comes from the chemicals industry, driven by ethylene production, which is projected to grow by 3.3% on average annually to meet growing demand for petrochemical products. Electricity accounts for a growing share of total industrial energy consumption, due in part to the increasing use in industry of heat pumps, as well as technical changes in industrial processes, such as the increased use of scrap-based steel production in the steel industry. Biomass use as a source of industrial heat increases in the chemicals, paper and pulp, and cement industries. In the New Policies Scenario, the success of policies to increase efficiency in energy use in energy-intensive industries, coupled with changes in industrial structure and processes, leads to a gradual decrease in energy intensity, measured as the amount of energy needed per tonne of output. However, the rate of decrease is slower than in the past, reflecting the fewer remaining energy saving opportunities for those industries.

¹ The industrial demand here includes energy used in blast furnaces, coke ovens and petrochemical feedstocks.

² Including iron and steel, chemicals, cement, and paper and pulp.

Energy consumption in non energy-intensive industries grows rapidly, at an annual average rate of 1.6%, and accounts for around 60% of the increase in energy demand in industry between 2014 and 2040. Electricity and gas consumption lead the growth and account for 50% and 30% of energy consumption in the non energy-intensive industry in 2040, respectively. The increased availability of gas imported from the United States facilitates the replacement of oil and coal as a source of heat, as well as wider use of electricity in manufacturing processes. Energy intensity in these industries is projected to improve quickly, by almost 30% between 2014 and 2040. Awareness of the potential for efficiency improvements is typically low in this sector, as energy costs account for a relatively low share of production costs, but government policies to promote efficiency among SMEs helps to realise some of the substantial savings available.

Figure 2.7 ▶ **Energy demand and savings in industry in Mexico in the New Policies Scenario, 2014-2040**



Efficiency policies and measures are effective in slowing the rise in industrial energy consumption in the New Policies Scenario

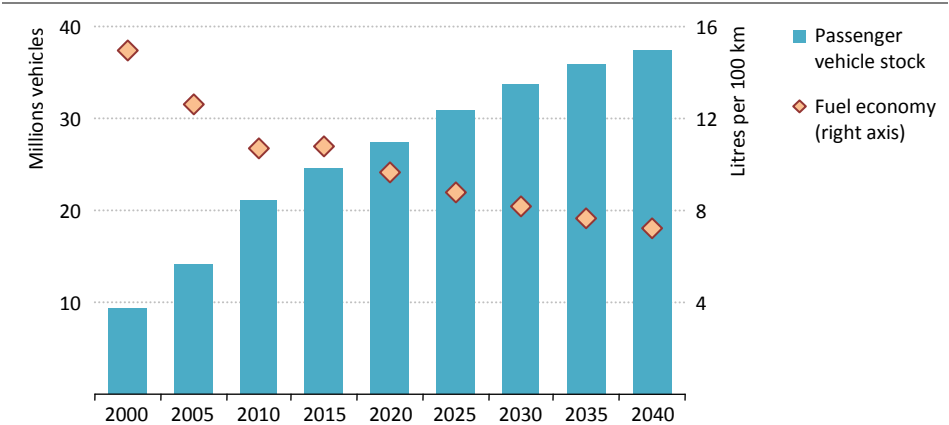
Note: The amount of energy efficiency savings reflects the cumulative effect of efficiency savings in different industrial sectors in the New Policies Scenario, based on a decomposition analysis of projected demand.

In the New Policies Scenario, cumulative savings linked to efficiency gains amount to around 16 Mtoe, equivalent to around 30% of industrial energy demand in 2040 (Figure 2.7). These gains are attributable to government policies to promote efficiency in industry, such as the adoption of energy management systems and the implementation of energy audits, as well as to industries’ own efforts to improve efficiency. Large industrial energy users have recently started to introduce energy management systems on a voluntary basis, with the National Commission for the Efficient Use of Energy (CONUEE) providing support to implement the systems in 3 500 large energy users. Such measures are expected to be adopted more widely in the period to 2040, including by a larger number of SMEs.

Transport

Transport is the largest of Mexico’s end-use energy sectors. It has been growing at a rate of 2.5% annually since 1990 and accounted for 43% of final energy consumption in 2014. The total number of passenger vehicles in Mexico has risen dramatically, from 9 million in 2000 to almost 25 million in 2014, making severe traffic congestion a major issue in cities and leading to poor urban air quality. A further challenge is the age of the vehicle fleet: while a restriction on imports of used cars is theoretically in place, with vehicles older than ten years banned, enforcement has been lacking and imports of old vehicles with low fuel-economy performance from the United States continue. As described in Chapter 1, comparison with other OECD countries suggests that there is room for additional growth in the vehicle fleet – the number of vehicles per 1 000 people is less than half the OECD average. The key question for Mexico is whether policy action can limit the adverse consequences of future growth in the number of vehicles in terms of energy demand and air pollutant emissions.

Figure 2.8 ▶ Passenger vehicle stock and fuel economy in Mexico in the New Policies Scenario, 2000-2040



Energy demand is driven by an increase in vehicle ownership, while vehicle fuel economy improves

Mexico succeeds in part in meeting this challenge in the New Policies Scenario. The passenger vehicle stock grows by around half by 2040 and road transport is responsible for almost all of the increase in transport energy demand, but efficiency policies limit this growth (Figure 2.8). The rise in road transport energy demand slows to an annual average rate of 0.6% over the period to 2040. This is much slower rate of growth than the historical rise in this sector in Mexico, but it remains significantly greater than the average rate in the OECD, where saturation in ownership levels, combined with efficiency policies, sees road transport energy consumption fall by an average of 0.9% per year to 2040.

Box 2.1 ▶ Transport solutions to Mexico's air pollution problem

The Mexico City metropolitan area is one of the largest in the world and has a population of 21 million. The city's car fleet of 5 million vehicles, consumes around 25 million litres of fuel per day and gives rise to the bulk of the city's transport-related carbon monoxide (98%) and nitrogen oxides (88%) emissions, four-fifths of black carbon emissions and half of greenhouse-gas emissions (SEDEMA, 2012). Although two-thirds of all journeys in the city are made by public transport, the public transport fleet is ageing and polluting. To address the joint air pollution and mobility crisis, the city government has developed the Metrobus project as one element of the PROAIRE policy (see Chapter 1). Metrobus is a Bus Rapid Transit (BRT) system based on dedicated bus lanes, enclosed stations, and large articulated and bi-articulated buses. It was implemented as an alternative to the costly construction of a subway system: constructing one kilometre of metro costs as much as building 22 kilometres of a BRT corridor.

The system currently serves more than one million passengers every day on more than 550 buses, 10% of which are hybrid (the first hybrid fleet in Latin America). The corridors, spanning 125 km, now cover 11 of the 16 municipalities of the metropolitan region, with future plans for expansion including a seventh corridor along the most emblematic avenue of Mexico City, *Paseo de la Reforma*, furnished with 90 double-decker Euro VI buses by 2017.

The Metrobus system has brought significant reductions in local air pollutants and greenhouse gases to Mexico City. The replacement of polluting buses, 1 500 of which have been scrapped, has improved not only the local environment but also the entire mobility framework. The Metrobus system was the first transport system in the world to commercialise carbon credits. During its operation, it has eliminated over 874 000 tonnes of carbon-dioxide equivalent (CO₂-eq). It has also achieved a significant modal shift: 17% of people using the Metrobus have chosen to leave their car at home in favour of the public transport system, accounting for a reduction of 187 000 passenger car journeys.

Metrobus is a highly energy-efficient transport system. To transport 1 000 people 10 km by car requires 835 private cars and consumes 650 litres of fuel. To transport the same number of people the same distance by the bus network requires only four bi-articulated buses and 40 litres of fuel, representing a 94% savings on fuel consumption. The BRT system has also had an important impact on public health: its implementation reduced commuters' exposure to carbon monoxide, benzene and particulate matter (PM_{2.5}) by a factor of between 20% and 70% (Wöhrenschiemmel, 2008).

Fuel-economy standards for passenger cars in Mexico are currently based on the limits imposed in the United States (combination of Tier 1 and Tier 2) and the European Union (EURO 4). There is a major opportunity to reduce oil demand and carbon-dioxide (CO₂) emissions by improving these standards. The average new car sold in Mexico emits around 180 grammes of CO₂ per kilometre (g CO₂/km) (according to emissions test cycles),

compared with a value of around 130 g CO₂/km in the European Union. More stringent standards are planned in 2018. In the New Policies Scenario, the fuel economy of new car sales in Mexico reaches almost today's level in the European Union by 2040, helping to achieve energy savings of 10% transport demand in 2040, compared with the Current Policies Scenario. Around one-fifth of the passenger vehicle stock is projected to have hybrid technology by 2040, compared with the situation today in which 95% of the passenger vehicles in Mexico are traditional combustion engines.

While improvements in efficiency are reached in the passenger light-duty vehicle fleet, energy inefficiency in the freight fleet becomes an increasingly significant issue in the period to 2040. Even though trucks are responsible for only around 13% of energy demand, in the absence of efficiency policies to mitigate energy demand (they do not feature in Mexican policies today, so similarly, are excluded in the New Policies Scenario), trucks are responsible for more than half the projected 8 Mtoe rise in transport energy demand over the period. However, policy actions are having an impact in other areas; efforts to promote public transport being a good example. Bus Rapid Transport, a system of giving priority road space to dedicated buses, is being increasingly used to promote good quality mass transit and is now in use in eight Mexican cities, including Mexico City (Box 2.1).

In terms of fuels, the transport sector in Mexico is set to remain relatively undiversified and oil-dependent in the New Policies Scenario. In contrast to the rest of the OECD where on average the share of oil is reduced to 80% of transport demand by 2040 (from 93% today), in Mexico, transport remains almost exclusively reliant on oil. This position is marginally challenged by natural gas in road freight (gas accounts for 2% of transport demand by 2040 as a result of compressed natural gas truck sales) and by electricity, through the limited uptake of electric passenger vehicles (which account for less than 1% of energy consumption in road transport in 2040). Electricity use in railways remains minute and freight transport is largely reliant on heavy trucks. As a result, energy consumption in trucks increases strongly, by around 70%, to 2040. Even though the share of biofuels use in transport in OECD countries grows from 4% to 10% share on average, in the absence of sustained policy support, biofuels do not find a place in Mexico's transport energy mix in the New Policies Scenario, since they do not feature in current plans.

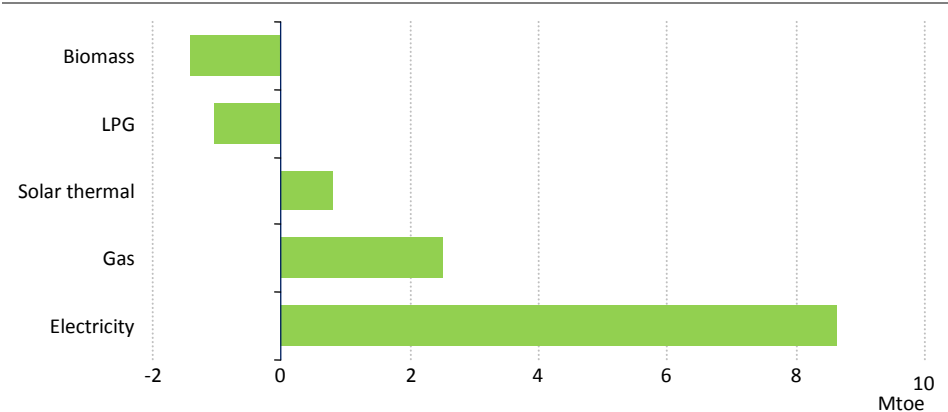
Buildings

Energy demand in buildings (both the residential and services sectors) represents one-fifth of current total final energy consumption. Over the period to 2040, its nature and composition is projected to change substantially as energy use becomes more efficient, more reliant on modern fuels – especially electricity – and the role of solid biomass diminishes. The residential sector today accounts for more than 80% of total demand in buildings. In rural areas, around half of households – some 15% of the overall population – rely on biomass for cooking and water heating, so that biomass constitutes almost one-third of overall residential energy demand. This share declines steadily in the New Policies Scenario, to less than 20% in 2040. In the past, the main fuel to replace biomass has been liquefied petroleum gas (LPG) and this substitution continues to take place in some rural areas. However, natural gas takes a rising share of demand for cooking and water heating

in our projections, as more and more households are connected to the grid. Overall, natural gas demand in the residential sector grows by 5% per year to 2040, while that of LPG declines by more than 1% per year.

The switch away from biomass represents a profound efficiency gain for residential energy use, keeping overall residential demand growth down to an annual average of 1% (reaching 25 Mtoe by 2040): if solid biomass were to be excluded, the rate of growth would increase to an annual average of 1.6%. The move away from biomass also represents a gain for welfare, as exposure to particulate matter from incomplete biomass combustion is a major health risk. In our estimation, around 12 500 premature deaths in Mexico were attributable to household air pollution in 2015. This value declines only marginally by 2040, even though the reduction in biomass use is significant (health problems are related to lifetime exposure to pollutants, so a change in energy use takes time to feed through into the projected health impacts). More could be done to bring these health impacts down further (IEA, 2016).

Figure 2.9 ▶ Energy demand growth by fuel in the buildings sector in the New Policies Scenario, 2014-2040



Electricity leads the demand growth in the buildings sector between 2014 and 2040

The largest increase in energy demand in the buildings sector comes from the demand for electricity (Figure 2.9). Residential electricity demand almost doubles over the period to 2040, electricity consolidating its position as the main source of final energy in the buildings sector (with its share rising from one-third to more than 50%). This increase in residential use is due mainly to increased use of cooling and major appliances. Electricity use for cooling systems grows rapidly, by an annual average of 4.8%, as the rate of household air conditioner ownership increases from 13% today to almost 40% in 2040. There is also a notable increase in the direct use of solar thermal for water heating, both in residential and in non-residential buildings.

Energy efficiency policies in the buildings sector have gained momentum in recent years, with Mexico making laudable efforts to reduce energy consumption through incentive-

based subsidies, and by tying mortgages for households and developers to packages of “eco-technologies” (Box 2.2). The increased use of solar thermal for water heating is due, in part, to the large uptake of INFONAVIT’s *Hipoteca Verde* (Green Mortgage Programme), as well as more recent initiatives, such as the ECOCASA Programme from *Sociedad Hipotecaria Federal* (Federal Mortgage Society). The government of Mexico has established a range of efficiency standards for buildings and their components, formulated a building energy code which works as a model for local authorities, but the implementation of efficiency policies in the buildings sector is complicated by the devolved policy responsibility to local jurisdictions. Limited resources and capabilities in local municipalities mean that only a limited number of cities, such as Mexico City, have adopted such building energy codes.

In our projections, without the efficiency gains stemming from the policies assumed in the New Policies Scenario, energy consumption in the buildings sector would be 20% higher in 2040. Beyond the policies mentioned above, specific measures include energy efficiency standards for windows, insulation and other building components, large-scale replacement of inefficient appliances and lighting, and loans for efficient housing.

Box 2.2 ▶ **Mexico’s push for sustainable housing**

Mexico has pioneered some innovative programmes to tackle both the increase in energy demand from residential buildings and the shortage of adequate and sustainable housing for the most vulnerable parts of the population. CONAVI (National Housing Commission) and INFONAVIT (National Housing Fund for Private Sector Workers) started in 2007 as a joint effort to foster the construction of houses with energy-efficient and water-saving technologies (eco-technologies), and renewable energy solutions, like solar water heaters. INFONAVIT’s Green Mortgage programme now accounts for 70% of all mortgages in the country, while CONAVI’s *Esta es tu casa* (This is your house) subsidy programme for low-income home buyers has, since 2012, included sustainability and criteria in its selection process.³ Both programmes aim to incentivise efficiency by increasing the amount of the mortgage or subsidy in cases where the property meets certain technology standards. Both programmes are credited with stimulating demand for low-energy consumption appliances and enabling low and middle-income households to access modern home designs that have reduced energy bills. They have also raised general public awareness of the importance of reducing energy and water consumption.

Mexico was the first country to submit to the United Nations Framework Convention on Climate Change a Sustainable Housing Nationally Appropriate Mitigation Actions (NAMA) in 2012, with support from a variety of national and international actors. This expresses its ambitions and goals regarding the reduction of greenhouse-gas emissions in residential buildings through affordable solutions for low-income households. According to estimates by the Mexican government, implementing the NAMA would

³ INFONAVIT’s *Hipoteca Verde* has provided an average of 376 000 green mortgages annually since 2011. CONAVI made 210 000 subsidies available between 2015 and 2016.

eliminate approximately 2 million tonnes of CO₂-eq emissions a year, equivalent to 0.5% of national energy-related CO₂ emissions in 2014.

The ECOCASA Programme, launched by the government in 2013, became the first pilot programme under the NAMA, providing housing developers with attractive loans if they offered designs that resulted in greenhouse-gas (GHG) emission reductions of at least 20% (compared to a determined baseline). Passive design solutions qualified as well as traditional ones (solar water heaters and insulation) for low- and middle-income households. The programme has so far awarded ECOCASA credits of approximately \$200 million to 20 000 households and has already built more than 16 000 houses (of a total of 27 600 planned), which are expected to reduce an estimated 630 000 tonnes of CO₂ over the 40 year life of the houses (Sociedad Hipotecaria Federal, 2016). A second phase, with more ambitious sustainability criteria is planned, with the inclusion of multi-story sustainable houses for rent.

2.3 Outlook by fuel in the New Policies Scenario

2.3.1 Overview

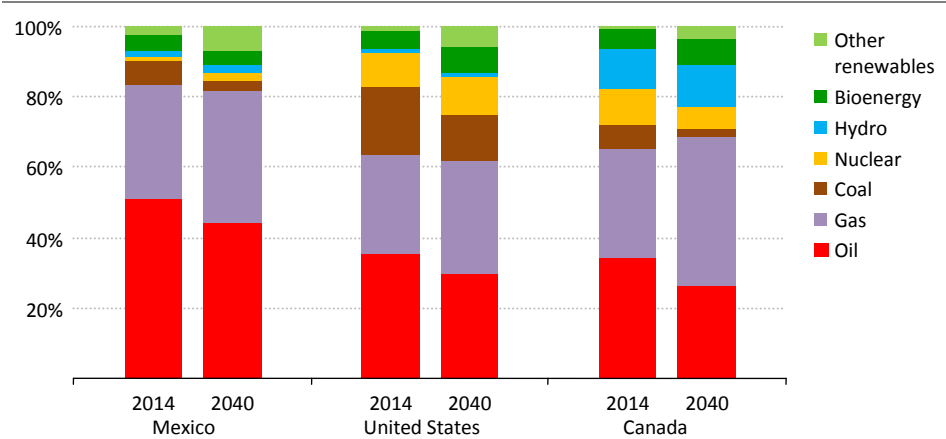
Mexico's energy mix is one of the most oil-dependent in the world, with oil products still accounting for more than half of total primary energy demand (Table 2.4). In the New Policies Scenario, the share of oil in the mix falls sharply, to 42%, but, at this level, it remains significantly higher than in the wider OECD. By contrast, the energy mix is one of the least dependent on coal: in our *Outlook*, coal is displaced almost entirely as coal-fired power plants are all but phased out. Natural gas demand grows by 1.3% per year, resulting in a significant increase in its share in the mix (from 32% to 38%). The share of renewables in total demand, including bioenergy and hydropower, increases from 8% in 2014 to 14%, with the majority of the increase attributable to the strong growth in wind and solar power generation (Figure 2.10).

Table 2.4 ▶ Primary energy demand by fuel in Mexico in the New Policies Scenario (Mtoe)

	2000	2014	2020	2030	2040	Shares		CAAGR*
						2014	2040	2014-2040
Fossil fuels	131	170	168	176	186	90%	83%	0.4%
Oil	89	96	91	95	95	51%	42%	-0.1%
Natural gas	35	61	68	74	86	32%	38%	1.4%
Coal	7	13	10	7	6	7%	3%	-3.1%
Renewables	17	16	19	25	31	9%	14%	2.7%
Hydro	3	3	3	4	5	2%	2%	1.4%
Bioenergy	9	9	9	9	9	5%	4%	0.6%
Other renewables	5	4	7	12	17	2%	8%	5.9%
Nuclear	2	3	3	5	7	1%	3%	4.2%
Total	150	188	190	206	225	100%	100%	0.7%

* Compound average annual growth rate.

Figure 2.10 ▶ Primary energy mix in Mexico and selected countries in the New Policies Scenario



Mexico's energy mix becomes more diverse, but is still more oil-dependent in 2040 than the United States or Canada are today

Note: Other renewables include geothermal, solar PV, concentrating solar power and wind.

2.3.2 Oil

Oil resources and production

Twelve geologic basins in Mexico are deemed to have active petroleum systems, but only six basins have established hydrocarbon production.⁴ Mexico's oil and gas development has historically focused on onshore and shallow water basins surrounding the Gulf of Mexico, and while not the focus of the upcoming bid round in December 2016, both onshore and shallow water areas are estimated to still have significant resource potential.

Onshore oil production has taken place in Mexico since the early 1900s and over 20 billion barrels have been produced to date. We estimate that a further 21 billion barrels are technically recoverable from onshore regions (Table 2.5). Many of these are within the Tampico-Misantla Basin, which includes Chicontepec, a super-giant field, yet it is a very complex onshore field that has so far experienced very low recovery rates (Figure 2.11). Development of Mexico's shallow offshore fields began in earnest during the 1960s. Over 28 billion barrels have already been produced, the overwhelming majority from the Sureste Basin, home to Mexico's largest offshore production areas which are the Cantarell and Ku-Malooob-Zaap complexes. The Sureste Basin still has significant untapped potential, however, more than 20 billion barrels of remaining technically recoverable resources are estimated to exist in shallow offshore regions.

⁴ A petroleum system exists if the following elements are present: mature source rocks expelling oil and gas, a migration pathway and reservoir rock trapping the migrated oil and gas under a seal.

Table 2.5 ▶ Remaining technically recoverable oil resources by category in Mexico, end-2014 (billion barrels)

	Technically recoverable resources	Cumulative production	Remaining recoverable resources	Remaining % of URR	Proven reserves
Conventional onshore	41.6	20.3	21.2	51%	3.0
Tight oil	13.1	0.0	13.1	100%	0.0
Shallow offshore	48.4	28.3	20.1	42%	7.8
Deep offshore	15.0	0.0	15.0	100%	0.0
Total Mexico	118.0	48.6	69.4	59%	10.8

Notes: Data include crude, condensate and natural gas liquids. URR = ultimately recoverable resources. Sources: IEA; SENER.

To date, there has been no production from tight oil prospects or from deep offshore regions in Mexico. Yet volumes of both are estimated to be large, collectively accounting for around 40% of Mexico’s remaining resources: around 13 billion barrels of tight oil, predominantly in the Tampico-Misantla and Burgos basins, and 15 billion barrels in the deep waters of the Gulf of Mexico. Several basins, such as the Yucatan platform, Chihuahua, the Sierra Madre fold belt and the Vizcaino-La Purisma-Iray Basin have not been explored and resource estimates do not exist for these basins.

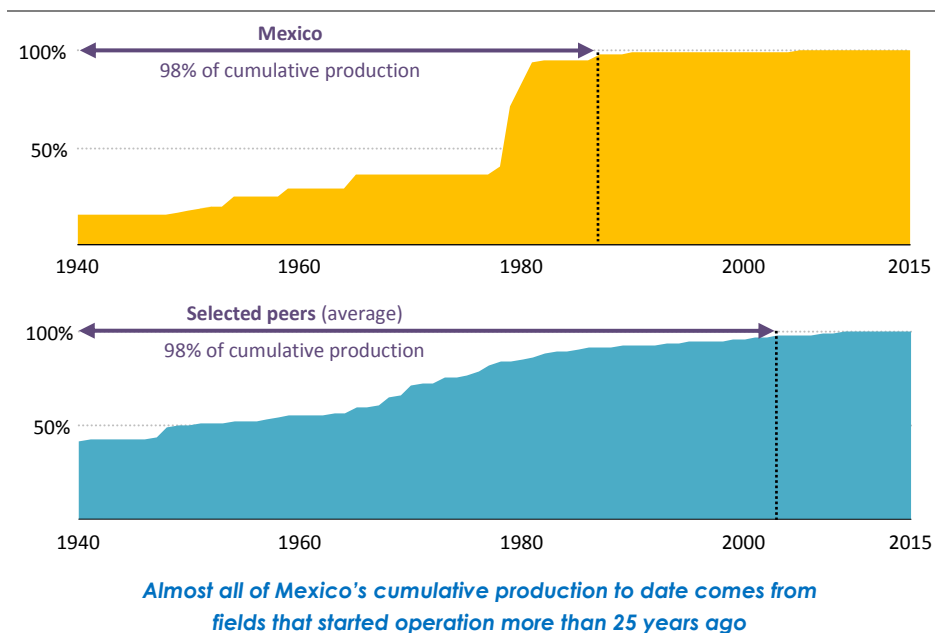
Figure 2.11 ▶ Hydrocarbon basins in Mexico



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

The age (and very high decline rates) of Mexico's main producing oil fields is a notable feature of the upstream sector. PEMEX, the productive state enterprise, has concentrated investment for decades in several large offshore fields using aggressive recovery techniques. This has served the nation well as a reliable source of revenue, but it has created a lack of resource diversity. Only 2% of cumulative historical production in Mexico comes from fields in which production started in the last 25 years, compared with 7% in the United States, 8% in Venezuela and 35% in the United Kingdom. After 2004 at the Cantarell complex, which was Mexico's largest at the time, decline accelerated, leading to a drastic fall in national production (Figure 2.12).

Figure 2.12 ▶ Cumulative oil production by year in Mexico and selected countries



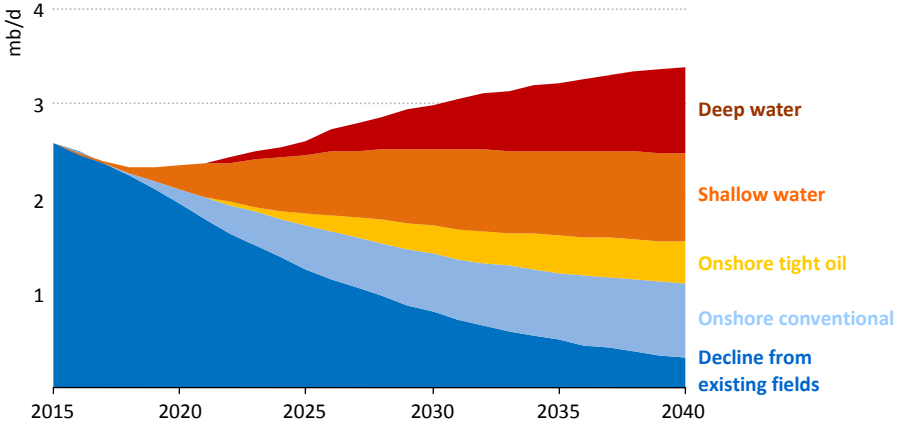
Note: The selected peers are the United States, United Kingdom, Venezuela, China and Russia.

A marked increase in capital spending by PEMEX over the past six years has effectively added deepwater assets to Mexico's portfolio; but production results will not be seen for some time and total oil production fell by 7% in 2015, to an average of 2.6 million barrels per day (mb/d), due to a combination of budget constraints and the high decline rate at mature fields. Investment also went into boosting production at newer shallow water developments and slowing decline at older fields. These large investments, in conjunction with PEMEX's fiscal responsibilities to the Mexican economy, overwhelmed its budget, an effect compounded by the fall in oil prices in mid-2014. These factors added urgency to the implementation of the Energy Reform measures. Mexican oil supply in the New Policies Scenario relies heavily on two features. The first is timely implementation of the Reform

measures, which allow the PEMEX association agreements and the bid rounds to proceed as documented in the Secretariat of Energy’s (SENER) current five-year plan. The second requirement is the successful execution of a majority of the projects awarded to the new entrants to Mexico’s upstream market (see Chapter 3).

In the New Policies Scenario, Mexico’s oil production falls in the medium term, with PEMEX likely to continue to provide nearly all of Mexico’s output. Conventional onshore production licences have already been awarded to winners of the round-one competition, but their scale is small and even investment made immediately is not likely to provide much of a production cushion to offset decline at the larger fields. There are opportunities to extend the lives of key assets like Ku-Maloo-Zaap through enhanced recovery schemes and our *Outlook* factors this in. Production from shallow waters will continue to play a major role in Mexico production, but the age of the resource base means that historic levels of shallow water output are unlikely to be seen again. After bottoming out at 2.3 mb/d towards the end of the current decade, by 2040 oil production is up to 3.4 mb/d, a net increase of 800 kb/d from 2015 (Figure 2.13).

Figure 2.13 ▶ Oil production in Mexico in the New Policies Scenario, 2015-2040



Mexico’s oil output gets back on a rising path in the New Policies Scenario, but it takes time for new projects to offset declines

Oil product demand

In the New Policies Scenario, Mexico’s total oil demand edges higher to reach nearly 2.1 mb/d in 2040 (Table 2.6). In this time, however, the product slate gets significantly lighter, as growth in transport and in industry (where volumes increase for petrochemical feedstocks), offsets a decline in consumption in the power sector (mainly heavy fuel oil) and in the residential sector.⁵ Naphtha is the fastest growing oil product, albeit from a low

⁵ In our discussion of product demand and trade, we include international aviation and marine bunkers as these are physically supplied by the country’s infrastructure.

base, as growing petrochemical sector demand coincides with a largely flat outlook for natural gas liquids production, constraining ethane availability and use, and leaving naphtha (which can also be supplied by refineries) to take a higher share in cracker feedstocks.

Table 2.6 ▶ Oil demand by product in Mexico in the New Policies Scenario
(mb/d)

	2014	2020	2030	2040	2014-2040	
					Delta	CAAGR*
Ethane	0.11	0.14	0.12	0.12	0.01	0.3%
LPG	0.31	0.27	0.26	0.26	-0.05	-0.6%
Naphtha	0.02	0.03	0.05	0.07	0.04	4.0%
Gasoline	0.75	0.75	0.76	0.76	0.01	0.1%
Kerosene	0.07	0.08	0.11	0.14	0.08	3.0%
Diesel	0.43	0.44	0.50	0.50	0.07	0.6%
Fuel oil	0.16	0.03	0.02	0.01	-0.15	-8.9%
Total oil demand**	2.01	1.93	2.04	2.09	0.09	0.2%

* Compound average annual growth rate. ** Total includes other products such as asphalt, waxes and lubricants. Note: total includes international bunkers.

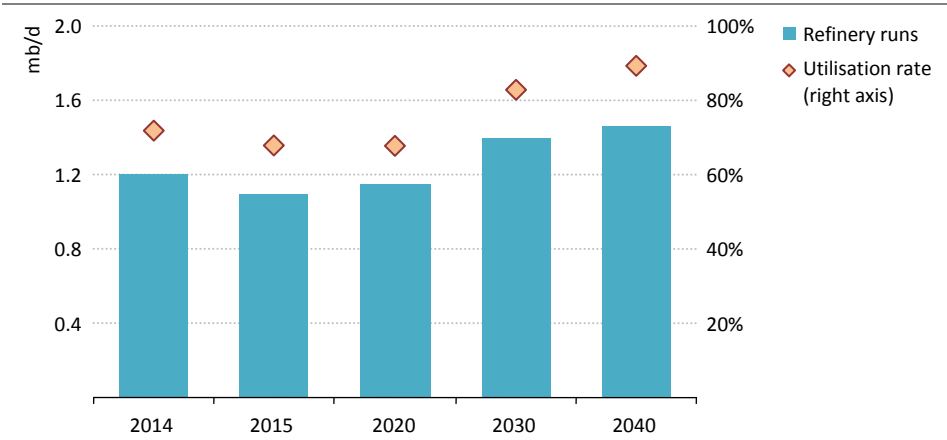
LPG demand bucks global trends, declining to 2040, primarily as a result of being replaced by natural gas in the residential sector. Kerosene is the fastest growing transport fuel, thanks to a doubling of international aviation bunkers. Gasoline sees modest growth, as increased mobility demand is offset, to a degree, by efficiency gains. Road freight demand pushes diesel use higher, offsetting declining consumption in the power sector. Fuel oil, used mostly in power generation, finds no alternative market and its use is almost entirely phased out.

Refining and trade

Mexico is the only large oil consumer⁶ in the OECD where oil product demand in 2040 is higher than it is today. This creates an interesting perspective for developments in the refining sector. Mexico's refineries have performed rather poorly in recent years, their utilisation rates falling to just 60% in early 2016. The low utilisation rate reflects the inability of the refiners to run profitably at higher rates, as crucial upgrades, necessary to process the increasingly heavier crude slate into oil products with tightening specifications, have been long-delayed. In our projections, refiners are expected to overcome financing problems and invest in refinery upgrading units. While no new stand-alone refining capacity is expected to come online in the next two-and-a-half decades, improved equipment and units at the existing refineries, at an estimated cost of \$20 billion, help to push utilisation rates to around 90% by 2040, resulting in refinery runs of almost 1.5 mb/d, (compared with only 1.1 mb/d in 2016) (Figure 2.14).

⁶ Countries with oil demand over 1 million barrels per day.

Figure 2.14 ▸ **Refinery runs and utilisation rate in Mexico in the New Policies Scenario, 2014-2040**



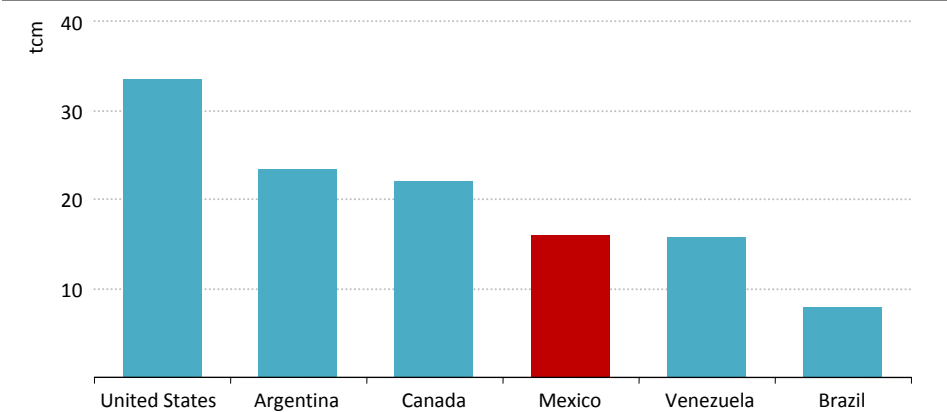
Upgrades at existing refineries help to push refinery runs up to 1.4 mb/d by 2040

2.3.3 Natural gas

Gas resources and production

Mexico’s remaining conventional recoverable gas resource is estimated at about 3 trillion cubic metres (tcm), mostly located offshore in deep water in the Gulf of Mexico (accounting for around one-third of the conventional resource base). These resources in Mexico are considerably better understood than unconventional resources, with more certainty on the estimates of their size. Though, Mexico’s unconventional gas resource is likely to be very sizeable (estimated by the US DOE/Energy Information Administration at about 16 tcm), almost all of it as shale (US DOE/EIA, 2015) (Figure 2.15).

Figure 2.15 ▸ **Recoverable unconventional gas resources in selected countries**



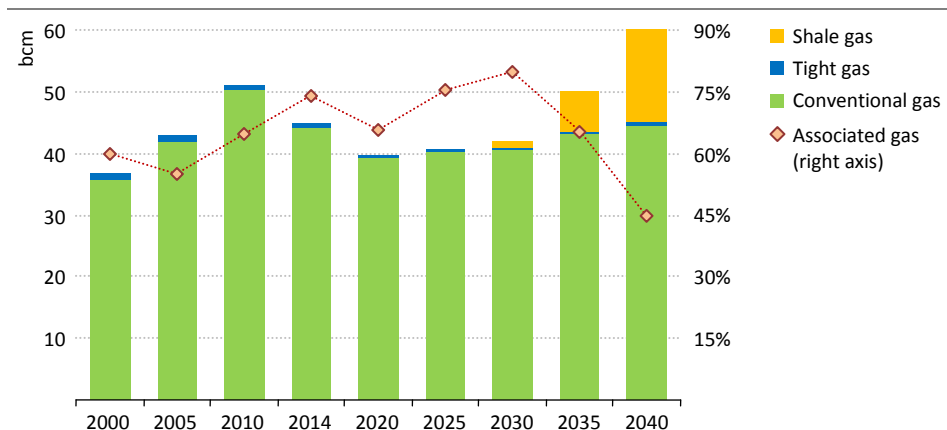
Mexico holds considerable promise for unconventional gas

Table 2.7 ▶ Natural gas production, proven reserves and resources in Mexico (tcm)

	Ultimate recoverable resource (URR)	Cumulative production	Remaining recoverable resources	Remaining % of URR	Proven reserves
Conventional	4.4	1.6	2.8	64%	0.4
of which Gulf of Mexico basin	1.6	0.0	1.6	100%	0.0
Unconventional	16.0	0.0	16.0	100%	0.0
of which Sabinas and Burgos basins	15.2	0.0	15.2	100%	0.0
Total Mexico	20.4	1.6	18.9	92%	0.4

The Burgos and Sabinas basins, for example, hold significantly larger resource promise than even Mexico's conventional plays (Table 2.7). Even if the shale gas resource were to prove to be significantly smaller than currently estimated, it could still represent a considerable source of gas for Mexico.⁷

Figure 2.16 ▶ Natural gas production by type in Mexico in the New Policies Scenario



Gas production is highly dependent on oil development until shale activity starts to ramp up in the late 2020s

In the New Policies Scenario, gas production increases by a little over one-third, to reach 60 billion cubic metres (bcm) by 2040 (by which time, around a quarter of total production is expected to come from shale resources). The timing of this increase is highly uncertain: the evolution of upstream costs and natural gas prices in the United States will have a large influence on the relative attractiveness of developments in Mexico (see Chapter 3). In the

⁷ The *Comisión Nacional de Hidrocarburos* estimates Mexico's shale gas resources to be a quarter (or about 4.7 tcm) of the current US DOE/EIA estimate.

interim, our *Outlook* for gas production is closely linked to that of oil: the high share of associated gas explains the near-term fall in gas production and the partial turnaround in the 2020s (Figure 2.16). The share of associated gas in production starts to fall back notably towards the end of the projection period, due to the start of shale gas production, most probably sourced from the Burgos and Sabinas basins. Non-associated gas output is produced from dry and gas-condensate fields, the liquids produced in the latter boosting project economics considerably. The majority of such fields are thought to be located in the Gulf of Mexico, underlining again the importance of deepwater technology to the hydrocarbon outlook.

Gas demand and trade

The build-out of natural gas import infrastructure to the United States and the prospects for the development of local resources makes gas a mainstay for the energy system in Mexico to 2040. Gas accounts for almost 70% of the growth in primary energy demand to 2040, while oil demand is essentially flat and coal declines. Three sectors contribute to the rise in gas demand. First, the power sector alone accounts for over half of total growth, with gas-fired generation capacity increasing two-and-a-half times to 2040. Second is industry, including feedstock use in the petrochemicals manufacturing. The third relates to developments in upstream oil and gas services, where natural gas is used in the extraction process (compressors and auto-generation).

Domestic natural gas production, though rising strongly, does not keep up with rapidly increasing demand and therefore Mexico continues to rely on pipeline imports to 2040 (see Chapter 3). To facilitate the increasing prominence of gas in the energy mix (and to adapt to the rising need for imports), the Energy Reform includes a number of changes to the regulation of the gas market. They mostly relate to the end of PEMEX's monopoly on marketing and transmission activities, and the transition to a competitive gas market. In this regard, the Energy Regulatory Commission (CRE) has ruled that PEMEX must relinquish a portion of its gas supply contracts, a move that would reduce its market share to less than 30% by 2020. To facilitate private sector competition, the ownership of the transmission network (SISTRANGAS) has been transferred to CENAGAS, the newly created independent operator, and in mid-2016, SENER announced that CENAGAS and SISTRANGAS were to carry out an open season to allocate current transmission capacity. A supporting pillar of the gas liberalisation associated with the Energy Reform is the implementation of a new method to determine the first-hand sale price, which is to be referenced to prices in the southern United States. This aims to correct a number of market distortions, including the end-user subsidy that came as a result of PEMEX selling gas at a loss and to encourage private sector participation in natural gas foreign trade as well as domestic trading and marketing. These measures are part of the wider objective of moving to a fully competitive natural gas market in 2018, when the price of natural gas will be determined by the market, in the hope that accurate market signals will eventually encourage domestic gas production (SENER, 2016d).

What are Mexico's options for gas storage?

Today the natural gas network in Mexico is concentrated in two main areas; the north, near the border with the United States and the south, linking gas production centres with major consuming areas, notably Mexico City. Interconnections between the two areas are relatively few and gas storage is notably absent. Swings in gas demand, therefore, are currently met through line packing or the drawing down of liquefied natural gas (LNG) stored at the country's three LNG import terminals.

More interconnections and more gas storage, common in other countries and regions, offer major benefits, including optimisation of the use of key production and import infrastructure, improved competition, better supply reliability and energy security. These considerations become more important as Mexico moves to significantly increase gas-fired power generation. This implies that natural gas demand may become much more seasonal (as power use increases to meet summer air conditioning load), or even more variable on a daily basis. The Hydrocarbons Law gives SENER the power to determine and manage natural gas storage levels.

CENAGAS, the new body responsible for system planning and operation, has made a promising start. It has identified key transmission interconnections, tendered for their construction and is overseeing their building which, in several important cases, is well advanced. However, the picture for storage is considerably more complex.

Various types of natural gas storage facilities differ markedly in construction and operating costs and in terms of characteristics such as the maximum drawdown volumes and rates of drawdown. Hence their value in optimising system operation can vary markedly. Widely used in other countries, depleted gas and oil fields have a number of advantages over other types of storage facilities. Where available, they usually have existing delivery infrastructure and the gas inevitably remaining in place forms an important part of the essential cushion needed to permit stock drawdown. Both features generally mean much lower capital cost on a unit basis.

For a system operator, selection of the storage type, size, location and timing of operation all represent difficult choices, all conferring benefits but also often involving substantial costs. The monopoly character of some storage options, especially larger ones, argues for effective regulatory involvement, such as regulated tariffs and mandatory open access. However, these can be a barrier to investment, especially given the dynamic gas and power market environment likely to be seen in Mexico over the next decade.

IEA countries with liberalised gas and power markets have sometimes found it difficult to increase investment in storage. In the United Kingdom, for example, gas storage is relatively small in volume, at around 5 bcm. It is mostly located in salt caverns or exhausted gas fields in the North Sea. The United States has some 400 gas storage

facilities, with depleted gas and oil fields accounting for four-fifths by storage volume. However, even the United States, with its well developed and flexible markets, has struggled to ensure adequate and well located gas storage over recent decades. In 2006, the Federal Energy Regulatory Commission relaxed open access provisions and allowed more unregulated operations in order to address this issue. In other IEA countries, major storage facilities date from a more regulated and centralised era. In some cases, the market has been slow to respond to the changing demand patterns, notably the greater use of gas-fired power to meet more volatile power demand.

From the viewpoint of CENAGAS, the transmission system operator in Mexico, a more market-oriented approach that encourages market-based returns may be necessary to encourage investment in gas storage, as well as a well-defined interim relaxation of open access requirements, spanning the first six-to-ten years, for example. This approach has been successfully used in the European Union to encourage investment in import infrastructure, notably in LNG terminals. It would seem likely to encourage a suite of technology types and storage locations to suit Mexican gas markets as they evolve.

The ample pipeline capacity to the United States and the proximity of Mexico's main demand centres to LNG facilities that can purchase shipments on the spot market at short notice, give the system a relatively high degree of flexibility. Future storage policy needs to be based on the rigorous assessment of the value attached to keeping physical storage on domestic territory.

2.3.4 Renewables

Mexico's abundance of renewable energy resource potential, particularly solar and wind, underpins the country's ambitions to decarbonise its energy system. Mexico is one of a small group of countries across the world to have translated its clean energy ambitions into law. The Energy Transition Law, approved in December 2015, sets a target of 35% of electricity generation from clean energy by 2024. To incentivise investment in renewables, the government has introduced clean energy certificates, a market instrument that is part of broader power sector Reform (see Chapter 3.3), designed to support the share of electricity consumption to be generated from clean energy sources.⁸ The revenue from the sale of certificates, which are purchased by producers and large electricity consumers, is intended to be invested in other renewable energy projects.

In the New Policies Scenario, Mexico meets its interim targets (for 2018 and 2024) and surpasses its 2035 target. This is primarily due to robust expansion of wind and solar photovoltaic (PV) power projects, which together account for around three-quarters of the growth in clean energy to 2040. Renewables account for 37% of electricity generated by

⁸ In 2015, the requirement was set at 5% to be reached by 2018 and is due to be reviewed periodically for possible increases in the mandate.

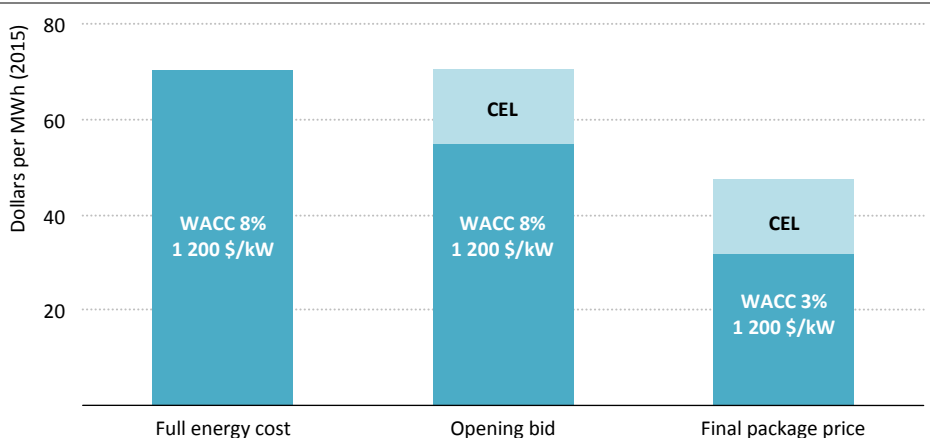
2040, of which 24% is from wind and solar power. Mexico's vast renewable energy potential offers the possibility of an even higher trajectory for their development. In the 450 Scenario, investment in renewables is almost 50% higher than in the New Policies Scenario to 2040. This allows for a significant increase in generation, with renewables meeting around 60% of electricity generated in the 450 scenario.⁹

Costs

To attract the desired investment for renewable energy development, the government has opted to hold auctions, underpinned by a guarantee for the winning bidder of a power purchasing agreement. Such agreements ensure a guaranteed rate for each unit of energy produced throughout the lifetime of the project. The results of the first two rounds of bidding show that this approach has proven an effective mechanism for minimising the cost of adding renewable electricity to the system (see Chapter 3.3.2).

Two factors have been particularly important in this regard: the availability of government-secured loans, which serve to reduce the cost of capital, and the strong incentive for bidding companies to pursue a cost-minimisation strategy, in the hope of establishing a foothold in a growing market. In the long term, as a result of better resource assessments and improved technology, we project a 30-50% reduction in cost for solar PV and a 5-20% cost reduction for wind power, which would contribute to a more profitable operation for companies (Figure 2.17).

Figure 2.17 ▸ Indicative cost and auction price for solar PV in Mexico



Auctions with long-term power purchasing agreements help to drive down the cost of increasing the use of renewables in the power system in Mexico

Notes: MWh = megawatt-hour; CEL = clean energy certificates; WACC = weighted average cost of capital; kW = kilowatt. These are indicative costs and prices for solar PV, showing how auctions can secure competitive bids and final prices.

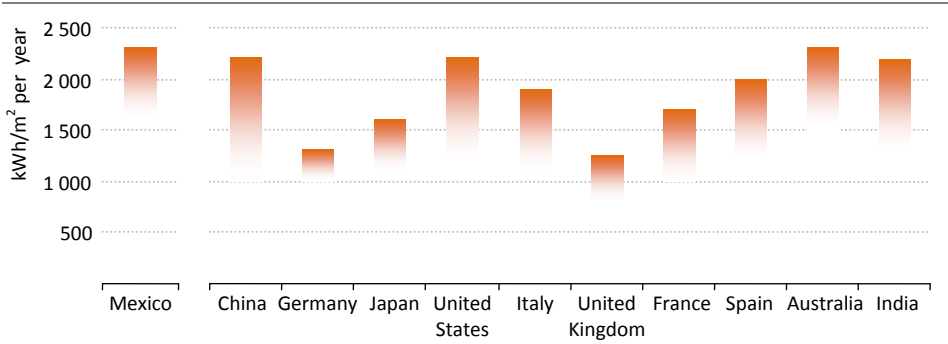
⁹ As described in Chapter 12 of *WEO-2016*, this level of renewables-based power generation would require close attention to a suite of system integration measures.

Besides costs, full consideration is given in the auctions to the value of renewables to the system as a whole, and this has been a factor in determining the award of projects. In particular, the location and time profile of variable renewable energy sources is taken into account in the evaluation to determine the share of different clean technologies.

Solar

Mexico’s solar resources are among the best in the world, with annual daily solar irradiance levels ranging between 4.4 kilowatt-hours per square metre (kWh/m²) and 6.3 kWh/m². The entire country lies between 15 and 35 degrees latitude, which is commonly considered the band most favoured for solar resources (with the lowest average levels in Mexico comparing favourably with the highest averages in Germany and Japan, the world’s second- and third-largest solar markets) (Figure 2.18). Mexico’s total solar resources are estimated at 5 000 GW (SENER, 2014), equivalent to 70-times the total installed power generation capacity today. Mexico’s installed capacity was 200 MW in 2014, in the form of utility-scale solar PV installations and 56 MW of distributed generation. Although the government has not released specific targets for solar PV capacity in its long-term electricity sector plan (PRODESEN), solar power is expected to play a prominent role in meeting the government’s clean energy targets. The Energy Reforms are structured to help achieve these aims through the clean energy certificates system and clean energy auctions (see Chapter 3). The prices offered in the auctions to date compared favourably with those in projects across the world.

Figure 2.18 ▸ Average solar irradiance range in selected countries



Mexico’s solar resource is among the best in the world

In the New Policies Scenario, solar PV, by some distance, is the fastest growing technology for power generation in Mexico, accounting for one-fifth of total capacity in 2040 (around 30 GW, making it the second-largest capacity after gas) and 10% of generation. The strong proliferation of solar PV, even though cost may be higher than wind turbines, reflects the inclusion in Mexico’s market design of a measure of relative value to the system based on project location (see Chapter 3.2).

There are a number of risks that impact the *Outlook*, including those arising from land and indigenous rights, which the government has been seeking to allay (see Chapter 1.3.4). The actions taken include a provision in the Hydrocarbons Law that assigns SENER responsibility to carry out community consultation for such projects. In the 450 Scenario, solar PV and concentrating solar power capacity is almost 30% larger than in the New Policies Scenario, reaching almost 40 GW in 2040.

Wind

Mexico's total wind power potential is estimated at around 50 GW, with the strongest sites spread across the Isthmus of Tehuantepec in Oaxaca (which currently holds around 80% of total installed capacity). The average capacity factor for wind power is currently more than 20% higher than the global average and is estimated to increase by nearly 30% over the projection period, reflecting the ample availability of suitable sites for turbines across the country. In the New Policies Scenario, wind power increases to over 22 GW, making it the second-largest renewable energy source in terms of capacity (after solar PV) in Mexico's power mix by 2040. In addition, wind is the largest contributor to electricity generation from clean energy sources by 2040. Competition for market share with solar PV will be a key factor limiting the further uptake of wind power in Mexico. In the 450 Scenario, wind plays a larger role, generating 31 TWh more electricity than in the New Policies Scenario, from a capacity of almost 31 GW. The integration of high wind power capacity into the power system is facilitated by a high capacity factor of around 35%.

Geothermal

Geothermal is a well-established power source in Mexico, benefiting from high capacity factors (averaging around 85%, compared with 20-25% for solar PV and 30-40% for wind) and not beholden to variability issues, thus being able to provide baseload capacity. Installed capacity was 866 MW in 2015, generating over 6 TWh and making Mexico one of the largest producers of geothermal-based power generation in the world. The commissioning of a new plant "Los Azufres", due to open in 2018, will increase capacity by around 25 MW.

Estimates of Mexico's geothermal resource potential vary widely, with the government assessing the potential resource size at around 13.4 GW (though only 2% of this is considered proven). Mexico announced in 2015 plans to boost geothermal development by awarding five concessions to CFE, which will help to clarify the resource size. Exploitation of geothermal resources for power generation has been impeded, in the past, by the inability of CFE to invest in new development due to restrictions in the investment criteria for public projects (not least, the obligation to produce electricity at the lowest possible price) that are directly linked to the high initial capital investment required for geothermal power development, as well as its risk profile, which can be very high in the exploration phase.

In the New Policies Scenario, geothermal power generation capacity reaches 980 MW, with further growth curtailed by strong competition from other renewables, namely solar and wind power, on the one hand, and competition with relatively low-cost gas-fired generation on the other.

Hydropower

By far, hydropower currently is the largest source of renewable energy in Mexico, accounting for around 75% of renewables-based generation and almost one-fifth of total generation capacity. Current hydropower capacity stands at around 12.5 GW and is concentrated in the western and south-western regions, in basins that drain into the Pacific Ocean. The three largest dams on the Grijalva River (Chicoasen, Malpaso, Angostura), account for around one-third of the country's total hydropower capacity.

CFE has identified around 100 river basins deemed suitable for hydropower development, and is in the process of carrying out pre-feasibility studies on several sites. SENER expressed interest in late 2015 to secure the technical assistance of the World Bank on the issue of pumped storage. In the New Policies Scenario, hydropower capacity increases strongly, to 20 GW.

Our projection in the New Policies Scenario is based on the assumption that sensitivities regarding water use (see Chapter 1.3.4), concerns over drought (which has in the past taken off 900 MW of capacity) and local opposition (which led to the cancellation of the El Caracol power plant on the Balsas River) persist, capping project expansions and delaying further large-scale capacity additions.

Bioenergy

The use of bioenergy, which currently accounts for less than 5% of total energy demand, is projected to remain stagnant in the period to 2040, as a slight increase in bagasse use in power generation (accounting for less than 1% of the total), is almost entirely offset by decreased use of solid biomass in residential buildings, where it is gradually replaced by LPG and piped natural gas for cooking and heating. The outlook for bioenergy consumption could change based on developments in the transport sector. In April 2016, Mexico started a regional pilot project involving a 5.8% ethanol mandate, with six companies awarded rights to market this blend in Veracruz, San Luis Potosi and Tampaulipas.¹⁰ Apart from reducing gasoline imports, the aim is to stimulate a local bioenergy industry.

2.3.5 Energy and the environment

Local air pollution¹¹

With rising incomes and population, energy demand in Mexico is expected to increase by about one-fifth above current levels by 2040. Today's energy sector in Mexico is unique in that oil makes up more than half of total energy demand and natural gas another third, while coal plays a relatively minor role (7%), compared with other countries. As we have seen, the strong policy push expressed through existing regulation and the climate pledge

¹⁰ Estimated at 155-221 million litres of ethanol.

¹¹ The issue of air pollution in Mexico is covered in *Energy and Air Pollution: World Energy Outlook Special Report*, available at: www.worldenergyoutlook.org/airpollution.

made at COP21 will help to diversify this energy mix, in particular by increasing the use of renewables. The effects of government action can already be seen in declining sulfur dioxide emissions (SO₂), in particular, and our projections in the New Policies Scenario show a strong decline in oil-based power generation, helping to cut overall SO₂ emissions from the energy sector by half by 2040. Other pollutant emissions also decrease in our projections. Despite a continued rise in demand for mobility and industrial activity, nitrogen oxide (NO_x) emissions fall to 1 million tonnes (Mt) by 2040, a decrease of one-third below today's level, while particulate matter (PM_{2.5}) emissions decrease only modestly to almost 15% below today's level, as declines in emissions from the buildings and transport sectors are partially offset by increases in the industry and transformation sector.

Climate change

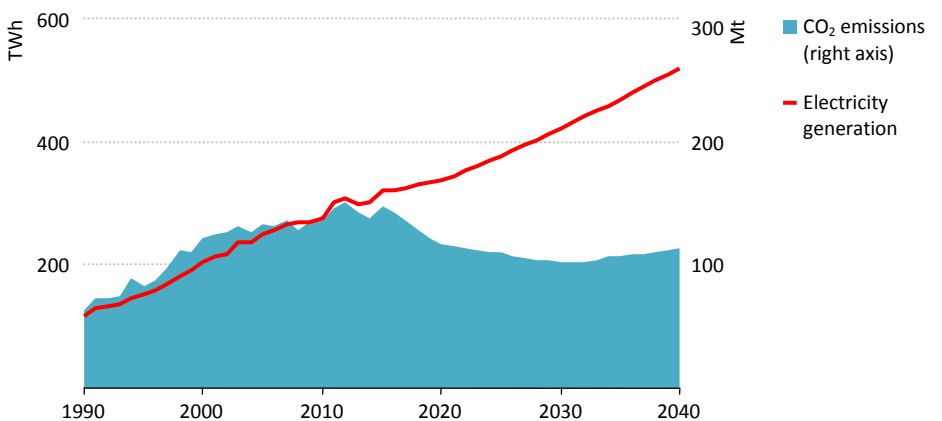
Climate change objectives are deeply entrenched in Mexico's current policymaking, not least in the Energy Reform. The country has a long history of commitment to addressing climate change issues and was the second country in the world to translate its climate change ambitions into law, and one of the first to publish a climate pledge ahead of the COP21 in 2015. The pledge includes an economy-wide target to reduce greenhouse-gas emissions and short-lived climate pollutant emissions by 25% below business-as-usual by 2030 (an unconditional target) and by up to 40%, subject to a range of considerations, including access to low-cost financial resources and technology transfer.

To meet these goals, Mexico is pursuing a number of concurrent strategies: it has set ambitious clean energy goals (see Chapter 1.3.2) and is in the process of designing a National Energy Efficiency Policy Strategy¹² which, among many benefits, is likely to help bring down Mexico's carbon intensity. In the New Policies Scenario, such measures help to cut the carbon intensity of the economy by more than half.

The strong proliferation of renewables in the power sector, where around one-in-two gigawatts of new capacity installed to 2040 is projected to be either wind or solar, coupled with a shift to natural gas from more polluting oil, makes a major contribution to the decrease in CO₂ emissions from the power sector (Figure 2.19). This is despite electricity generation increasing by 70%. CO₂ emissions related to power generation fall by almost 20% by 2040, implying a 52% drop in carbon intensity. In the transport sector, the largest emitter of CO₂ in Mexico, emissions continue to increase, but at a much more moderate pace compared with previous trends: between 1990 and 2014, CO₂ emissions increased by over 80%, to reach 151 Mt CO₂; by 2040, they are expected to reach 170 Mt CO₂, a 13% increase (while car ownership increases by more than one-fifth).

¹² This strategy was mandated by the Energy Transition Law, passed in December 2015, which provides a framework for clean energy, energy efficiency and GHG emission reductions.

Figure 2.19 ▸ Electricity generation and energy-related CO₂ emissions, 1990-2040



After years of parallel growth, Mexico successfully decouples electricity generation from power sector CO₂ emissions

Note: Mt = million tonnes.

Although Mexico reaches (and even surpasses) its clean energy targets in the New Policies Scenario, reaching the overall GHG mitigation goal will be a challenging endeavour. The lower bound of the pledged target requires GHG emissions in total to be reduced to around 760 Mt in 2030. In the New Policies Scenario, energy-related GHG emissions fall modestly to around 460 Mt in 2030, meaning that emissions from other sectors (such as agriculture or waste) would need to roughly stabilise at the present level if the lower end of the GHG target is to be achieved. The higher end of the pledge would require GHG emissions to drop to around 620 Mt in 2030, an emissions budget that without additional measures would already be largely absorbed by the energy sector.

Mexico's Energy Reform in focus

What's the benefit of a new direction?

Highlights

- Mexico's energy pathway in this *Outlook*, based on the assumptions of the New Policies Scenario, is determined in large measure by the *Reforma Energética* (Energy Reform) now being implemented. This secures a return to growth in the upstream oil sector and a more efficient, cost-effective and rapidly decarbonising electricity sector. The Reform generates a range of positive interactions with international markets, via flows of capital, technology and best practice, as well as energy trade via an increasingly interconnected North American energy system.
- A series of bidding rounds that began in 2015 is opening the oil and gas sectors to private investment and technology, leaving PEMEX to focus its resources and expertise on a narrower range of projects, either alone or in joint ventures. This new investment helps to slow the decline in output in shallow water areas — the traditional mainstay of Mexico's production — while bringing forward new projects in deepwater and developing new onshore resources, including tight oil. The rise in output to 3.4 mb/d in 2040 makes Mexico one of a handful of global producers that increase production over the period to 2040.
- The unbundling of CFE and a further opening of the power sector to private participation play a major role in mobilising the \$10 billion per year that Mexico needs to upgrade the electricity network and to keep pace with growing demand. Long-term auctions for energy, capacity and clean energy certificates provide an entry point for new players on a competitive basis and a cost-effective way to bring low-carbon generation into the mix. A strengthened transmission and distribution system and reduced losses help to moderate the costs of electricity supply.
- A hypothetical No Reform Case considers what Mexico's energy outlook might have been in the absence of the Reforms introduced since 2013. Projecting the future on the basis of the historical relationship between oil revenue and PEMEX upstream spending permits an alternative outlook for upstream investment to be drawn. This severely limits Mexico's capacity to fund expansion and enhanced recovery projects in legacy fields, and delays the start of technically challenging deepwater and tight oil development projects. As a result, by 2040, oil production is some 1 mb/d lower than in the New Policies Scenario. In the power sector, without the efficiency gains made in networks and other parts of the system in the New Policies Scenario, the cost of electricity supply is higher. Without specific policies to increase the role of clean energy, lower deployment of renewables leaves Mexico well short of its clean energy targets. The No Reform Case leaves Mexico's economy 4% smaller in 2040 than in the New Policies Scenario.

3.1 Four angles on Mexico's Energy Reform

Mexico's oil, gas and electricity sectors are in a period of profound transformation, with far-reaching implications for all aspects of the country's energy provision, trade, investment and environmental performance. In this chapter, we assess in more detail the outlook for the sectors most affected by Mexico's Energy Reform. The results in the New Policies Scenario are set against the results of the "No Reform Case", which rolls back the profound Reform of recent years, assumes the state monopoly is maintained in oil and gas and excludes new private participation and restructuring in the electricity sector. This comparison provides a measure of the value unlocked by the Reform now in process, both for the energy sector and for the wider Mexican economy.

This chapter addresses four sets of questions:

- **Upstream oil:** How does the new configuration of the upstream sector shape the development of Mexico's oil potential? How do the challenges, players, costs and investment needs vary across shallow, deepwater and onshore resources?
- **Power market:** Can Mexico improve the efficiency of its power system, with lower generation costs and transmission losses, while simultaneously pursuing its clean energy goals?
- **North American energy integration:** How are Mexico's energy choices and prospects affected by its participation in a dynamic and increasingly interconnected regional market?
- **Value of reform:** What would Mexico's energy and economic outlook be like in the absence of reforms to the oil, gas and electricity sectors?

3.2 Mexico's upstream oil: fighting against decline

In the New Policies Scenario, Mexico's oil production initially continues to fall from the level of 2.6 million barrels per day (mb/d) seen in 2015, reaching a low point of around 2.3 mb/d before gradually rising again in the early 2020s as the impact of new investment starts to outweigh the field declines from existing production (Table 3.1). There are three main components to this outlook. The first is Mexico's shallow water production, which accounts for nearly 70% of current total output. This is an area in which Petróleos Mexicanos (PEMEX) has a long track record and unrivalled expertise, but where productive assets are ageing rapidly. Second there are the deepwater resources, a highly promising but demanding new frontier for Mexico. In addition, there are the untapped resources that lie onshore, including tight oil.

These three areas face very different challenges and require various approaches to unlock their potential, but a common denominator across the entire upstream is the need for investment. There has been a significant upswing in spending by PEMEX since the early 2000s, but average annual upstream investment over the last ten years – of around \$16 billion per year – is well short of the \$30-45 billion per year required, in our estimation, to lift Mexico's output from the lows reached in the early 2020s in the New Policies

Scenario up to the projected levels for 2040. Despite its deep competency in key technical areas, PEMEX has limited experience of deepwater development or tight oil. It would be a major challenge to quickly develop the required skills on its own.

Table 3.1 ▶ Oil production by type in Mexico in the New Policies Scenario (mb/d)

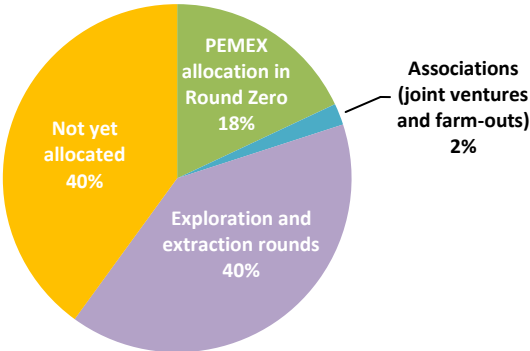
	2000	2005	2015	2020	2025	2030	2035	2040	2015-2040
	Delta								
Conventional	3.5	3.8	2.6	2.4	2.5	2.7	2.8	3.0	0.4
Crude oil	2.9	3.2	2.2	2.0	2.1	2.3	2.4	2.4	0.3
Existing fields	2.9	3.2	2.2	1.6	1.0	0.7	0.4	0.3	-1.9
New fields	-	-	-	0.3	1.0	1.6	1.9	2.1	2.1
Enhanced oil recovery	-	-	-	-	0.0	0.0	0.0	0.0	0.0
Natural gas liquids	0.6	0.6	0.4	0.4	0.4	0.4	0.5	0.5	0.1
Unconventional	0.0	0.0	0.0	0.0	0.1	0.3	0.4	0.4	0.4
Tight oil	-	-	-	-	0.1	0.3	0.4	0.4	0.4
Total	3.5	3.8	2.6	2.4	2.6	3.0	3.2	3.4	0.8
<i>Shallow water</i>	2.5	2.9	1.8	1.6	1.5	1.4	1.2	1.1	-0.6
<i>Deep water</i>	-	-	-	0.0	0.2	0.5	0.7	0.9	0.9
<i>Onshore</i>	1.0	0.9	0.8	0.8	1.0	1.2	1.3	1.3	0.5

Note: Mexico possesses significant quantities of heavy oil, but these do not fit the WEO description of extra-heavy (unconventional) and are thus included in the conventional crude classification.

The 2013 Energy Reform package, which is carried through in the New Policies Scenario, is designed to open Mexico’s oil and gas resources to outside investment, both foreign and domestic (see Chapter 1.3.2). Opening the sector should achieve a more efficient allocation of capital and skills, which will, in turn, give Mexico an excellent chance of returning production to a growth trend. Assets were requested by and assigned to PEMEX in the “Round Zero” auction, prior to opening of the competitive bid rounds, to reflect the intent of focusing PEMEX’s attentions on areas where it has established experience.

A *World Energy Outlook* analysis of Secretariat of Energy (SENER) data suggests PEMEX now has rights to 20% of Mexico’s remaining recoverable oil and gas resources, which can be developed either in association with others or solely by PEMEX (Figure 3.1). Although some of the assigned resources are onshore, the largest share is in southern Mexico’s shallow offshore waters, adjacent to legacy fields developed and operated by PEMEX. This allows the company to concentrate its efforts in a region where it already has particular expertise. In addition to the shallow water allocations, an estimated 13% of the Round Zero assignment is in deepwater areas, including the Perdido area in the northern Gulf of Mexico, near the maritime border with the United States. PEMEX has already conducted a successful exploration programme there, but has yet to move to production. Partnership with experienced deepwater operators can facilitate faster development of Mexico’s resources while allowing PEMEX to gain valuable experience, exposing it to less risk than doing it alone.

Figure 3.1 ▶ Total oil and natural gas resource allocation



The allocation of resources under SENER's five-year development plan leaves PEMEX in a strong position, while opening up broader opportunities in Mexico's upstream

Note: The PEMEX share includes resources allocated in Round Zero, plus future production from PEMEX fields already in production.

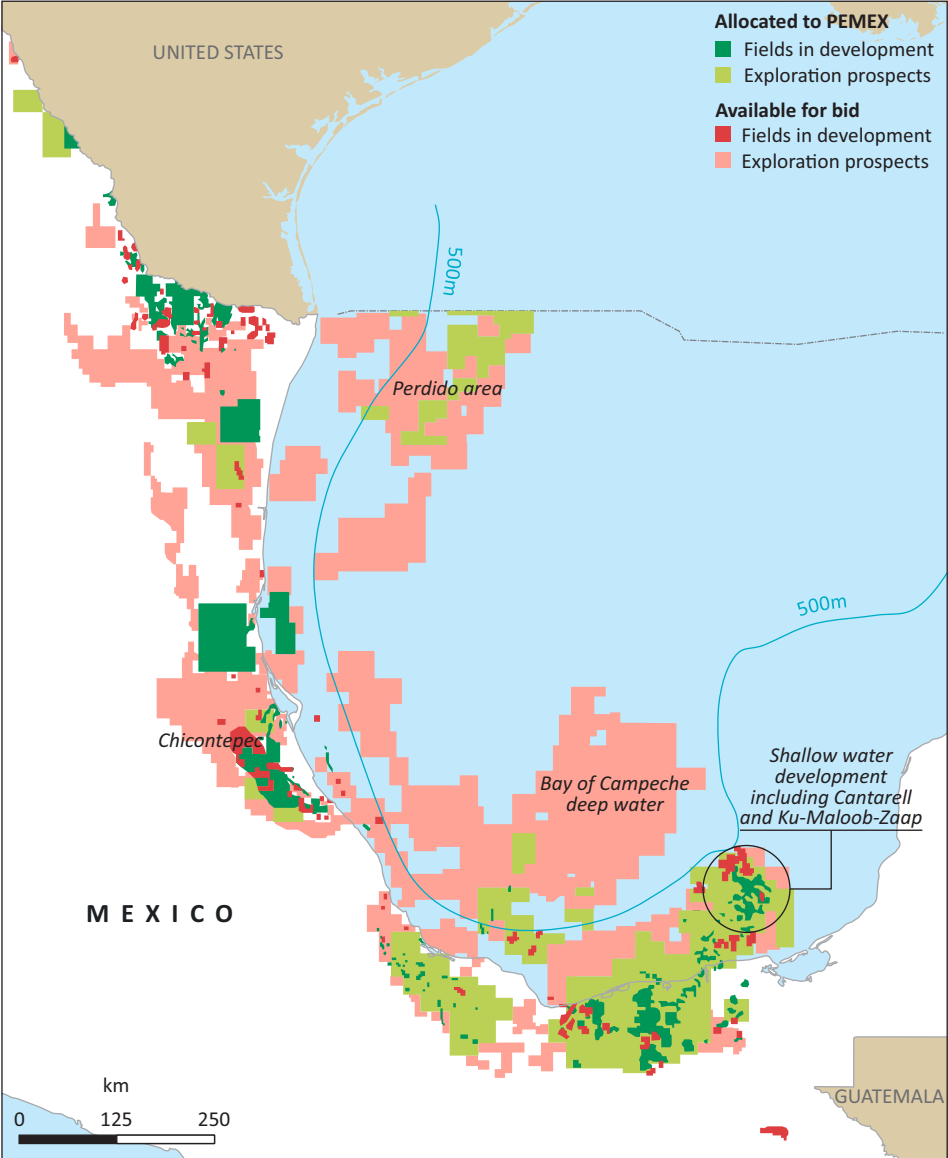
Sources: IEA analysis based on IEA databases and SENER documentation.

For the time being, the resources offered for association contracts (in partnership with PEMEX), are concentrated in areas in which PEMEX chooses to participate, but which currently lie either outside its preferred operational scope, such as the labour-intensive but low production Chicontepec field¹, or outside its set of core competencies, such as production of heavy oils from shallow water fields and deepwater development. An association with PEMEX for the Trion project in the northern Gulf of Mexico is one of the first deepwater opportunities to be offered to the private sector. This is aimed at speeding up deepwater production while allowing PEMEX to remain involved in operations as it gains experience. PEMEX also has the option to allocate assets for association in the future, as well as bidding against others for yet to be assigned assets in future bid rounds organised by *Comisión Nacional de Hidrocarburos* (National Hydrocarbons Commission) (CNH). Essentially, this means the allocations for PEMEX shown in Figure 3.1 may not be exploited exclusively by PEMEX.

A further estimated 40% of remaining recoverable oil and gas resources is allocated for the exploration and extraction rounds foreseen under the initial five-year allocation in the Energy Reform. The remaining 40% of oil and gas resources are yet to be allocated. These resources consist mainly of deepwater exploration blocks in the southern Gulf of Mexico, tight oil and gas prospects onshore in northern Mexico, and heavy oil fields in shallow waters off the central coast.

¹ Chicontepec is included in our onshore conventional figures, but discussed separately because it is estimated by SENER to be the play with the largest remaining resource. Recovery rates, however, are believed to be less than 10% range, making it unlikely that production will ever be commensurate with the size of the resource base.

Figure 3.2 ▶ Resource allocation in SENER's current five-year plan



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Investment alone, however, is not enough to guarantee success. Outcomes will also depend on the capacity and performance of the regulatory institutions that have responsibility for the upstream, including those charged with health, safety and environmental oversight. There are also other problems and opportunities, described in the next section, that could arise in meeting the production trajectory envisaged in the New Policies Scenario, bearing in mind that, although Mexico has a relatively large resource

base, its largest fields are well past their days of peak production and the remaining reservoirs have varying degrees of complexity. More challenging resources, like deepwater reservoirs, some heavy oil prospects and tight oil, are essentially untouched. In most key aspects, resource types, geological and technical challenges and upstream players the future of Mexico's oil production looks very different from its past.

3.2.1 Offshore production

Shallow water - Gulf of Mexico

Shallow water fields contain Mexico's largest concentration of ultimately recoverable oil reserves (URR), at 48 billion barrels, with 20 billion barrels of remaining recoverable resource (RRR) (see Chapter 2.3.2). These fields have, therefore, been the mainstay of Mexico's oil production for decades, allowing PEMEX to develop first-class expertise in the sector. Even so, the company has not been in a position to exploit this resource efficiently. For example, a dearth of investment has meant that no major new producing assets have been added to the shallow water inventory in Mexico since 1987.

The combination of challenging geology in ageing assets and constrained investment in new ones mean that decline rates are relatively high. Natural decline rates reach in excess of 15% per year in many of the large fields. Observed decline (the decline that occurs despite continued investment in existing fields) has averaged 3% in recent years, but it increased to 7% in 2015. The largest of Mexico's fields are declining at a high rate, but investment by PEMEX during the past several years has resulted in expansion projects at the ageing Abkatún-Pol-Chuc and Ku-Maloob-Zaap complexes and fields in the Litoral de Tabasco region are still ramping up to design capacity. By 2020, nearly 700 thousand barrels per day (kb/d) of production from these fields will be lost due to decline.

The Cantarell complex in southern Mexico's shallow waters dominated oil production for nearly three decades before succumbing to sharp decline after 2004. The main producing area is the Akal field, which provides about half of the complex's production. There are multiple horizons of naturally fractured carbonate and sand, through which oil has high mobility, that have been relatively easy to produce.² Secondary recovery techniques have been used for some time in the mature fields. By the mid-1990s, PEMEX had decided on a massive application of nitrogen injection at Cantarell, which began in 2000. The intent was to temporarily stabilise reservoir pressure and to accelerate oil production from the fractures by gravity segregation, therefore bringing cash flow forward in time. The programme succeeded, but the (expected) associated rapid decline started in 2004, when production from the field reached 2.2 mb/d. By 2015, output was down to 350 kb/d and it continues to fall.

² Mobility refers to the ease at which oil flows through the reservoir. Oil sands have low mobility, while high porosity conventional oilfields typically have high mobility.

When oil is produced in a high permeability reservoir, gas that has accumulated at the top of the reservoir applies downward pressure, forcing oil towards the wellbore. Water from below displaces most of the oil and gas displaces the remainder. While this process is underway, the reservoir loses pressure as the gas expands in volume and oil is evacuated. Water has now invaded one of the flanks of Akal and, being quite mobile, has resulted in the closure of several hundred wells, hastening the field's production decline. Natural fractures also accelerate the water mobility. At the same time, reservoir pressure has fallen to 25-35% of its original level, as the gas cap grows steadily, further complicating extraction. In addition, the natural gas in the reservoir has been diluted by nitrogen, meaning that it now has limited value, other than for re-injection or consumption as fuel in the production facilities. Future enhanced recovery schemes need to address water mobility by using advanced techniques such as foamed nitrogen. Chemical solutions that change the properties of the oil remaining within the rock matrix, allowing it to be pushed from the pores, may also be employed. The Akal field at Cantarell provides a good example of the difficulties of enhanced recovery: the experience gained there can be useful elsewhere, particularly in other (albeit smaller) shallow water fields with similar geological characteristics. Many of these are at an earlier development stage, so it is not too late to incorporate enhanced recovery schemes into the design and thereby achieve higher recovery rates.

Ku-Maloob-Zaap and Ek-Balam are two large complexes adjacent to Cantarell, where development occurred later and at a slower pace. Ku-Maloob-Zaap is Mexico's largest producing asset today and it is set to remain an integral part of future supply. A substantial investment programme has been put in place, with the objective of maintaining output levels as long as possible. This programme expands the existing use of nitrogen injection, plus additional wells. Lessons learned at Cantarell may be of value, as Ku-Maloob-Zaap is believed to be early enough in its life to benefit greatly from a well-designed enhanced recovery programme.

Technologies to further enhance recovery exist, but they are expensive and are not available at scale in Mexico today. In the Round Zero bidding, triggered as a result of the Reform process, PEMEX retained ownership of the largest producing fields in shallow water and, with it, the burden of improving recovery from them. However, under the Reform, PEMEX can form joint ventures. If done with care, this approach could greatly improve the chances of applying new technologies to improve recovery from ageing fields in shallow waters, reducing the cost of operations through competition and sharing knowledge. Timing is important, because delay may result in the fields passing beyond the point at which enhanced oil recovery (EOR) programmes can be implemented most successfully.³

IEA analysis of the Energy Reform and the SENER five-year plan indicates that PEMEX is likely to be the operator of a dominant share of the remaining recoverable oil resources

³ Adoption of EOR programmes are time and resource intensive, and payback time can be long. Therefore it is best to have EOR design in mind well in advance. If implementation is delayed too long, production may fall to the point at which EOR is not viable (see *World Energy Outlook-2013*).

that lie in shallow water (and the possibility of more when associations are included in the calculation). Although PEMEX was assigned shallow water exploration prospects, its prime task is the development of known reservoirs. Of the resources now available directly to new entrants, only about 25% are conventional developments, while the remainder are technically challenging heavy oil prospects.⁴ The *Outlook* includes the assumption that all blocks on offer in the five-year plan are awarded and eventually developed, though with some flexibility in the start date to account for changes to the schedule of the rounds and the possibility of a block not being awarded in the designated round.

In the New Policies Scenario, production at shallow water fields falls during the projection period from a level of 1.8 mb/d in 2015 to 1.1 mb/d in 2040, despite the addition of more than some 900 kb/d of production from new shallow water projects. These projects include both new fields and investments designed to increase recovery from existing fields. Recovery from existing fields focuses on two aspects: superior reservoir management and the deployment of EOR techniques. Secondary recovery, through the use of nitrogen injection, is already used extensively and is expected to continue on a large scale; but enhanced recovery techniques, including chemical injection and the injection of miscible gases that change the properties of the oil are expected to play a growing role in future production.

Deepwater - Gulf of Mexico

The resources that lie in deep water in the Gulf of Mexico hold considerable promise, both for the Mexican authorities looking to maximise their value and for private companies that have shown an interest in investing. Our analysis of Mexico's deepwater production prospects is based on an estimate of 16 billion barrels of remaining recoverable oil. Exploration drilling has been conducted, but no production exists today. The greatest concentrations of Mexico's deepwater resources are thought to be within the Perdido fold-belt structure in northern Gulf of Mexico, and to the south in the Bay of Campeche. SENER believes that approximately 50% of the country's prospective conventional oil and gas resource lies in deep waters, which makes these resources an attractive proposition for international oil companies. PEMEX, though, has limited operating experience in this environment. Its first discovery was announced at the Trion 1 well, in the Perdido area, during 2012. Further discoveries have been made in the surrounding blocks and, based on test results, SENER estimates that the Perdido area holds about one billion barrels equivalent of recoverable oil and gas.

Although these discoveries were made and evaluated by PEMEX, a different set of skills is needed to bring them into production. The Perdido area includes the Trion Field, which PEMEX has said contains an estimated 480 million barrels equivalent of oil and gas. It will

⁴ Although Mexico's heavy oil fields have a low API gravity, the oil in them is not distributed in a continuous fashion. This oil does not meet the *WEO* definition of extra-heavy oil, but still requires additional technical capacity than is currently available to PEMEX at scale. Therefore, Mexico's heavy oil resources are included in the shallow water conventional resource total.

be the first of Mexico's assets to be offered to bidders as an association prospect under the new hydrocarbons law, enabling PEMEX to gain deepwater production experience and reducing the time to first production. Although the Trion discovery lies about 200 km from the shoreline, it is only 40 km from Shell's Perdido complex on the US side of the maritime border, which is already in production. Such proximity offers Trion (and other blocks in the area) an opportunity to use existing infrastructure on the US side. Development by means of a floating production, storage and offloading vessel is another option. Trion will require some \$11 billion to develop.⁵ By comparison, the Perdido project on the US side of the border has required investments of an estimated \$7.3 billion between inception and 2013, the year in which production peaked. Several billion additional dollars are expected to be required to keep the US based Perdido project running until it is eventually decommissioned.

As stated, the Perdido area lies far from shore and transportation is difficult compared with existing fields in the south. Mexico has done well by encouraging port expansions, including of Matamoros, near the US border. If the Matamoros expansion project is delayed, the alternative is to ship from the southern port of Ciudad del Carmen, which supports the projects operating in the Bay of Campeche. The distance from Ciudad del Carmen to Perdido is nearly four-times that of Matamoros to Perdido and this route is limited to relatively small vessels that can fit into existing port facilities. A positive aspect of logistics is that equipment not available in Mexico can be shipped from the United States with relative ease, in accordance with North American Free Trade Agreement (NAFTA) rules.

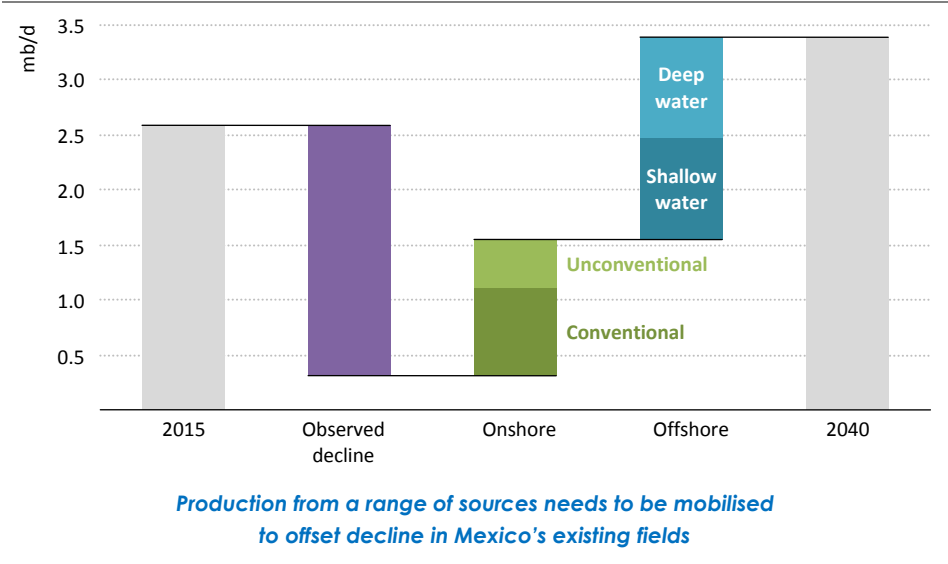
Despite relative proximity to Mexican support bases, many challenges remain for deepwater exploration and production in the Bay of Campeche in southern Gulf of Mexico. Water depths exceed 3 000 metres, a range at which only the most recent drilling rigs can operate. In addition, the sea floor is believed to be quite rugged which makes placement of sub-sea equipment difficult. Exploration wells have yet to be drilled. Despite these challenges, the area has attracted a high level of investment in surface exploration activities such as seismic surveying since the implementation of Reform. Processing these data is difficult and lengthy, and complete results are not likely to be available until 2017, but we nonetheless anticipate that some resources in the southern Gulf of Mexico are developed, as around half of the region's estimated resources are to be offered to bidders in the initial SENER five-year plan. The state holds the remainder, and our *Outlook* assumes the release of another three billion barrels of prospective resources after 2025.

Production from deepwater fields contributes the most to the growth in oil output projected to 2040, adding 900 kb/d to capacity (Figure 3.3). This will require considerable investment, with projects in deepwater accounting for almost 40% (about \$215 billion between now and 2040). We have assumed lead times for the arrival of deepwater

⁵ Mexico's Energy Reform was preceded by the United States-Mexico Trans-Boundary Hydrocarbons Agreement, signed in 2012. This lifted a moratorium on drilling in the border region that had been in place since 2000. The agreement also gave PEMEX and US companies the option to develop oil and gas resources that straddle the maritime border.

production of between four and six years between the award of a block and first production. The shorter term within this range was assigned to the Trion prospect, which is scheduled to be developed jointly by PEMEX and the winner of an association contract that is expected to be awarded in December 2016. Other concession blocks outlined in the five-year plan are assumed to start production between 2022 and 2025, given the additional time required to develop the necessary infrastructure. The time between a final investment decision and first production is likely to decrease later in the projection period.

Figure 3.3 ▶ **Observed decline and production by type, 2015-2040**



3.2.2 Onshore production

While enhanced recovery at Mexico’s ageing giant fields offers a way to limit decline and deepwater developments have the best chance of eventually increasing national production, onshore tight oil (though challenging) and Chicontepec resources offer the potential to fill the gap while deepwater programmes develop. In the New Policies Scenario, onshore production reaches 1.3 mb/d in 2040, of which 150 kb/d is from existing fields. Most production is sourced from areas that are currently not producing. Tight oil production starts in earnest in the early 2020s, growing to 440 kb/d by 2040, while production from Chicontepec increases several years earlier and reaches 220 kb/d in 2040.

Conventional onshore fields requiring smaller operations are likely to gain renewed interest from local firms that can give more focus than PEMEX can. Small does not necessarily mean inexpensive, because age and the level of depletion can also push up operating costs dramatically. It is likely, however, that a nimble start-up company can find efficiencies that eluded PEMEX and ultimately bring on production at a lower cost per barrel.

Tight oil

There is currently no tight oil production in Mexico. But the extension of the US Eagle Ford play into Mexico's Burgos Basin, and other tight oil resources in the Tampico-Misantla Basin further to the south hold promise (gas may prove to be the dominant mode of production in Burgos, but some condensate and natural gas liquids are likely to follow). Low oil prices have delayed the launch of Mexico's unconventional resource bidding round. Despite this, SENER has indicated that nominations or requests by potential investors that certain assets be added to future bidding rounds have exceeded expectations in basins containing tight oil resources. Bids are not an unequivocal sign of future production, but are nonetheless a positive indicator.

Aside from a supportive oil price, three factors are needed for profitable development of a tight oil resource. The first is favourable geological conditions, over which a nation has no control. The majority of Mexico's 13.1 billion barrels of prospective tight oil resources are distributed between the northern Burgos Basin and the Tampico-Misantla Basin to the south. Explorers have noted that Mexico's portion of the Eagle Ford appears to have similar geology to its US neighbour, but it lies at greater depth, requiring more expensive wells to access. The prospective tight oil targets within Tampico-Misantla lie at shallower depths than in Burgos, which should improve the economics, but the geology is made more complex by faulting. The second factor for success in tight oil development is an efficient supply chain, on which policy-makers and regulators can have an immense impact. This is important because of the high number of wells needed to recover sufficient hydrocarbons (each well has a small drainage area), and the quantities of proppant and water needed to fracture each well. The proximity of water and sand or proppant resources to the oil field can make or break a project's economics. Transportation infrastructure is vital, whether rail or good-quality roads capable of supporting large volumes of heavy traffic.

The third is access to land, which can be achieved through a combination of sensitive regulation which wins confidence in the protection of communities and surface resources, and responsible behaviour by the exploration and production companies. Communities may not be willing to allow access to unconventional resources unless they are confident of effective support from state and federal governments. To ensure an environment that is conducive to investment, Mexico's regulators are increasingly working with the regional and local governments, who will seek to benefit from the new federal hydrocarbon laws (see Chapter 1.3.2). Without local government commitment, it will be difficult to attract the investment necessary to build and maintain the supply chain needed to make tight oil and gas profitable. Security is a related factor, as much of the tight oil and gas resources lie in areas currently troubled by drug-related violence.

Tight oil is first produced in the early 2020s in our *Outlook*, but in small quantities. Development of known reservoirs in the Tampico-Misantla Basin, using horizontal wells and multi-stage fracturing, is expected first. Production is likely to spread to the Burgos Basin later, when development of shale gas begins in earnest (see Chapter 2.3.3). Tight oil

production reaches 300 kb/d by 2030 and 440 kb/d in 2040. Initial development costs are expected to be higher than those in the United States today. Though Mexico will certainly benefit from lessons learned at tight oil and gas projects in the United States, Canada and Argentina, such benefits are likely to be outweighed, at least in the medium term, by the high investments needed to build infrastructure and materials supply chains. Higher tight oil production than shown in our *Outlook* is possible, if solutions to the challenges described can be demonstrated early.

Chicontepec

The Chicontepec region is particularly interesting due to its combination of geographic extent, its low recovery factor and the commercial methods used to deliver production to date. SENER has estimated Chicontepec's resource size at an astonishing 42 billion barrels equivalent of oil and gas, but the reservoir quality is not homogenous and low porosity and permeability limit oil flow. This means that a large number of wells are needed to develop the area, which is vast. Chicontepec is similar to tight oil and gas in this respect⁶. The large number of wells needed means that the project economics are extremely sensitive to cost per well. In 2008, PEMEX proposed a drilling programme of 13 500 wells over a 13-year period with the intent of producing up to 1 mb/d from the field. By 2010, Chicontepec production was 55 kb/d, significantly less than the intended target for that year, which illustrates the complexity of producing this field. In the same year, PEMEX launched a programme that allowed engineering and service firms to develop parts of the field on a fee per barrel model. Some success was achieved and production reached 100 kb/d in 2013, but it has since fallen, due to a combination of decline and limited interest from bidders in a continuation of the service contract model. This had evolved from an early, simple fee per barrel system to a model that required the contractor to cover the development costs and receive compensation from PEMEX for each barrel produced, after recovery of operating costs using an elaborate formula.

Due to the heterogeneous reservoir quality across Chicontepec's vast area, and its low permeability and porosity, present recovery rates for the region are thought to be less than five percent of the resource in place. Mexico hopes to increase this low level by inviting foreign technology and investment. Due to its geological and topographical complexity, Chicontepec also requires a relatively high oil price to keep investment flowing. The necessary techniques and scale are beyond PEMEX's current comfort level and most of Chicontepec is expected to remain available to outside investors through the bidding rounds afforded by the Energy Reform. Even when oil prices return to profitable levels, attracting investment to the field will be contingent on the terms which must compete with the best on offer elsewhere, both in terms of the potential return on investment and the avoidance of undue contract complexity. Our projection is based on a slow resumption of drilling activity in Chicontepec towards the end of this decade, which will bring about

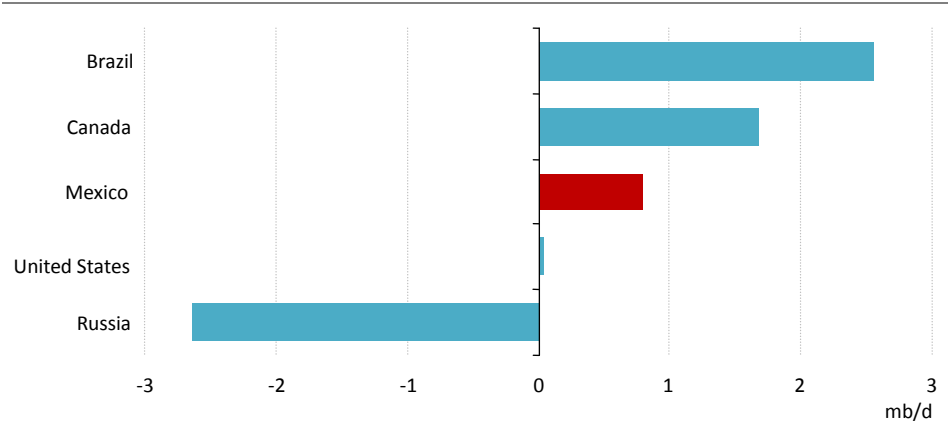
⁶ Chicontepec shares some characteristics with tight oil fields, but does not currently use large-scale hydraulic fracturing and, accordingly, is included with onshore conventional oil in this *Outlook*.

40 kb/d of new production by 2020, steadily rising to 220 kb/d by 2040, so as to then provide around 20% of Mexico's total onshore production.

3.2.3 Implications for trade

Mexico's oil production returns to levels that provide a boost to the global balance reflecting the international market conditions prevailing in the New Policies Scenario, its large but challenging resource base and upstream investment triggered by the Energy Reform. It comes in a context where non-OPEC production in aggregate levels off in the mid-2020s and then starts a steady decline. Mexico is one of the very few countries that have higher production in 2040 than today (Figure 3.4). In this sense, the concentration of Mexico's growth in the second-half of our *Outlook*, i.e. post-2025, implies an important role in mitigating potential risks to oil security during a period of more concentrated reliance on output and export from a limited number of sources.

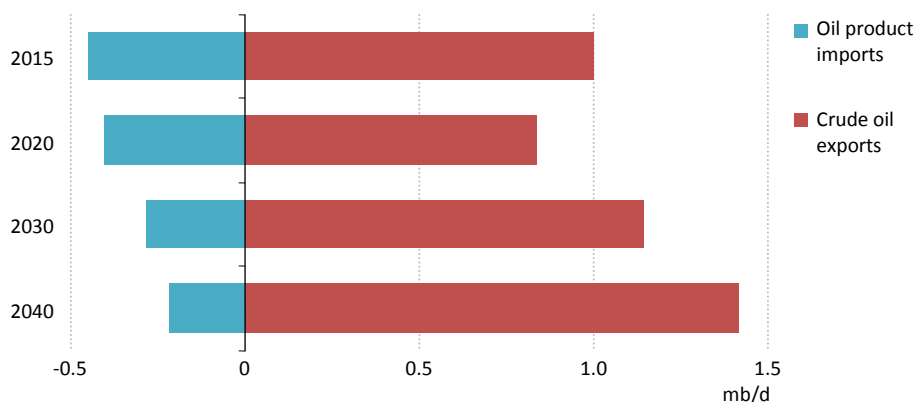
Figure 3.4 ▶ Change in total oil production in selected non-OPEC producers to 2040



Mexico is one of the few non-OPEC countries to increase its production to 2040

Despite refining more of its oil domestically, Mexico's crude exports still grow, allowing it to play a significant role in turning the North American continent into a net exporter of crude oil to the rest of the world (Figure 3.5). Most exports go to the growing Asian refining centres, but some go to Europe. Increased production from the Americas as a whole does create some challenges for Mexico. Import dependency in the United States falls sharply, while production in Canada, Mexico and Brazil looks set to rise. This means there will be increased competition among North American and Latin American producers to ship crude oil and oil products to countries in Asia, where existing exporters – such as Russia and the Middle East – already have a strong foothold.

Figure 3.5 ▶ Crude oil exports and net refined product trade



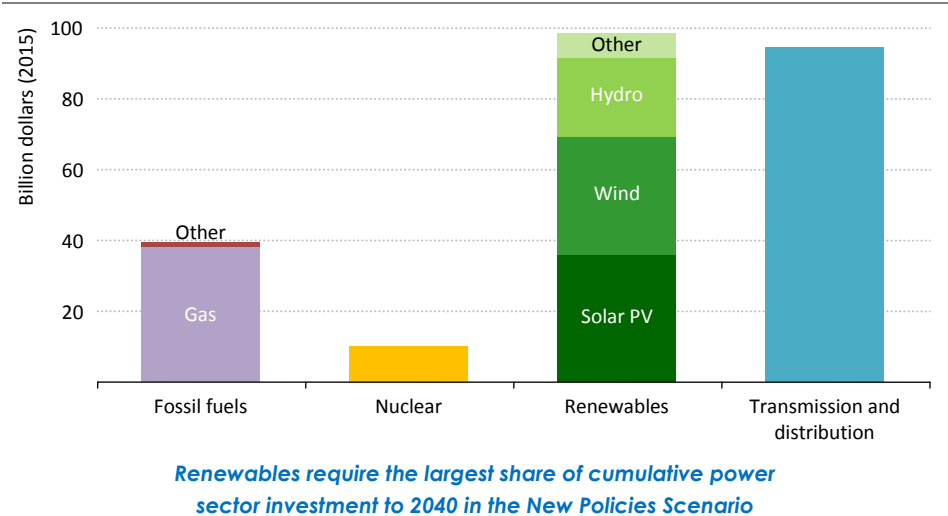
Rising crude exports and lower reliance on imported petroleum products improves Mexico's overall oil trade position

3.3 Power markets: can cleaner power come at lower cost?

The power sector component of the Energy Reform seeks to introduce vigour into a sector under the stewardship of an overburdened state-owned utility, *Comisión Federal de Electricidad* (CFE). At the onset of the Reform process, CFE owned more than 60% of power generation capacity, predominantly fossil-fuelled plants. In the future the company will function as a “productive state enterprise”, charged to achieve commercial viability in a competitive market framework that is increasingly geared towards clean energy investments. In the New Policies Scenario, some \$240 billion in capital investment – an annual average of around \$10 billion – is required in the power sector over the period to 2040, of which \$100 billion goes to new renewables-based capacity, primarily solar photovoltaic (PV), wind and hydropower (Figure 3.6). Attracting capital on this scale to the power sector in order to meet long-term clean energy objectives and at the same time reducing electricity unit costs represents a formidable task for the authorities, regulators and operating companies, but is one that – if accomplished – can bring major dividends.

Mobilising this level of investment will support an increase in electricity generation from around 300 terawatt-hours (TWh) in 2014 to more than 500 TWh in 2040 and enable Mexico to achieve its clean energy targets, as the share of renewable energy in electricity generation rises from 18% to almost 40% by 2040. Moreover, average wholesale electricity generation costs are projected to fall by around 10% by 2040, compared with 2014. In our analysis, we examine the market design and regulatory policies that promote efficient operation of the system and incentivise necessary investment, and the combination of factors that achieves an overall reduction in the total costs of electricity supply.

Figure 3.6 ▶ Cumulative investment to 2040 in power sector in Mexico in the New Policies Scenario



Note: Other in fossil fuels includes oil and coal; other in renewables includes bioenergy, geothermal and concentrating solar power.

3.3.1 Market design, regulation and investment

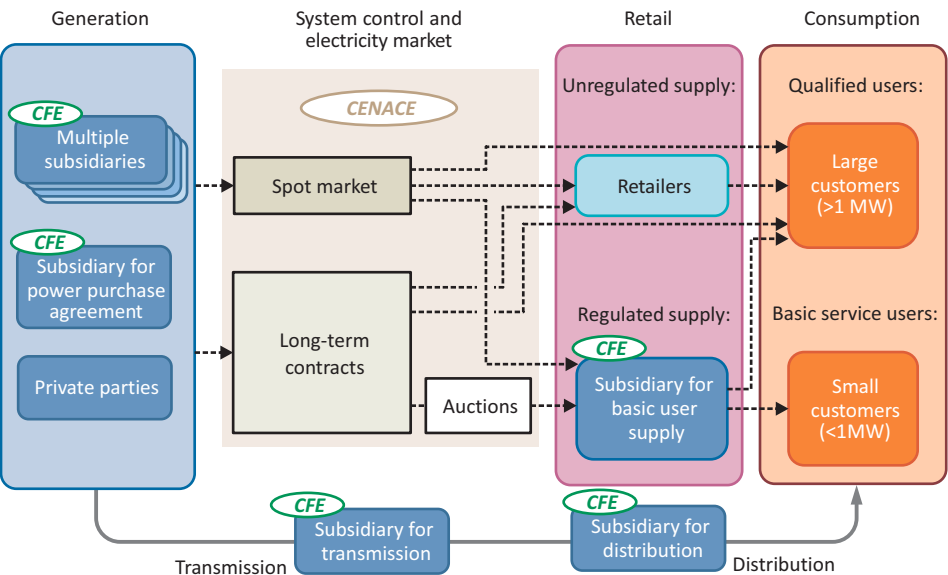
Primary elements in the Reform for the electricity sector are the restructuring of CFE and its unbundling, the introduction of competitive electricity markets for energy, capacity and ancillary services, financial transmission rights⁷ and clean energy certificates. In 2015, CFE was transformed from a government administration into a “productive state enterprise” and unbundled, both vertically (generation, and transmission and distribution) and horizontally (into a series of companies) (Figure 3.7). Various generation companies inherited a portfolio of power plants, diversified by technology and geography, in order to lay the ground for competitive power markets. At this stage, however, all the generating companies are only managerially unbundled: they have different managements but they all remain subsidiaries of CFE and are state owned, though they can be turned into affiliates in future.⁸ Responsibility for system operation has been transferred from CFE to a new, independent entity, the *Centro Nacional de Control de Energía* (CENACE).

⁷ To cope with different energy prices at various nodes of the network, a system of financial transmission rights is foreseen to allow market participants to hedge against the risk of congestion. This mechanism has not been implemented at the same time as the other market reforms, reflecting its innovative character and the consequent need for a longer lead time before full implementation.

⁸ Article 57 of the Electricity Industry Law allows CFE to turn its fully owned subsidiaries into affiliates (except for transmission and distribution). Though the affiliates are still owned by CFE, its ownership can be reduced to up to 51%. Establishment of an affiliate is subject to approval by CFE, which takes into consideration their economic viability and strategic importance to the government.

There are already private players involved in generation following previous reforms that date back to the 1990s. Independent power producers (IPPs) can and do own and operate power plants; but they must sell all power produced to CFE under long-term power purchase agreement.⁹ In addition, large industrial consumers have been allowed to secure their own power, including by means of long-term supply contracts with private generators under a permission scheme. By 2015, IPPs accounted for some 20% of installed capacity and other privately owned capacity accounted for around 17%. By allowing private players to participate in the generation sector freely, the Reform intends to further increase competition in the generation sector over the coming years, leading to most new capacity being built by the private sector.

Figure 3.7 ▶ **New structure of the power sector in Mexico**



The power sector in Mexico is set to become competitive, as CFE is unbundled both vertically and horizontally

The transmission and distribution networks remain subsidiaries of CFE, although they have been legally unbundled from its other activities. Private sector companies can finance, design, build, operate and maintain networks with the approval of SENER. Against this backdrop, a strong and pro-active *Comisión Reguladora de Energía* (CRE) becomes increasingly important in order to ensure non-discriminatory access to the grid for all market participants, including new entrants. Price regulation remains in place for households and small industrial consumers, called “basic service users”. Only qualified

⁹ The existing IPPs will continue operating with the existing long-term power purchase contracts. A separate CFE subsidiary is charged with commercialising the energy procured from IPPs.

users (mainly large industry) can initially opt out of regulated tariffs and buy electricity directly from the market, but in coming years the eligibility threshold could progressively lower from the current 1 megawatt (MW), gradually allowing more competition at the retail level.

A key challenge for the new market is to ensure sufficient investment in new capacity. The New Policies Scenario projects that around 120 gigawatts (GW) will be required by 2040, including over 60 GW of renewables. To stimulate the needed investments to meet growing electricity demand, the new market design is based on the offer of long-term contracts for various products and services: a centrepiece of the Reform effort is an auction system for energy, capacity and clean energy certificates that allows new players into the market (Box 3.1).¹⁰ The auctions offer long-term contracts (15 years for energy and capacity, and 20 years for clean energy certificates) that provide some certainty for future cash flows, reduce risks and consequently the cost of capital. The auctions are technology-neutral for clean energy options: the buyer (which in practice is CFE at this stage) sets out the requirements in terms of energy, capacity or clean energy certificates while the choice of technology is left to the market.

The markets for energy, capacity and ancillary services, transmission rights and clean energy certificates are under development in 2016. Once fully operational, they are intended to provide a sophisticated set of signals to the market about the costs and value of electricity at different locations and times, thereby providing incentives for investors to fill the gaps in the system in an efficient way. These markets are operated by CENACE.

The introduction of short-term wholesale electricity markets enables prices for energy and ancillary services to be calculated on an hourly basis for each node of the grid, refining the previous dispatching tool used by CFE. Reflecting the dominant position of CFE, the current market is strictly cost-based (meaning that the bids of each power plant have to reflect its marginal costs, which are monitored by SENER and CRE). A simplified version of the energy market, calculating day-ahead prices started in early 2016. Once fully implemented for the real-time market, the locational marginal pricing model aims to ensure economic dispatching of the least-cost power, while respecting the security constraints of the grid. In addition, energy prices will reflect the value of generation at different locations in the system by taking into account congestion in the network, sending signals to investors about where new clean generation investments might bring the best returns.

A second market is for capacity, to help generators recover fixed investment costs that may not be fully covered in an energy market strictly based on marginal cost. A unique characteristic of this market is that it is an *ex-post* market, an approach justified by the need to avoid handing undue advantage to CFE, which compensates only the capacity that actually performs when the system needs it. The capacity market will also remunerate

¹⁰ Clean energy certificates are granted to companies that produce power from the designated clean energy technologies. All load serving entities including regulated suppliers (i.e. CFE) and qualified consumers participating in the market are required to purchase these tradable certificates.

clean energy, in particular wind and solar PV, according to their expected availability and generation during peak demand periods, although the detailed rules are yet to be defined and thus this is not featured in the underlying assumptions in the New Policies Scenario. The first stage of the capacity market is planned to be introduced in February 2017. This market functions as a backstop, to ensure that sufficient generation capacity is available in the short-term energy market.

Box 3.1 ▶ Locational signals and long-term electricity auctions in Mexico

Two long-term auctions for electricity under the new regime have been held in 2016. These have provided important momentum to the Reform effort. There was a high level of interest from bidders, including from international energy players. There were 18 successful bids from 11 companies in the first auction and 57 successful bids from 23 companies in the second auction, which won 15-year contracts to provide CFE with energy and capacity, and 20-year contracts for clean energy certificates, beginning in 2018. Solar PV and onshore wind power were the preferred technologies. A distinctive characteristic of the auctions in Mexico is that they seek to capture the relative value for the system of various generation technologies by location and production profile. Projects located in higher price areas of the country, or which are capable of delivering power at peak times, can earn higher revenues and therefore attract more attention from potential investors.

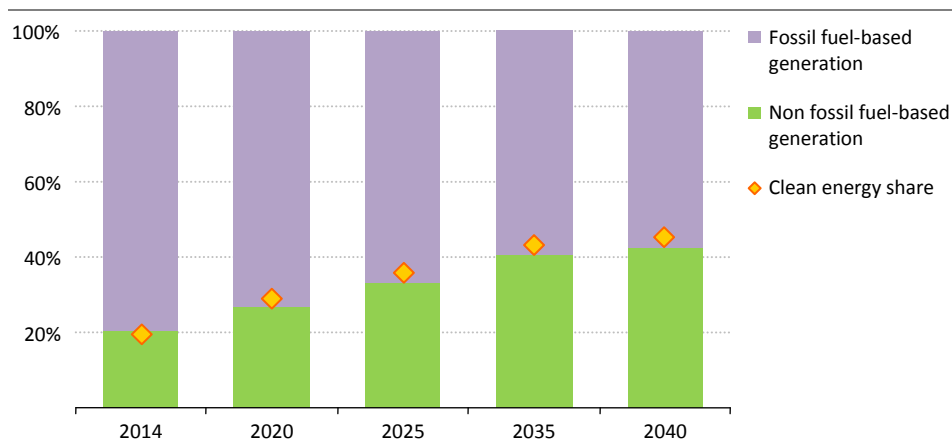
In the first auction, SENER calculated future electricity prices for various locations across Mexico to assess the expected value of new investments and adjusted bids in the auction on this basis. The impact of their methodology could be seen in the outcome. The lowest prices for solar PV were around \$40 per megawatt-hour (MWh) – a resounding vote of confidence both in Mexico’s power market design and in its solar potential. But several solar PV projects were also selected at higher prices (around \$60/MWh) in the Yucatan peninsula (where future electricity prices are expected to be higher), because of their added value to the system as a whole. The result of the second auction, held in September 2016, has further succeeded in lowering prices with more market participants: the average price offered was \$33/MWh, down by 30% from the first auction (SENER, 2016). As more clean energy is deployed and markets become more mature, the government may be able to move to a system in which participants are exposed directly to locational price signals coming from the market. The aim is not just to attract investment, but to ensure the choice of site and technology brings the most benefit to the system.

In addition, to promote clean energy investment, SENER has established requirements to use a percentage of clean energy that all load-serving entities, including retailers and large consumers, must fulfil by procuring required shares of clean energy certificates from CRE certified clean energy generators, or buying them in the market that will be put in place in 2018. A distinguishing feature of Mexico’s Reform in the power sector is that clean energy

obligations were integrated into the Reform package from the outset to take advantage of the country's exceptionally good wind and solar resources. In most other OECD countries, decarbonisation policies have been introduced at least ten years after the introduction of competitive markets.

In the New Policies Scenario, the share of clean energy rises to 35% by 2024 and 43% by 2035, allowing the government to meet its clean energy target, with gas-fired generation accounting for almost all of the rest as coal and oil are pushed out of the generation mix (Figure 3.8). The increased use of clean energy, together with a shift to natural gas leads to savings of around 120 million tonnes (Mt) of carbon dioxide (CO₂) in 2040, compared with the situation wherein the power generation retained its 2014 mix. In the absence of explicit carbon pricing in Mexico, the clean energy certificates allows the market to choose between a variety of technologies, in particular wind and solar. New investments are expected to be driven by long-term contracts, with the market for clean certificates becoming a residual market.

Figure 3.8 ▶ **Share of clean energy in power generation in Mexico in the New Policies Scenario, 2014-2040**



The share of clean energy in power generation rises to more than 40% by the 2030s in the New Policies Scenario

Note: Clean energy includes nuclear, hydropower, other renewables and efficient cogeneration, as defined by Mexico's Electricity Law.

An open question on the clean energy front is how the envisaged expansion of nuclear capacity will play out. Mexico plans to build 4 GW of nuclear capacity by 2030, in addition to the existing 1.5 GW at the Laguna Verde site. There is no specific financing mechanism for nuclear and currently the intention is that nuclear power projects should be financed through the same mechanisms of energy and prices, and clean energy certificates. The price levels from the auction held thus far and the duration of the available contracts (15 years for energy and capacity, and 20 years for clean energy certificates) raise questions

about whether nuclear power plants can be financed under this system. In our projections to 2040, 2 GW of nuclear capacity are added, though this may, require additional intervention.

An IEA review of Mexican energy policies finds that the design of Mexico's electricity Reform is well-conceived and that the early results indicate that it is capable of delivering the required investments, including a step-change in investment in clean energy.¹¹ But implementation is still at an early stage and – even though the pace of change thus far has been impressive – much remains to be done to develop the regulatory framework, the institutions and the capacity to ensure that it continues to function well. In particular, the restructuring of CFE into a “productive state enterprise” is a vital aspect of the Reform process – and one that will take time and enduring political will to realise in full.

3.3.2 Generation, network and other costs

One of the key objectives of the Reform is to keep the costs of electricity under control, so that consumers can benefit from lower prices – or fewer price increases – and that the government can ultimately phase out the subsidies that it pays to keep down residential and agricultural end-user prices. There are a number of aspects to this: driving expensive oil-fired power out of the mix; ensuring efficient investment in new capacity to meet rising demand; pursuing efficiency gains within a restructured CFE; and reducing the high losses in the transmission and distribution network.

The switch away from oil-fired power generation has been underway for some time and the process is set to accelerate as new infrastructure is built to allow Mexico to benefit further from relatively cheap natural gas imports from the United States. CFE managed to reduce its generation costs by around 10% in the 2014-2015 period, helping to reduce electricity tariffs for industrial users by around 20%.¹² Thanks to measures already taken, the gap between electricity prices in the southern United States and in Mexico has narrowed considerably. In our projections, reliance on oil-fired power dwindles rapidly over the coming years and is almost completely eliminated by 2020.

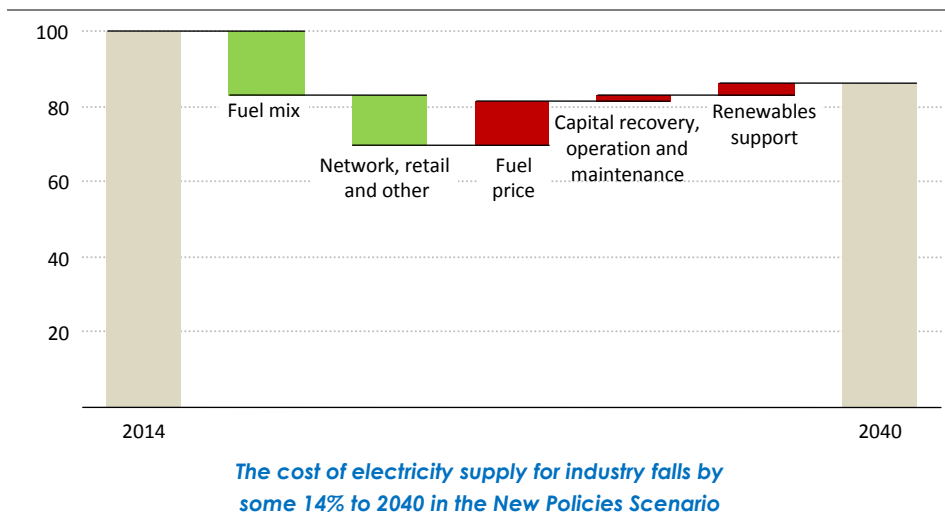
Fuel switching plays a major role in bringing down overall costs during the period to 2040, but it is not the only factor in play (Figure 3.9). Operational efficiency gains and reduced network losses also play a very significant role. The former stems largely from the competitive pressures on CFE to reduce costs in a market environment. The latter is the result of measures taken to improve billing and cut down on non-payment, as well as technical improvements. Some of these actions are already underway: new meters and investment in distribution lines have reduced network losses from 16% in 2010 to 13% in 2015. In the New Policies Scenario, network losses fall further to 8.6% by 2040, closer to

¹¹ IEA, *Energy Policies Beyond IEA Countries: Mexico, 2017*, OECD/IEA, forthcoming.

¹² The early cost reduction helps to foster support for the Reform process, but makes it more difficult for new entrants to compete with CFE, even for the industrial consumers that represent around 60% of electricity consumption.

today's average level for OECD countries. The average interruption time for supply per user has also fallen by around 40% since 2010 (to 35 minutes per year in 2015). A substantial increase in network investment is projected. In the New Policies Scenario, this amounts to more than \$90 billion to 2040, or around \$4 billion per year – a commitment of capital higher than that envisaged in the *Programa De Desarrollo Del Sistema Electrico Nacional* (PRODESEN). The Reform provides channels to keep investment at around these levels by allowing the private sector to participate in the financing, construction, and operation and maintenance (O&M) of the network.

Figure 3.9 ▶ **Contributing factors to the changes in electricity supply cost for industry in Mexico** (indexed to 2014 level)



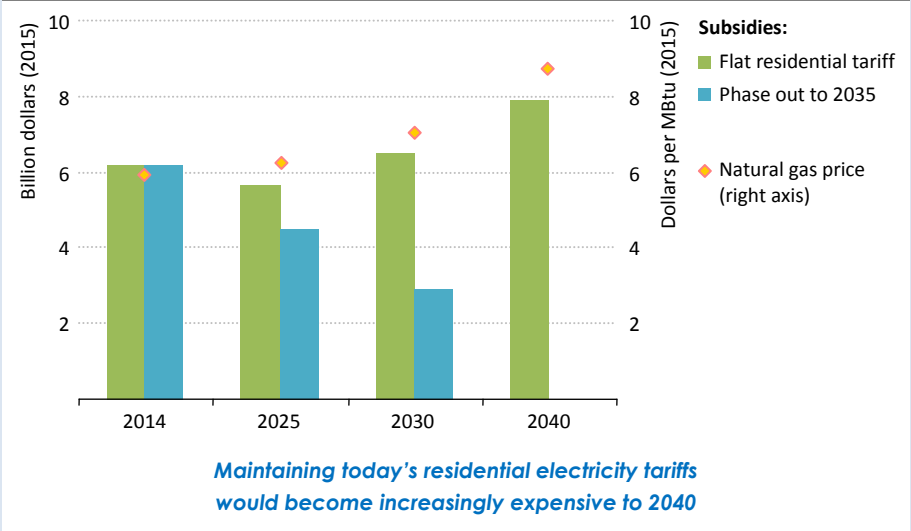
The cost reductions are offset by some upward pressures over the period to 2040. The main factor is the expected gradual rise in the cost of natural gas available to the power sector. As discussed in more detail in the next section, the intensive development of the shale resources in the United States means that operators there gradually have to move to less productive areas, pushing up production costs (despite continued upstream efficiency improvements). By the late 2020s, the projected price for natural gas at Henry Hub reaches \$5 per million British thermal units (MBtu) in the New Policies Scenario and the gradual upward trend continues thereafter. This has the effect of incentivising more shale gas development in Mexico itself, but gas-fired power plants still find themselves facing higher input costs. Increased capital investment and support to renewables also play a role in pushing costs higher, but only to the extent of around 2-3% of electricity cost, thanks to the competitive market environment offered by the Reform and continued technology cost reductions for wind and solar PV over the period. The net effect is to create a much more favourable environment for electricity prices to consumers to become fully cost-reflective (Box 3.2).

Box 3.2 ▶ **Impact of the Energy Reform on end-user prices**

In the longer term, the sustainability of the Energy Reform will require a move towards fully cost-reflective prices. Maintaining regulated tariffs may be necessary as long as CFE continues to enjoy considerable market power, but, ultimately, a well-functioning power sector requires the phase-out of electricity subsidies. This is not an explicit part of the Reform agenda, but it is a process that would be greatly facilitated by the lower costs of electricity supply engendered by the Reform. The improved cost structure for electricity generation also helps Mexico to address the overhang of debt and unfunded pension liabilities that are part of CFE’s legacy.

In the New Policies Scenario, industrial electricity prices decrease in real terms over the period to 2040: most of the large gains from the switch from oil to gas-fired power generation have already been realised, but productivity improvements in the power sector maintain downward pressure on industrial tariffs. The impact on residential tariffs depends on the tariff policy adopted by the government. For the moment, residential tariffs are heavily subsidised for all except the largest consumers. The subsidy bill was over \$6 billion in 2014. We assume that these residential electricity subsidies are gradually phased out over the projection period, such that they disappear completely by 2035. Mexico, as a member of G20 and APEC, has committed to phase out inefficient fossil-fuel subsidies and has taken an important first step by transferring part of the responsibility for the subsidy to the Ministry of Finance and including a specific item in the annual state budget (previously it was absorbed into CFE’s balance sheet).

Figure 3.10 ▶ **Residential electricity subsidies in the New Policies Scenario, 2014-2040**



Phasing out residential electricity subsidies by 2035 and their replacement by more targeted support for vulnerable segments of the population are assumed in the New Policies Scenario. If, however, residential electricity prices were to be kept constant at today's levels, then – in our estimate – the overall cost of the annual subsidy would fall in the medium term but then rise steadily towards \$8 billion per year in 2040, as the price of natural gas pushes up generation costs (Figure 3.10). This would represent a very substantial drain on public finances. In the absence of electricity sector reform, the cost of the subsidies would be also higher than in the New Policies Scenario, a case examined in the last part of this chapter. As it stands, the cumulative subsidy to 2040 with a flat residential tariff would be around \$160 billion – almost 70% of the entire capital investment cost for the power sector.

3.4 Influence of North American energy market integration

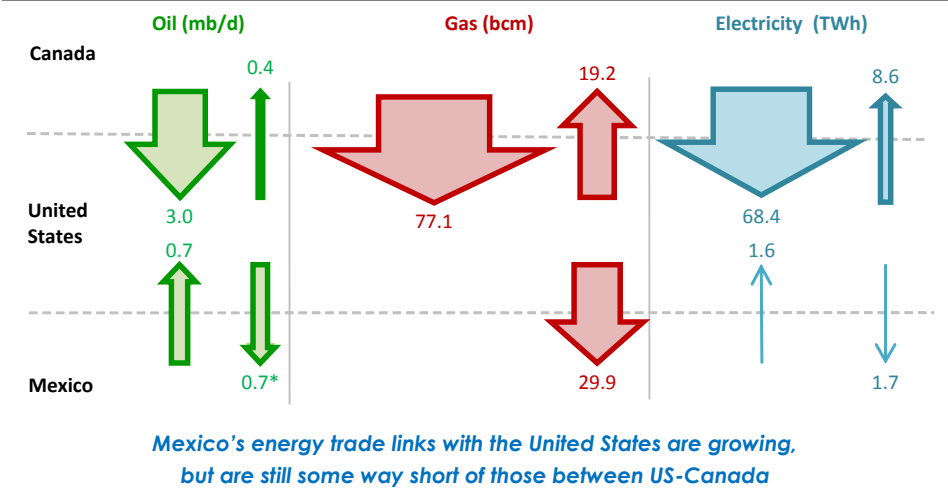
Energy integration in North America is an increasingly important element of the context for Mexico's Energy Reform. There is a policy element to this integration in the close alignment in energy and environmental priorities between Mexico, Canada and the United States.¹³ There is also a strong market element, given the synergies between low-cost oil and natural gas production centres in the southern United States and the growing market in Mexico. This section examines the way in which more integrated energy markets shape Mexico's energy outlook to 2040, with a particular focus on trade in natural gas, crude oil and oil products. Reliable cross-border connections can have a strong positive impact on energy security, enabling more efficient allocation of resources, as well as providing an effective response to disruptions or fluctuations in demand. Energy integration and co-operation can also accelerate flows of investment and transfers of technology – including clean energy technologies – with a beneficial impact on the prospects for the Energy Reform and for attaining Mexico's greenhouse-gas emissions reduction goals.

The United States has traditionally been a large net recipient of regional cross-border energy flows, within North America as a whole, but imports have fallen rapidly since the start of the shale gas and tight oil boom. The main arteries of regional trade have been between the United States and Canada – and these remain considerably larger than those between the United States and Mexico (Figure 3.11). However, the importance of the United States-Mexico energy trade relationship has been growing fast. As of 2015, exports of crude oil from Mexico to the United States were roughly balanced by a reverse flow of petroleum products. Similarly, cross-border flows of electricity – albeit on a much smaller

¹³ The North American Leader's Summit held in June 2016, for example placed clean energy at the centre of discussions, leading to the three countries agreeing to set a target of 50% for clean power across North America by 2025; Mexico joining a standing commitment to reduce its methane emissions by 40-45% by 2025; and the promise to align fuel efficiency standards by 2025 and greenhouse-gas emission standards by 2027.

scale – were roughly in balance.¹⁴ But natural gas imports to Mexico from the southern United States have been on a sharply rising trajectory, more than tripling between 2010 and 2015. Geographic proximity and closer energy integration promises to have a significant impact on Mexico’s energy outlook, in particular for natural gas and the supply of oil products.

Figure 3.11 ▶ Energy trade across North America, 2015



*Refined products.

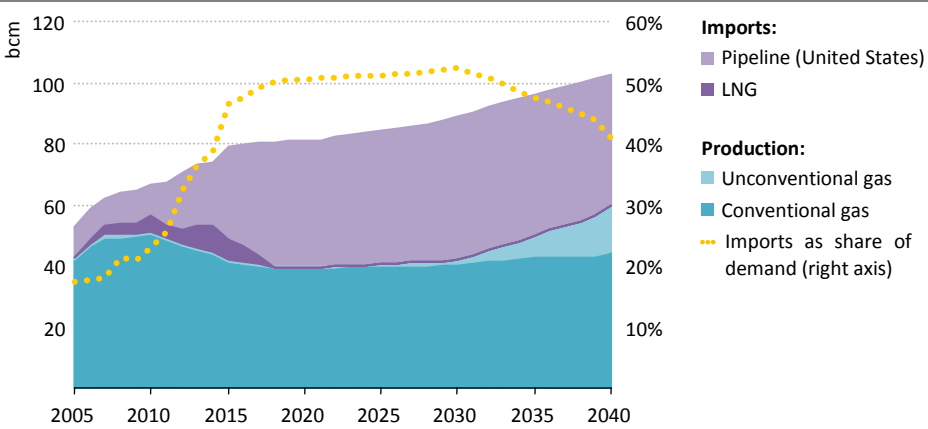
Natural gas

Mexico’s imports of natural gas from the United States have a major impact on our projections in the New Policies Scenario. With natural gas being the main source of power generation in Mexico, these imports are critical both to the reliability and costs of electricity supply. They also act as a key determinant of the pace at which Mexico’s own gas resources are developed. The upward trend in gas imports has been spurred by the US shale gas boom and the commercial case for importing gas remains strong throughout the period to 2040, although it diminishes somewhat over time with the gradual anticipated increase in US wholesale natural gas prices. Once domestic (primarily associated) gas is accounted for and liquefied natural gas (LNG) imports into Mexico are backed out¹⁵, there is room for around 45 billion cubic metres (bcm) of imported US gas in Mexico’s natural gas mix in the New Policies Scenario – making up more than half of total supply until the 2030s (Figure 3.12).

¹⁴ US and Mexican data sources are not fully aligned on the metrics of electricity trade. We are using Mexican data as provided by *Comisión Federal de Electricidad* and *Centro Nacional de Control de Energía*.

¹⁵ LNG imports began in 2006 but have become a more costly source than natural gas via pipeline from United States. We assume that LNG imports will continue to decrease rapidly over the coming three to four years, even if this were to result in Mexico having to pay a penalty for not taking the contracted LNG volumes (as would be the case under standard take-or-pay terms that are common in long-term supply contracts).

Figure 3.12 ▸ Natural gas production and imports by type, 2005-2040



Pipeline imports from the United States rise to more than half of Mexico's total gas supply

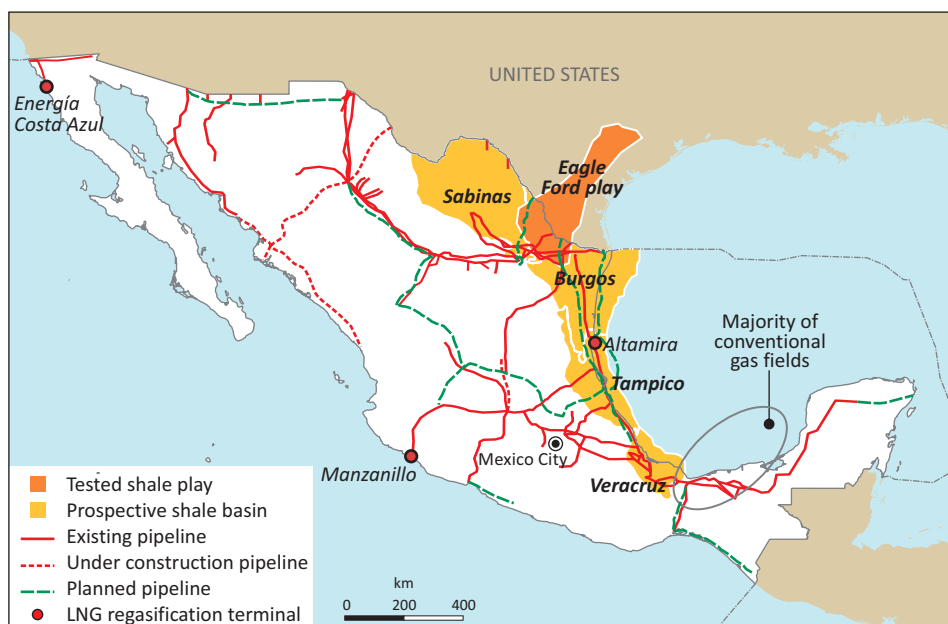
This reliance could be even higher. Pipeline developers and the Mexico’s administration are making contingency plans for higher volumes of cross-border pipeline capacity and trade, over 100 bcm of imports by the end of this decade. This level of imports cannot be ruled out, but would require some combination of higher electricity demand (and consequently more gas demand for power generation¹⁶), more rapid expansion of the gas distribution grid to reach additional residential and industrial consumers, or the possibility that some of the gas would be shipped onwards from Mexico, either to Central America or exported as LNG.¹⁷

The future balance between imported and domestically produced natural gas depends on a range of market and policy elements – and a key uncertainty is the extent to which Mexico pursues development of its large unconventional gas resources. Current resource estimates for shale gas are more than adequate to meet Mexico’s gas needs in full, but the resource base and regulatory framework, for now, are insufficiently defined and the shale gas industry and supply chain are still at a very nascent stage (relative to the United States) (see Chapter 2.3.3). Pemex’s upstream monopoly was a world away from the proliferation of operators that enabled rapid learning-by-doing and cost reductions in the main US plays, meaning that shale gas development in the United States has had a significant head-start on its southern neighbour. And – as experience elsewhere in the world has amply demonstrated – it is far from simple to replicate US conditions in other jurisdictions, even allowing for the changes introduced by Mexico’s upstream reforms.

¹⁶ This would imply higher GDP growth than we assume in the New Policies Scenario, (see the sensitivity analysis on GDP in Chapter 2).

¹⁷ Pemex has announced a proposal to convert an under-utilised LNG import facility on Mexico’s Pacific Coast into a liquefaction terminal for export. Export of LNG is subject to approval by SENER and, if the feed gas is sourced from the United States, by the US Department of Energy. Our projections do not include LNG export from Mexico.

Figure 3.13 ▸ Natural gas resources and infrastructure in Mexico



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Over the longer term, Mexico does have strong potential for shale gas development, especially once – as we anticipate in the New Policies Scenario – the gradual depletion of US shale resources starts to push up production costs there. Four geological basins in Mexico are expected to contain oil and gas shale resources (Figure 3.13). While seismic data have been acquired to delineate the extent of the shale deposits, drilling is required to test the productivity of the shale formations. The main focus for operators thus far has been in the north, where the prolific Eagle Ford shale play in Texas extends across the border. This is where PEMEX has focused its exploration and appraisal drilling programme to date, with 18 wells over the last four years, albeit with mixed results. Resource uncertainty aside, the key question is whether there is much of an incentive for PEMEX or other operators (most likely US based or international majors) to invest in Mexico’s shale gas development in the near to medium term, given that the United States provides operators with a known regulatory and operationally safer environment, with a well-developed, readily accessible gas infrastructure to bring gas to markets. For the moment, the estimated costs of developing Mexico’s shale gas are well above those in the southern United States, meaning that imported gas remains a far more attractive value proposition. Social acceptance and water use are further issues which need to be addressed before large-scale shale development can take place in Mexico.

Currently Mexico plans to offer tight oil and shale gas blocks to investors through a bidding round in 2017, with tight oil likely to draw most of the initial interest. In our projections, the cost equation continues to work against Mexico’s shale gas development until the latter part of the 2020s, by which time the Henry Hub price rises above \$5/MBtu. In our

view, given the additional transportation costs to bring gas to the Mexican market, this is the price level that can start to trigger larger scale unconventional resource development in Mexico. This is projected to pick up in the 2030s, to reach 7 bcm in 2035 and 15 bcm in 2040. This projection is based on the assumption that, in the interim, Mexico succeeds in developing a regulatory framework that caters to the specificities of unconventional resources, both in terms of fiscal and permitting issues, as well as social and environmental aspects. Applying the experience gained in the United States and Canada can do much to facilitate future development by putting in place appropriate regulation on responsible water management, high technical standards and industry transparency, and by establishing baselines against which the industry's environmental performance can be measured in the future. SENER and CNH are already working with other regulatory bodies – the Agency for Safety, Energy and Environment (ASEA) and the National Water Commission (CONAGUA) – to establish a co-ordinated and comprehensive regulatory framework for key environmental aspects and to put in place an appropriate system for reporting and monitoring.

As the analysis indicates, a key variable in our projection is the price at which US natural gas imports are available. Our projections are based on the assumption that the size of the remaining recoverable resource base of US shale gas is 22 trillion cubic metres (tcm) and assumptions about how the costs of producing it might evolve in the future. However, as examined in detail in the *WEO-2016*¹⁸, resource estimates for the United States vary quite considerably: our analysis of the various estimates of US shale gas resources points to a conceivable range of 14-34 tcm. If the actual size were to be towards the top of that range, the commensurately higher availability of gas would allow for cheaper imports by Mexico for longer. This would affect Mexico's outlook by lowering electricity generation costs, although the benefit of lower electricity prices would be offset in some respects by diminished incentives to push ahead with indigenous gas production (beyond the associated gas that will come with upstream oil developments) and a consequently higher reliance on imported natural gas to satisfy demand. The example underlines the growing interdependencies that are taking shape in different domains across the continent (Box 3.3).

Box 3.3 ▶ A broader agenda for energy integration

SENER's long-term power sector plan places a premium on increasing interconnections and working towards more intensive transmission grid integration with Mexico's neighbours. To the southeast, Mexico is already an important supplier of electricity to Guatemala¹⁹ and Belize, but there is significant potential to increase its position as a key energy exporter in the region, for example by joining the Central American Interconnection System (SIEPAC)²⁰, which has linked the grids of six countries across the

¹⁸ See Chapter 4 of the forthcoming *World Energy Outlook-2016*, to be released on 16 November 2016.

¹⁹ Plans to build a pipeline linking the existing network from Salina Cruz to Tapachula near the Guatemala border have been outlined in SENER's latest plans, presenting the possibility of greater trade with Central America.

²⁰ SIEPAC currently includes Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica and Panama.

region since 2013. Enhanced integration would allow a more efficient flow of energy; potentially alleviating the risk of shortages associated with variable renewables supply, and would allow companies in Mexico to monetise any excess energy they generate. Enhancing electrical and natural gas interconnections between Mexico and Central America could presage a widespread structural shift in electricity generation, with a shift from oil to gas, helping to reduce prices while reducing the carbon intensity of the generation mix.

To the north, Mexico shares 11 electricity transmission interconnections with the United States²¹, but trade is limited, totalling just 4 TWh in 2014, with each country exporting around as much as it imports. Despite these limits, electricity trade, on occasion, has played an important role in maintaining security of electricity supply in response to power outages.²² Mexico's Energy Reform increases the prospects of more collaborative projects between northern Mexico and southern US states, since the Reform, for the first time, allows private power producers, including in the United States, to sell their electricity in Mexico's wholesale market (such producers were restricted to selling to captive producers, or to CFE, under the previous regulatory regime). Such exports started in 2015 when the 524 MW Frontera power plant in Texas began exporting power to Mexico, with the intention of allocating its entire capacity to the Mexican market.

Just as an increasingly integrated North American market generates the economies of scale required to develop natural gas projects, increasing electricity grid interconnections would allow Mexico to capture rent from some of its most important renewables resources. For example, those in Mexico's Baja California peninsula, which has some of the best wind and solar conditions in the country, but where the population is small and sparse. The Sierra Juarez project in Baja California, for example, is a 156 MW wind power development that exports exclusively to the San Diego Gas and Electric Company through a 20-year power purchase agreement. Such a project is not likely to have been developed if it were restricted to sales to the Mexican market.

Crude and petroleum products

When considering trade in all types of energy carriers, crude oil and petroleum products usually require fewer formal intergovernmental agreements and land-based fixed infrastructure than other energy forms. In the absence of fiscal duties, as is the case in North America, it is price arbitrage on international markets that essentially defines where crude oil or products flow. Following the removal of the US crude oil export ban at the end of 2015, North American crude oil and product markets are almost entirely liberalised. However, certain infrastructure limitations and regulations in related industries have created a uniquely fragmented market system.

²¹ This is due to increase to 12 interconnections, following SENER's instructions to CFE to build a new interconnection between Seonora (Mexico) and Arizona (US), which is planned to begin operation in 2018.

²² An example is the emergency import of electricity generated in Mexico to support the system in Texas during outages in 2014: www.oe.netl.doe.gov/docs/eads/ead100914.pdf.

In recent years, the US Gulf Coast has become a major export source for petroleum products, with a refinery network that can process around 9 mb/d of crude oil. Most of these products are shipped outside the United States, instead of going into deficit areas in the northeast United States or parts of the west coast. For the northeast region, flows from the Gulf Coast are constrained by Jones Act regulations, which add to the shipping costs. Therefore, currently it makes more economic sense to import gasoline (and occasionally diesel) from Europe or Russia to the northeast United States, and to export gasoline from the Gulf Coast to Mexico, Latin America or Africa. Therefore growing import requirements for gasoline in Mexico have been welcome news for the US exporters that have large gasoline surpluses (see Chapter 2.3.2). Mexican crude oil, which has relatively easy access to seaborne terminals, also finds a natural outlet in US Gulf Coast refineries, as they are best-equipped with the cokers necessary to process heavy Mexican grades at a profit.

Even if Jones Act restrictions on US cabotage shipping²³ were to be lifted, and the US domestic market become more integrated, it would probably not immediately affect the product trade between the US Gulf Coast and Mexico. Geographic proximity and already well-established trading patterns mean that the Gulf Coast refiners are expected to remain a competitive force in Mexican markets, especially as Mexico's Energy Reform liberalises the trade and fuel retail sectors. In the New Policies Scenario, the refined products market in Mexico does not become self-sufficient, even though the import dependence for gasoline decreases, from 56% currently to 35% in 2040 (corresponding to a fall in imports from 450 kb/d to 270 kb/d), while diesel imports all but disappear. To achieve this, refinery throughputs are expected to reach 1.4 mb/d, up from current lows of 1.1 mb/d, thanks to upgrades that are projected to cost over \$33 billion. Having the US Gulf Coast as a neighbour limits the economic prospects of an alternative strategy to attain self-sufficiency in refined products, or indeed to start exporting them, as this would require a considerably higher capital expenditure.

3.5 Measuring the impacts of Energy Reform: a No Reform Case

The New Policies Scenario presented in this *Outlook* outlines a pathway for Mexico that is determined in large measure by the Reform package and the effect that it has on investment. It includes a return to growth in the upstream oil and gas sector and the evolution of a more efficient, cost-effective and rapidly decarbonising electricity sector. But what would Mexico's outlook have looked like if there had been no Reform? To answer this question, we have modelled an additional No Reform Case, in which the Reform is wound back and pre-reform trends are resumed. We assess the ramifications of such a case for the oil and electricity sectors, and also the potential implications for the Mexican economy as a whole.

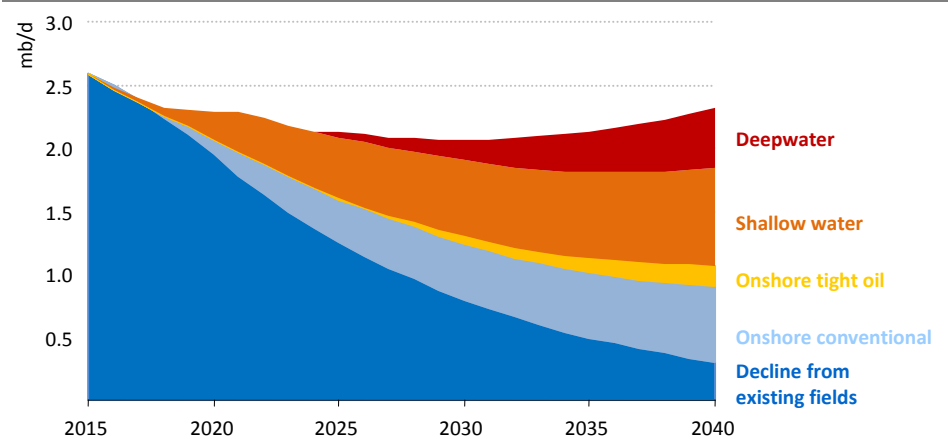
²³ Cabotage shipping is the transport of goods or passengers between two places in the same country by a transport operator from another country.

The oil industry has long been an important source of export earnings, as well as the largest single contributor to industrial value added in Mexico (15% in 2013). The Reform was aimed at reversing a steady decline in the performance of the sector, marked by declining output and a shortfall of new projects (both upstream and in refining). A “No Reform” trajectory would give rise to a much more difficult struggle to turn the oil production trajectory around, a continued squeeze on capital spending and diminished oil-related revenues for the state. Likewise, in the absence of Reform in the electricity sector, there would be higher costs in generation, continued inefficiencies in networks and other parts of the power system and – as a result - either higher prices for consumers or a much larger subsidy bill for the state. Concentrating on these two sectors, the No Reform Case presents a diminished outlook for Mexico, compared with the outcome in the New Policies Scenario.

3.5.1 The oil sector in a No Reform Case

The difference in projected oil production between the New Policies Scenario and the No Reform Case widens steadily over the period to 2040, by which time it exceeds 1 mb/d (2.3 mb/d versus the 3.4 mb/d reached in the New Policies Scenario) (Figure 3.14). The divergent trajectories take some time to become apparent, reflecting the lead times of the projects that are awarded in the New Policies Scenario but that fail to proceed in the No Reform Case. The key difference between the two trajectories is the amount of capital available for the upstream investment. In the New Policies Scenario, investment (and technology) comes from many sources. In the No Reform Case, the more limited capital available to PEMEX (especially in the current period of lower oil prices) needs to be spread over a wide range of assets, including capital-intensive deepwater projects. The company continues to do a commendable job (as it has done, for example, in exploring the deepwater Perdido area in the northern Gulf of Mexico), but the amount of upstream activity is significantly lower.

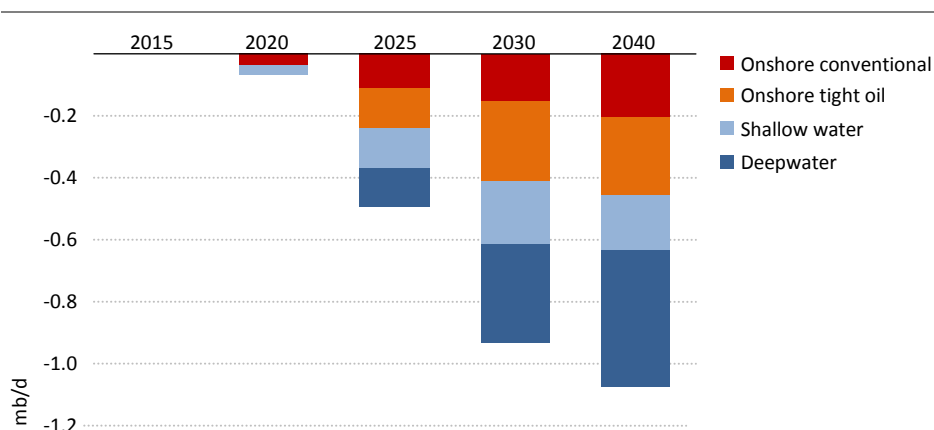
Figure 3.14 ▶ Oil production in Mexico in the No Reform Case



Mexico oil output stays lower for longer in No Reform Case

The investment constraint on PEMEX was modelled in the No Reform Case by calculating an indicative budget for capital spending, using as inputs the previous year's oil and gas production and expenditure, the oil price trajectory (essentially the same as in the New Policies Scenario) and historical PEMEX cost ratios.²⁴ The crucial difficulty for PEMEX is that, particularly in the early years of the projection, it is caught in a spiral of lower prices and falling production that severely limits the capital available to fund expansion and enhanced recovery projects in legacy fields and delays the start of technically challenging deepwater and tight oil development projects. By 2025, production in a No Reform Case is around 500 kb/d less than in the New Policies Scenario: the largest difference is in shallow water areas, where heavy oil projects are delayed and investment in enhanced recovery programmes is cramped (Figure 3.15). The New Policies Scenario includes some 120 kb/d of production from deepwater by 2025, which does not appear in the No Reform Case.

Figure 3.15 ▶ Oil production in the No Reform Case relative to the New Policies Scenario



The No Reform Case sees reduced investment straight away – and a sharp reduction in output by the mid-2020s

By 2030, oil output is around 900 kb/d below that of the New Policies Scenario. Legacy shallow water assets are in steep decline, and – given the assumption that PEMEX would continue to invest in deepwater and onshore assets – suffer from a reduction in funding for projects and enhanced recovery, compared with the New Policies Scenario. Despite some investment, the disparity in deepwater and tight oil production between the two trajectories rises to more than 550 kb/d by 2030 and continues to increase thereafter. PEMEX has already begun investments in these sectors, but would have difficulty in giving them the technical and capital attention needed for rapid development in the absence of the Reform. A partnership between PEMEX and service companies to develop tight oil,

²⁴ PEMEX revenues, costs and production quantities were sourced from the company's annual reports for 2000-2015.

similar to that used at Chicontepec cannot be ruled out in a No Reform Case, but it is unlikely to be able to deliver the same results as those seen in the New Policies Scenario.

Deepwater production takes the biggest hit in a No Reform Case by 2040. This is predicated on the assumption that PEMEX alone would not be able to sustain the high investment levels needed to support growth in deepwater production seen in the New Policies Scenario. It is likely that PEMEX would continue to invest in Perdido projects in the northern Gulf of Mexico, but would divert its remaining resources to enhancing production from shallow water fields, a realm in which its expertise currently excels. Large-scale investment in southern, deepwater exploration would therefore be less likely.

The lower oil output would have strong repercussions for the national oil balance. Oil demand is similar in the No Reform Case (as reduced demand due to the impact on gross domestic product [GDP], discussed below, is offset by increased oil use in power generation to compensate for lower renewables deployment), but oil production is hit hard and crude export revenue falls by almost half, meaning that the oil trade balance deteriorates sharply. Funds for refinery investment are limited, meaning that the capacity modernisation envisaged in the New Policies Scenario fails to materialise to the same extent and refinery runs remain at around the current level of 1.1 mb/d. The cumulative value of the lost oil output over the projection period amounts to around \$650 billion, while cumulative upstream investment is lower by some \$260 billion. The loss is felt in different parts of the economy, notably in fiscal revenue (which, as discussed below, would have to be made good either by higher taxation on other sectors, or lower expenditure). A No Reform Case would also have repercussions beyond Mexico, in that it would diminish an important source of global supply. The volumes would not necessarily be sufficient to have a significant impact on the oil price, but their loss would accelerate the pace at which the world becomes heavily reliant on a few large resource-holders for incremental supply.

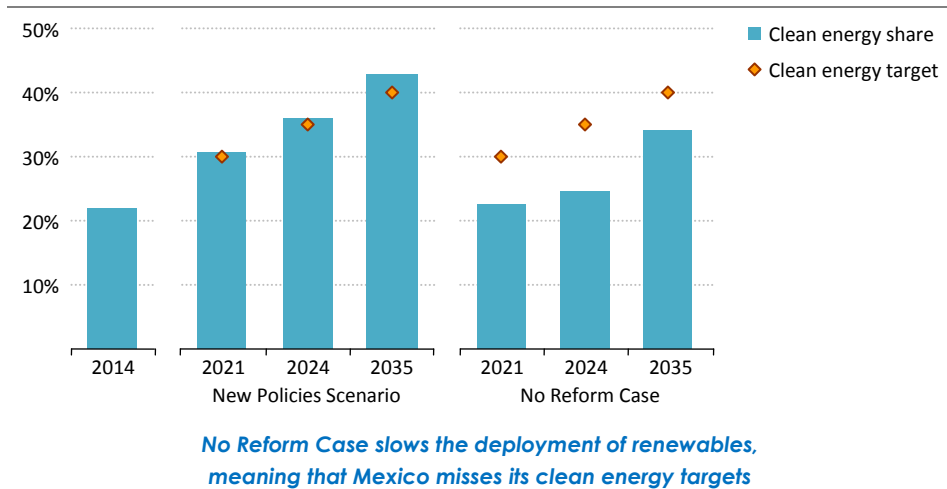
3.5.2 The power sector in a No Reform Case

The Reform relies on several levers to achieve the stated objective of bringing down prices while promoting clean energy; the key elements that are missing in a No Reform Case are the unbundling and restructuring of CFE and the introduction of competitive electricity markets for energy, capacity and clean certificates. Their absence puts the power market in Mexico on a different trajectory and leads to a different electricity mix, compared with the New Policies Scenario. In terms of generation, even though electricity demand in 2040 is around 2% lower than in the New Policies Scenario (again, largely because of the adverse impact on GDP), almost the same amount of power needs to be generated in the No Reform Case, because the losses and inefficiencies in the network are not addressed with the same effectiveness.

Without specific policies to increase the role of clean energy in power generation, notably the introduction of clean energy certificates and the long-term auction system, the No Reform Case has a slower uptake of clean energy for power generation, especially of wind and solar power. Although efforts are assumed (encouraged by global cost reductions

in renewable technologies) to deploy more renewable resources, the share of clean energy in power generation falls short of the government target of 40% by 2035 (as well as its intermediary targets in 2021 and 2024) (Figure 3.16). CO₂ emissions from the power sector also increase, by around 20% in 2040, relative to the New Policies Scenario, undermining the government's ambitions to cut greenhouse-gas emissions through the increased use of clean energy. Mexico's capacity to meet the obligations included in its COP21 climate pledge would be undermined.

Figure 3.16 ▶ Share of clean energy in power generation in Mexico in the No Reform Case



Notes: Clean energy includes nuclear, hydropower, other renewables and efficient cogeneration. Clean energy targets for 2021 and 2024 are based on the Energy Transition Law. The clean energy target for 2035 is based on the Law for the Development of Renewable Energy and Energy Transition Financing.

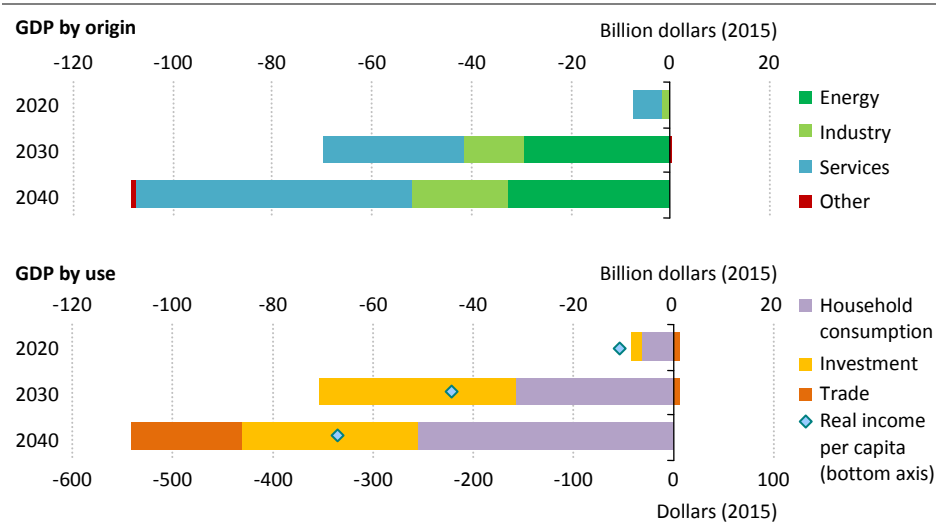
Fuel switching away from oil continues in the No Reform Case, as this is a continuation of a policy push that dates back to the late 1990s. However, the pace at which oil is replaced by gas is slowed, which, together with the slower improvement in transmission and distribution losses and lower operational efficiency, increases electricity prices in a No Reform Case: electricity prices for industrial consumers are around 14% higher in 2040 than the New Policies Scenario.

For residential consumers, we assume end-user prices at the same level as in the New Policies Scenario, in which electricity subsidies are phased out by 2035. In practice this translates to an additional subsidy bill in the No Reform Case (felt either as losses absorbed by CFE or explicit subsidies financed by the state budget) as the system as a whole is less efficient. The average cost of generating and delivering power to residential consumers in a No Reform Case is around 16% higher than in the New Policies Scenario. The cumulative additional subsidy bill over the period to 2040 is around \$50 billion.

3.5.3 Repercussions for Mexico's economy of a No Reform Case

The reductions in investment in the oil and gas sector and the efficiency loss in the power system have implications well beyond the energy sector. These were assessed by coupling the results of the IEA World Energy Model with the OECD's computable general equilibrium model, ENV-LINKAGES. The decline in total investment in the economy in the No Reform Case is larger than the initial cut in upstream spending and leads to losses in other areas, including household consumption and trade, and the loss of value extends well beyond the energy sector (Figure 3.17).

Figure 3.17 ▶ Changes in GDP in the No Reform Case relative to the New Policies Scenario



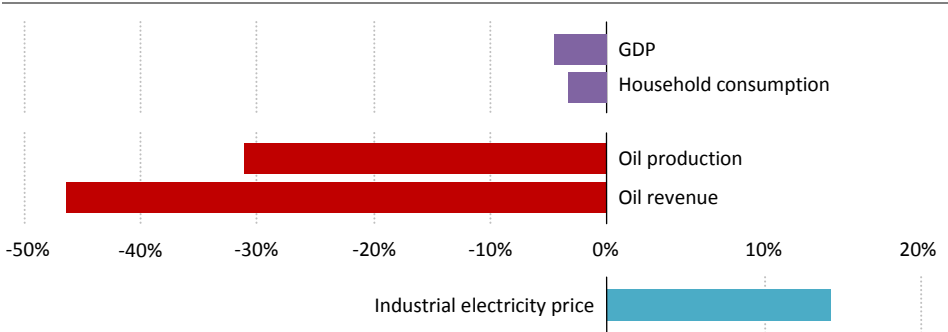
No Reform Case leads to a loss in value well beyond the initial impact on energy investment

The impacts are complex, but lower investment in the oil sector is felt not only by PEMEX itself, but by a range of companies that provide services or materials, such as the construction industry, equipment manufacturers and logistics firms. For all of these entities, lower output translates into lower revenue. For the government, the loss of fiscal revenue requires either higher taxes on other sectors to compensate or a decrease in expenditure. For individuals employed in the oil and gas sectors, or in related industries, lower incomes translate into lower consumption, which then reduces investment in other sectors of the economy, and so on.

Within the power sector, the failure to tackle inefficiencies results in a less productive sector. For the economy as a whole, it means inefficient allocation of investment. The government fiscal balance is hit by higher expenditure on electricity subsidies. Companies in different sectors of the economy face an increase in production costs, to which they

respond either by reducing activity or cutting their margins. Either way, the knock-on effect is felt in lower investment. In this way, whether looked at from the supply or demand side of the economy, GDP is more than \$100 billion lower by 2040 compared with the New Policies Scenario, meaning that Mexico’s economy is more than 4% smaller (with cumulative loss of GDP above \$1 trillion over the period as a whole) (Figure 3.18).

Figure 3.18 > **Changes in key economic variables in the No Reform Case relative to the New Policies Scenario**



No Reform Case takes a toll on household budgets, industrial output and economic growth

Mexico projections

General note to the tables

The tables detail projections for *energy demand*, *gross electricity generation* and *electrical capacity*, and *carbon-dioxide (CO₂) emissions* from fuel combustion in Mexico. The tables present historical and projected data for the New Policies, Current Policies and 450 Scenarios, as well as the No Reform (NRC) and Enhanced Growth Cases (EGC).

Data for *fossil-fuel production*, *energy demand*, *gross electricity generation* and *CO₂ emissions* from fuel combustion up to 2014 are based on IEA statistics, published in *Energy Balances of OECD Countries*, *Energy Balances of non-OECD Countries*, *CO₂ Emissions from Fuel Combustion* and the *IEA Monthly Oil Data Service*. Historical data for *gross electrical capacity* are drawn from the Platts World Electric Power Plants Database (April 2016 version) and the International Atomic Energy Agency PRIS database.

Both in the text of this book and in the tables, rounding may lead to minor differences between totals and the sum of their individual components. Growth rates are calculated on a compound average annual basis and are marked “n.a.” when the base year is zero or the value exceeds 200%. Nil values are marked “-”.

Definitional note to the tables

Total primary energy demand (TPED) is equivalent to power generation plus other energy sector excluding electricity and heat, plus total final consumption (TFC) excluding electricity and heat. TPED does not include ambient heat from heat pumps or electricity trade. Sectors comprising TFC include industry, transport, buildings (residential, services and non-specified other) and other (agriculture and non-energy use). Projected gross electrical capacity is the sum of existing capacity and additions, less retirements. Total CO₂ includes emissions from other energy sector in addition to the power generation and TFC sectors shown in the tables. CO₂ emissions and energy demand from international marine and aviation bunkers are not included. CO₂ emissions do not include emissions from industrial waste and non-renewable municipal waste.

Mexico: New Policies Scenario

	Energy demand (Mtoe)							Shares (%)		CAAGR (%)
	1990	2014	2020	2025	2030	2035	2040	2014	2040	2014-40
TPED	124	188	190	196	206	215	225	100	100	0.7
Coal	4	13	10	8	7	6	6	7	3	-3.1
Oil	81	96	91	93	95	96	95	51	42	-0.1
Gas	23	61	68	70	74	80	86	32	38	1.3
Nuclear	1	3	3	3	5	5	7	1	3	4.2
Hydro	2	3	3	4	4	4	5	2	2	1.4
Bioenergy	9	9	9	9	9	9	9	5	4	0.2
Other renewables	4	4	7	10	12	15	17	2	8	5.9
Power	27	60	59	61	65	70	77	100	100	1.0
Coal	2	8	6	4	3	2	2	14	2	-5.8
Oil	15	9	1	1	1	0	0	14	0	-11.5
Gas	3	32	38	38	38	42	45	53	58	1.3
Nuclear	1	3	3	3	5	5	7	4	9	4.2
Hydro	2	3	3	4	4	4	5	6	6	1.4
Bioenergy	-	2	2	2	2	2	2	3	3	1.3
Other renewables	4	4	6	9	11	14	15	6	20	5.7
Other energy sector	23	35	32	34	35	36	36	100	100	0.1
<i>Electricity</i>	<i>1</i>	<i>4</i>	<i>4</i>	<i>4</i>	<i>5</i>	<i>5</i>	<i>6</i>	<i>12</i>	<i>15</i>	<i>1.1</i>
TFC	83	118	128	134	143	150	156	100	100	1.1
Coal	1	3	2	2	2	2	2	2	2	-0.3
Oil	51	73	76	77	80	81	81	62	52	0.4
Gas	14	14	17	19	21	23	25	12	16	2.3
Electricity	9	22	25	28	32	35	39	18	25	2.3
Bioenergy	9	7	7	6	6	6	7	6	4	-0.2
Other renewables	0	0	0	1	1	1	2	0	1	8.8
Industry	26	34	37	40	43	46	49	100	100	1.5
Coal	1	2	2	2	2	2	2	7	5	-0.4
Oil	7	6	6	6	6	6	6	17	11	-0.2
Gas	11	12	15	16	17	19	20	36	41	1.9
Electricity	5	12	13	15	16	18	19	36	40	1.8
Bioenergy	2	1	1	1	1	2	2	3	4	2.7
Other renewables	0	0	0	0	0	0	0	0	0	10.2
Transport	28	51	53	54	57	59	59	100	100	0.5
Oil	28	51	53	54	56	57	57	100	97	0.4
Electricity	0	0	0	0	0	0	1	0	1	8.4
Biofuels	-	-	-	-	-	-	-	-	-	n.a.
Other fuels	-	0	0	0	0	1	1	0	2	17.1
Buildings	18	24	26	27	29	31	33	100	100	1.3
Coal	-	-	-	-	-	-	-	-	-	n.a.
Oil	7	8	7	7	7	7	7	33	20	-0.5
Gas	1	1	2	2	3	3	4	5	11	4.7
Electricity	3	8	10	12	14	15	17	36	52	2.7
Bioenergy	7	6	6	5	5	5	5	26	14	-1.0
Other renewables	0	0	0	0	1	1	1	1	3	6.6
Other	11	10	12	13	14	14	15	100	100	1.6

Mexico: New Policies Scenario

	Electricity generation (TWh)							Shares (%)		CAAGR (%)
	1990	2014	2020	2025	2030	2035	2040	2014	2040	2014-40
Total generation	116	301	339	377	422	469	518	100	100	2.1
Coal	8	34	24	18	11	7	7	11	1	-5.6
Oil	62	33	5	4	2	2	1	11	0	-11.5
Gas	14	172	219	230	245	270	290	57	56	2.0
Nuclear	3	10	12	12	20	20	28	3	5	4.2
Hydro	23	39	37	43	48	52	55	13	11	1.4
Bioenergy	-	1	2	2	3	3	3	0	1	2.8
Wind	0	6	21	38	52	62	71	2	14	9.7
Geothermal	5	6	6	7	7	7	7	2	1	0.8
Solar PV	0	0	12	23	33	43	52	0	10	23.4
CSP	-	-	-	0	1	2	3	-	1	n.a.

	Electrical capacity (GW)							Shares (%)		CAAGR (%)
	2014	2020	2025	2030	2035	2040	2014	2040	2014-40	
Total capacity	69	87	106	124	142	161	100	100	3.3	
Coal	5	5	5	5	4	4	8	2	-1.3	
Oil	17	11	9	5	4	3	24	2	-6.3	
Gas	29	39	47	57	67	76	42	47	3.8	
Nuclear	2	2	2	3	3	4	2	2	3.4	
Hydro	12	14	16	18	19	20	18	12	1.8	
Bioenergy	1	1	1	1	1	1	1	1	0.9	
Wind	3	7	12	16	19	22	4	14	8.6	
Geothermal	1	1	1	1	1	1	1	1	0.7	
Solar PV	0	7	13	19	24	29	0	18	23.8	
CSP	-	-	0	0	1	1	-	1	n.a.	

	CO ₂ emissions (Mt)							Shares (%)		CAAGR (%)
	1990	2014	2020	2025	2030	2035	2040	2014	2040	2014-40
Total CO₂	257	431	417	421	430	443	455	100	100	0.2
Coal	15	48	37	31	24	20	20	11	5	-3.2
Oil	193	245	225	228	234	236	234	57	51	-0.2
Gas	48	137	155	162	172	187	200	32	44	1.5
Power	64	138	117	110	103	107	114	100	100	-0.7
Coal	7	34	24	18	11	7	7	25	6	-5.8
Oil	49	29	5	3	2	1	1	21	1	-11.6
Gas	8	75	88	88	90	99	106	54	93	1.3
TFC	163	241	252	259	271	277	280	100	100	0.6
Coal	4	10	9	9	9	9	9	4	3	-0.4
Oil	131	201	205	207	214	216	214	83	77	0.3
<i>Transport</i>	83	151	156	159	167	169	169	63	60	0.4
Gas	27	31	38	43	48	53	57	13	20	2.4

Mexico: Current Policies and 450 Scenarios

	Energy demand (Mtoe)						Shares (%)		CAAGR (%)	
	2020	2030	2040	2020	2030	2040	2040		2014-40	
	Current Policies Scenario			450 Scenario			CPS	450	CPS	450
TPED	194	219	246	186	187	184	100	100	1.0	-0.1
Coal	10	8	7	10	6	4	3	2	-2.3	-4.2
Oil	95	101	106	90	84	67	43	37	0.4	-1.4
Gas	68	80	96	64	58	53	39	29	1.8	-0.5
Nuclear	3	5	7	3	7	12	3	6	4.2	6.0
Hydro	3	4	5	3	4	5	2	3	1.3	1.6
Bioenergy	9	9	10	9	13	18	4	10	0.4	2.8
Other renewables	6	12	16	7	15	25	6	14	5.5	7.5
Power	62	70	85	57	56	63	100	100	1.3	0.2
Coal	6	4	3	6	2	1	3	2	-4.0	-7.5
Oil	3	1	1	1	1	0	1	1	-9.9	-12.0
Gas	37	43	52	35	26	20	62	31	1.9	-1.9
Nuclear	3	5	7	3	7	12	9	18	4.2	6.0
Hydro	3	4	5	3	4	5	6	8	1.3	1.6
Bioenergy	2	2	2	2	3	4	3	6	1.3	3.0
Other renewables	6	11	15	6	13	22	17	34	5.5	7.1
Other energy sector	33	37	40	31	30	25	100	100	0.5	-1.3
Electricity	4	5	6	4	4	4	16	16	1.7	-0.1
TFC	129	150	169	125	132	132	100	100	1.4	0.4
Coal	2	2	2	2	2	2	1	1	-0.2	-1.2
Oil	77	85	91	75	71	58	54	44	0.8	-0.9
Gas	17	22	26	17	20	23	16	17	2.6	1.9
Electricity	26	33	42	24	27	32	25	25	2.5	1.6
Bioenergy	7	7	7	7	10	14	4	10	0.1	2.7
Other renewables	0	1	1	0	2	3	1	3	6.6	11.7
Industry	38	44	51	36	38	41	100	100	1.6	0.8
Coal	2	2	2	2	2	2	4	4	-0.3	-1.4
Oil	6	6	6	6	5	5	11	12	-0.1	-0.8
Gas	15	18	21	14	16	16	41	40	2.1	1.1
Electricity	14	17	20	13	14	15	40	38	2.0	0.9
Bioenergy	1	1	2	1	1	2	4	5	2.9	3.5
Other renewables	0	0	0	0	0	1	0	2	3.3	17.4
Transport	54	61	66	53	54	48	100	100	1.0	-0.3
Oil	54	60	65	52	49	36	98	75	0.9	-1.4
Electricity	0	0	0	0	1	2	1	4	5.0	12.2
Biofuels	-	-	-	-	3	7	-	15	n.a.	n.a.
Other fuels	0	0	1	0	1	3	1	6	16.6	22.0
Buildings	26	31	37	25	26	28	100	100	1.7	0.7
Coal	-	-	-	-	-	-	-	-	n.a.	n.a.
Oil	7	8	8	7	6	6	21	20	0.1	-1.2
Gas	2	3	4	2	3	3	11	11	5.1	3.9
Electricity	11	15	19	10	12	14	51	49	3.1	1.9
Bioenergy	6	6	5	6	5	4	14	16	-0.5	-1.1
Other renewables	0	0	1	0	1	2	2	6	5.2	8.7
Other	12	14	15	12	13	15	100	100	1.7	1.6

Mexico: Current Policies and 450 Scenarios

	Electricity generation (TWh)						Shares (%)		CAAGR (%)	
	2020	2030	2040	2020	2030	2040	2040		2014-40	
	Current Policies Scenario			450 Scenario			CPS	450	CPS	450
Total generation	346	448	559	323	361	424	100	100	2.4	1.3
Coal	25	15	12	24	9	5	2	1	-3.9	-7.4
Oil	13	4	2	5	2	1	0	0	-9.8	-11.9
Gas	218	270	334	201	161	122	60	29	2.6	-1.3
Nuclear	12	20	28	12	26	44	5	10	4.2	6.0
Hydro	37	48	55	37	50	58	10	14	1.3	1.6
Bioenergy	2	3	3	3	6	8	1	2	2.8	6.7
Wind	21	49	67	21	58	102	12	24	9.4	11.2
Geothermal	6	7	7	6	7	9	1	2	0.8	1.5
Solar PV	11	31	49	12	40	66	9	16	23.1	24.5
CSP	-	1	2	-	3	8	0	2	n.a.	n.a.

	Electrical capacity (GW)						Shares (%)		CAAGR (%)	
	2020	2030	2040	2020	2030	2040	2040		2014-40	
	Current Policies Scenario			450 Scenario			CPS	450	CPS	450
Total capacity	88	128	166	84	118	158	100	100	3.4	3.2
Coal	5	5	4	5	5	4	2	2	-1.3	-1.3
Oil	12	7	4	11	5	3	2	2	-5.3	-6.8
Gas	39	60	84	36	42	51	50	32	4.2	2.2
Nuclear	2	3	4	2	4	6	2	4	3.4	5.3
Hydro	13	17	20	14	18	21	12	14	1.8	2.1
Bioenergy	1	1	1	1	2	2	1	1	0.9	3.8
Wind	7	16	21	7	19	31	13	20	8.4	10.1
Geothermal	1	1	1	1	1	1	1	1	0.7	1.5
Solar PV	7	18	27	7	22	36	16	23	23.4	24.8
CSP	-	0	1	-	1	3	0	2	n.a.	n.a.

	CO ₂ emissions (Mt)						Shares (%)		CAAGR (%)	
	2020	2030	2040	2020	2030	2040	2040		2014-40	
	Current Policies Scenario			450 Scenario			CPS	450	CPS	450
Total CO₂	429	464	513	406	355	285	100	100	0.7	-1.6
Coal	38	28	25	37	20	14	5	5	-2.4	-4.6
Oil	236	251	264	222	203	151	51	53	0.3	-1.8
Gas	155	185	224	147	132	119	44	42	1.9	-0.5
Power	125	119	136	111	71	51	100	100	-0.0	-3.7
Coal	25	15	12	24	9	4	9	9	-4.0	-7.5
Oil	11	4	2	5	2	1	1	2	-9.9	-12.0
Gas	88	100	123	82	60	46	90	89	1.9	-1.9
TFC	256	287	311	249	239	198	100	100	1.0	-0.8
Coal	9	9	9	9	8	6	3	3	-0.3	-1.7
Oil	208	228	242	202	187	141	78	72	0.7	-1.3
Transport	159	178	192	154	144	106	62	53	0.9	-1.4
Gas	39	50	60	38	45	50	19	25	2.6	1.9

Mexico: No Reform and Enhanced Growth Cases

	No Reform Case			Enhanced Growth Case			Shares (%)		CAAGR (%)	
	2020	2030	2040	2020	2030	2040	2040		2014-40	
							NRC	EGC	NRC	EGC
TPED (Mtoe)	193	208	226	195	221	245	100	100	0.7	1.0
Coal	10	6	6	10	7	6	2	2	-3.1	-2.8
Oil	95	98	97	95	104	106	43	43	0.0	0.4
Gas	69	77	88	68	78	92	39	38	1.4	1.6
Nuclear	3	5	7	3	5	7	3	3	4.2	4.2
Hydro	3	3	4	3	4	5	2	2	0.4	1.4
Bioenergy	9	11	14	9	9	9	6	4	1.7	0.3
Other renewables	3	6	11	7	14	19	5	8	4.2	6.3
Power (Mtoe)	62	69	82	60	68	83	100	100	1.2	1.2
Coal	6	3	2	6	3	2	2	2	-5.8	-5.8
Oil	5	4	3	1	1	0	3	0	-4.4	-11.4
Gas	39	44	50	38	41	49	61	59	1.8	1.7
Nuclear	3	5	7	3	5	7	9	9	4.2	4.2
Hydro	3	3	4	3	4	5	5	6	0.4	1.4
Bioenergy	3	4	7	2	2	2	8	3	5.2	1.3
Other renewables	3	6	10	6	13	17	12	21	4.0	6.1
TFC (Mtoe)	128	142	155	133	156	174	100	100	1.0	1.5
Coal	2	2	2	2	3	3	2	2	-0.3	0.1
Oil	76	80	81	80	89	92	52	53	0.4	0.9
Gas	17	21	26	17	23	28	17	16	2.4	2.7
Electricity	25	31	38	26	34	43	25	25	2.2	2.7
Bioenergy	7	7	7	7	7	7	5	4	0.0	-0.1
Other renewables	0	1	1	0	1	2	1	1	6.4	9.1
Generation (TWh)	345	425	518	344	449	565	100	100	2.1	2.4
Coal	26	11	7	24	11	7	1	1	-5.6	-5.6
Oil	21	14	10	5	2	1	2	0	-4.4	-11.3
Gas	228	283	321	223	260	317	62	56	2.4	2.4
Nuclear	12	20	28	12	20	28	5	5	4.2	4.2
Hydro	36	40	43	37	48	55	8	10	0.4	1.4
Bioenergy	4	10	16	2	3	3	3	1	9.8	2.8
Wind	11	27	53	23	60	81	10	14	8.4	10.2
Geothermal	6	7	7	6	7	7	1	1	0.8	0.8
Solar PV	2	12	29	12	38	62	6	11	20.6	24.2
CSP	-	1	3	-	1	3	1	1	n.a.	n.a.
CO₂ Emissions (Mt CO₂)	435	446	466	431	465	503	100	100	0.3	0.6
Coal	39	23	20	38	25	22	4	4	-3.3	-3.0
Oil	238	243	241	237	259	265	52	53	-0.1	0.3
Gas	158	180	205	157	180	216	44	43	1.5	1.8
Power (Mt CO₂)	135	127	134	118	108	124	100	100	-0.1	-0.4
Coal	26	10	7	24	11	7	5	6	-5.8	-5.8
Oil	18	12	9	5	2	1	7	1	-4.4	-11.4
Gas	91	104	118	89	95	115	88	93	1.8	1.7
TFC (Mt CO₂)	253	270	280	265	301	317	100	100	0.6	1.1
Coal	9	9	9	9	9	10	3	3	-0.5	-0.0
Oil	205	213	214	216	239	245	76	77	0.2	0.8
<i>Transport</i>	<i>156</i>	<i>164</i>	<i>165</i>	<i>167</i>	<i>189</i>	<i>196</i>	<i>59</i>	<i>62</i>	<i>0.3</i>	<i>1.0</i>
Gas	38	48	58	39	52	63	21	20	2.5	2.8

Definitions

This annex provides general information on terminology used throughout the report including: units and general conversion factors.

Units

Coal	Mtce	million tonnes of coal equivalent
Energy	Mtoe	million tonnes of oil equivalent
	MBtu	million British thermal units
	kWh	kilowatt-hour
	MWh	megawatt-hour
	GWh	gigawatt-hour
	TWh	terawatt-hour
Gas	mcm	million cubic metres
	bcm	billion cubic metres
	tcm	trillion cubic metres
	mcf	million cubic feet
Mass	kg	kilogramme (1 000 kg = 1 tonne)
	kt	kilotonnes (1 tonne x 10 ³)
	Mt	million tonnes (1 tonne x 10 ⁶)
	Gt	gigatonnes (1 tonne x 10 ⁹)
Monetary	\$ million	1 US dollar x 10 ⁶
	\$ billion	1 US dollar x 10 ⁹
	\$ trillion	1 US dollar x 10 ¹²
Oil	b/d	barrels per day
	kb/d	thousand barrels per day
	mb/d	million barrels per day
Power	W	watt (1 joule per second)
	kW	kilowatt (1 Watt x 10 ³)
	MW	megawatt (1 Watt x 10 ⁶)
	GW	gigawatt (1 Watt x 10 ⁹)
	TW	terawatt (1 Watt x 10 ¹²)

Energy conversions

Convert to:	TJ	Gcal	Mtoe	MBtu	GWh
From:	multiply by:				
TJ	1	238.8	2.388×10^{-5}	947.8	0.2778
Gcal	4.1868×10^{-3}	1	10^{-7}	3.968	1.163×10^{-3}
Mtoe	4.1868×10^4	10^7	1	3.968×10^7	11 630
MBtu	1.0551×10^{-3}	0.252	2.52×10^{-8}	1	2.931×10^{-4}
GWh	3.6	860	8.6×10^{-5}	3 412	1

Currency conversions

Exchange rates (2015 annual average)	1 US Dollar equals:
British Pound	0.65
Chinese Yuan	6.23
Euro	0.90
Japanese Yen	121.04
Mexican Peso	15.85

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