N°3

November 2015

Etudes de l'AFD

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an application of the ThreeME model

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AGENCE FRANÇAISE DE DÉVELOPPEMENT

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Designed and produced by: Flexedo, info@flexedo.com

Printed by: Imprimerie de la Centrale Lens - ICL

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Abstract

This document offers an empirical application of the notion of energy transition to the Mexican economy and it takes the next step of simulating medium- and long-term impacts of proposed and future energy and fiscal policy on the environment and the Mexican economy. The starting point of the analysis is the ThreeME framework, a Multi-sectoral Macroeconomic Model based on Keynesian theory. It is designed to address the dynamics of global economic activity, energy system development and carbon emissions causing climate change. The ThreeME model is well-suited for policy assessment purposes in the context of developing economies as it informs the transitional effects of policy intervention. In particular, disequilibrium can arise in the form of involuntary unemployment, the inertia of technical systems and rigidity in labor and energy markets as a result of delayed market clearing in the goods markets and slow adjustment between prices and quantities over the simulation time path.

Calibrated to updated sectoral and aggregated national accounts data, a Mexican version of the ThreeME has been developed and accounts for 24 commodities – including 3 energy sources – and 32 sectors, with an explicit distinction between 11 energy sectors and 7 transport sectors. Electricity production is disaggregated into 9 technologies: hydro, geothermal, wind, solar, biomass, nuclear, coal-based, oil-based and gas-based. The ThreeME-Mexico model is used to gauge the economic and environmental effects of energy and fiscal policy measures in Mexico (namely the phasing-out of energy subsidies and the implementation of a carbon tax). Different policy scenarios are assessed, each reflecting a different strategy of fiscal revenue recycling. We consider fiscal policy (in the form of carbon taxation) for Mexico's energy transition and simulate how alternative government schemes for transferring tax revenues impact the Mexican economy and its carbon emissions. The level of the carbon tax is endogenously computed to meet the national emissions reduction targets set out in Mexico's Climate Change Law.

In line with a scenario that we name the "IDEAL scenario", we consider emission cuts of 40% by 2030 and 50% by 2050, as compared with the baseline and 2000 levels respectively. This requires carbon tax to reach US\$100/tCO_2 in 2030 and US\$700/tCO_2 in 2050. We take the case of no tax compensation for this first scenario. Because of substitution effects in energy-intensive production inputs and consumption goods, the policy successfully reduces CO_2 emissions by 75% by 2050 with respect to the baseline or business-as-usual (BAU) scenario. But the environmental goal is achieved at a very high economic cost, with GDP dropping approximately 8% after 2040 compared to the reference scenario.

We then test the hypothesis of a full redistribution of carbon tax revenues among consumers (by reducing household income tax) and producers (by compensating for social security payroll taxes), which appears to be a way of reconciling environmental and economic goals. It is shown that

this pattern of revenue transfer has beneficial impacts both on GDP and CO_2 emissions reduction. With respect to the no-redistribution scenario, the gains on emissions reduction are slightly lower (a 72% as opposed to a 75% decrease in emissions) because of rebound effects: increased economic activity from redistribution leads to enhanced production and consumption, which ultimately drives up energy use. Our results support the notion that promoting a carbon tax is compatible with both environmental and economic gains.

Sensitivity tests are undertaken, including the utilization of alternative parameter values for the alternative substitution mechanisms. It is found that CO_2 emissions reduction is low when the elasticity of substitution between capital and energy is constant (in absence of endogenous energy efficiency) and when the elasticity of substitution across types of commodities is low. Moreover, the economic gains from the tax crucially depend on the inflationary pressure resulting from the taxation policy (and therefore on the wage-setting process) and on the responsiveness of Mexico's economy to foreign competition.

This document is the result of a two-year research collaboration involving the Mexican National Institute of Ecology and Climate Change (INECC), the French Economic Observatory (OFCE) and Agence Française de Développement (AFD).

1. Introduction

Global warming represents a major threat for the development and prosperity of humanity. According to the Fifth Assessment of the IPCC (2014), the current emission trends of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. The same report indicates that surface temperature is projected to rise over the 21st century under all assessed emission scenarios and that it is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. Finally, it concludes that climate change will amplify existing risks and create new risks for natural and human systems. These risks are unevenly distributed and are generally greater for disadvantaged people and communities in countries at all levels of development (IPCC, 2014).

Current United Nations efforts aim at developing a new approach that is to replace the Kyoto Protocol and would require all nations to reduce their greenhouse gas (GHG) emissions. Reducing GHG emissions will entail the cooperation of at the least those fifteen countries (including large emerging economies like China, India, Brazil, South Korea, Mexico and South Africa) and one region (the European Union) that together account for some 80% of global carbon dioxide equivalent (CO_2e) emissions. The new global agreement seeks to limit the average global temperature rise to below 2°C compared to pre-industrial levels as a prerequisite to avoiding dangerous climate change. According to a World Bank report on carbon pricing trends (World Bank, 2014), global GHG emissions reached approximately 50 gigatons of CO_2e ($GtCO_2e$) in 2010 and are projected to climb to 59 $GtCO_2e$ by 2020. The report also states that the international community needs to reduce GHG emissions by 15 $GtCO_2e$ to reach 44 $GtCO_2e$ in order to limit temperature rises to 2°C during the 21st century.

Achieving the United Nations emissions reduction target would reduce economic growth by about 0.06% annually from now until 2100, according to the IPCC (IPCC, 2014). This cost projection assumes optimal conditions such as the immediate implementation of a common global price or tax on carbon dioxide emissions, a significant expansion of nuclear power and the advent and widespread use of new, low-cost technologies to control emissions and provide cleaner sources of energy.

Faced with this scenario, tackling climate change means it is crucial to extend emissions reductions and lower their cost. This requires the implementation of market and economic instruments as well as regulatory frameworks and, moreover, all these policies will need to complement each other. Given the considerable financial resources required and the limited public funds available to address the problem, carbon-pricing instruments are essential.

Within this context, Mexico is both vulnerable[1] to climate change and an important contributor to the problem.[2] This vulnerability stems partly from the country's geographical characteristics, including drastically uneven distribution of precipitation between northern and southern regions. A factor that further aggravates this vulnerability is the high inequality in income distribution, which places half of its population in different degrees of poverty.[3] Development based on fossil fuel exploitation has led to environmental degradation and public health problems nationwide. The high dependency of Mexico's economic growth on crude oil production and fossil fuel consumption presents serious challenges to the implementation of both mitigation and adaptation measures.

1.1. Technical cooperation between INECC-AFD-OFCE

Energy resources are essential inputs for most economic activities. Understanding the dynamics of anthropogenic climate change means taking into account the complex relationship between economic activity and environmental impact linked to fossil fuel consumption and GHG emissions. On the one hand, the level of economic activity determines the technological progress of production processes and consumption patterns. It promotes the innovation and diffusion of more efficient technologies that can satisfy the same level of activity with less environmental damage. On the other hand, it determines the capital available for investment in infrastructure used by energy-intensive activities (*i.e.*, transport and industry). These structural changes require massive investments, which in turn require the creation of economic measures that can change patterns of consumption and production. These economic measures will have an impact on production costs and thus on the competitiveness of the economy and the distribution of household wealth. Considering all the aforementioned points, the mitigation of climate change is a complex task requiring economic evaluation instruments that can show the different paths, in the medium and long term, of a given environmental and economic strategy.

The Multi-sector Macroeconomic Model for the Evaluation of Environmental and Energy policy (ThreeME) developed by the French Economic Observatory (OFCE) in collaboration with the Netherlands Organisation for Applied Scientific Research (TNO), and funded by the French Environment and Energy Management Agency (ADEME), makes it possible to analyze this complex system. The model has been used in France to estimate the macroeconomic effects of prospective scenarios for the 2030–2050 energy transition prepared by ADEME. These prospective scenarios provide a vision of energy demand as well as of the energy mix required on the supply side.

Technical cooperation was established between the National Institute of Ecology and Climate Change (INECC), an independent technical institute of the Mexican Government, and OFCE with the support of Agence Française de Développement (AFD) to develop the ThreeME model for the

[1] Mexico is particularly vulnerable to extreme weather events such as hurricanes, floods, droughts and heat waves and cold. From 1999–2011, the human losses and economic damage from hydro-meteorological events represented an annual average of 154 deaths and 21,368 million pesos (INECC, 2012).

[2] According to the IEA (2012), Mexico is the world's 14th largest emitter of energy-related CO_2.

[3] According to CONEVAL (Consejo Nacional de Evaluación de la Política de Desarrollo Social), 45.5% of the total population in Mexico in 2012 was living in some degree of poverty: http://www.coneval.gob.mx/Medicion/Paginas/Medici%C3%B3n/Pobreza%202012/Pobreza-2012.aspx

Mexican economy. This cooperation began in mid-2013 with the objective to provide INECC with the appropriate tools for analyzing the country's energy and climate policies. In this respect, the environmental taxes included in the 2014 tax reform are the Mexican Government's very first step towards institutionalizing the mechanisms and economic measures needed to limit GHG emissions. Economic evaluation is the key to estimating both the costs and benefits of such measures as well as their optimal level, so as to feed the policy debate on the economic and social impact.

The Mexican economy will be modeled using ThreeME, which is a neo-Keynesian dynamic general equilibrium model in which prices and quantities adjust slowly to their optimal values; this allows transition mechanisms to be identified in the short and medium term. These mechanisms are essential for an accurate assessment of the effects on employment and economic activity. Another important feature is its hybrid component, since it combines macroeconomic modeling (top-down) and technical modeling of energy consumption (bottom-up). This ensures an explicit treatment of the effects of decisions regarding the national economy, and takes into consideration direct and indirect impacts, such as feedback between prices and quantities and rebound effects. Likewise, the multi-sectoral nature of the modeling reveals the effects of an activity transfer from one sector to another.

1.2. Structure of the report

The present report is divided into five sections. Section 2 describes Mexico's national policy on climate change. It also provides elements that give further insight into the current Mexican economic context as well as the recently approved reforms, in particular the energy reform. This section concludes with an overview and outlook of the country's most important energy sectors. Section 3 provides a short description of the ThreeME model and how it has been adapted to Mexico. Section 4 presents the simulation results and Section 5 presents the report's conclusions.

2. Mexican context and national policy on climate change and energy

2.1. Climate change policy

Mexico has been an active player in the search for solutions to climate change in the international arena. The progress achieved at Cancun during COP16 is clear evidence of this commitment. Mexico advocated that public and private funding be mobilized for the mitigation and adaptation of climate change in developing countries under the Green Climate Fund, including technology transfer mechanisms, instruments to enhance the transparency of national commitments, and an international scheme to reduce deforestation, which includes market mechanisms.

At the national level, climate change is also a major issue on Mexico's domestic agenda. Mexico is one of the few developing countries to have a domestic law that addresses climate change, including specific emission targets relative to a baseline scenario in the short term and relative to a base year in the long term. It has also published diverse national planning documents such as the National Development Plan 2013–2018 (PND, 2013), which includes the topic of climate change, the National Climate Change Strategy (ENACC, 2013) and the Special Program on Climate Change 2014–2018 (PECC, 2014).

2.1.1. General Law on Climate Change

The General Law on Climate Change (LGCC, 2012) governs the scope and content of the national climate change policy. It defines the obligations of the state authorities and of the three levels of government. In order to ensure effective coordination between the different levels of government and cooperation between public, private and social sectors, the LGCC mandates the integration of the National Climate Change System (SINACC). This system should promote synergies to jointly tackle the country's climate-related vulnerability and risks, and identify priority actions for mitigation and adaptation actions. The SINACC includes the Inter-ministerial Commission on Climate Change (CICC), the National Institute of Ecology and Climate Change (INECC), the Council on Climate Change (C3), the federal states, associations of local authorities and the Congress. In terms of mitigation policy, the LGCC sets mitigation targets for Mexico for the years 2020 and

2050. The two targets are a 30% reduction of GHG emissions with reference to a baseline in the year 2020 and a 50% reduction relative to emissions in the year 2000.

There had been an earlier Special Program on Climate Change, published in 2009, which launched a series of mitigation actions taken by the federal government agencies and aimed at mitigating 50 million tons of CO_2e ($MtCO_2e$) by 2012. The program included regulations, subsidies and direct interventions designed to change the supply side in different economic sectors. The mitigation measures ranged from energy efficiency standards to voluntary standards for the construction sector. It also included measures for public information, cash-for-clunkers programs for heavy- and light-duty vehicles, mandates for the two state energy monopolies (CFE and PEMEX) to reduce emissions through investment, and the mass phasing-in of energy-efficient light bulbs and equipment. It is important to highlight that this program did not include any economic instruments aimed at changing the economic decisions of producers or consumers by internalizing the social costs of their emissions. A second climate change program with the same vision was launched under the current administration (PECC 2014–2018). This second PECC aims for an 83 $MtCO_2e$ reduction by 2018. All these efforts, though well-intentioned, are not enough to radically shift the now fossil-fuel dependent economy to a low-carbon economy.

2.1.2. Tax reform

In 2013, Mexico introduced the country's first carbon tax as part of the economic package for the fiscal year 2014. The tax covers about 40% of total GHG emissions nationwide. It is not a tax on the total carbon content of fuels but rather on the additional emissions compared to natural gas. Natural gas, therefore, is not subject to the carbon tax. This needs to be changed rapidly if a real energy transition is to be achieved, since a large supply of natural gas may delay investment in renewables and thus block their development.[4] The tax rate varied between 10 and 50 pesos per ton of CO_2 (US$1–4/$tCO_2$) in 2014 depending on the fuel type and with a 3% limit on the sales price of fuel. According to the Law on Federal Revenues for fiscal year 2014, it was estimated that the Federation would receive 14,641.7 million pesos (approximately US$1 billion, representing 0.328% of the Federal Government's total revenue). For the year 2015, revenue of 9,871.8 million pesos (0.210% of total revenues) is expected. So far, the revenues from this tax are not earmarked for direct investment in environmental measures.

2.1.3. Energy reform

The energy sector has a crucial role to play in the country's transition to a low-carbon economy. The characteristics of the energy supply are closely linked with the emissions of global and local pollutants – so much so that if energy dependence on non-renewable fossil fuels is not reduced, any energy-efficiency improvements, although welcome, will be inadequate.

[4] According to Davis and Shearer (2014), without new climate policies, the increased supply of natural gas makes energy cheaper, thereby encouraging higher energy consumption and discouraging investment in energy efficiency. It also competes for market share not only with coal, but also with very low-carbon energy sources such as renewables and nuclear.

In 2014, Mexico approved a series of structural reforms in the power generation sector. The recently adopted energy reform offers many opportunities to enhance the generation of clean energy. The reform introduces a sustainability mandate stipulating that the State should seek to protect the environment through sustainability criteria and promote cleaner energy and fuels. This regulation favors the entry of the private sector into the business of producing and selling electricity, as well as into transmission and distribution activities – and this more competitive environment will help to diversify the energy mix. However, it is also important to mention that the reform is expected to boost investment in, and thereby increase, the production of unconventional sources of energy such as deep-water oil, heavy and ultra-heavy oil, and in particular tight oil and shale gas. These unconventional sources have a lower energy return on investment (EROI) and a higher environmental impact. All of these new sources will increase Mexico's oil and gas production and consequently its GHG emissions. If the Government's projections on the basis of the reform are correct, oil and gas production will increase from 2.1 million barrels per day (MMbd) of crude oil to 3.6 MMbd by 2030 (SENER, 2014*a*), and this most likely will increase emissions from 87 $MtCO_2e$ in 2013 to 150 $MtCO_2e$ by 2030 (INECC, 2014*a*).

2.2. Macroeconomic context

Mexico is facing some major economic challenges. In order to escape the middle-income trap, the country needs to find a way of increasing its productivity to achieve higher rates of growth. According to the National Institute of Statistics (INEGI, 2015*a*), GDP has grown at an average annual rate of 2.1% since 2000, while GDP per capita has grown at a rate of only 0.8%, which translates into approximately US$12,130 per capita (2010–2014 World Bank PPP conversion factor) in 2013. This ranks Mexico as the economy with the lowest income among OECD countries. Despite a promising outlook for economic growth and a demographic dividend, both of which could be exploited in the coming years,[5] there are huge barriers to be overcome. According to a McKinsey report (McKinsey Global Institute, 2014), Mexico has two economies moving at different speeds. The first is a modern fast-growing Mexico with globally competitive multinationals and cutting-edge manufacturing plants that are increasing productivity by 5.8% a year. The second is a Mexico of small slow-growing enterprises whose productivity is falling by 6.5% a year. The report concludes that Mexico must triple its productivity growth from the recent yearly average of 0.8% if it is to increase national growth to above 2.0%.

Past economic reforms were aimed at increasing economic and productivity growth by opening up the economy to international trade, but they failed to encourage competition and break up the country's inefficient public and private monopolies. At the same time, if Mexico introduced greater competition it would also need to create strong institutions to watch over market rules and ensure property rights. To achieve this, the Mexican Government needs to achieve higher rates of tax collection, as one of its main problems is the country's very small tax base. Tax collection in Mexico is not only the lowest among OECD countries, but it is also lower than the average in Latin America, if oil revenue is not included (OECD, 2010). The dominant role of indirect taxation and

[5] According to the World Bank, the age dependency rate in Mexico in 2014 was 54. This is defined as the ratio of dependents (aged under 15 or over 64) to the working-age population (aged 15–64). It is presented per 100 working-age population.

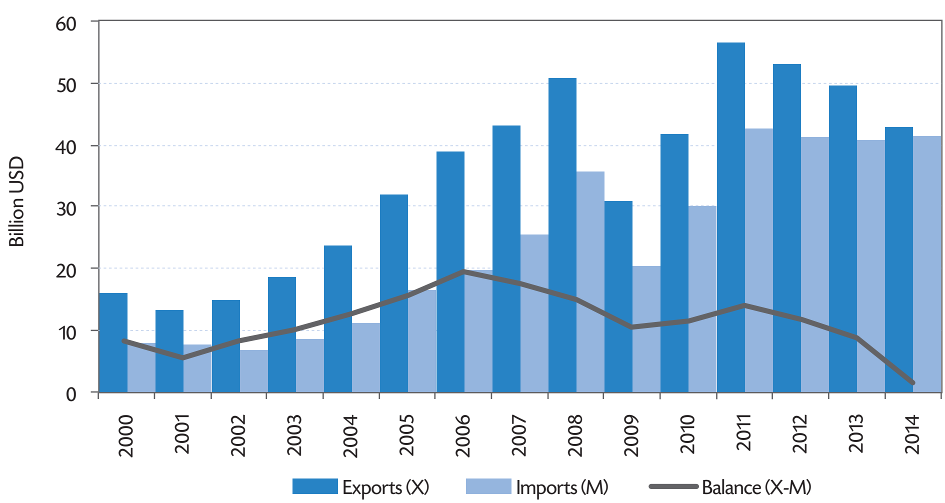
the low level of income tax collection thus contribute to reducing the progressiveness of the tax system as a whole.

One key feature of the Mexican economy is that growth is underpinned by the exploitation of non-renewable hydrocarbons. Yet, this kind of growth based mainly on oil rents can lead to inequalities, since its benefits are only enjoyed by the small well-organized groups that capture this rent. Such privileges are perpetuated through the promotion of generalized subsidies, monopolistic markets, poor accountability and inadequate regulatory enforcement (Karl, 2007; Schubert, 2006). Overall, this results in a huge loss of social welfare, a more polluted environment and a weak economy that depends on oil prices and is unable to compete with the high added-value products and services from innovative economies.

This weakness is reflected in the major role that the currency exchange rate plays in the Mexican economy. Following the 2008 recession, the rate remained relatively stable, fluctuating between 12 and 14 Mexican pesos against the US dollar. However, in January 2015, with falling international oil prices, the Mexican currency, the 'peso', reached its lowest level against the US dollar (INEGI, 2015*a*) since 2009. In the face of these developments, the Federal Government recently announced a budgetary reduction of around 9.5 billion pesos, as well as the cancellation of some infrastructure project expenditures for 2015.

The trade balance has also been impacted as, overall, Mexico is a net importer of goods. Although Mexico is a net oil exporter, in 2014 its oil imports increased by around 1% compared to 2013, while oil exports decreased by 13.5%. As shown in Figure 1, the gap between exports and imports of fossil fuels (including crude oil and natural gas) has been narrowing since 2006. Moreover, most of the refined oil products consumed in Mexico are imported, whereas the country does not export any of these products – which goes to highlight the fact that Mexico is not independent in terms of energy production (INEGI, 2015*b*).

Figure 1. Fossil fuel trade balance, Mexico, 2000–2014



Source: Banco de Información Económica (INEGI, 2015a).

Despite falling oil production and the heavy reliance on imported refined oil products, especially from the United States, general prices in the economy have been kept at adequate levels in recent years. Inflation rates in Mexico have been stable for a decade with levels between 3% and 5% per year and a 6.5% peak during the 2008 recession. The target inflation rate is 3% and the Mexican Central Bank (Banco de México) as an autonomous body is mandated with maintaining this rate. Currently, interest rates are at their lowest historical levels at around 3%.

Employment has also been stable in recent years. According to INEGI, only 3.7% of the economically active population is unemployed. This is one of the lowest unemployment rates among OECD countries. However, 28.3% of the total economically active population come under the 'informal employment' category (INEGI, 2015*b*), defined as employees working for enterprises that are either not registered, lack accountability or operate on a very small scale. This implies low productivity and low added value for at least one-fourth of the total employment, which is naturally detrimental to the economy.

Under this administration, the Federal Government has implemented reforms in different sectors to tackle all these issues. Since 2014, amendments have been made to legislation on labor, education, fiscal and energy. According to the Federal Government, the implemented reforms aim to promote productivity, innovation and quality education, which are key variables when it comes to increasing competitiveness.

The labor law reform is designed to modify the labor market structure so as to make hiring more flexible and stimulate the creation of new formal jobs, especially for young people and women. Meanwhile, educational reform aims to improve the quality of basic education by reducing inequality in access to schooling and by improving the quality of education through evaluation of teachers' performance. The tax reform aims to expand tax collection in order to increase public spending in priority areas such as education, health, social security and infrastructure. To achieve this, the reform proposes to reduce informal employment by simplifying taxes and reducing inequalities in the current tax system. It is still too early to say if these reforms will fully yield the expected results. It is likely that the adjustments will take time and the question remains of whether Mexico will be able to accomplish this before the momentum of its demographic dividend is lost.

2.3. Energy outlook

Mexico's energy supply relies heavily on fossil fuels. According to the National Balance of Energy (BNE, 2013), 88.09% of the total primary energy supply (TPES) in 2013 came from fossil fuels (64.29% from oil, 22.68% from natural gas and 1.12% from condensate liquids). Renewable energy accounted for 7.05%, nuclear for 1.36% and mineral carbon for 3.51%. Table 1 summarizes the gross domestic energy supply by energy source.

Although Mexico remains one of the world's biggest energy producers (the 10th largest crude oil producer), it is still a net importer of natural gas and refined petroleum products to meet its domestic energy demand. In 2013, the primary energy trade balance showed a deficit of 7.3% compared to 2012. In 2013, the country's domestic energy consumption in fact attained the same level as its domestic energy production for the first time, due to a constant annual reduction in energy production of around 0.4% over previous years and a constant 2.3% increase in energy consumption since 2005 (BNE, 2013).

Table 1. Gross domestic supply by energy source (in petajoules, PJ)

	2012	2013	Change (%) 2013/2012	Share (%) 2013
Total	**8,809.36**	**9,011.83**	**2.30**	**100**
Coal and coke	554.26	560.85	1.19	6.22
Natural gas and liquefied products	3,626.06	3,834.28	5.74	42.55
Oil and oil products	3,932.76	3,880.19	-1.34	43.06
Nuclear energy	91.32	122.60	34.26	1.36
Renewables	620.22	634.44	2.29	7.04
Net trade of electricity	-15.26	-20.54	34.57	0.23

Source: BNE, 2013.

On the demand side, domestic energy consumption grew by 2.3% in 2013 compared to 2012. Energy consumption by energy production sector[6] accounted for 33.97% of total domestic energy consumption, while final energy consumption accounted for 56.95%. In 2013, final energy consumption (*i.e.*, the energy consumed for goods production and final use) increased by 0.6% compared to 2012.

Table 2 shows the energy consumption by sector. Transport turns out to be the most energy-intensive sector accounting for nearly 44% of total energy consumption, followed by industry (31%) and the residential and commercial sector (17.72%).

In this increasingly worrisome scenario of energy balance, energy-efficiency measures play a crucial role in energy consumption with economic impacts in the public and private sectors, triggering a better use of energy resources. So far, the largest impacts on energy efficiency have come through highly efficient systems and equipment and better practices. The instruments used to promote these include: standards, equipment substitution programs, and information and educational programs. According to PRONASE (2014), the energy savings derived from energy-efficiency norms (NOM) from 1995 to 2012 stood at 47,508 gigawatt hours (GWh); whereas energy savings from programs promoting efficient equipment (*e.g.* clean fluorescent lamps, CFL, and labeling) accounted for 17,000 GWh in consumption and 3,500 MW in demand. In the public sector, energy-efficiency programs for public buildings have saved around 5,483 GWh by promoting energy efficiency in the operation of buildings and the vehicle fleet used by government institutions.

Energy consumption and economic growth are tightly interlinked and play a key role given that harnessing economic development inevitably requires increasing the energy supply to meet future needs in the coming years. According to the International Energy Agency (IEA, 2012), energy

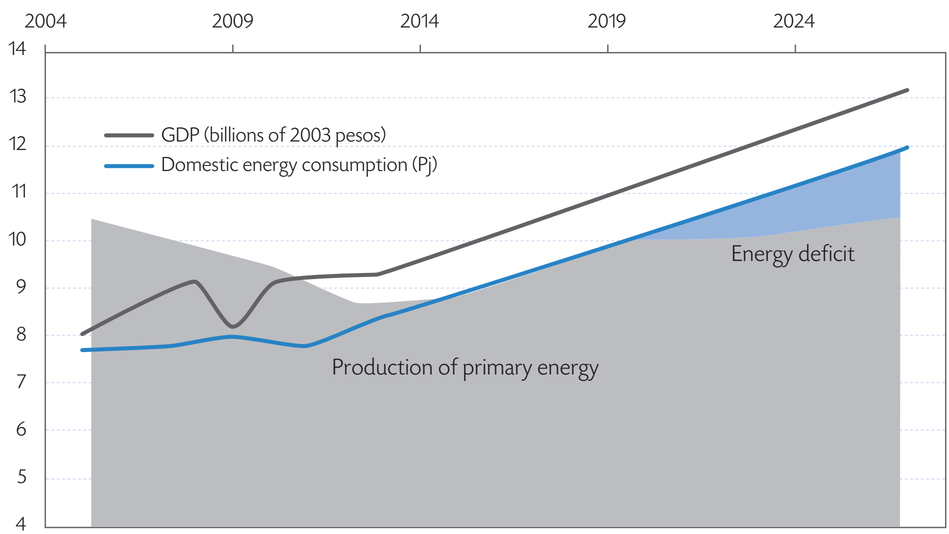
[6] This is the energy consumed for conversion purposes (60.3%), *i.e.*, energy used in the processes that convert primary energy into secondary energy. It also includes the producers' own consumption of energy (33.6%), *i.e.*, the energy absorbed by equipment supporting the transformation processes. Losses in transmission, transport and distribution (6.0%) are also included.

Table 2. Total final energy consumption (PJ)

	2012	2013	Change (%) 2013/2012	Share (%) 2013
Total final Consumption	**5,100.35**	**5,132.32**	**0.63**	**100**
Total non-energy consumption	**200.05**	**190.91**	**-4.57**	**3.72**
PEMEX petrochemical branch	112.56	136.53	21.30	2.66
Other branches	87.49	54.38	-37.84	1.06
Total energy consumption	**4,900.30**	**4,941.41**	**0.84**	**96.28**
Transport	2,298.82	2,262.28	-1.59	44.08
Industry	1,522.30	1,612.31	5.91	31.41
Residential, commercial and public	920.73	909.22	-1.25	17.72
Agriculture and livestock	158.45	157.6	-0.54	3.07

Source: BNE (2013)

Figure 2. Energy balance trend



Source: Estrategia Nacional de Energía (ENE, 2013).

demand will continue to rise at an average 1.5% a year until 2035, assuming an expansion of the global economy of around 140% and a population increase of 1.7 billion.[7] According to the Mexican National Energy Strategy 2013–2027 (ENE, 2013), the average energy consumption growth rate over the last decade has been higher than the GDP growth rate, in general terms as well as per capita, *i.e.*, growth today is more expensive than ten years ago in terms of energy consumption. In fact, Mexico's energy demand could increase by more than 50% by 2027 with respect to energy demand in 2011 (see Figure 2).

2.4. Key energy sectors

2.4.1. Electricity sector

Over the past fifty years, the national electric system has been controlled by the Federal Government through the Federal Commission of Electricity (CFE), a state monopoly responsible for the supervision, generation, transmission and commercialization of electricity nationwide. Electricity has thus been produced in a non-competitive environment, where prices are not determined by market criteria. This has led to net losses for the CFE, weak competitiveness and low investment in infrastructure, as well as in high subsidies mostly for residential and agricultural customers. Under this scheme, central planning has focused mainly on fossil-fuel-based technologies, especially natural gas, and thus fostered an undiversified system that is vulnerable to fuel availability and price volatility.

In 2012, the sub-sector of electricity generation, transmission and distribution accounted for a 3% share of GDP (PROMEXICO, 2013) and employed 127,252 people (INEGI, 2015*d*), *i.e.*, 0.25% of the economically active population. Exports accounted for 2.2% of GDP, imports 2.5% and foreign direct investment 0.3% (PROMEXICO, 2013). Regarding energy consumption, the electricity sector accounted for 27% of national energy consumption in 2013, with 81.7% of power generation based on fossil-fuel technologies (50.6% natural gas, 18.9% oil products and 12.3% coal), 4.6% based on nuclear and the remaining 13.7% on renewable energy (10.6% hydro, 2.4% geothermal and 1% wind) (SENER, 2013*a*). In terms of GHG emissions, the power generation sector emitted 126.6 $MtCO_2e$ in 2013 (INECC, 2014*a*), representing 26% of total GHG emissions in the country, and was the second largest emitter after the transport sector.

The energy transition in the power sector entails sweeping changes in at least three areas. The most important one is deregulation. As mentioned earlier, the recently approved energy reform furnishes an opportunity to transform the sector by diversifying the sources of power generation, by favoring market entry for new private producers and by creating new investment opportunities for renewables. Effective implementation of different instruments such as the clean-energy certificates market will be vital to incentivize clean generation technologies. The second area of opportunity is the new Energy Transition Law (LTE) which is due to replace the LAERFTE (Law on the Use of Renewable Energies and Financing of Energy Transition) but still under discussion, and its mandates to generate 35% of electricity from clean energy by 2024 and 50% by 2050.

[7] Given a current population of around 7.3 billion people, according to the UN Population Division, this will represent a 23% increase in world population by 2035 compared to 2015.

Confirmation of these targets will provide clarity for new investments in the sector. The third area of opportunity concerns electricity prices. In 2013, electricity subsidies accounted for 0.85% of GDP (INECC, 2014*b*). Electricity tariffs have risen sharply over recent years, with industrial customers bearing the brunt of the increases. Industrial customers pay electricity rates that are 70% higher than those in the U.S., which deals a heavy blow to the competitiveness of Mexico's industry. Additionally, substantial government subsidies account for more than 60% of the cost of electricity for residential and agricultural customers. Gradually phasing out these subsidies in the years to come would increase the real costs, thus incentivizing energy efficiency and making renewable energy competitive relative to fossil fuels.

2.4.2. Oil and gas sectors

Mexico is one of the world's leading producers and exporters of crude oil, with production totaling 2.5 million barrels per day (MMbd) in 2013. However, domestic production has shown a declining trend due to the fact that 80% of the national production comes from mature fields that are currently in decline (SENER, 2014*a*). The marginal increase in production during the recent years is essentially due to unconventional oil, mainly deep-water oil.

In 2012, the sales revenues of the oil and gas sector accounted for 10.56% of GDP (calculation based on PEMEX, 2012 and INEGI, 2015*a*). Although the 2013 annual export earnings from crude were down by 8.8% on 2012 (SENER, 2014*b*), they still represented 26% of total exports and 3.8% of GDP. As such, Mexico remains an important producer of fossil fuels but it has lacked the capacity to process and refine its own oil products to meet the domestic demand.

Oil and gas production has steadily decreased over the 2006–2013 period after peaking in 2004 at 3.4 MMbd (EIA, 2015). A more technically difficult oil extraction process involving higher costs has caused the country to shift from relatively cheap and abundant oil to exactly the opposite situation within a few years. If the recent trend continues, Mexico could soon become a net importer of oil products due to its decreasing domestic production and increasing demand for refined oil products.

In the context of Mexico's energy reform, one of the key objectives is to step up the extraction of natural gas. This strategy includes investments in domestic production of natural gas, the expansion of pipeline infrastructure, the exploration of potential oil and shale gas reserves and the expansion of hydrocarbon production. Expectations are that Mexico's oil production will increase from 2.5 MMbd in 2013 to 3.4 MMbd in 2030 and that natural gas production will triple from 4.5 million cubic feet per day (MMcfd) in 2013 to 12 MMcfd in 2030. Refined oil products will remain stable, with production at 1.2 MMbd in 2013 and 1.4 MMbd in 2030. Finally, a decrease in the production of basic petrochemicals is expected to fall from 2.5 MMcfd to 0.8 MMcfd in 2030 (SENER, 2014*b*).

Regarding GHG emissions, a specific feature of the oil and gas sector is that although its energy consumption is not significantly high compared to other sectors, oil and gas extraction accounts for a relatively high amount of fugitive emissions (methane, CH_4). Emissions from the oil and gas sector in 2013 totaled 52.5MtCO_2,[8] representing 12% of total GHG emissions from energy consumption (INECC, 2014*a*).

[8] Emissions from energy consumption in the extraction process, not including fugitive emissions.

2.4.3. Industry sectors

Basic industries, such as cement, iron and steel, chemicals and chemical products, cellulose and paper, and glass, are key components of economic growth in Mexico. From 1994 and 2010, their average contribution to GDP was around 30%, including the manufacturing industry (González, 2012). However, this share decreased from 2003 to 2013 due to a low average growth rate of 2.1% over this same period (INEGI, 2015*a*).

Industry's economic growth has gone hand in hand with increasing pressure on the environment. As a highly energy-intensive sector, industry accounted for 32.6% of total energy consumption in 2013 (BNE, 2013), which ranks it the second largest consumer just behind transport. From 2003 to 2013, energy demand from industry rose by 32%, while CO_2 emissions have increased steadily over recent years. Industry accounted for 105.37 $MtCO_2e$ of GHG emissions in 2013 (INECC, 2014*a*). Even though the sector has improved its levels of energy efficiency in the face of growing international competition, its energy consumption continues to rise, particularly in the extractive industry, given that extraction and transformation of increasingly scarce raw materials require an increasing amount of energy. Furthermore, the industry sector's productivity has stagnated in recent years: gross value added (GVA) has barely increased from 29.3% to 29.8% as a share of the gross production value (INEGI, 2015*a*).

The growing demand for energy has also driven emissions higher. GHG emissions increased by 13% from 2000 to 2010, that is, from 104.5 to 117.9 $MtCO_2e$ (INECC, 2013). According to INEGI (2015b), the cost associated with the depletion and exhaustion of natural resources was around 3.79% of the total environmental cost to the economy as a whole, or 1.7% of the industry sector's GDP in 2012.

2.4.4. Transportation sector

Transport is the most energy-intensive sector in Mexico and accounted for 44.7% of the country's total energy consumption in 2012. Of total transport consumption, the share of road transport represents 91.9%, air 5.3%, sea 1.43%, rail 1.16 % and electric-powered transport 0.17 %. In terms of fuel consumption, the figures show an undiversified matrix based on 97.7% of fossil fuels such as gasoline and diesel. All modes of transport are completely dependent on oil and the sector contributes 37.8 % of total GHG emissions from fossil fuel consumption (BNE, 2012).

Moreover, the transport sector plays a crucial role in competitiveness. It is a key determinant of a country's efficiency and economic development. In this sense, it is important to distinguish between the movement of goods and passengers. Whereas the movement of goods falls with the scope of trip demand and therefore counts as an economic activity, the movement of passengers is considered as mobility and does not in itself represent an economic activity. This explains why the transport sector makes a small contribution to GDP, with 5% in 2014 (INEGI, 2015*a*), yet has a great impact on total GHG emissions.

Since 2002, the demand for fossil fuels in this sector has increased at a rate of 3.8 % per year and is expected to continue rising over the next two decades (SENER, 2014*b*). This huge increase is driven by the growth of the vehicle stock, which can in part be explained by constant real fuel prices, the supply of cheap import used vehicles and, in general, a high income elasticity that characterizes this sector. The motorization rate per 1,000 inhabitants is up from 179 in 2008 to 206 in 2013 (INECC, 2015). The total demand for vehicles in the country was around 1.9 million vehicles in 2013 (including new and imported used, light- and heavy-duty vehicles as well as motorcycles). With an income elasticity ranging from 0.72 to 0.86 depending on the vehicle category, it is expected that vehicle ownership could reach 328 vehicles per 1,000 inhabitants by 2030 (INECC, 2015).

Finally, the policy of keeping real fuel prices constant over the last two decades has distorted the vehicle market not only in terms of stock but also energy efficiency. The new light-duty vehicle fleet has barely changed its fuel economy, with an annual rate of 2.6% over the period 2008–2012 (Islas *et al.*, 2012). Recent changes in fuel price policy together with the approved energy efficiency regulation for new light-duty vehicles (NOM163, published in 2013 for the period 2014–2016) will incentivize technological change as well as a change in the sales mix of passenger vehicles versus light trucks. Both measures will have a positive impact on the fuel economy of the fleet. During the period 2010–2014, regular gasoline and diesel prices increased approximately 38% in real terms (2010 Mexican pesos), reducing the implicit subsidy and sending the right price signal to consumers. However, having a tax or a subsidy depends on international prices and the recently approved Hydrocarbons Law (2014) states that prices will only adjust for inflation in the period 2015–2017, leaving it up to the Federal Government to control national prices in the case of high volatility in the international market. It is only from 2018 that prices will be set under market conditions but the law does not mention any other change in fiscal terms regarding a fuel tax. This means that price policies could still veer and adversely impact the fuel economy. If no new fuel economy regulation is put in place for the period 2017–2025 (as already launched in the USA), any lean gains that may have been recently acquired would quickly vanish.

3. ThreeME for Mexico

3.1. Main characteristics of ThreeME

ThreeME (Multi-sector Macroeconomic Model for the Evaluation of Environmental and Energy policy) is a country-generic and open source model developed since 2008 by the ADEME (French Environment and Energy Management Agency), the OFCE (French Economic Observatory) and TNO (Netherlands Organisation for Applied Scientific Research).[9] Initially developed to support the energy/environment/climate debate in France, ThreeME has now been applied to other national contexts such as Mexico and Indonesia.

The model is specially designed to evaluate the medium- and long-term impact of environmental and energy policies at the macroeconomic and sector levels. To do so, ThreeME combines several important features:

- Its sectoral disaggregation allows the effect of transferring activities from one sector to another to be analyzed, particularly in terms of employment, investment, energy consumption and trade balance.
- The energy disaggregation allows analysis of the energy behavior of economic agents. Sectors can arbitrate between different energy investments: substitution between capital and energy when the relative energy price increases; substitution between energy sources. Consumers can substitute between energy sources, between types of transport or between goods.
- ThreeME is a CGEM (Computable General Equilibrium Model). It therefore takes into account the interaction and feedback between supply and demand (see Figure 3). The demand (consumption, investment) defines the supply (production). In return, supply defines demand via the income generated by the production factors (labor, capital, etc.). Compared to bottom-up energy models such as MARKAL or LEAP, ThreeME goes beyond a simple description of the sectoral/technological dimension by linking these with the global economic system.
- ThreeME is a neo-Keynesian model. Compared to standard Walrasian-type CGEM, prices do not instantaneously clear supply and demand. Instead, the model is dynamic and prices and quantities adjust slowly. This has the advantage of allowing for situations of disequilibrium

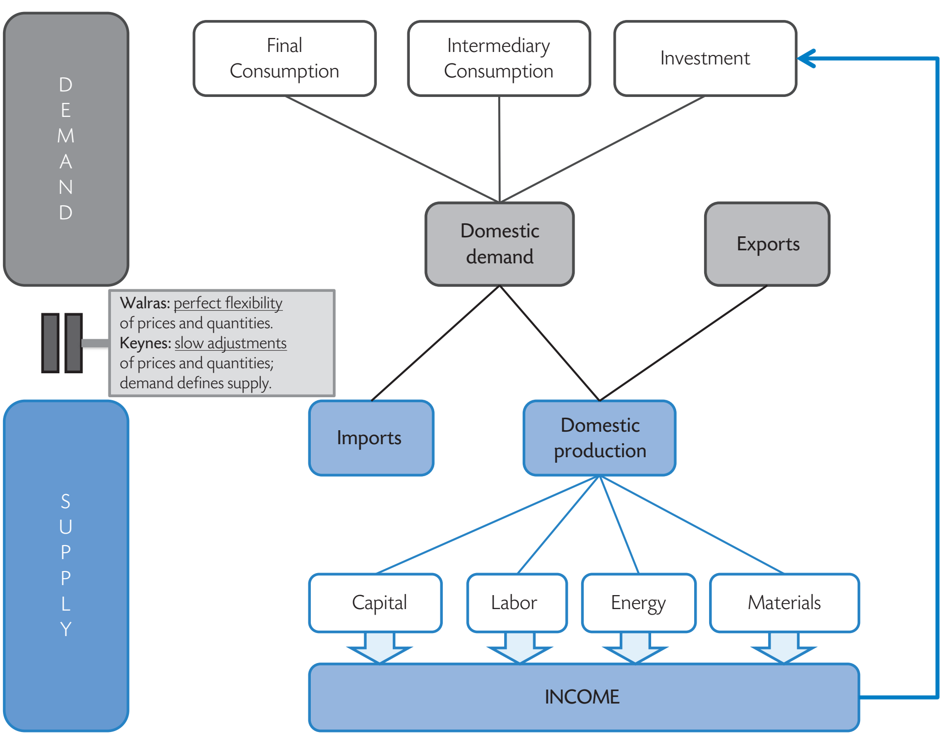
[9] (OFCE/ADEME/TNO, 2013). A full description of ThreeME is provided on: www.ofce.sciences-po.fr/indic&prev/modele.htm.

between supply and demand (in particular the presence of involuntary unemployment). This framework is better suited to policymaking purposes as it provides information on the transition phase of a particular policy (not only on the long term).

Being a neo-Keynesian CGE model, ThreeME takes into account:

- *general equilibrium effects*: supply influences demand and vice versa,
- *direct and indirect effects of the energy transition*: the direct effects are the impacts on the energy, building, transport sectors, whereas the indirect effects (or rebound effects) are the impacts on the rest of the economy (particularly the other sectors, the Government, households),
- *a double dividend (environmental and economic) is possible* through improvement of the trade balance, reduction of fiscal distortion (*e.g.*, reduction of taxes on labor and capital financed by a carbon tax) and the positive macroeconomic effects due to the increase in demand (positive multiplier).

Figure 3. Architecture of a CGEM



Source: OFCE/ADEME/TNO, 2013.

ThreeME can be used to simulate the economic impact of various policies. Examples of scenario simulations related to energy and climate policies include:

- a carbon tax,
- a phasing-out of energy subsidies,
- a tax credit in favor of energy renovation in the building sector,
- subsidies in favor of green investments in buildings, automotive and public transport sectors
- the impact of transitions in the energy sectors (such as the increased use of renewables).

3.2. Main characteristics of the Mexican version of ThreeME

The Mexican version of the ThreeME model follows a generic architecture also used in the French version. The choice of sectors is specific to Mexico and these are shown in Table 4. The model has 24 commodities (including 3 energy sources: refined oil, gas and electricity) and 32 sectors with an explicit distinction between 11 energy sectors and 7 types of transport. The rationale behind this disaggregation is the energy intensity of sectors and the contribution of each sector to CO_2 emissions. National data sources have been used for the calibration (INEGI, 2012, 2013): supply and use[10] tables and input-output tables (262 Branches) and the institutional sector (household accounts and Government accounts).

Year 2008 is used as the base year since it corresponds to the most recent release regarding input-output tables at the time this project began. Additional public sector data such as the financial situation of the Federal Government and social security come from the Mexican Ministry of Finance (SHCP[11]). Population projection comes from the National Council of Population (CONAPO[12]) and the 2008 level of CO_2 emissions is calibrated using the National Inventory of Greenhouse Gases (INEGEI[13]) data. Finally, for the disaggregation of energy sectors, we use data from the Energy Information System (SIE-SENER[14]): more specifically, domestic gas sales and gas imports and final energy consumption by power technologies and sectors.

Table 3 provides some of Mexico's key macroeconomic data for 2008. Energy subsidies represent 97% of total subsidies and 2.2% of total GDP. Mexico's crude oil exports represent 3.8% of GDP, and the country imports a large amount of refined oil and gas products: 2.6% of GDP. Tax on hydrocarbons is an important source of revenue for the Federal Government, representing 7.5% of GDP and 32% of its total revenue in 2008. Accounting for 415 million tons of CO_2 from energy consumption, Mexico is the world's 14th largest emitter and the biggest source of CO_2 emissions in Latin America. Moreover, Mexico is ranked 100th in terms of its level of emissions per capita.[15]

[10] Set of matrices that describe the magnitude of the inter-industrial flows depending on the production levels of each economic sector (INEGI, 2012), (INEGI, 2013)

[11] http://www.shcp.gob.mx/POLITICAFINANCIERA/FINANZASPUBLICAS/Estadisticas_Oportunas_Finanzas_Publicas/Informacion_mensual/Paginas/ingresos_gasto_financiamiento.aspx

[12] Consejo Nacional de Población, http://www.conapo.gob.mx/

[13] (INEGEI, 2013) http://www.inecc.gob.mx/descargas/cclimatico/inf_inegei_public_2010.pdf

[14] http://sie.energia.gob.mx/

[15] http://www.eia.gov/

Table 3. Key macroeconomic data for Mexico in 2008 (base year)

Features 2008			
Public Deficit, %GDP	1.7%	Import of refined oil and gas product % GDP	2.6%
Debt, %GDP	31%	Export of refined oil and gas product % GDP	0.6%
Energy Subsidies (electricity and oil), %Total subsidies	97%	Export of crude oil % GDP	3.8%
Energy Subsidies (electricity and oil), % GDP	2.2%	Emissions of CO_2 from energy uses $MtCO_2$	415
Tax on Hydrocarbon (Derechos a los hidrocarburos), % GDP	7.5%	Household emissions, %	31%
Trade Balance, %GDP	-2.7%	Sector emissions, %	69%

Source: INEGI, 2012

Table 4. Sectoral disaggregation of ThreeME for Mexico

Nº	Sectors	Production %	Nº	Sectors	Production %
1	Agriculture, livestock and fishing	2.9%	17	Transport via pipeline	0.1%
2	Forestry	0.1%	18	Other transports	0.6%
3	Mining	1.3%	19	Business services	33.8%
4	Manufacture of food, beverages and snuff	7.0%	20	Public services	6.7%
5	Manufacture of articles of paper and paperboard	0.9%	21	Extraction of oil	4.7%
6	Manufacture of chemicals	2.5%	22	Manufacture of refined petroleum products	3.7%
7	Manufacture of cement and concrete	0.4%	23	Manufacture and distribution of gas	1.7%
8	Manufacture of steel	0.8%	24	Hydraulic	0.3%
9	Manufacture of motor vehicles and trucks	2.0%	25	Geothermal	0.1%
10	Other industries	15.1%	26	Wind	0.0%
11	Construction of buildings	9.1%	27	Solar	0.0%
12	Air transport	0.5%	28	Biomass	0.0%
13	Rail transport	0.1%	29	Nuclear	0.1%
14	Water transport	0.1%	30	Coal-based	0.2%
15	Freight transport by road	2.4%	31	Oil-based	0.4%
16	Passenger transport by road	1.6%	32	Gas-based	0.9%

Source: INEGI, 2012

The electricity sector is disaggregated into 9 technologies: hydro, geothermal, wind, solar, biomass, nuclear, coal-based, oil-based and gas-based. However, the development of each of these technologies is determined exogenously. This assumption is realistic for the electricity production sector, since it is the Government that delivers authorizations for installing power plants. Hence, the investment choices for the electricity technology sectors do not obey the same market rules as the other economic activities. They are almost entirely determined by public policy (something that is expected to change in the coming years with full implementation of the energy reform). The parametrization of the electricity mix in the base year uses data from the Energy Information System. For each technology, the share of labor, capital, intermediary consumption and fuel consumption in the production cost have been parametrized using data from the Ministry of Energy (SENER, 2014*a*).

In Mexico, anthropogenic CO_2 emissions represent about 65% of total greenhouse gas emissions.[16] They come mainly from the combustion of fossil fuels (more than 80% of total CO_2 emissions), industrial processes, land-use change and forestry. The modeling of the demand for fossil fuels is detailed by type of economic agent and by type of fossil energy (oil, coal or gas). This allows for a precise estimation of the variation in domestic CO_2 emissions. In the Mexican version of ThreeME, we consider only CO_2 emissions from the combustion of fossil fuels. The calculation of emission levels is obtained by multiplying the fossil energy demand by the corresponding emission coefficient. These coefficients are specific to each economic actor, each sector and each energy source depending on their carbon intensity. CO_2 emissions from the combustion of fossil fuels by sector and households are proportional to the quantity of energy consumed.

Technological innovations are a key factor in reducing the impact of economic activity on the environment since they enable a reduction of emissions per unit of GDP. Improvements in energy efficiency mitigate the impact of economic growth on climate change, although the final impact of energy efficiency on energy use and CO_2 emissions is uncertain due to the "rebound effect".[17] In the model there are two types of energy efficiency that have impacts on the results. The first is exogenous, given the observed historical trends in Mexico in the production and consumption sectors, as explained in the next section. The second type of energy efficiency is endogenous since it depends on the energy prices in the model. We assume that higher energy prices, which may be the result of environmental policy, stimulate energy efficiency in economic sectors through a higher elasticity between capital and energy.

3.2.1. *Observed trends of energy efficiency in Mexico*

Energy efficiency plays a key role in the model, since it has relevant effects on energy intensity by sector. According to SENER (2011), energy efficiency in the industry sector has evolved over time, depending on the sub-sector. The highest energy-intensive sector is manufacturing, which in 2009 accounted for 9.8 megajoules (Mj) per 2003 US dollar produced; however, energy intensity

[16] See INEGEI, 2013, p.28.

[17] In this report, we focus on the interpretation of the rebound effect at the macroeconomic level, which includes direct and indirect effects. The macroeconomic rebound effect implies that the aggregate energy saving from climate change measures might be offset by an associated increase in energy demand and therefore in CO_2 emissions, due to the boost in economic activity brought about by these same measures (Barker, Ekins & Foxon, 2007).

Table 5. Energy intensity by industry and primary sector

Sector	Indicator	1993	2009	Growth rate per year 1993-2009
Manufacturing (total)	Energy intensity (MJ/GDP)	11.2	9.8	-0.8%
	Energy consumption share (%)	90.8	88.4	-0.2%
Basic metals	Energy intensity (MJ/GDP)	20.5	14.9	-1.9%
	Energy consumption share (%)	9.2	7.7	-1.1%
Non-Ferrous minerals	Energy intensity (MJ/GDP)	12.4	13.2	0.4%
	Energy consumption share (%)	7.9	9	0.8%
Chemical products	Energy intensity (MJ/GDP)	18	8	-4.9%
	Energy consumption share (%)	17.7	8.5	-4.5%
Cellulose and paper	Energy intensity (MJ/GDP)	15.2	10.4	-2.4%
	Energy consumption share (%)	2.6	2.6	-0.1%

Source: SENER, 2011.

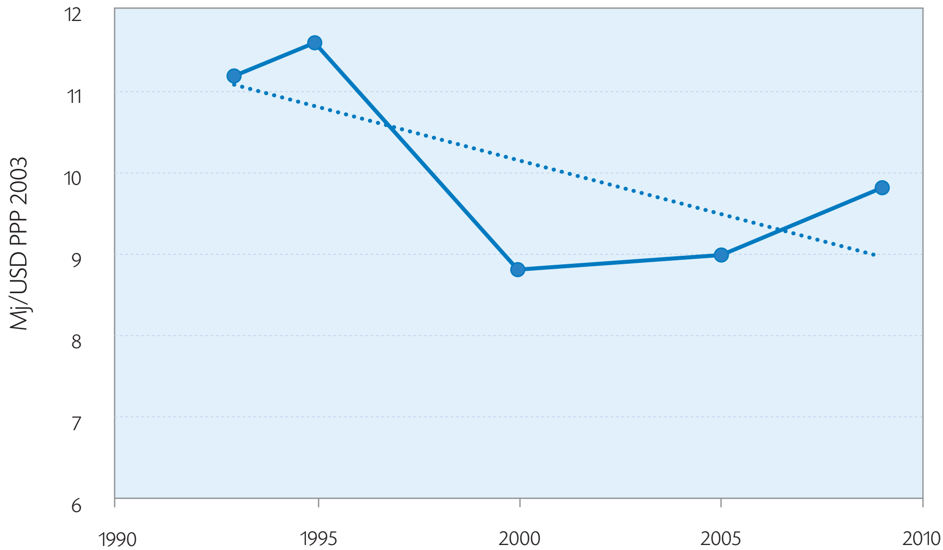
was reduced by 0.8% per year between 1993 and 2009. Within the manufacturing sub-sector, the ferrous and nonferrous minerals, chemical products and cellulose and paper industries have shown an energy intensity growth rate of -1.9, 0.4, -4.9 and -2.4% respectively.

The energy efficiency path of the manufacturing sector from 1993 to 2009 is reported in Figure 4. It shows a decreasing trajectory from 1993 to 2009. According to Enerdata (2011), industrial energy intensity fell by 2% per year; however, as from 2000 it decreased less rapidly, at an annual 0.5%. The largest energy efficiency improvements were achieved in steel production (2.2% per year on average from 1990 to 2008), whilst the chemical industry saw a rapid drop in its energy intensity of around 7% per year as from the year 2000.

In sum, energy intensity varies differently across sectors. If we consider energy intensity to be an adequate indicator of energy efficiency, and taking account the above discussion, a 1% increase per year for the production sector would seem to be a reasonable assumption for energy efficiency. Future modeling efforts will have to take into account different efficiencies that vary across sectors.

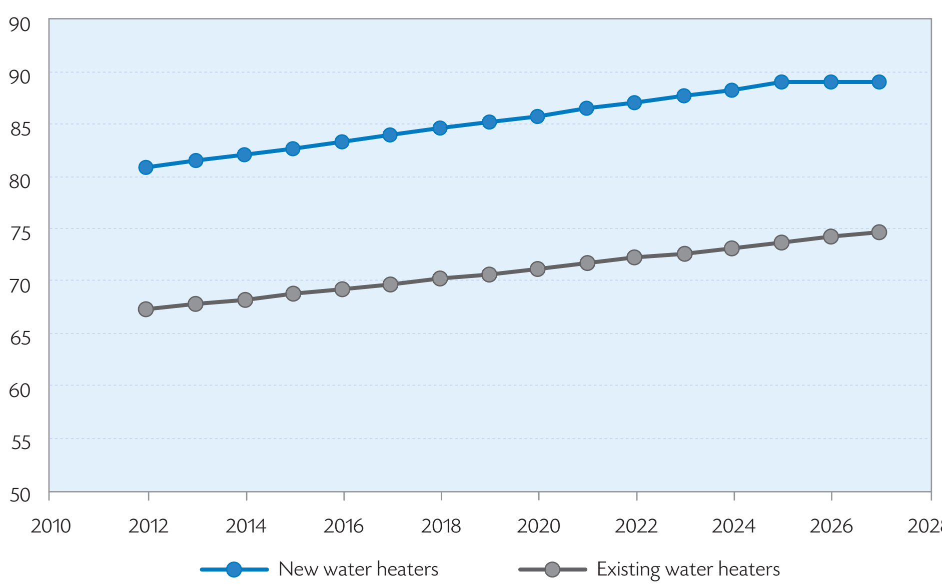
In the residential and commercial sectors, energy efficiency will also be a key determinant of energy intensity. Most of the energy gains in the upcoming years will be due to lighting and water-heating improvements. In the case of water-heating, 12.9 Mbd of liquefied petroleum (LP) gas were saved through improved energy efficiency for water heaters (67.9%), stoves (28.7%) and microwaves (3.4%). For water-heating, it is expected that efficiency gains will be 0.6% of the average annual efficiency rate for water heaters from 2013 to 2027 (SENER 2013*a*). Figure 5 shows the trend of water-heater efficiency. As in the case of industry, the model will assume a 0.5% annual increase in efficiency for the residential sector. These efficiency gains will mainly stem from the increased efficiency of water heaters and other cooking appliances using gas.

Figure 4. Energy intensity of the manufacturing sector



Source: SENER, 2011.

Figure 5. Water heater efficiency (%) 2012–2027



Source: SENER, 2013a.

4. Simulation results

As indicated in the previous descriptions of energy sector, reducing CO_2 emissions will mean implementing policies and measures to support green investments in both the short and long run. A carbon tax accompanied by appropriate compensation mechanisms appears to be one way of reconciling environmental and economic goals. This would not only attract funds for low-carbon investments, but also boost public and private investments as well as employment.

The purpose of the carbon tax is to boost green activity in order to steer the Mexican economy onto the track of a real reduction in carbon emissions and implement a cost-effective way of achieving the ambitious national mitigation commitment set out in the Climate Change Law.[18] This aims at a 30% decrease in emissions with respect to the baseline by 2020, and a 50% reduction by 2050 compared to the year 2000. A progressive carbon price is one of the tools designed to ensure that carbon emissions reduction actually happens.

Recent experience has shown that carbon pricing is likely to encounter serious opposition. A high carbon price would have negative effects that need to be taken into consideration, mainly through three channels (OFCE/ECLM/IMK, 2015):

1. Loss of consumption by high carbon emitters among households. High carbon emitters may be vulnerable households with little possibility of substitution given that energy is a primary good and the choices made by households rule out rapid adaptation to a large shift in relative prices.
2. The same effect occurs for producers that cannot rapidly shift investments (without depreciating of a large amount of capital) related to their production function in the event of a change in relative prices. A high carbon price would have a strong negative impact on their balance sheet or their capacity to run their business. The irreversibility of investment (as in the case of households) is the cause of the loss incurred.
3. Emissions reduction at the global level may not even be achieved because of the free-rider problem:
    a. A general loss of competitiveness in the short term generated by a higher cost of energy compared to the cost of energy in other parts of the world where such a carbon price would not be applied.

[18] See LGCC, 2012.

b. A reduced energy demand from those countries that have applied carbon pricing may lead to a decrease of global energy prices, which ultimately triggers higher energy demand elsewhere. This is tied to the rebound effect.

c. A carbon leakage – given that carbon-emitting industrial processes may be located in places where prices and taxes are lower – could result in an overall increase of global carbon emissions and job destruction in countries that implement carbon pricing.

Positive effects from carbon pricing policies are often experienced when a comprehensive policy package, including decreases in other taxes, is implemented to help the transition.[19] A full carbon price recycling scheme would thus be part of the policy package, making the pricing of carbon more attractive. Redistribution of the carbon tax revenue is thus a means of offsetting the stepwise increase in carbon prices. As this tax can target specific individuals or sectors, it allows for different carbon pricing for different economic agents.

Box 1

Carbon tax trend

The idea of a carbon tax comes from the theoretical concept that the English economist Arthur Pigou developed in order to address market failures. It involves levying a tax on goods that impose spillover costs on society that are not borne by the source of the externality. Adding a tax thus allows the social cost to be reflected in a cost-effective way, through private markets. Climate change has been identified as a negative externality for society as it creates a less favorable environment and is directly linked to GHG emissions generated by our fossil fuel consumption. There is a broad consensus on taxing carbon dioxide as a way of reducing GHG emissions, although a debate persists on its socially optimal price. The externality is quite difficult to clearly identify and estimate given that, despite strong scientific evidence on the nature of the phenomenon, there is still uncertainty on its magnitude.

For the purpose of pricing carbon, some countries have implemented empirical experiments either unilaterally or regionally and there is some evidence of a relatively high carbon price. For instance, the Swedish carbon tax is up to US\$168/tCO_2 and the Tokyo Cap-and-Trade carbon price reaches US\$95/tCO_2. The majority of prices in existing systems lie below US\$35/tCO_2. A recent IMF study (Parry *et al.*, 2014) calculates what the CO_2 emissions price should be for the top twenty emitting countries, based solely on the domestic co-benefits gained from reducing negative externalities (other than climate change) such as local pollution, health damages and traffic congestion. The authors found that the average nationally efficient price is US\$57.5/tCO_2. In the Deep Decarbonization report (Sachs *et al.*, 2014), the authors propose, at least for France, a carbon price trajectory – initially formulated by the Quinet commission (Centre d'Analyse Stratégique, 2009) and compatible with the objectives of 75% emissions reduction by 2050 – starting at USD^{2008} 36/tCO_2 in 2010, USD^{2008} 63/tCO_2 in 2020 and USD^{2008} 112/tCO_2 in 2030.

[19] See World Bank, 2014.

Compensation is thus justified as it has a positive impact on the economy in the short term and makes carbon pricing politically acceptable and less costly for economic agents. It may also bolster the ambition to engage the economy on a path towards lower carbon emissions and heighten the chances of success.

The following section presents the results of the different scenarios obtained using the Mexican version of the ThreeME model. We propose that its negative effects be addressed through a compensation scheme. These scenarios include the phasing-out of energy subsidies and the implementation of carbon tax with different schemes of fiscal revenue recycling. They also take account of the different electricity mixes[20] envisaged by 2050. The level of the carbon tax has been chosen so as to comply with the target of the "IDEAL scenario" designed by the National Institute of Ecology and Climate Change (INECC) for energy-related GHG emissions. It considers a reduction of 40% by 2030 compared to the baseline and a reduction of 50% by 2050 compared to the year 2000.

4.1. Baseline scenario

The baseline (reference or business-as-usual [BAU]) scenario is the path predicted by the model when all exogenous variables follow their "business-as-usual" trend and is meant to be a conservative vision of the future rather than a real forecast. It is the virtual scenario predicted by the model for a given trajectory of the exogenous variables. Although it excludes cyclical fluctuations, the idea is to reflect as far as possible the expected changes regarding key exogenous variables such as population, productivity gains, tax rates, elasticities and external demand. By definition, the baseline scenario always excludes the impact of any policy being studied since this can be seen as a shock compared to the baseline scenario and is simulated as an alternative scenario (see Section 4.2).

Although the impact of a new policy is measured as a difference from the baseline expressed as a percentage, the choice of the baseline may affect the results of the simulated scenario. It is therefore important to define a coherent vision of the future, which may prove to be a difficult task in terms of calibration. To achieve the construction of a realistic baseline scenario, we focus on obtaining projections for a few key macroeconomic variables, such as real gross domestic product (GDP), population, the evolution of labor productivity and the evolution of international energy prices.

GDP projections for the Mexican economy to 2030 are drawn from a study that is part of the Facilitating Implementation and Readiness for Mitigation (FIRM) project (INECC*b*) funded by the Danish Ministry of Foreign Affairs and the French Agency for Development (AFD) and implemented through the United Nations Environment Programme (UNEP) in partnership with UNEP DTU and INECC. The overall goal of this project was to improve Mexico's GHG emissions baseline. In Mexico, as in any other industrialized economy, economic growth and energy commodity prices are key drivers of greenhouse gas emissions. Estimates of likely developments in gross domestic product and fuel prices are major components of quantitative greenhouse gas emission scenarios used for planning purposes. Understanding the uncertainty associated with these estimates makes it possible to assess the uncertainty of the corresponding scenarios and, thereby, supports more robust

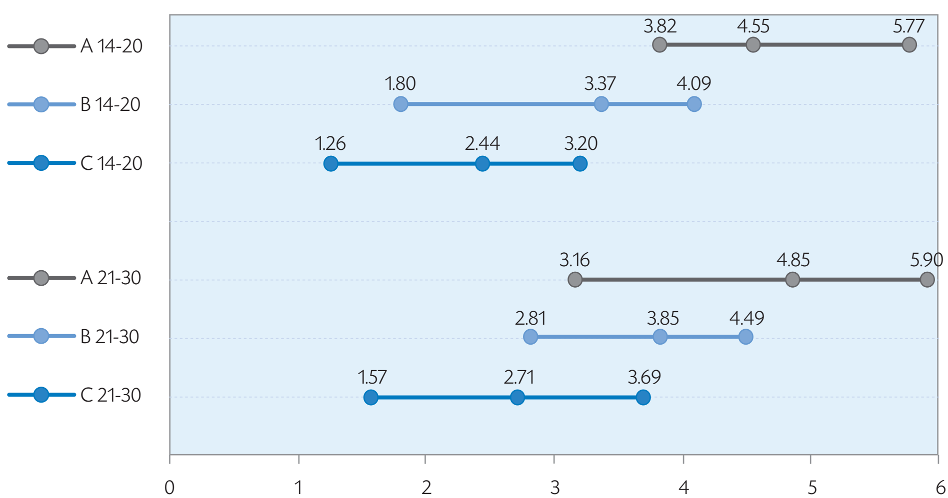
[20] Defined as the share of the different technologies producing electricity.

planning. The project used the Cooke[21] method to quantify the uncertainty around economic growth rates and energy commodity prices, to support the Government of Mexico's revision of its greenhouse gas emission scenarios.

Among the methods used to estimate uncertainty, behavioral and mathematical approaches are available to elicit and aggregate individual expert opinions. Behavioral methods involve having experts interact in order to reach agreement on information of relevance regarding their assessments of the variables of interest. In contrast, mathematical methods construct a "combined" probability distribution per variable by applying procedures or analytical models that operate on the individual assessments produced by each expert. For this project, a mathematical approach was preferred as the outcome of group interactions in behavioral approaches is often a "false consensus" that simply reflects the position of the dominant expert or experts in the group. More specifically, the project used the so-called Cooke method because it provides a more comprehensive treatment of conditionalization and dependence.

The final outcomes of this exercise in terms of economic growth showed a range of GDP growth rates for each one of three scenarios (high, medium and low) for the 2014–2020 and 2021–2030 periods, as shown in Figure 6.

Figure 6. Range of GDP growth rate (%) for three scenarios ('A' high, 'B' medium and 'C' low) for two periods : 2014–2020 (referred to as '14-20') and 2021–2030 (referred to as '21-30')



Source: Mexico's FIRM Project (INECC, 2014b).

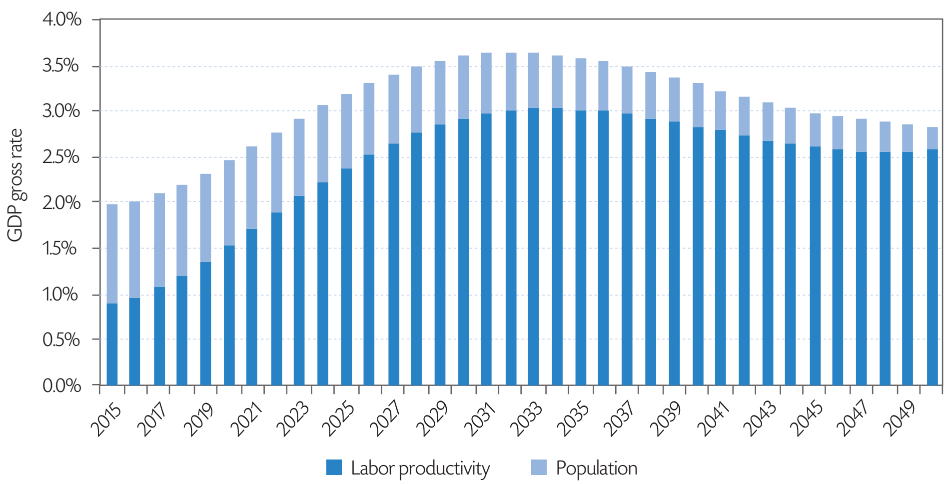
[21] More information about the Cooke method can be found in: "The 'Cooke Method': A Route to More Reliable Expert Advice": www.rff.org/Documents/Features/294-295%20Opinion%20-%20Aspinall%20pr.pdf

For the purposes of this work it was decided to use the low scenario for both periods. It is worth, mentioning that this low scenario assumes that important macroeconomic variables for the Mexican economy maintain an observed historical trend: from 3.0 to 3.5 for the Mexican interest rate; from 5.0 to 5.4 for unemployment; from 3.0 to 3.5 for the inflation rate and; from 2.8 to 3.3 for the US GDP rate of growth.

Population data is collected from CONAPO's demographic projections (2010–2050). The projection for labor productivity is derived from the two previously mentioned series and is calculated as the GDP per capita. Assumptions on population and productivity are not sufficient for the simulation to reproduce the targeted GDP because of the dynamic of the model and because the demand side should also be coherent with this target. Using a solver, the trends of public expenditure and external demand were calibrated so as to reproduce our GDP target. This way, the evolution of the baseline GDP follows its long-term determinant and grows at a rate equal to the sum of the population and labor productivity growth rates (See Figure 7).

Regarding the international oil and gas prices, we use the projection of the US Energy Information Administration.[22] Oil and gas prices increase respectively by 3.7% and 4.7% per year from 2015 to 2050 (see Figure 8). The consumer price (derived endogenously) increases by 2.9% per year.

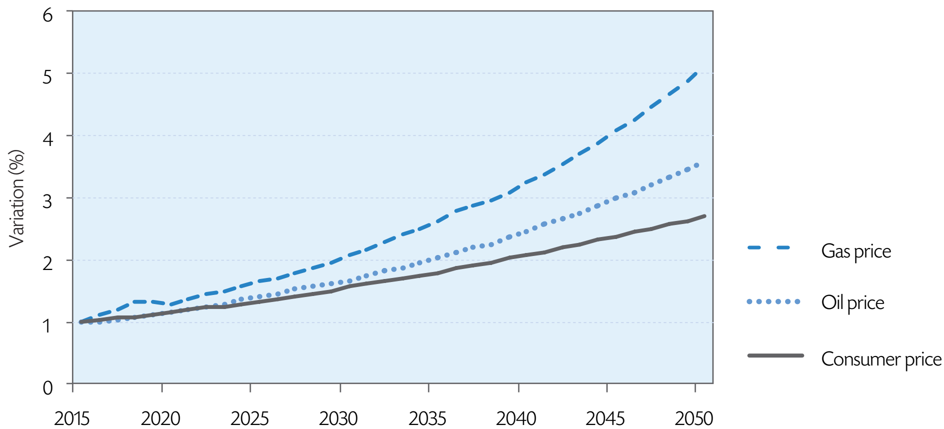
Figure 7. Contribution to GDP



Source: own estimation.

[22] http://www.eia.gov/

Figure 8. Consumer, oil and gas prices



Source: US Energy Information Administration and own estimation.

The baseline scenario is also characterized by some key underlying hypotheses summarized below:

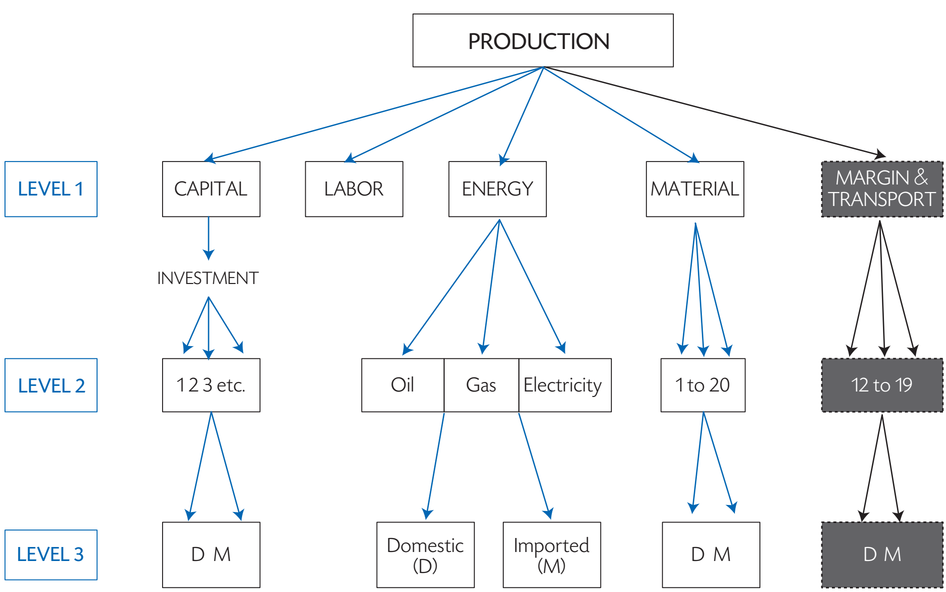
- Energy efficiency increases exogenously by 1% on average per year for production sectors and 0.5% for households (see Section 3.2.1). No exogenous trend for the price of energy technology was considered.
- The rate of subsidies on the volume of energy consumed is assumed constant whereas the tax rates on energy quantities increase at the same rhythm as inflation.
- Conservative elasticities of substitution have been used in the model, which assumes a three-level production structure (see Figure 9). The level of elasticity used in each level is presented in Table 6. The first level assumes a technology with four production factors (capital, labor, energy and material), using a Variable Output Elasticities Cobb-Douglas function. This function is a generalization of the constant elasticity of substitution function that allows the integration of different values of elasticity between each couple of production factors (OFCE/ADEME/TNO, 2013). The first level has a fifth element: the transport and commercial margins. These cannot be considered as production factors strictly speaking since they intervene downstream of the production process. They are thus not substitutable with the production factors. But they are closely related to the level of production since, once a good has been processed, it has to be transported and commercialized. At the second level, the investment, energy, material and margin aggregates are further decomposed. Elasticities of substitution between energies (oil-coal refining, gas and electricity) are assumed equal to 0.6. The same value is assumed for the transport margin, whereas there is no substitution possible between material goods and between investment goods. We consider that the substitution between some modes

of transport is not possible, as for example between pipelines and the other types of transport and between trucking and passenger transport. At the third level, the demand for each factor is either imported or produced domestically for each type of use (such as intermediary consumption, investment, final consumption and public investment). In all cases, we assume an Armington elasticity of substitution of 0.8.

- Endogenous energy efficiency is taken into account by assuming that the elasticity between capital and energy depends on their relative prices: an increase of the energy price relative to the price of capital leads to a higher level of elasticity of substitution. The elasticity between the elasticity of substitution and relative prices is 1.5. In addition, we assume that this effect is irreversible so that a decrease of the price of energy relative to the price of capital does not lead to a decrease of the elasticity of substitution. In the baseline scenario, these elasticities are relatively stable since the relative price between capital and energy is quite stable. This is not the case in the policy scenarios that include a carbon tax.

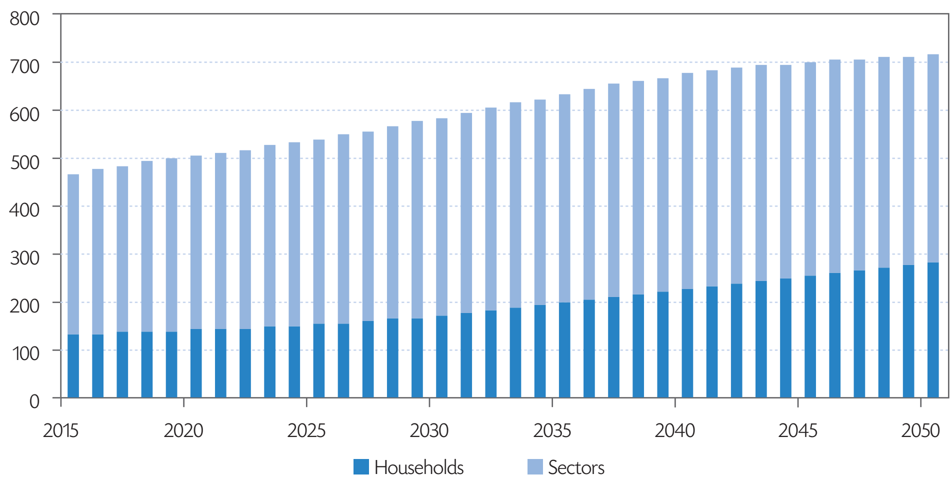
All the hypotheses listed above lead to total CO_2 emissions from energy uses of 715 million tons by 2050. The model considers two main emitting segments in the economy: households and productive sectors. These segments contribute 283 (40%) and 432 (60%) million tons respectively (see Figure 10). Households include transport for domestic use only (private light-duty fleet) and residential emissions. In the productive sectors, electric power, transport for commercial services and industry represent respectively 13%, 17% and 17% of the total emissions.

Figure 9. Production structure



Source: OFCE/ADEME/TNO, 2013.

Figure 10. CO_2 emissions from energy consumption (in millions of tons)



Source: own estimation.

Table 6. Value of the elasticity of substitution

Description	Value
Level 1: KLEM Elasticity	
Between Capital and labor in all sectors	0.5
Between Capital and energy[23]	0.6
Between Labor and energy in non-energy sectors	0.3
Between Labor and energy in energy sectors	0
Between Capital and materials, Labor and materials and Energy and materials in all sectors	0
Level 2	
Between energy intermediate input in all sectors	0.6
Between transport margins	0.6
Between investment goods and between material goods	0
Level 3	
Armington elasticity of substitution between domestic and foreign goods	0.8
Between final consumption goods	1
Elasticity of exports	0.6

[23] This elasticity is endogenous; it depends on their relative price. The value of 0.6 corresponds to the calibration for the base year 2008.

4.1.1. Soft link with POLES for the power sector

INECC, in cooperation with the Danish Energy Agency and ENERDATA, used the POLES[24] model in order to establish the baseline generation of electricity as well as the desired electricity matrix to set the GHG mitigation goal for 2050. The outputs from this project were useful in that they provided a more detailed disaggregation at the technological level, due to the fact that the model has a strong engineering background. As input, the ThreeME model needed the percentages by generation technology per year but, as this is an exogenous variable, it was necessary to have a solid foundation to strengthen the projection of technologies given the time horizon of the projection.

The most important characteristics for the electricity sector modeling were:

- Same macroeconomic variables taken into account in ThreeME: GDP growth and population,
- Fuel efficiencies and merit order calibrated on historical data,
- Simulation of future capacity development by technology, including endogenous technology learning ("learning-by-searching", "learning-by-doing"),[25]
- Different limitations on the development of renewables: geographical constraints and technical limitations,
- Power production is differentiated for: "must-run" technologies (technologies with a small or negligible variable cost), and "merit-order" technologies (technologies with a high variable production cost).

Assumptions for the development of the baseline:

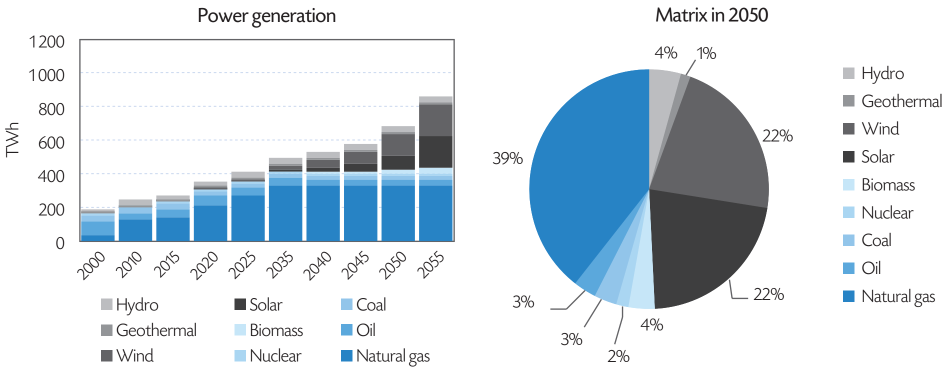
- For the 2013–2027 period, incorporation of the capacities and technology mix from the SENER[26] forecast (an attempt was made to match the expected generation). Due to inherent difficulties in reconciling capacities and generation because of differences in technology costs, efficiencies and merit order, the different scenarios consider identical technology penetration rates. For the 2028–2050 period, the model runs by itself, taking into account all the characteristics mentioned above.
- There is substitution between gas and oil technologies due to higher oil prices projected up to 2030. Given Mexico's characteristics, this means the phase-out of fuel oil combustion.
- There is a substantial penetration of renewables between 2030 and 2050. It is important to highlight that the share of clean energy in the electricity matrix is 50% by 2050. Although this might appear to be a mitigation scenario, POLES forecasts that renewable energy will be competitive against fossil fuels, where the Levelized Cost of Electricity (LCOE) in terms of US$/kWh becomes equivalent for both sources in the year 2030. This is due mainly to trends

[24] More information on the POLES (Prospective Outlook on Long-term Energy Systems) model can be found at: http://www.enerdata.net/enerdatauk/solutions/energy-models/poles-model.php

[25] IEA World Energy Outlook database available at: http://www.worldenergyoutlook.org/weomodel/investmentcosts/

[26] Ministry of Energy, Prospective of the electricity sector 2013-2027.

Figure 11. Baseline for the electricity matrix



Source: own estimation based on POLES.

of: 1) higher fossil fuel prices; 2) decrease of technological costs and; 3) rates of learning-by-doing for renewables (for example, for solar power plants, hybrid CSP/PV[27] plants is 10%; distributed photovoltaics 18% and onshore wind 5%).

4.2 Alternative scenarios

To test the impact of specific policies, we simulate alternative scenarios that we can compare to the baseline scenario. The policies considered are shown in Table 7. We consider three policies. The first involves the implementation of a carbon tax (PCO2TAX). The second is the removal of energy subsidies (PSUB), and the third is the redistribution of revenues generated by the carbon tax and the removal of energy subsidies (PREDIS).

The impact of the above-described policies can be explored relative to various targets. Table 8 provides a summary of the targets we consider. We define two types of targets. The first one refers to the level of CO_2 emissions from energy consumption (TCO_2). The second type of target concerns gradual changes in the electricity generation matrix for the period of analysis, which means changes in the share of the different technologies producing electricity (TMIX). The objective of this exercise is to conduct a sensitivity analysis of two different scenarios, and to be able to look at the impacts in terms of carbon tax, emissions reduction and macroeconomic variables, to highlight the importance of a clean electricity matrix. For this exercise, the scenarios considered are:

- TMIX-RENEW. This target portrays a major potential for renewables. By 2050, 82% of the mix is from clean energy. ThreeME assumes the same scenario as the clean energy scenario undertaken by POLES.
  - The POLES scenario sets out a potential path that allows Mexico to align with a 2°C global effort. This means that all the assumptions in POLES are aligned with a world that is also

[27] CPS denotes concentrated solar power, and PV photovoltaic.

pursuing policies to align with this target. This assumption impacts all the variables involved, especially fossil fuel prices and technology costs for renewables. It complies with the target set by the LAERFTE to have 35% of power generation based on clean energy by 2024.

- Clean power, including wind, solar, biomass and nuclear, plays a very significant role in decarbonizing Mexico's power sector. Solar power costs are currently higher than onshore wind, but falling quickly.
- Fossil fuel technologies are still needed to provide both baseload and peak power but, given the time horizon, technologies such as carbon capture and storage may be considered as able to fill this gap.
- The 82% penetration of clean energy in the matrix indicates that the electricity sector has much greater potential than other sectors, thus offsetting the lack of emissions reduction or the higher costs of undertaking it. It is important to point out that this scenario involves about 200 additional terawatt hours (TWh) compared to the baseline scenario in 2050. This shows an effect where all the other energy sectors in the economy are switching to electricity. This has a double benefit: other energy sectors switch to electricity leaving behind other alternative sources of energy such as fossil-fuel-based thermal energy and they switch to a low-emission electricity matrix.

Table 7. Policies

PCO2TAX	Implementation of a carbon tax
PSUB	Removal of energy subsidies • All energy subsidies are phased out within 10 years (by 2024)
PREDIS	Redistribution of all revenues from carbon tax collection and from the removal of energy subsidies • Revenues from the removal of energy subsidies are redistributed by reducing income tax for households. • Revenues from the carbon tax are redistributed by reducing income tax for households and payroll tax for the productive sectors. The carbon tax paid by households is fully reimbursed to them. The carbon tax paid by productive sectors is fully reimbursed to them through a reduction of the average payroll tax rate. This means that high (resp. low) energy-intensive sectors receive less (resp. more) than their contribution to the tax.

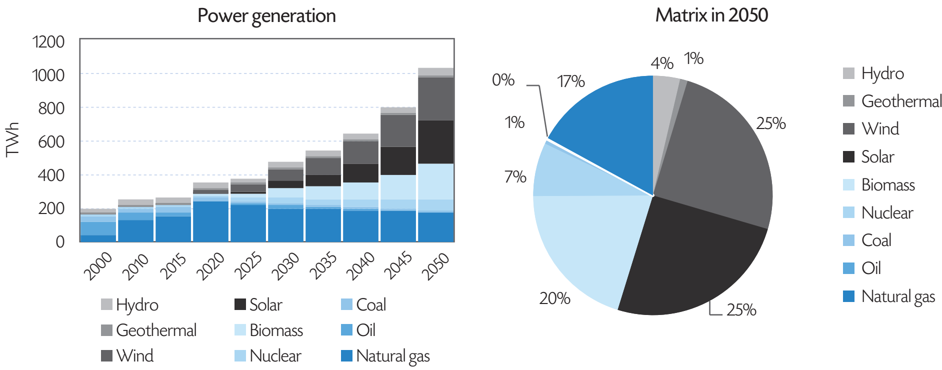
Table 8. Targets for the electricity mix and the level of CO_2 emissions

TCO_2	CO_2 emissions target for emissions from energy consumption, INECC's "IDEAL scenario": a reduction of emissions from energy uses of 55 million tCO_2[28] by 2018, by -40% in 2030 compared to the baseline, and -50% compared the 2000 level by 2050[29] (175 million tCO_2 of emissions).
TMIX	• **TMIX-RENEW**: 35% from clean energy by 2024 and a renewable-intensive electricity mix where 82% of the mix is from clean energy by 2050 given the carbon tax imposed to meet the target of 2000 levels by 2050. • **TMIX-FOSSIL**: Fossil-intensive electricity mix, that is to say, 74% of the mix is natural gas and 5% coal by 2050

[28] This is estimated from the GHG emission target (83 $MtCO_2$) stated in the Special Programme on Climate Change 2014–2018 (PECC, 2014). Emissions from energy uses correspond to about 66% of total GHG emissions in 2018.

[29] LGCC, 2012.

Figure 12. Electricity matrix with carbon tax



Source: own estimation based on POLES.

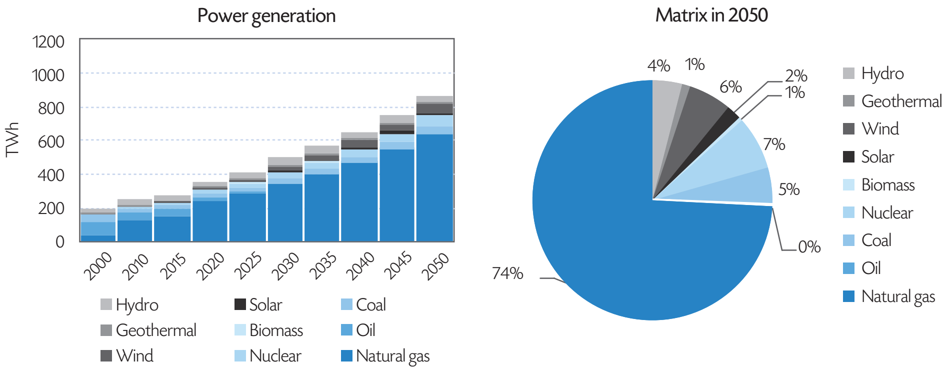
- TMIX-FOSSIL. 79% based on fossil fuels: 74% of the mix is from natural gas and 5% from coal by 2050.

In order to perform the sensitivity analysis, a scenario representing an energy matrix based on fossil fuels was developed, so that a wide range of possible impacts could be quantified. However, this scenario could not be seen as economically feasible before 2050, at least given the high cost forecasted for fossil resources. According to POLES, and assuming this trend, more renewable energy penetration is possible in the coming years; nonetheless, it was considered important to show the impacts of continuing with a fossil fuel investment scheme. While Mexico has a climate change law that specifies goals for the power sector, it is also concurrently promoting a major penetration of natural gas. This could delay the proposed transition or make it more expensive in the future, as the country is investing heavily in infrastructure that will support the current approach, at least for the next 20 years.

In this scenario, the share of natural gas in the energy matrix is 74%. The policy for phasing out fuel oil is retained, since historical data show that it has been decreasing over time (3.4% annual average since 2004 (SENER, 2014*b*)). And over the next fifteen years it does not appear to be economically feasible given the natural gas prices and efficiency. As for coal, the CFE plans to gradually reduce use of this at an annual average rate of 0.7%, but it remains an option considering that the plants using it as a primary energy source constitute a mature technology. Furthermore, coal is the primary energy source with the largest global reserves and its price has been less volatile compared to other fuels (SENER, 2014*b*).

The evolution of the electricity mix is therefore defined exogenously and is not sensitive to the relative prices between energy technologies in ThreeME. This assumption would be strong in a fully deregulated and decentralized electricity market. However, Mexico has only recently begun to deregulate its market, so it is most likely that decisions relating to electricity production will still be largely dominated by the state power company, CFE.

Figure 13. Electricity matrix based on fossil fuels



Source: own estimation based on POLES.

Table 9. Alternative scenarios simulated

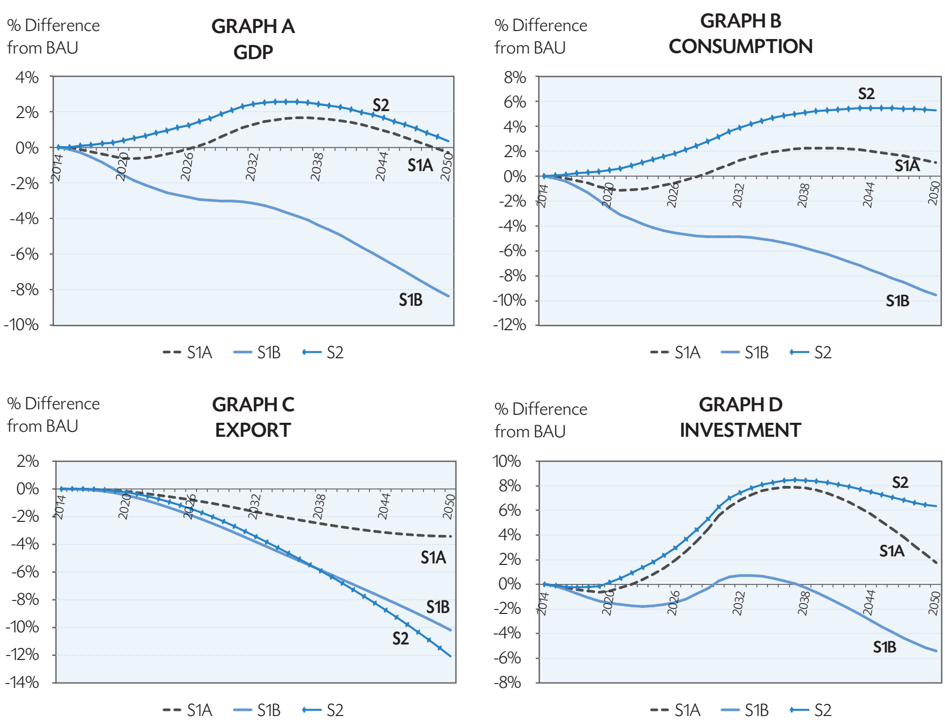
Scenarios	Policies	Target mix	Target CO_2 emissions
S1. Fiscal policy without redistribution • S1A. Phasing-out of energy subsidies • S1B. Phasing-out of energy subsidies and implementation of a carbon tax	PSUB PSUB + **PCO2TAX**	TMIX-**RENEW** TMIX-**RENEW**	TCO_2
S2. Fiscal policy with redistribution • Phasing-out of energy subsidies and implementation of a carbon tax	PSUB + PCO2TAX (S1)+ **PREDIS**	TMIX-**RENEW**	
S3. Changing the electricity mix (and fiscal policy with redistribution) • S3. Fossil-intensive electricity mix	PSUB + PCO2TAX (S1) + PREDIS	TMIX-**FOSSIL**	

The alternative scenarios simulated are constructed by combining the different policies and targets (Table 9). We define three groups of scenarios. The first one concerns fiscal policy without redistribution. This corresponds to increased taxation of fossil energy by phasing out energy subsidies (S1A) and the implementation of a carbon tax (S1B). Scenario S2 tests the impact of accompanying measures that are meant to reduce the negative economic impacts of the increase in energy taxation. Scenario S3 tests in addition the effect of changing the electricity mix.

4.3. Macroeconomic results

Except when indicated otherwise, all results are reported as a difference from the baseline expressed as a percentage. The main macroeconomic results are shown in Figure 14 and Figure 15. The two fiscal policy scenarios without redistribution (S1A and S1B) have similar effects since they both increase the price of energy. However, they show two main differences. The first relates to the tax base of the fiscal instrument. Whereas the carbon tax is based exclusively on fossil energy, 16% of energy subsidies are spent on electricity. Even if the share of fossil energy in electricity production drops from 46% to 18% in these scenarios, a large part of the subsidy for electricity can be viewed as a fossil energy subsidy. The second and main difference between S1A and S1B concerns the order of magnitude of the shock: the carbon tax (S1B) leads to a stronger increase in energy prices, which amplifies the phasing-out of energy subsidies (S1A). Whereas the GDP decreases marginally in S1A until 2025, it drops by more than 4% after 2040 in S1B. The positive effect in S1A after 2025 is possible thanks to the high penetration of renewable energies in the electricity mix. In much the same way, the electricity mix limits the negative effect of GDP between 2025 and 2040 in S2 (see Figure 14.A). The level of the carbon tax has been chosen such that we reach a target of 353 and 175 million tons of CO_2 in 2030 and in 2050 respectively (see TCO_2 in Table 8). This requires a carbon tax at MX\$^{2015}1,500 (US\$100) in 2030 and MX\$^{2015}10,500 (US\$700) in 2050 (see Figure 16D). Compared to the baseline scenario, this corresponds to a 40% decrease in CO_2 emissions from energy consumption by 2030 and 75% by 2050 (see Figure 15.D).

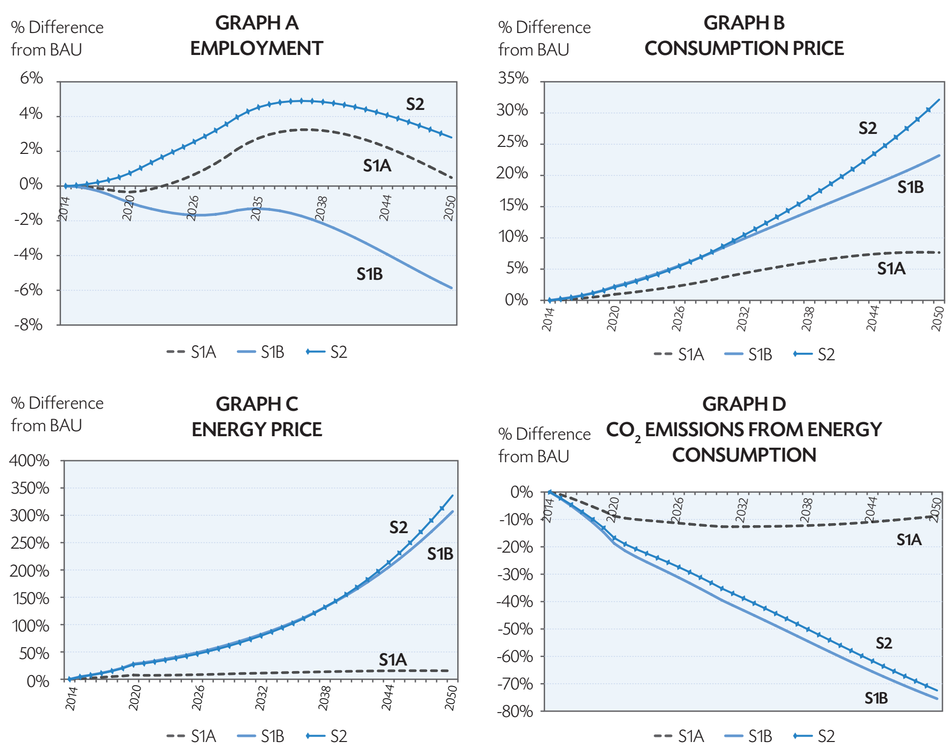
Figure 14. GDP, Consumption, Export and Investment



The significant GDP decrease in S1B stems from the recessionary shock caused by the implementation of the carbon tax. The carbon tax increases the energy price by more than 300% by 2050 (see Figure 15.C), which results in higher overall prices. The increase of the consumer price by nearly 25% (see Figure 15.B) has a negative impact on consumption, which drops by 10% (see Figure 14.B). Since we assume that the rest of the world does not follow a similar policy, the Mexican economy suffers from a loss of competitiveness due to higher production costs and thus higher prices. This leads to an 8% decrease in exports after 2040 (see Figure 14.C). As a consequence of these negative multiplier effects, the recessionary trend is reinforced by a decline in investment, down by 4% by 2040 (see Figure 14.D). Noticeably different from consumption, investment starts to increase from 2030 to 2035 (see Figure 14.B&D) because of the substitution from energy to capital. However, this substitution effect is too weak to offset the recessionary effect.

As expected, the GDP decrease in S1B leads to a decrease in employment, which falls by more than 4% by 2040 (see Figure 15.A). This limits the progression of wages and explains why inflation tends to stabilize at the end of the period. It also explains why the consumption price is lower than in S2, where GDP increases (see Figure 15.B), whereas the price of energy continues to rise sharply in both cases (see Figure 15.C). Because of the substitution effects, CO_2 emissions decrease by more than 75% by 2050 (see Figure 15.D). But this environmental dividend comes about at the cost of a recession, which makes this policy difficult to accept politically, at least in the short run.

Figure 15. Employment, Consumption price, Energy price and CO_2 emissions



By contrast, the implementation of the carbon tax with the tax revenue being fully redistributed (by reducing income tax for households and the payroll taxes for productive sectors) as in S2 indicates a way of reconciling environmental and economic objectives: the effect on GDP is certainly positive (see Figure 14.A), whereas the decrease in emissions is only a slightly lower than in S1B (see Figure 15.D).

Several reasons can explain why redistribution leads to a positive effect on GDP. First, the average real revenue remains more or less stable since the tax revenue is given back to households.[30] Second, redistribution also limits the increase of production costs especially for labor-intensive industries. By penalizing energy-intensive sectors – which also happen to be less labor-intensive (see the sector results of Section 4.4) – the level of employment increases and thus consumption too. Third, the Keynesian multiplier effects act in the opposite way to the case without redistribution. They generate a virtuous cycle for growth: more economic activity leads to more employment, consumption and investment, which in turn leads to more economic activity. This virtuous cycle can be maintained as long as inflationary pressures are not too high.

Higher GDP means more employment (see Figure 15.A), which leads to higher wage increases. The resulting increase in production costs leads to more inflation. This explains why the consumer and the energy prices are higher in S2 than in S1B (see Figure 15.B & C). As GDP is higher in S2 compared to S1B, CO_2 emissions are logically higher when the revenue of the tax is redistributed (see Figure 15.D). This is a classic example of a rebound effect: more economic activity means more production and more household consumption, which means more energy consumption. Yet this rebound effect is relatively small as the increase in CO_2 emissions is relatively limited. This result is quite interesting. It shows that it is possible to implement a carbon tax in a way that is acceptable economically (and therefore politically) without forgoing much of the potential offered by the tax in terms of environmental dividend. In other words, the model shows that substitution effects induced by changes in relative prices can affect energy consumption in larger proportion than the revenue effect (caused by the fiscal revenue transfers). Of course, this result depends on the capacity of the economy to adapt to the change in energy prices, as captured in the simulation by the elasticity of substitution parameter. We thus investigate in the sensitivity analysis (Section 4.5) how these results change when we retain alternative levels of substitution.

Figure 16 shows the impact of a change in the energy mix by comparing scenarios S3 to S2. Both S2 and S3 scenarios assume full redistribution of tax revenues and the same carbon tax level (see Table 8). As summarized in Table 7, S2 assumes a renewable-intensive electricity mix where 75% of the mix is from renewables by 2050 (TMIX-RENEW). By contrast, scenario S3 retains the fossil-intensive electricity mix where 75% of the mix is from natural gas by 2050 (TMIX-FOSSIL). The renewable-intensive scenario S2 leads to a higher GDP (see Figure 12.A) and lower CO_2 emissions compared to the fossil-intensive scenario S3[31] (see Figure 16.B). This result is logical. On the one hand, more renewable (resp. fossil) energy in the electricity mix means a reduction (resp. increase)

[30] In fact, the average real revenue decreases slightly because the tax base shrinks as fossil energy is substituted by other commodities. This means that the amount redistributed becomes smaller while at the same time the substitution is not at a high enough level to offset the increase in energy prices (unless we assume that commodities are perfectly substitutable with each other, that is to say, a level of elasticity of substitution tending to infinity).

[31] All scenarios produce the same results until 2020 because the mix is almost the same across all scenarios until this date.

Figure 16. GDP, Energy price, Energy demand and Carbon tax price

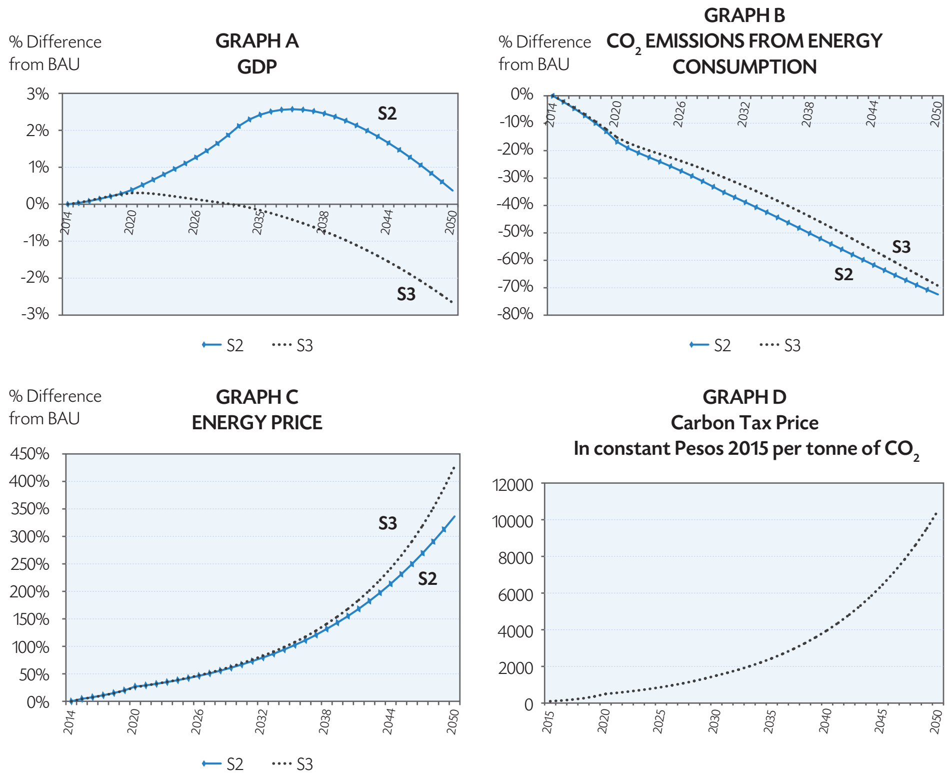
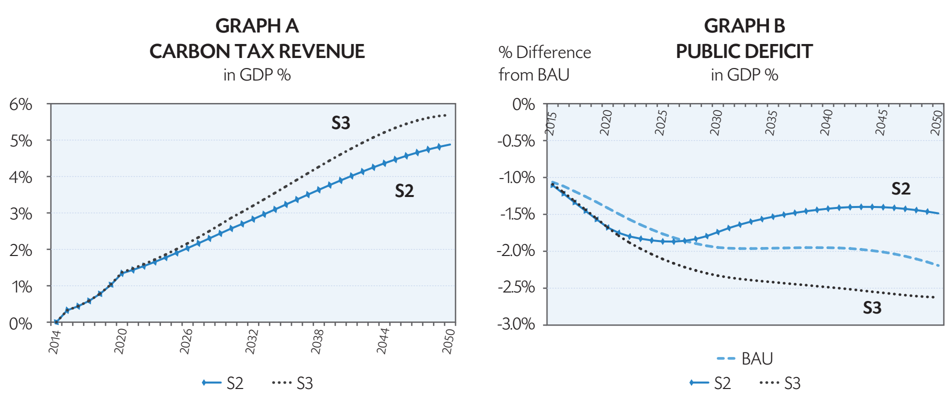


Figure 17. Carbon tax revenue and Public deficit, in % of GDP



of CO_2 emissions from the electricity sector, which for a given aggregate electricity demand leads to less (resp. more) CO_2 emissions at the aggregate level. On the other hand, more renewable energy in the electricity mix in the context of an increase of the price of fossil energy (because of the carbon tax) leads to a lower energy price in S2 compared to S3 (see Figure 16.C). This has a positive effect on consumer purchasing power and the competitiveness of economic sectors. This explains why the economic activity is more favorable in S2. Of course, higher economic activity also means more energy consumption, which produces a rebound effect. This can be seen in Figure 16.B where the decrease in energy consumption is smaller in S2 than in S3. However, this rebound effect is too weak to reverse the CO_2 emissions reduction made possible by the greater penetration of renewable energy: emissions are still lower in S2 compared to S3. This result suggests that, in the context of higher fossil energy prices, efforts to enhance the penetration of renewable energy are more efficient both economically and environmentally.

The carbon tax revenue in S2 and S3 represents from 5% to 6% of GDP in 2050 (See Figure 17.A), while the value-added tax revenue represents 3.7% of GDP over the same period. The tax revenue is higher in S3 compared to S2 since emissions are higher due to the intensive use of natural gas in the electricity mix. It should be remembered that, in these scenarios, the carbon tax revenue is redistributed by decreasing other taxes. Ex ante, payroll tax and income tax are reduced to keep total tax collection at the initial level. Ex post, any change in the public deficit is due to endogenous adjustment and depends on how the policy affects other variables. The difference in how the public deficit evolves in S2 and S3 depends chiefly on the evolution of GDP: in S2, GDP improves compared to the baseline scenario, whereas the contrary is true for S3.

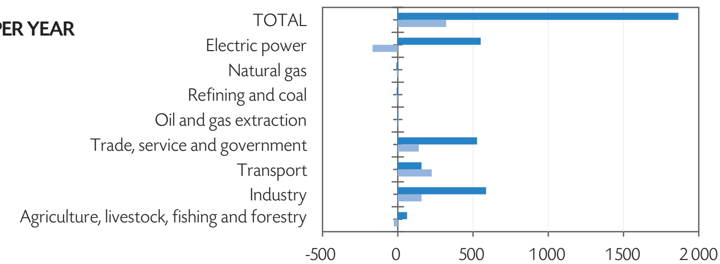
4.4. Sectoral results

The aforementioned macroeconomic results show that redistributing the carbon tax revenues has the advantage of generating a double dividend. Additionally, both dividends are higher when this fiscal policy is coupled with the development of renewables in electricity production. This result can be seen in Figure 18: the average employment creation per year is higher in S2 with more reduction of CO_2 emissions. Almost all sectors benefit from the measures, particularly the labor-intensive sectors such as services, industry and electric power.

Moreover, the electric power sector that has a high level of renewables is more labor-intensive than the fossil fuel sectors. This explains why the loss of employment in fossil fuel sectors is limited with the implementation of a carbon tax (see Figure 18.A), contrary to what happens in the energy sectors that are capital-intensive. Indeed, the decrease in energy demand penalizes the activity of fossil fuel sectors and therefore their investment (see Figure 19.A). All other sectors benefit from the increase in economic activity driven by the compensation of households and industry and the increase in their investments. As the carbon tax is introduced in all sectors, CO_2 emissions fall across the whole economy (see Figure 18.B). The impact on aggregate CO_2 emission is higher in S2, even though the reduction of total energy consumption is lower in S2 due to a higher GDP (see Figure 19.B).

Figure 18. Employment and CO_2 emissions by sector

GRAPH A
AVERAGE CREATION OR LOSS EMPLOYMENT PER YEAR
In thousands, 2015-2050



GRAPH B
CO_2 EMISSION FROM ENERGY CONSUMPTION IN 2050
% Difference from BAU

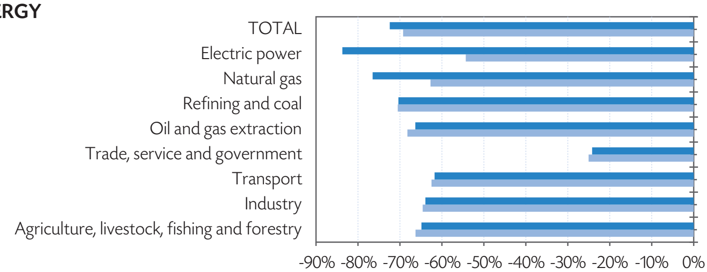
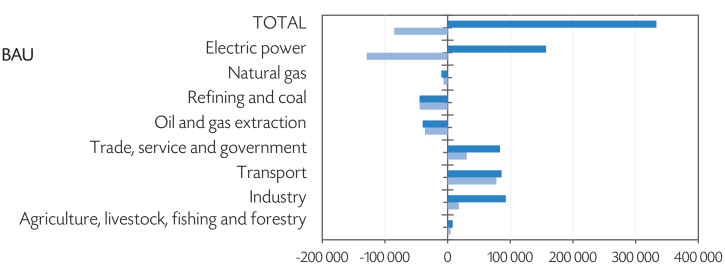
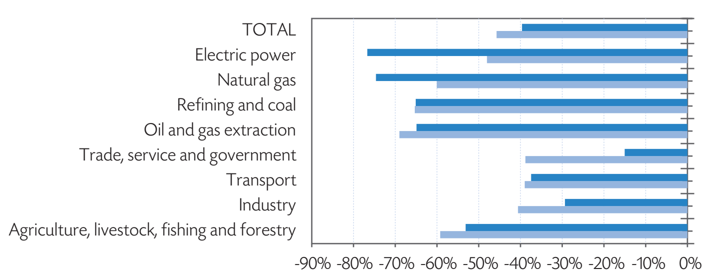


Figure 19. Investment and Energy consumption by sector

GRAPH A
AVERAGE INVESTMENT PER YEAR, 2015-2050
In million pesos, Difference from BAU



GRAPH B
ENERGY CONSUMPTION BY SECTORS IN 2050
% Difference from BAU



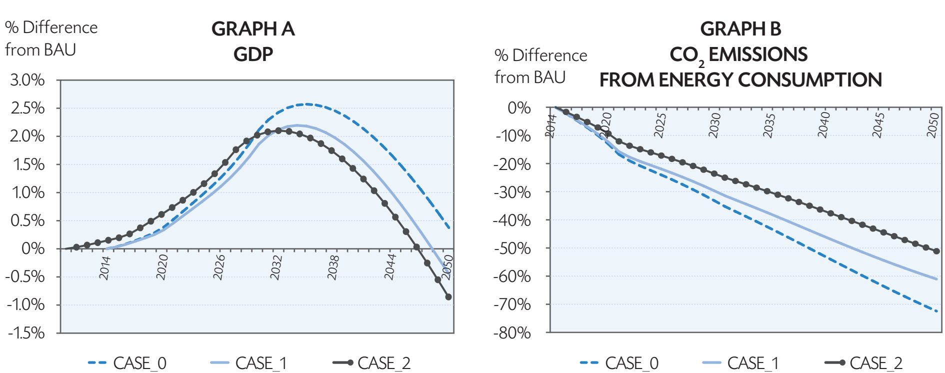
4.5 Sensitivity analysis

In the sensitivity analysis, we examine scenario S2 for all the cases shown in Table 10. The base case (case 0) considers the assumptions and parameters taken into account in Sections 4.2, 4.3 and 4.4. In case 1, the assumption on endogenous energy efficiency is removed. The sensitivity parameter between "the elasticity of substitution between capital and energy" and their relative price is equal to 1.5 in the base case but to 0 in case 1. The elasticity of substitution between capital and energy thus remains constant throughout the entire simulation period at 0.6. Case 2 integrates case 1 plus a change in value of the elasticity of substitution between final consumption goods. This elasticity is equal to 1 in case 0 and to 0.5 in case 2. Case 3 provides a sensitivity analysis on the elasticity of substitution between domestic and foreign goods for each type of use (*e.g.*, intermediary consumption, investment, final consumption and public investment). While the base case assumes 0.8, case 3 assumes 1. In case 4, we consider change in competitiveness. In the base case, export elasticity is 0.6. In case 4, it is 0.8. Finally, case 5 analyses the sensitivity of wages to the unemployment rate. Case 5 adopts an elasticity of 0.3 and case 0 assumes 0.1.

Table 10. Sensitivity analyses: changes in assumptions

Description		Value Case 0	Value
Case 0	Base case		
Case 1	Sensitivity to relative price in the elasticity of substitution between capital and energy	1.5	0
Case 2	Case 1 + Elasticity of substitution between final consumption goods	1	0.5
Case 3	The Armington elasticity of substitution between domestic and foreign goods	0.8	1
Case 4	Export Elasticity	0.6	0.8
Case 5	Wage elasticity, sensitivity to the unemployment rate	0.1	0.3

Figure 20. GDP and CO_2 emissions from energy consumption

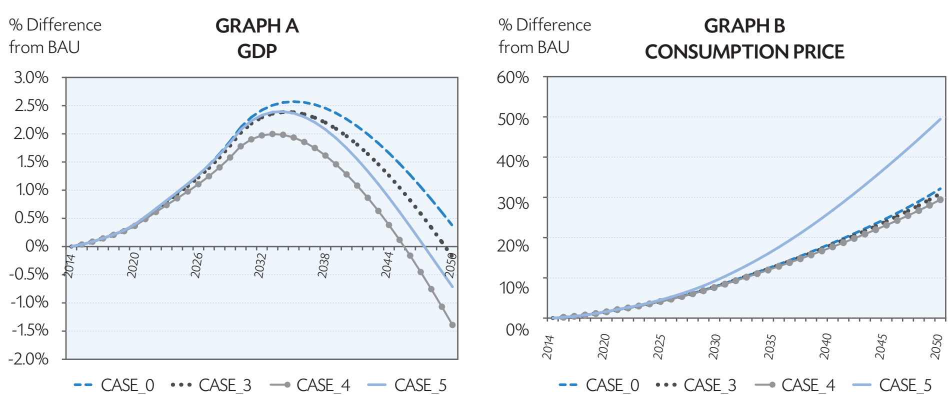


The results in Figure 20 show that changes in assumptions of elasticities between capital and energy and between consumption goods affect the double dividend in the medium and long term. In particular, removing the endogenous energy efficiency (case 1) leads to higher CO_2 emissions compared to case 0. We observe a gap of more than 10% by the end of the period. If we consider case 2, which additionally includes a halving of the elasticity of substitution between final consumption goods, this gap is doubled (See Figure 20.B). The whole economy is rigid, while sectors and households struggle to adapt to higher energy prices. The impact on GDP is limited until 2045, but thereafter we observe a negative effect caused by the higher cost of energy bills due to low flexibility. Agents are unable to further reduce their energy consumption. This implies that their investment choices preclude any deep adaptation to a large shift in relative prices. The rigidity of investment, induced by a constant low elasticity of substitution between capital and energy, is the cause of the loss in activity and the concomitant lower environmental dividend (See Figure 20.A). Other simulations, which are not reported here due to space limits, show that an opposite outcome is achieved when a flexible economy assumed: in particular GDP and the emissions reduction are higher when rigidity of the economic setting is removed

Cases 3, 4 and 5 have no impact on the environmental dividend. Reductions in CO_2 emissions from energy consumption remain at the same level as in the base case (not shown), for same reasons as already mentioned: the substitution effects due to changes in relative prices have more impact on energy consumption than the revenue effect (here a lower GDP); in other words, rebound effects are much smaller than substitution effects.

The assumption underlying the Armington elasticity is that domestic goods and imported goods are imperfect substitutes. Higher elasticities in case 3 are equivalent to a decrease in trade barriers Because foreign prices are less expensive[32] than domestic prices, agents import more and thus penalize national activity. However this negative effect is lower than in case 4 and case 5. In case 4,

Figure 21. GDP and consumption price



[32] Note that we assume that the rest of the world does not follow a carbon tax policy.

the impact of the relative price between export prices[33] and world prices for external demand[34] increases. Since export prices are higher than world prices, external demand decreases more compared to case 0, affecting GDP negatively (See Figure 21). In case 5, wages are more strongly related to the unemployment rate than in case 0. In the event of lower unemployment, the bargaining power of trade unions is reinforced, leading to steeper wage rises, which then affect production costs and thus inflation. That explains why the consumption price is higher is case 5 than in the base case (see Figure 21.B). This means that the inflationary pressure resulting from the taxation policy reverses the economic gain because the Mexican economy is less competitive externally.

[33] This depends on the production cost and reflects the price competitiveness of domestic products.

[34] Under the assumption of a "small open economy", external demand and the export price are negatively related for a given world price.

5. Conclusions

Our results show that a double dividend is possible. A carbon tax will incentivize the energy transition and low-emission development of the Mexican economy, achieving at the same time higher levels of social welfare through policies that ensure an appropriate redistribution of the carbon tax revenues. How large these benefits will be and how fast they can be achieved will depend on the readiness and flexibility of the production and consumption sectors. The sooner Mexico triggers a change of relative prices by sending explicit atmospheric scarcity signals, the sooner investments in energy efficiency and clean energy will start, followed by wide-sweeping changes in production and consumption patterns. Long-term public policy commitments are needed in order to give clarity and certainty to the economic actors so that they will engage in the necessary technological and behavioral changes.

So far, Mexico has built the institutional framework needed to put its national climate policies in order. This is certainly a necessary condition, but it is not enough. The final step to ensure a real coherence with its climate goals is to start fully implementing carbon price policies such as an emission-trading scheme and a bold carbon tax. On the latter count, our research shows that constant increases in the current carbon tax up to US\$30/tCO_2 by 2020 and to US\$100/tCO_2 by 2030 will create the necessary and sufficient conditions for engaging on the path to a totally decarbonized economy by 2050. On this basis, the model forecasts higher rates of growth that show annual differences of up to 2.5% compared to the baseline scenario. In absolute values, this means that Mexico could ultimately attain annual growth rates of more than 3.9%, which would lift the country out of the middle-income trap in the years to come.

Despite Mexico's significant efforts, time is running out for the country to change its development pathway and the coming years will be critical in terms of making the right investment choices. Mexico is at a crossroads: either it implements the above-mentioned climate policies and creates the conditions for the growth of a clean energy industry, or it continues on the business-as-usual pathway with a soft transition, deferring crucial investments and becoming locked-in to fossil fuel technologies. The soft option carries high risks given the high costs involved in changing producer and consumer patterns that cannot to adapt rapidly to a world that will soon be implementing severe restrictions on carbon emissions.

Mexico recently presented its Intended Nationally Determined Contributions (INDCs) to the United Nations Framework Convention on Climate Change (UNFCCC). Its proposal states unconditional GHG mitigation of 22% compared to a baseline by 2030 and conditional mitigation of up to 36% for the same year. According to Mexico's INDC proposal, the conditional target is subject to an international agreement on carbon price policies, carbon border adjustments, technical cooperation, access to low cost financial resources, and technology transfer. Clearly, all these conditions are necessary but it is quite unlikely that this will be the outcome of COP21. Mexico should not wait for all this to happen in order to begin its own decisive transition. Even in a world where the convergence of international agreements to tackle climate change is slow, these policies still make good economic sense. As shown by the results of this paper, early action will reduce emissions and go hand in hand with domestic environmental, social and economic benefits that clearly offset the costs of implementation.

In terms of next steps for research, there are still relevant issues that future works may want to address. In order to have a more comprehensive picture of the consequences of the energy and climate policies, INECC needs to continue working with the ThreeME model. One important issue to be solved involves carbon tax predictions in the long run. The model predicts a carbon tax of around US$700/t$CO_2$ for the year 2050. This high cost is related, among other variables, to the technology costs faced by industry, as this sector fails to change over time in all scenarios. Decreasing cost trends must be included in the next modeling exercises. Regarding the foreign sector, the model predicts a loss of competitiveness and a drop in exports. This is linked to the assumption of whether or not the world commits to reduce GHG emissions. In order to have more realistic scenarios, different assumptions on the degrees of commitment of the rest of world need to be adopted. A further issue is that distributional effects are not within the scope of this assessment. It is absolutely vital to disaggregate households by income in order to see the level of regressivity or progressivity of the carbon tax. The availability of new information such as the new 2012 input-output matrix will update the modeling to a different base year. It is also crucial to disaggregate the transport sector, as was done for the electricity sector. Exogenous technological changes to the on-road fleet will enable us to identify the impacts of specific policies, such as regulations or government programs to change auto fleet technology. Finally, continuous modeling efforts are still needed in order to establish the right price elasticities that provide a better fit with the national context, and to produce a more sophisticated Mexican version of the ThreeME model.

6. Appendix

Table 11. Summary table, Scenario Business as Usual (BAU)

VARIABLE		2008	2013	2015	2020	2030	2040	2050
Real GDP (in million pesos)	1	12 256 864	13 426 992	13 954 396	15 580 633	21 358 495	30 259 340	40 678 583
Value-added market sector (in million pesos)	2	10 903 262	11 946 268	12 403 004	13 809 596	18 827 989	26 668 823	35 894 583
Household consumption (In million pesos)	3	8 250 896	9 175 204	9 454 943	10 318 826	13 572 980	19 148 618	25 448 829
Investment (in million pesos)	4	2 830 420	3 096 765	3 201 895	3 515 697	4 720 294	6 897 760	9 730 182
Investment (commercial sectors, in million pesos)	5	955 531	1 055 986	1 091 231	1 192 694	1 569 538	2 242 917	3 068 145
Exports (in million pesos)	6	3 270 613	3 495 892	3 698 733	4 329 766	6 332 385	8 776 865	11 568 147
Imports (in million pesos)	7	3 600 182	3 953 769	4 107 160	4 576 892	6 164 280	8 556 743	11 256 981
Real household income (in million pesos)	8	9 281 214	10 284 620	10 622 896	11 620 505	15 298 377	21 528 634	28 617 281
Saving rate	9	11%	11%	11%	11%	11%	11%	11%
Household consumption price	10	1.00	1.15	1.22	1.41	1.89	2.53	3.30
Production price	11	1.00	1.14	1.21	1.39	1.88	2.51	3.27
Export price	12	1.00	1.15	1.22	1.41	1.90	2.54	3.32
Import price	13	1.00	1.13	1.20	1.39	1.88	2.55	3.45
Real wage (in million pesos)	14	0.08	0.09	0.09	0.09	0.12	0.16	0.21
Real Labor Cost (in million pesos)	15	0.09	0.10	0.10	0.09	0.09	0.10	0.09
Employment	16	47 439 094	50 467 400	51 617 151	54 263 005	58 544 436	61 681 232	64 035 869
Unemployment rate	17	4.16%	4.15%	4.11%	4.07%	4.22%	4.42%	4.36%
Trade balance (points of GDP)	18	-2.69	-3.08	-2.44	-1.14	1.09	0.57	-0.36
Public deficit (points of GDP)	19	-1.73	-1.00	-1.06	-1.41	-1.95	-1.95	-2.19
Public debt (points of GDP)	20	31.07	30.29	29.54	28.69	29.20	30.49	33.88
GDP index	21	100	110	114	127	174	247	332
CO_2 emissions ($MtCO_2$)	22	415	455	468	505	584	676	715
Sector	23	287	327	338	363	412	448	432
Household	24	128	128	131	142	172	228	283
CO_2 emissions (index 2008)	25	100	110	113	122	141	163	172

Table 12. Summary table, Scenario 1A

VARIABLE		2015	2020	2030	2040	2050
Real GDP (% difference from BAU)	1	-0.03	-0.61	0.88	1.50	-0.29
Value-added market sector (% difference from BAU)	2	-0.06	-0.78	0.82	1.46	-0.47
Household consumption (% difference from BAU)	3	-0.04	-1.06	0.58	2.26	1.07
Investment (% difference from BAU)	4	-0.11	-0.52	5.58	7.41	1.75
Investment (commercial sectors, % difference from BAU)	5	-0.01	-0.55	0.36	2.26	1.37
Exports (% difference from BAU)	6	0.00	-0.18	-1.34	-2.75	-3.42
Imports (% difference from BAU)	7	-0.07	-0.89	1.13	2.91	1.47
Real household income (% difference from BAU)	8	-0.06	-1.10	0.60	2.15	0.97
Saving rate (difference from BAU)	9	-0.02	-0.04	0.01	-0.10	-0.09
Household consumption price (% difference from BAU)	10	0.05	0.96	3.67	6.66	7.66
Production price (% difference from BAU)	11	-0.01	0.60	3.53	6.64	7.67
Export price (% difference from BAU)	12	0.00	0.58	2.91	5.25	6.04
Import price (% difference from BAU)	13	-0.01	0.11	0.31	0.20	0.07
Real wage (% difference from BAU)	14	-0.06	-0.48	2.96	5.60	5.76
Real labor cost (% difference from BAU)	15	0.00	-0.13	2.68	5.15	5.43
Employment	16	-9 404	-187 420	1 240 467	1 846 604	311 692
Unemployment rate (difference from BAU)	17	0.01	0.19	-1.17	-1.51	-0.21
Trade balance (difference from BAU in points of GDP)	18	0.02	0.34	-0.01	-0.23	0.25
Public deficit (difference from BAU in points of GDP)	19	-0.07	-0.50	-1.07	-1.46	-1.35
Public debt (difference from BAU in points of GDP)	20	-0.07	-1.87	-7.95	-15.15	-19.97
GDP (index 2008)	21	114	126	176	251	331
CO_2 emissions ($MtCO_2$)	22	464	461	510	596	652
CO_2 emissions (% difference from BAU)	23	-0.95	-8.80	-12.63	-11.91	-8.76
Sector (% difference from BAU)	24	-1.18	-9.42	-16.00	-17.62	-14.06
Household (% difference from BAU)	25	-0.37	-7.21	-4.52	-0.70	-0.69
CO_2 emissions (index 2008)	26	112	111	123	143	157
Carbon tax value (in pesos 2008)	27	0.00	0.00	0.00	0.00	0.00
Real carbon tax revenue (in pesos)	28	0.00	0.00	0.00	0.00	0.00
Carbon tax revenue (points of GDP)	29	0.00	0.00	0.00	0.00	0.00

Table 13. Summary table, Scenario 1B

VARIABLE		2015	2020	2030	2040	2050
Real GDP (% difference from BAU)	1	-0.10	-1.54	-3.00	-4.94	-8.35
Value-added market sector (% difference from BAU)	2	-0.15	-1.90	-3.61	-5.87	-9.64
Household consumption (% difference from BAU)	3	-0.16	-2.57	-4.84	-6.27	-9.57
Investment (% difference from BAU)	4	-0.18	-1.55	0.30	-1.06	-5.42
Investment (commercial sectors, % difference from BAU)	5	-0.04	-1.36	-4.04	-5.60	-8.68
Exports (% difference from BAU)	6	-0.01	-0.45	-3.15	-6.55	-10.19
Imports (% difference from BAU)	7	-0.18	-2.15	-3.26	-4.14	-6.61
Real household income (% difference from BAU)	8	-0.25	-2.73	-4.89	-6.51	-9.94
Saving rate (difference from BAU)	9	-0.08	-0.15	-0.05	-0.23	-0.37
Household consumption price (% difference from BAU)	10	0.24	2.23	8.42	15.68	23.20
Production price (% difference from BAU)	11	0.06	1.60	7.94	15.32	23.41
Export price (% difference from BAU)	12	0.05	1.40	6.91	13.59	21.83
Import price (% difference from BAU)	13	0.01	0.27	0.58	0.45	0.18
Real wage (% difference from BAU)	14	-0.25	-1.35	-0.08	-0.76	-4.79
Real labor cost (% difference from BAU)	15	-0.08	-0.73	0.07	-0.71	-5.02
Employment	16	-19 390	-524 952	-817 984	-1 653 862	-3 755 556
Unemployment rate (difference from BAU)	17	0.03	0.55	0.70	1.45	3.14
Trade balance (difference from BAU in points of GDP)	18	0.06	0.81	1.66	2.48	3.99
Public deficit (difference from BAU in points of GDP)	19	-0.35	-1.52	-3.04	-4.90	-6.82
Public debt (difference from BAU in points of GDP)	20	-0.37	-5.09	-21.10	-43.13	-72.00
GDP (index 2008)	21	114	125	169	235	304
CO_2 emissions ($MtCO_2$)	22	457	410	353	282	175
CO_2 emissions (% difference from BAU)	23	-2.37	-18.80	-39.51	-58.28	-75.47
Sector (% difference from BAU)	24	-2.16	-17.31	-38.08	-55.10	-71.00
Household (% difference from BAU)	25	-2.91	-22.61	-42.94	-64.53	-82.26
CO_2 emissions (index 2008)	26	110	99	85	68	42
Carbon tax value (in pesos 2008)	27	100	500	1 500	3 969	10 500
Real carbon tax revenue (in pesos)	28	45 585	204 532	523 945	1 098 192	1 795 778
Carbon tax revenue (points of GDP)	29	0.33	1.33	2.53	3.82	4.82

Table 14. Summary table, Scenario 2

VARIABLE		2015	2020	2030	2040	2050
Real GDP (% difference from BAU)	1	0.04	0.39	2.12	2.26	0.37
Value-added market sector (% difference from BAU)	2	-0.01	0.11	1.77	1.64	-0.62
Household consumption (% difference from BAU)	3	0.05	0.47	3.18	5.30	5.29
Investment (% difference from BAU)	4	-0.10	0.15	6.31	8.27	6.33
Investment (commercial sectors, % difference from BAU)	5	0.05	0.68	3.01	5.38	5.34
Exports (% difference from BAU)	6	0.01	-0.24	-2.69	-6.81	-12.08
Imports (% difference from BAU)	7	-0.08	-0.38	1.74	3.55	3.68
Real household income (% difference from BAU)	8	0.07	0.42	3.11	5.03	4.83
Saving rate (difference from BAU)	9	0.02	-0.04	-0.06	-0.23	-0.39
Household consumption Price (% difference from BAU)	10	0.20	2.11	8.66	18.67	32.14
Production price (% difference from BAU)	11	0.01	1.37	8.02	18.23	32.58
Export price (% difference from BAU)	12	-0.06	0.80	6.16	14.67	27.41
Import price (% difference from BAU)	13	0.01	0.26	0.57	0.44	0.19
Real wage (% difference from BAU)	14	-0.20	-0.72	3.47	6.53	6.86
Real labor cost (% difference from BAU)	15	-0.66	-2.72	-1.43	-1.03	-3.11
Employment	16	18 568	404 102	2 323 170	2 881 006	1 789 856
Unemployment rate (difference from BAU)	17	-0.02	-0.43	-2.10	-2.37	-1.42
Trade Balance (difference from BAU in points of GDP)	18	0.01	0.21	0.17	0.57	1.78
Public deficit (difference from BAU in points of GDP)	19	0.04	0.26	-0.21	-0.53	-0.71
Public debt (difference from BAU in points of GDP)	20	0.00	0.34	-1.49	-6.11	-10.50
GDP (index 2008)	21	114	128	178	252	333
CO_2 emissions ($MtCO_2$)	22	458	420	378	311	197
CO_2 emissions (% difference from BAU)	23	-2	-17	-35	-54	-72
Sector (% difference from BAU)	24	-2	-15	-34	-51	-68
Household (% difference from BAU)	25	-3	-20	-38	-60	-79
CO_2 Emissions (index 2008)	26	110	101	91	75	47
Carbon Tax Value (in pesos 2008)	27	100	500	1 500	3 969	10 500
Real carbon tax revenue (in pesos)	28	45 666	209 861	561 216	1 204 463	1 991 931
Carbon tax revenue (points of GDP)	29	0.33	1.34	2.57	3.89	4.88

Table 15. Summary table, Scenario 3

VARIABLE		2015	2020	2030	2040	2050
Real GDP (% difference from BAU)	1	0.04	0.30	-0.03	-0.97	-2.66
Value-added market sector (% difference from BAU)	2	0.00	0.04	-0.53	-1.82	-3.94
Household consumption (% difference from BAU)	3	0.05	0.46	0.75	0.79	-0.21
Investment (% difference from BAU)	4	-0.05	-0.22	-0.81	-2.40	-1.04
Investment (commercial sectors, % difference from BAU)	5	0.05	0.67	1.08	1.47	2.09
Exportations (% difference from BAU)	6	0.01	-0.21	-1.75	-4.14	-8.84
Importations (% difference from BAU)	7	-0.06	-0.36	-0.66	-0.97	-0.83
Real household income (% difference from BAU)	8	0.07	0.41	0.66	0.58	-0.65
Saving rate (difference from BAU)	9	0.02	-0.04	-0.08	-0.18	-0.40
Household consumption price (% difference from BAU)	10	0.21	1.96	6.44	12.71	25.19
Production price (% difference from BAU)	11	0.02	1.18	5.68	12.22	26.21
Export price (% difference from BAU)	12	-0.04	0.67	3.80	8.68	20.34
Import price (% difference from BAU)	13	0.02	0.22	0.38	0.30	0.14
Real wage (% difference from BAU)	14	-0.21	-0.81	-0.27	-0.83	-3.69
Real labour cost (% difference from BAU)	15	-0.67	-2.82	-5.45	-9.69	-15.48
Employment	16	21 957	338 786	519 259	342 224	-76 937
Unemployment rate (difference from BAU)	17	-0.03	-0.35	-0.46	-0.28	0.07
Trade balance (difference from BAU in points of GDP)	18	0.01	0.19	0.56	1.18	2.46
Public deficit (difference from BAU in points of GDP)	19	0.03	0.26	0.38	0.53	0.43
Public debt (difference from BAU in points of GDP)	20	-0.02	0.34	1.86	3.30	2.97
GDP (index 2008)	21	114	128	174	244	323
CO_2 emissions ($MtCO_2$)	22	459	428	410	352	220
CO_2 emissions (% difference from BAU)	23	-2	-15	-30	-48	-69
Sector (% difference from BAU)	24	-2	-13	-26	-41	-62
Household (% difference from BAU)	25	-3	-20	-39	-62	-80
CO_2 emissions (index 2008)	26	111	103	99	85	53
Carbon tax value (in pesos 2008)	27	100	500	1 500	3 969	10 500
Real carbon tax revenue (In pesos)	28	45 746	213 979	612 034	1 381 017	2 253 422
Carbon tax revenue (points of GDP)	29	0.33	1.37	2.87	4.61	5.69

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Tables

Figures

Transitioning towards a low-carbon economy in Mexico:
an application of the ThreeME model

Simultaneously achieving climate protection, energy security and economic development to address the long-term wellbeing of individuals, while reducing their exposure to significant environmental risks and challenges, is at the core of the low-carbon policy agenda worldwide.

Forecast to be one of the largest energy consumers and energy-related CO_2 emitters in the near future, the Mexican economy is particularly concerned by the urgent need for a rapid shift towards low-carbon development pathways, which involve switching to sustainable energy systems.

To assess the opportunities associated with transitioning to a low-carbon economy and avoid the potentially high costs of this transition, what is lacking or insufficiently developed is a robust research framework, which allows to investigate alternative future pathways of the energy, environmental and technology dimensions of developmental challenges and their solutions.

This study aims to provide such a framework by offering a dynamic general equilibrium modeling analysis that quantitatively builds the link between the energy economy and the environment in Mexico. As such, its purpose is to inform the design of effective policy aimed at promoting sustainable environmental management while still boosting economic growth in the medium- and long-term.

To do so, the study develops a Mexican version of the Multi-sector Macroeconomic Model for the Evaluation of Environmental and Energy policy (Three-ME) and uses it to assess the long-term effect of policy measures implemented under Mexico's "Climate Change Law" (e.g., carbon tax) on the energy sector's structure and dynamics, on related greenhouse gas emissions, and on economic activity. The study takes the next step of assessing the redistributive effects of alternative policy scenarios, each reflecting a different strategy for recycling tax revenues.

Interestingly, it is found that implementing a carbon tax on the Mexican economy acts so as to curb carbon emissions while still increasing social welfare, under certain carbon tax revenue recycling schemes. These findings support the double-dividend hypothesis, which assumes that "green" taxation allows to simultaneously achieve environmental and socio-economic goals.

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