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Double Dividend of Low-carbon Growth in Mexico: A Dynamic General Equilibrium Assessment

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Abstract

This paper simulates the medium- and long-term impact of proposed and expected energy policy on the environment and on the Mexican economy. The analysis has been conducted with a Multi-sector Macroeconomic Model for the Evaluation of Environmental and Energy policy (Three-ME). This model is well suited for policy assessment purposes in the context of developing economies as it indicates the transitional effects of policy intervention. Three-ME estimates the carbon tax required to meet emissions reduction targets within the Mexican "Climate Change Law", and assesses alternative policy scenarios, each reflecting a different strategy for the recycling of tax revenues. With no compensation, the taxation policy if successful will succeed in reducing CO2 emissions by more than 75% by 2050 with respect to Business as Usual (BAU), but at high economic costs. Under full redistribution of carbon tax revenues, a double dividend arises and the policy is beneficial both in terms of GDP and CO2 emissions reduction

ACKNOWLEDGMENT

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I. Introduction

Policy advocacy for urgent transition in the energy system, away from traditional fossil fuel based technology, is becoming increasingly intense in the view of both the economic and environmental implications of traditional energy industry using fossil energy sources like coal, gas and oil. Concerning the former, the exposure to external price-making power of oil producers along with threatening geopolitical instability is impelling oil importing countries to curtail dependency on oil and other fossil fuels and to commit to energy transition. Oil exporting countries on the other hand are facing the recent drop in oil prices; some more than others, like Mexico, Venezuela and Ecuador. As for the latter, the urgent need for cutting down carbon emissions has spurred massive transition of the energy system worldwide towards low-carbon development, with potentially high environmental external benefits both at the local (e.g. air pollution control) and the global (e.g. climate change mitigation) scale. Thus it is in the interest of developing and emerging countries to implement national strategies and reforms for energy transition, which involve improved efficiency and security of the energy system, and especially in that concerning electricity production and distribution.

This is especially the case of Mexico, which alone among the developing countries has undertaken very significant steps towards energy transition for climate change mitigation. In 2012, Mexico defined the transition process for achieving a lower carbon growth with the General Law on Climate Change. This law establishes long term Green-House Gas (GHG) emission mitigation targets in two steps: emissions must be reduced by 30% below the business-as-usual trend level by 2020 and by 50% below the 2000 level by 2050. Three years after the General Law was passed and despite a new Administration, these targets remain the national commitments pledged under the UN Framework Convention on Climate Change. This is one of the strengths of the Mexican climate change policy: the transition towards a low carbon growth is today a consensual objective in the political arena and the key point of the discussions is only on the ways and means to reach a lower carbon growth.

Among the drivers of this political awareness is the depletion of the nation's oil resources. It is worth noting that the peak oil attained in 2004 is resulting in many challenges as economic growth and State revenues are significantly dependent on oil production levels and oil prices. This is the reason why the energy reform launched in 2013 aims at reducing the national consumption of fossil resources. Regarding the power sector, the reform creates economic incentives for renewable energy in order to get 35% of electricity generation from renewable sources by 2024. The reform also aims to improve energy efficiency in residential and industrial sectors where the energy-saving potential is estimated as 39 TWh until 2027 (for an annual power production of 250 TWh). Establishing energy-efficiency targets is all the more relevant in view of the expected increasing energy consumption from the transportation and building sectors as a consequence of growing urbanization. With their 46% and 19% respectively of the total energy demand, the potential for energy savings in these sectors is considerable.

This paper aims at assessing the economic link between the targets stated within the energy transition strategy of Mexico, and the key challenges for its long-term economic development. To do so, it has developed a dynamic, computable general equilibrium model of the Mexican economy. The starting point is the Multi-sectorial Macroeconomic Model for the Evaluation of Energy and Environmental Policy: Three-ME (OFCE/ADEME/TNO, 2013). By relying upon a neo-Keynesian approach to investments, economic growth and distribution mechanisms, Three-ME addresses the dynamics of global economic activity, energy system development and carbon emissions causing climate change. The Three-Me model is well suited for policy assessment purposes in the context of developing economies as it shows the transitional effects of policy intervention. In particular, disequilibrium can arise in the form of involuntary unemployment, the inertia of technical systems and the rigidity of the labor and energy markets, as a result of delayed market-clearing in the goods, capital or labor markets and slow adjustment between prices and quantities over the simulation time path.

The Three-Me-Mexico model is used to gauge the economic and environmental effects of energy fiscal policy measures in Mexico that are included in the energy transition strategy, 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. The level of the carbon tax is computed to meet national emissions reduction targets in 2050, as stated in the Mexican "Climate Change Law". In line with INECC's "IDEAL scenario", we are considering emission cuts of 40% in 2030 and 50% in 2050 as compared

with the baseline and the 2000 levels respectively. First, we evaluate the case of no-tax compensation and assess the policy effectiveness in terms of its efficiency in achieving CO_2 emissions reduction targets with respect to business-as-usual (BAU). Then we test the hypothesis of full redistribution of carbon tax revenues among consumers (through reducing household income taxes) and producers (through compensating for social security payroll taxes), which appears as a way to reconcile environmental and economic goals. The underlying idea of our analysis is to provide quantitative insights in the context of the debate over possible convergence between carbon tax implementation and improved economic performance. In this sense we aim to add to the ongoing scientific debate on the double dividend of energy fiscal policy and its operationalization in regard to economic development.

The paper is organized as follows : Section 2 provides a short description of the Three-ME model, whereas its calibration over the Mexican energy and economic systems is given in Section 3. Section 4 presents the simulation results. Section 5 concludes.

II. Three-ME for Mexico

This section offers a detailed description of the Computable General Equilibrium (CGE) modeling architecture which has been developed to analyze long-term trajectories of the energy economy of Mexico. The starting point for further modeling developments and adaptation to the Mexican context is the Multi-sectorial Macroeconomic Model for the Evaluation of Energy and Environmental Policy (Three-ME), which 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 Organization for Applied Scientific Research). Initially developed to support the energy/environment/climate debate in France, Three-ME is now been applied to other national contexts such as Mexico and Indonesia.

a. The Generic Modelling Setting

Three-ME is specially designed to evaluate the medium- and long-term impact of environmental and energy policies at the macroeconomic and sector levels. For this, Three-ME (OFCE/ADEME/TNO, 2013) combines several important features:

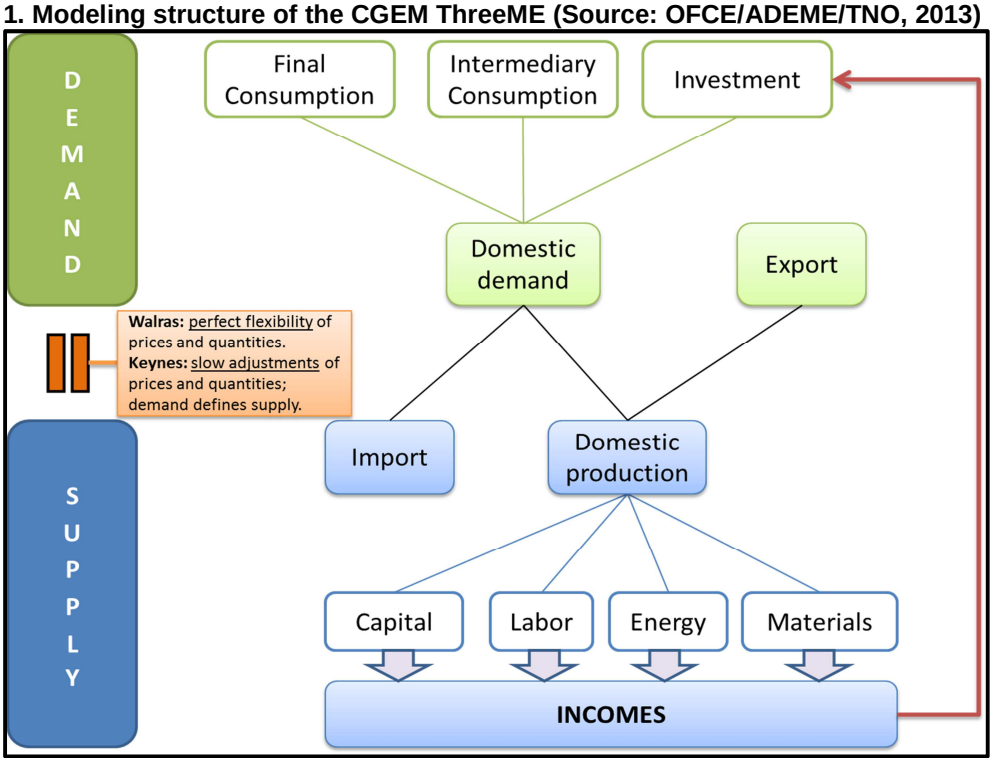
- Its sectorial disaggregation allows for the analysis of the effect of transfer of activities from one sector to another in particular in terms of employment, investment, energy consumption or trade balance.

- The energy disaggregation allows for the 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 transports or between goods.

- Three-ME is a CGEM (Computable General Equilibrium Model). It therefore takes into account the interaction and feedbacks between supply and demand (consumption, investment) defines the supply (production). The supply defines in return the demand through the incomes generated by the production factors (labor, capital, etc.). Compared to bottom-up energy models such as MARKAL (Fishbone & Abilock, 1981) or LEAP (Heaps, 2008), Three-ME goes beyond a mere description of the sectoral/technological dimensions by linking them with the global economic system.

- Three-ME is a neo-Keynesian model. Compared to a 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 to allow for situations of disequilibrium between supply and demand (in particular the presence of involuntary unemployment). This framework is better suited for policy purposes because it provides information regarding the transition phase of a particular policy (not only about the long term).

Figure 1. Modeling structure of the CGEM ThreeME (Source: OFCE/ADEME/TNO, 2013)



b. Main Characteristics of the Mexican Version of Three-ME

The Mexican version of the Three-ME model follows a generic architecture as used in the French version. The choice of sectors is specific to Mexico and they are shown in Table 1. 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 in terms of CO_2 emissions.

Table 1. Sectorial Disaggregation of Three-ME for Mexico (Source: INEGI 2012)

N°	Sectors	Production %	N°	Sectors	Production %
1	Agriculture, livestock and fishing	2.9%	17	Transport via pipeline	0.1%
2	Forestry	0.1%	18	Other transport	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%

National data sources have been used for the calibration (INEGI, 2012, 2013): supply and use[1] tables and input-output tables (262 Branches) and the institutional sector (household accounts and Government accounts). 2008 is used as the base year since it corresponds to the most recent release regarding input-output tables when this project began. Additional data regarding the public sector such as the financial situation of the federal government and social security come from the Mexican Ministry of Finance (SHCP[2]). Population projections come from the National Council of Population (CONAPO[3]) and the 2008 level of CO_2 emissions is calibrated using the National Inventory of Greenhouse Gases (INEGEI, 2013) data.[4] Finally, for the disaggregation of energy sectors, we use data from the Energy Information System (SIE-SENER[5]): more specifically, domestic sales of gas and import of gas and final energy consumption, by power technologies and sectors.

Table 2 provides some key Mexican macroeconomic data for 2008. Energy subsidies represent 97% of the total subsidies and 2.2% of the total GDP. Mexico's crude oil export represents 3.8% of GDP and the country imports a large amount of refined oil and gas products: 2.6% of GDP. The 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 14th largest emitter in the world and the largest source of such emissions in Latin America. However, Mexico is ranked 100th in terms of the level of emissions per capita[6].

[1]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)
[2]http://www.shcp.gob.mx/POLITICAFINANCIERA/FINANZASPUBLICAS/Estadisticas_Oportunas_Finanzas_Publicas/Informacion_mensual/Paginas/ingresos_gasto_financiamiento.aspx
[3]Consejo Nacional de Población, http://www.conapo.gob.mx/
[4]http://www.inecc.gob.mx/descargas/cclimatico/inf_inegei_public_2010.pdf
[5]http://sie.energia.gob.mx/
[6]http://www.eia.gov/

Table 2. Key Macroeconomic Data for Mexico in 2008 (base year) (Source: INEGI 2012)

Features 2008			
Public Deficit, %GDP	1.7%	Import of refined oil and gas products % GDP	2.6%
Debt, %GDP	31%	Export of refined oil and gas products % 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%	Emisions of CO2 from energy uses MtCO2	415
Tax on Hydrocarbon (Derechos a los hidrocarburos), % GDP	7.5%	Household emisions, %	31%
Trade Balance, %GDP	-2.7%	Sector emisions,, %	69%

The electricity sector is disaggregated into 9 technologies: hydro, geothermal, wind, solar, biomass, nuclear, coal-based, oil-based and gas-based. The evolution of each technology is determined exogenously. This assumption is realistic for the electricity production sector, since the government delivers the authorization for installing power plants. Hence the investment choices in electricity technologies 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 years to come 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, intermediate consumption, and fuel consumption into the production cost have been parameterized using data from the Ministry of Energy[7].

In Mexico, anthropogenic CO_2 emissions represent about 65% of total greenhouse gas emissions[8]. They derive 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 and gas). This allows for a precise estimation of the variation in domestic CO_2 emissions. In the Mexican version of Three-ME we consider CO_2 emissions from the combustion of fossil fuels for sectors and households. The calculation of emission levels consists in multiplying the fossil energy demand by the corresponding emission coefficient. These coefficients are specific for each economic actor, each sector and each energy source depending on their own 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 for the reduction the impact of economic activity on the environment since they allow for a reduction of emissions per unit of GDP. Improvements in energy efficiency mitigates 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"*[9]. In the model there are two types of energy efficiency that impact 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. As in Kumhof & Muir (2012), we assume that higher energy prices, that may be the result of environmental policy, stimulate energy efficiency in economic sectors through a higher elasticity between capital and energy.

[7] See (SENER, 2013b), (SENER, 2014)

[8] See (INEGEI, 2013), p.28.

[9] 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 CO_2 emissions, due to the improvement of economic activity allowed for by those same measures (Barker, Ekins, & Foxon, 2007)

III. Simulation Results

Reducing CO_2 emissions will entail the implementation of policies and measures to support green investments in the short and in the long run. Positive experiences from the implementation of carbon price are often obtained through a full policy package that helps the transition, including decreases in others taxes (World Bank, 2014). The following section presents the results of different scenarios obtained with the Mexican version of the Three-ME model. These scenarios include the phasing out of energy subsidies and the implementation of a carbon tax with a different strategy of fiscal revenue recycling. They also account for different electricity scenarios by 2050 in terms of the alternative technology options that are availbale for electricity generation.[10] The level of the carbon tax is chosen such that we reach the targets regarding emissions from energy uses of the "IDEAL scenario" of INECC. This scenario considers a reduction of 40% in 2030 compared to the baseline and a reduction of 50% in 2050 compared to 2000 level.

a. Baseline Scenario

The baseline (reference or business-as-usual or BAU) scenario is the path the model predicts when all exogenous variables follow their "business-as-usual" trend. The baseline scenario is meant to be a realistic vision of a possible 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 nearly 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 reference scenario, and is simulated as an alternative scenario (see Section b).

Although the impact of a new policy is measured as a percentage difference from the baseline, the choice of the baseline may affect the results for a given simulated scenario. Therefore it is important to define a coherent vision of the future, but this may prove a difficult task in terms of calibration. To achieve the construction of a realistic baseline scenario, we have focused 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 taken from a study that is part of the "*Facilitating Implementation and Readiness for Mitigation" (FIRM)* project (INECC, 2014). The overall goal of this project was to improve Mexico's GHG emissions baseline. The project used the *"Cooke"*[11] method to quantify the uncertainty surrounding economic growth rates and energy commodity prices, in support of the government of Mexico's greenhouse gas emission scenarios. The final outcomes of this exercise in terms of economic growth consisted in a range of GDP rates of growth for three scenarios (high, medium and low) for the 2014-2020 and 2021-2030 periods.

For the purpose of this work it was decided to use the low scenario for both periods. This scenario assumes that important macroeconomic variables for the Mexican economy keep their observed historical trend: between 3.0 to 3.5 for Mexico's interest rate; between 5.0 to 5.4 for the unemployment rate; between 3.0 to 3.5 for the inflation rate; and between 2.8 to 3.3 for the growth rate of GDP.
Population data are collected from demographic projections (2010-2050) of CONAPO. 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 dynamics of the model and because the demand side should also be consistent 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 growth rate of the population and of labor productivity (See Figure 2).

[10] Choice to yield simulations on the technology options for electricity generation in addition to a carbon tax is in line with the recent policy debate in Mexico around the proposal by the Governemnt for the technology costs to reflect the price of the carbon externality.
[11] 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

Figure 2. GDP Growth and its Contribution

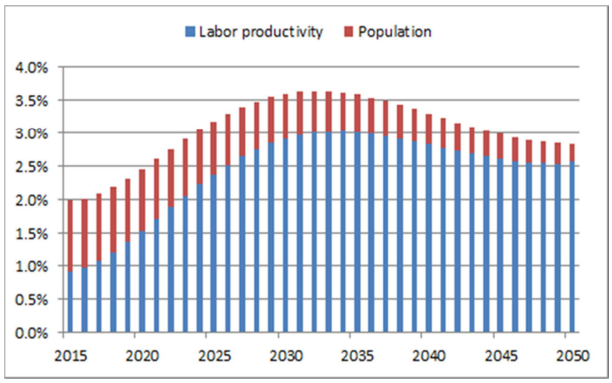
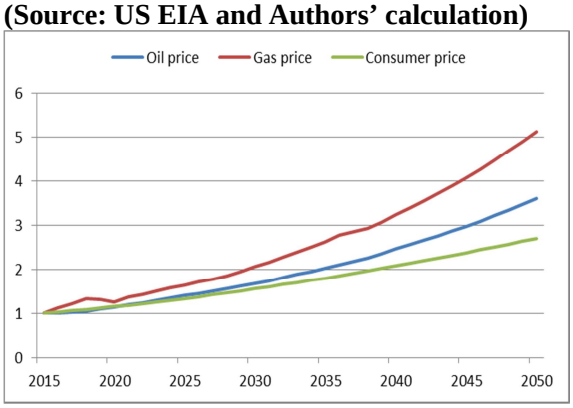


Figure 3. Consumer, Oil and Gas Prices (Source: US EIA and Authors' calculation)



Regarding the international oil and gas prices, we have used the projection of the US Energy Information Administration[12]. Oil and gas prices increase respectively by 3.7% and 4.7% per year between 2015 and 2050 (see Figure 3). With these assumption, the endogenous consumer price increases by 2.9% per year. The baseline scenario is also characterized by certain key underlying hypotheses summarized below:

- Energy efficiency plays a key role in the model; since it has relevant effects on energy intensity by sector. We assume that it increases exogenously by 1% on average per year for the production sectors, which is consistent with the historical trend.[13] For household a 0.5% of annual increase in efficiency will be assumed[14]. No exogenous trend for the price of energy technology was considered.

- The rate of subsidies[15] on the volume of energy consumed decreases until reaching the observed rate in 2013; for the next periods it is assumed constant. The tax rates on energy quantities increase, in accordance with the rate of inflation.

- Conservative elasticities of substitution have been used in the model that assumes a three-level production structure (see Figure 5). The level of elasticity used in each level is presented in Table 3. The first level assumes a technology with four production factors (capital, labor, energy and material), using a Variable Output Elasticities Cobb-Douglas function. This flexible function allows for a different level of substitution between each input pair (Reynès, 2011).

- As in (Kumhof & Muir, 2012), 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 (between capital and energy)" and relative prices is 1.5. In addition, we assume that this effect is irreversible so that a decrease in the price of energy relative to the one of capital does not lead to a decrease in the elasticity of substitution. In the baseline these elasticities are relatively stable since the relative price between capital and energy is quite stable. This is not the case in the alternative scenarios that include a carbon tax.

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

[13] According to recent data, industrial energy intensity has been falling at 2% per year; however, it has been decreasing less rapidly since 2000 at 0.5% per year (Enerdata, 2011). However heterogeneity exists across sectors: the largest energy efficiency improvements were achieved in steel production (2.2% percent per year on average between 1990 and 2008) whilst the chemical industry has seen a rapid reduction in its energy intensity, of around 7% per year since 2000.

[14] These efficiency gains will mainly come from the increase in water heater efficiency and other cooking appliances using gas (SENER, 2013a).

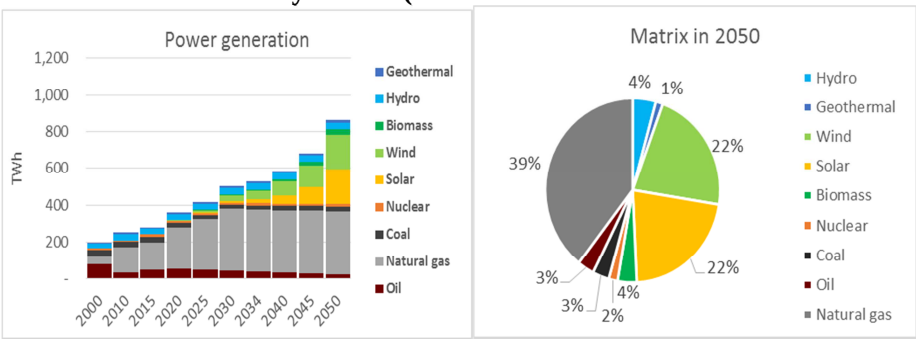
[15] Energy subsidies are equivalent to 2.2% of GDP in 2008 (base year) whereas in 2013 they represent 0.8% of GDP.

Table 3. Value of Elasticity of Substitution

Description	Value
Level 1: KLEM Elasticity	
Between Capital and Labor in all sectors	0.5
Between Capital and Energy[16]	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

The Three-ME model requires as input the production share of electricity per technology over time. For that we have used the electricity generation scenario of the POLES model project in Mexico[17]. The outcomes of this project provide useful insights regarding the electricity supply per technology since it benefits from a model with an engineering background. According to this scenario, there is a major penetration of renewables between 2030 and 2050 (See Figure 4). It is important to emphasize that the share of clean energy in the electricity matrix is 50% by 2050 (LAERFTE, 2013). POLES forecasts that renewable energy will be competitive against fossil fuels, where the Levelized Cost of Electricity (LCOE) in terms of $/kwh becomes equivalent for both sources in the year 2030. This is due mainly to trends of: 1) higher fossil fuel prices; 2) a decrease in technological costs and; 3) rates of learning by doing for renewables.

Figure 4. Baseline for Electricity matrix (Source: Authors' calculation based on POLES)



All the above hypotheses lead to a total CO_2 emission from energy uses of 715 millions of tons by 2050. The model considers two main emitting segments in the economy: households and productive sectors. These segments respectively amount to 283 (40%) and 432 (60%) millions tons (see Figure 6). Households include transport for domestic use only (private light-duty fleet) and residential emissions. For sectors, electric power, transport for commercial services and industry represent respectively 13%, 17% and 17% of the total emissions.

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

[17] INECC, in cooperation with the Danish Energy Agency and ENERDATA, used the POLES 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. More information on the POLES model can be found in: http://www.enerdata.net/enerdatauk/solutions/energy-models/poles-model.php

Figure 5. Production Structure (Source: OFCE/ADEME/TNO, 2013)

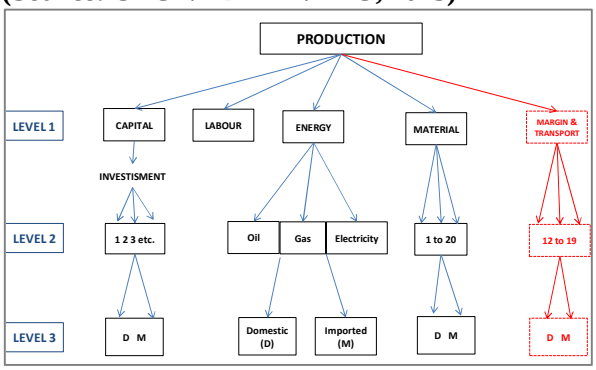
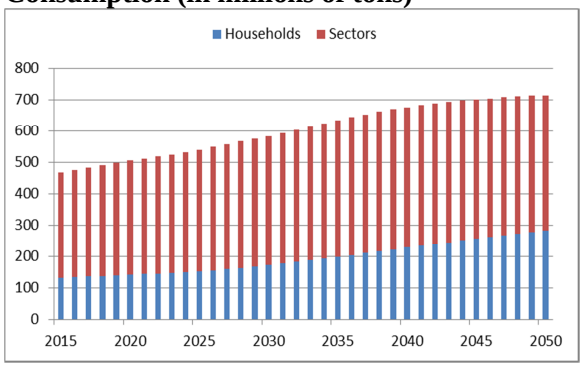


Figure 6. CO_2 Emissions from Energy Consumption (in millions of tons)



b. Alternative Scenarios

To test the impact of specific policies, we simulate alternative scenarios that we are able to compare with the baseline scenario. The policies considered are shown in Table 4. We consider three policies. The first one is the implementation of a carbon tax (PCO2TAX). The second one is the elimination of energy subsidies (PSUB). Finally, the third one is the redistribution of revenues from the carbon tax and from the elimination of the energy subsidies (PREDIS).

Table 4. Policies

PCO2TAX	Implementation of a carbon tax
PSUB	Elimination of energy subsidies • All energy subsidies are phased out over 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 through a reduction of the income tax for households. • Revenues from the carbon tax are redistributed through a reduction of income tax for households and of a payroll tax for sectors. The carbon tax paid by households is fully reimbursed. The carbon tax paid by sectors is fully reimbursed by reducing the average payroll tax rate. This means that high (resp. low) intensive energy sectors receive less (resp. more) than their contribution to the tax.

The impact of the above-described policies can be explored according to various targets. Table 5 provides a summary of the targets we consider. We define two types of targets. The first refers to the level of CO_2 emissions from energy consumption (TCO_2). The second type of targets concerns gradual changes in the electricity generation matrix for the period of analysis; this means different 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 electricity mix scenarios, and to be able to look at the impacts in terms of carbon tax, emission reduction and macroeconomic variables, to highlight the importance of a clean electricity matrix.

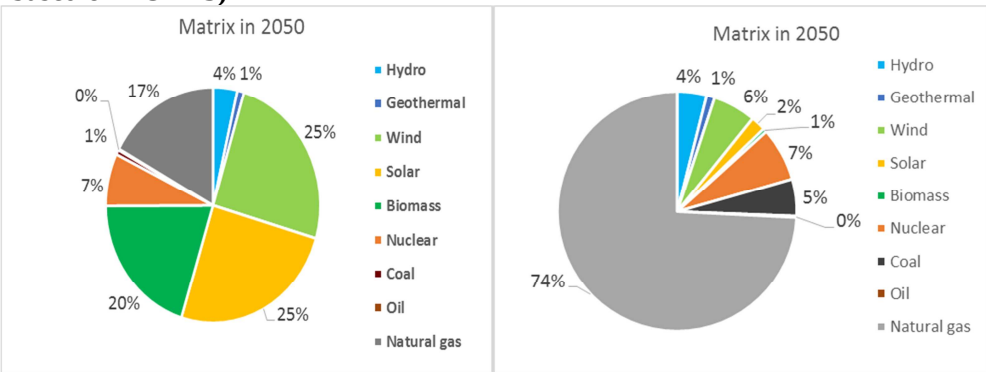
Table 5. Targets for the Electricity Mix and the Level of CO_2 Emissions.

TCO2	CO_2 emissions target for emissions from energy consumption, INECC "IDEAL scenario": reduction of emission from energy uses of 55 $MTCO_2$[18] in 2018, by -40% in 2030, compared to the baseline and -50% compared 2000 level in 2050(LGCC, 2012), (175 million of ton CO_2 emission).
TMIX	• **TMIX-RENEW:** 35% from clean energy in 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 in 2050**.** • **TMIX-FOSSIL**: Fossil intensive electricity mix, that is 74% of the mix is natural gas and 5% coal by 2050

[18] It is estimated from GHG emission target (83 $MtCO_2$) stated in the Special Program of Climate Change 2014-2018 (PECC, 2014). Emissions from energy uses correspond about 66% of total GHG emissions in 2018.

The evolution of the electricity mix is therefore defined exogenously and is not sensitive to the relative prices between energy technologies in Three-ME. This assumption would be valid in a fully deregulated and decentralized electricity market. However, Mexico has just recently begun to deregulate its market, so it is most likely that decisions related to electricity production will still be largely dominated by the state controlled power company CFE. Moreover, we use the electricity scenarios undertaken by POLES model which simulates future capacities development by technology on a cost-based competition, including endogenous technology learning (See Figure 7).

Figure 7. Electricity Matrix TMIX-RENEW (Left) and TMIX-FOSSIL (Right) (Source: Authors' calculation based on POLES)



The alternative scenarios that are simulated are constructed by combining the different policies and targets (Table 6). We define three groups of scenarios. The first concerns fiscal policy without redistribution. It corresponds to an increase of the taxation on fossil energy through the phasing out of 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 of energy taxation. Scenario S3 tests in addition the effect of changing the electricity mix.

Table 6. Alternative Scenarios Simulated

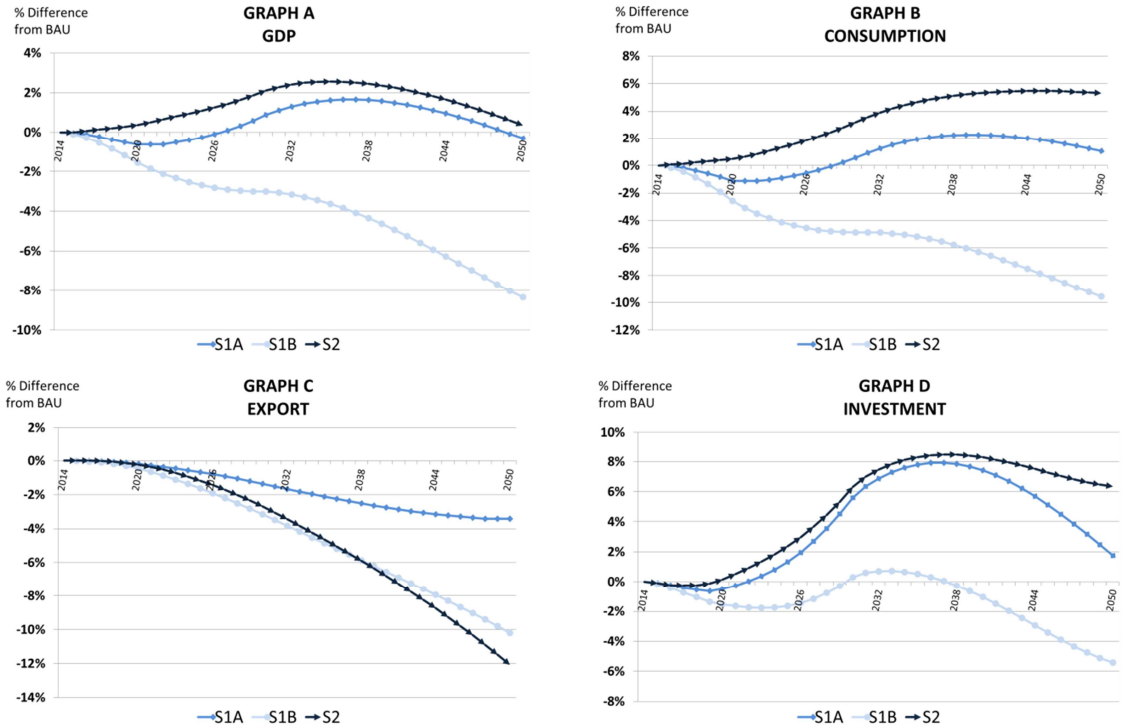
Scenarios	Policies	Target mix
S1. Fiscal policy <u>without</u> redistribution • S1A. Phasing out of energy subsidies • S1B. Phasing out of energy subsidies and implementation of a carbon tax	PSUB PSUB + **PCO2TAX**	TMIX-**RENEW** TMIX-**RENEW**
S2. Fiscal policy <u>with</u> redistribution • Phasing out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

c. Macroeconomic results

Unless stated otherwise all results are reported as a percentage difference compared to the baseline. The main macroeconomic results are shown in Figure 8 and Figure 9. The two fiscal policy scenarios without redistribution (S1A and S1B) have similar effects since they both increase the energy price. However, they have two main differences. The first concerns the basis of the fiscal instrument. Whereas the carbon tax is based exclusively on fossil energy, 16 percent of the energy subsidies concern electricity. Even if the share of fossil energy in electricity production goes from 46% to 18% in these scenarios, a large part of the subsidy on electricity is directly a subsidy on fossil energy. 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 that amplifies the phasing out of energy subsidies (S1A). Whereas the GDP marginally decreases in S1A until 2025, it drops by more than 4% after 2040 in S1B. The positive effect in the S1A after 2025 is allowed thanks to the high penetration of renewable energies in the electric mix. The level of the carbon tax is chosen such that we reach a target of 353 and 175 millions of tons of CO_2 respectively in 2030 and in 2050 (see TCO_2 in Table 5). This requires a carbon tax at 1500 MX$[2015] (US$100) in 2030 and 10500

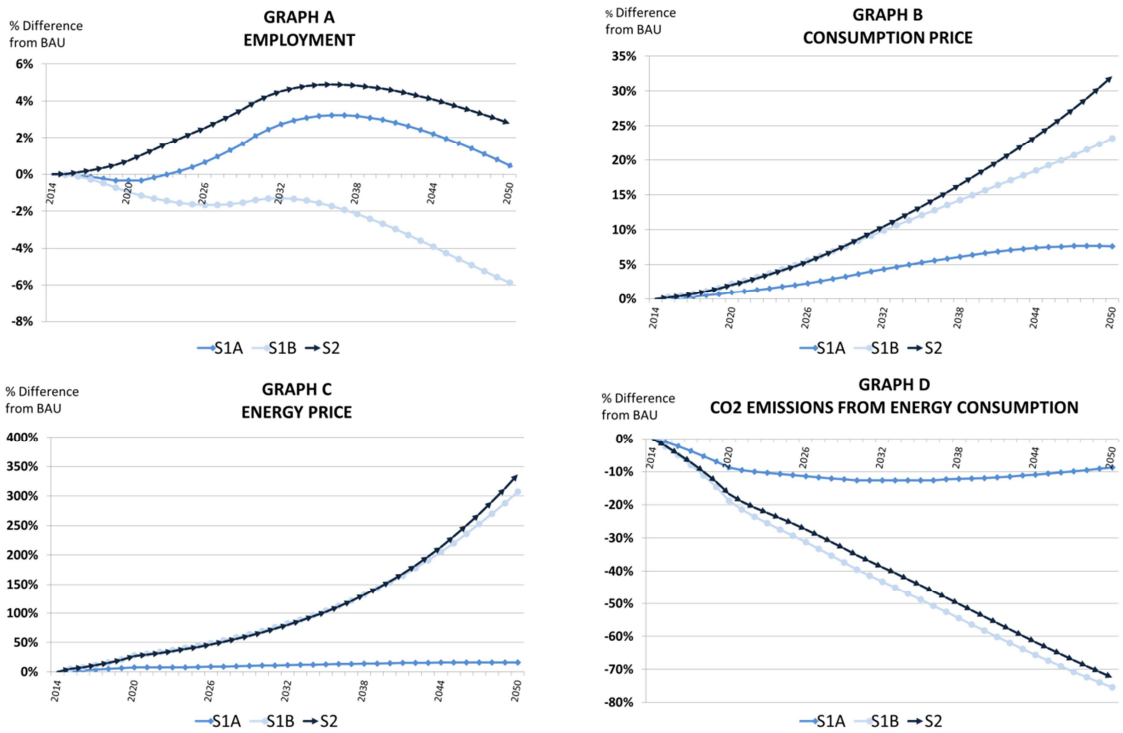
MX$2015 (US$700) in 2050 (see Figure 10.D) . Compared to the baseline scenario, this corresponds to a 40% decrease in CO2 emissions from energy consumption in 2030 and 75% in 2050 (see Figure 9.D).

Figure 8. GDP, Consumption, Export and Investment



The strong GDP decrease in S1B comes 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 9.C) which results in higher overall prices. The increase in the consumer price by nearly 25% (see Figure 9.B) has a negative impact on consumption, which drops by 10% (see Figure 8.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 therefore higher prices. This leads to a decrease in exports by 8% after 2040 (see Figure 8.C). As a consequence of the negative multipliers effects, the recession is reinforced by the decrease in investment that drops by 4% by 2040 (see Figure 8.D). A noticeable difference with consumption is that investment starts to increase between 2030 and 2035 (see Figure 8.B &D) because of the substitution from energy to capital. But this substitution effect is insufficient to compensate for the recessionary effect.
As expected, the GDP decrease in S1B leads to a decrease in employment, which drops by more than 4% by 2040 (see Figure 9.A). This limits the progression of wages and explains why inflation tends to stabilize at the end of the period, whereas the price of energy still continues to strongly increase (see Figure 9.C). Because of the substitution effects, CO2 emissions decrease by more than 75% by 2050 (see Figure 9.D). But this environmental dividend appears at the cost of a recession. This makes this policy difficult to accept politically at least in the short run.

Figure 9. Employment, Consumption Price, Energy Price and CO2 Emissions



By contrast, the implementation of the carbon tax with the full redistribution (by reducing income tax for households and the payroll tax for sectors) of the tax revenue (S2) appears as a way to reconcile environmental and economic objectives: the effect on GDP is indeed positive (see Figure 8.A), whereas the decrease in emissions is only slightly smaller than in S1B (see Figure 9.D).

There are several reasons explaining why redistribution allows for a positive effect on the GDP. First, the average real revenue remains more or less stable since the tax revenue is given back to households[19]. Secondly, redistribution also limits the increase in production costs especially for labor-intensive industries. By penalizing energy intensive sectors, which also happen to be less labor-intensive (See section 0), the level of employment and therefore of consumption increases. Third, the Keynesian multipliers effect play the other way around compared to the case without redistribution. They generate a virtuous cycle for growth: more economic activity leads to more employment, consumption and investment which lead in return to more economic activity. This virtual cycle can be maintained for as long as inflationary pressures are not too high.

Higher GDP means more employment (see Figure 9.A) which leads to higher wages increases. This increase in production cost leads to more inflation. This explains why the consumer and the energy price are higher in S2 than in S1B (see Figure 9.B & C). With GDP being higher in S2 compared to S1B, CO2 emissions are logically higher when the revenue of the tax is redistributed (see Figure 9.D). This is a classic example of a rebound effect: more economic activity means more production and more households' consumption which means more energy consumption. But this rebound effect is small since the increase in CO_2 emission 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 renouncing much of the potential of the tax in terms of an environmental dividend. In other words, the model shows that the

[19] Actually the average real revenue decreases slightly because the basis of the tax decreases with the substitution of fossil energy to other commodities. Therefore the amount redistributed becomes smaller, while the substitution is not important enough to compensate the increase of the energy prices (unless we assume that commodities are perfectly substitutable to each other, that is a level of elasticity of substitution tending to infinity).

substitution effects due to the changes in relative prices can have more impact on energy consumption 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, that is on the level of elasticity of substitution assumed in the simulation. Therefore, we investigate in the sensitivity analysis (Section e) how these results are altered when we retain alternative levels of substitution.

Figure 10. GDP, Energy Price, Energy Demand and Carbon Tax Price

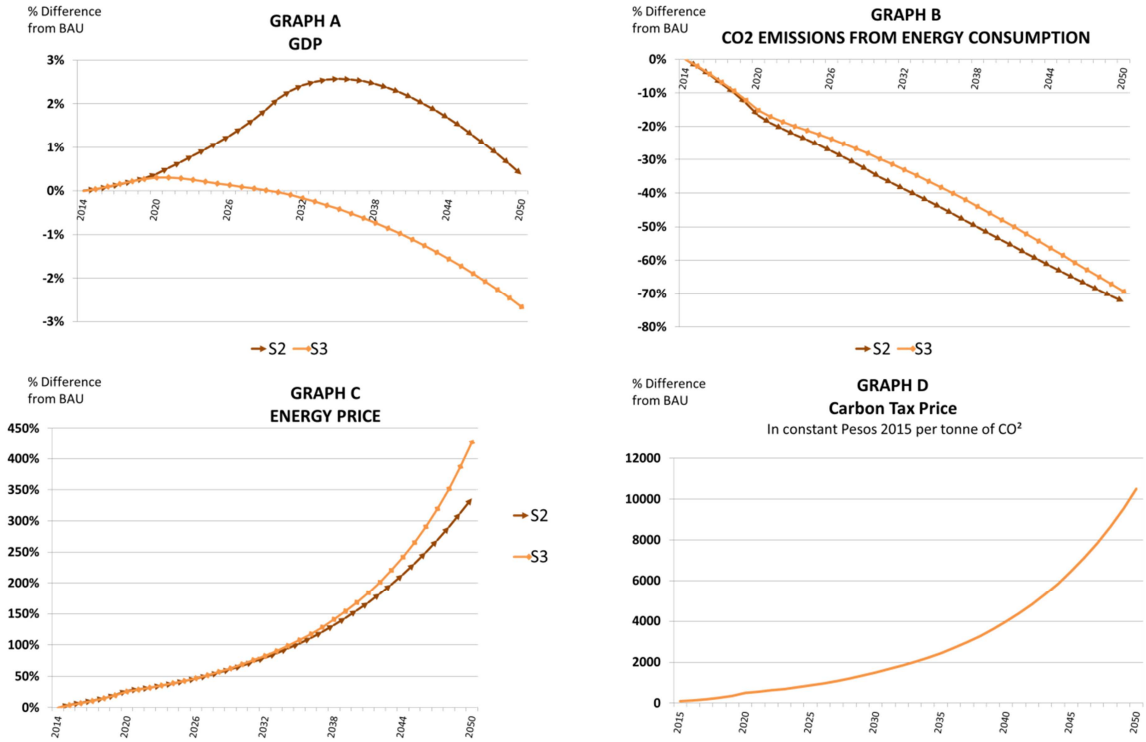


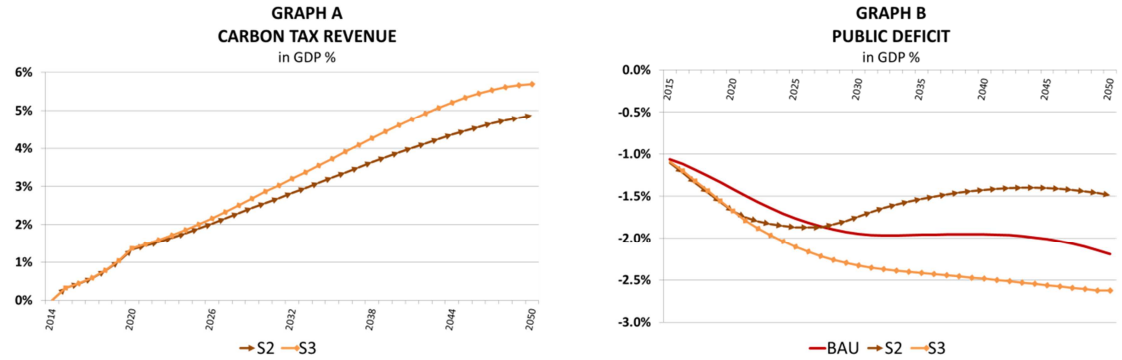
Figure 10 shows the impact of a change in the energy mix by comparing scenarios S3 to S2. As for S2, scenarios S3 assume the full redistribution of tax revenues and the same carbon tax level (see Table 4). As summarized in Table 5, S2 assumes a renewable intensive electricity mix where 75% of the mix is from renewable 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 10.A) and lower CO_2 emissions compared to the fossil intensive scenario S3[20] (see Figure 10.B). This result is logical. On the one hand, more renewable (resp. fossil) energy in the electricity mix means a reduction (resp. increase) 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 10.C). This has a positive effect on the purchasing power of consumers and on the competitiveness of the economic sectors. This explains why the economic activity is more favorable in S2. Of course, higher economic activity means also more energy consumption which plays as a rebound effect. This can be observed in section 0 (Figure 13.B) where the decrease in the energy consumption is smaller in S2 than in S3. But this rebound effect is too small to reverse the reduction of CO_2 emission allowed by a higher 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 in improving the penetration of renewable energy are more efficient both economically and environmentally.
The carbon tax revenue of S2 and S3 represents between 5% and 6% of the GDP in 2050 (See Figure 11.A). This is quite substantial given that, the value added tax revenue represents 3.7% of GDP in the same

[20] All scenarios produce the same results until 2020 because the mix is almost the same across all scenarios up to that date.

period. The revenue from the carbon tax is higher in S3 compared to S2 because of higher emissions due to an intensive use of natural gas in the electricity mix. In those scenarios the carbon tax revenue is redistributed through the decrease of others 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 adjustments and depends of the policy effect on other variables. The difference in evolution regarding the public deficit in S2 and S3 mainly comes from the evolution of the GDP: in S2, GDP improves compare to the baseline scenario whereas the contrary is true for S3.

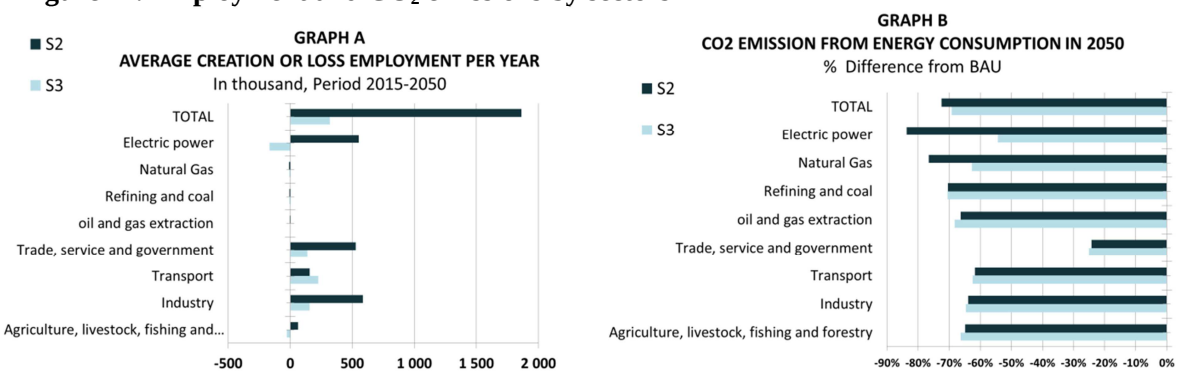
Figure 11. Carbon Tax Revenue and Public Deficit, in % of GDP



d. Sectoral Results

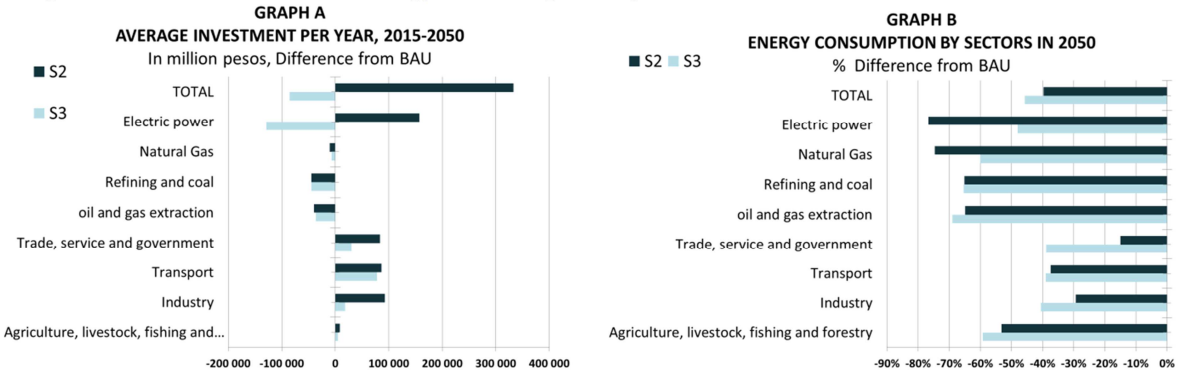
The aforementioned macroeconomic results show that the redistribution of the revenues of the carbon tax has the advantage of leading to a double dividend. In addition both dividends are higher when this fiscal policy is coupled with the development of renewables in the production of electricity. This result can be seen in Figure 12 : the average employment creation per year is higher in S2 with more reduction of CO2 emissions. Almost all sectors benefit from the measures, particularly, those labor-intensive ones, such as services, industry and electric power.

Figure 12. Employment and CO_2 emissions by sectors



Moreover, the electric power sector (that has a high level of renewable) is more labor-intensive than the fossil fuel sectors. This explains why the loss of employment in the fossil fuel sectors is limited with the implementation of a carbon tax. Figure 12.A). Because energy sectors are capital intensive, the decrease in energy demand penalizes the activity of the fossil fuel sectors and therefore their investment (see Figure 13.A). All other sectors benefit from the increase in economic activity resulting from the compensation of households and industry and their investment increases. As the carbon tax is introduced for all sectors, CO_2 emission fall across the whole economy. Figure 12.B). The impact in the aggregate CO_2 emission is higher in S2, even if the reduction of total energy consumption is lower in S2 due to a higher GDP (See Figure 13.B).

Figure 13. Investment and Energy Consumption by Sectors



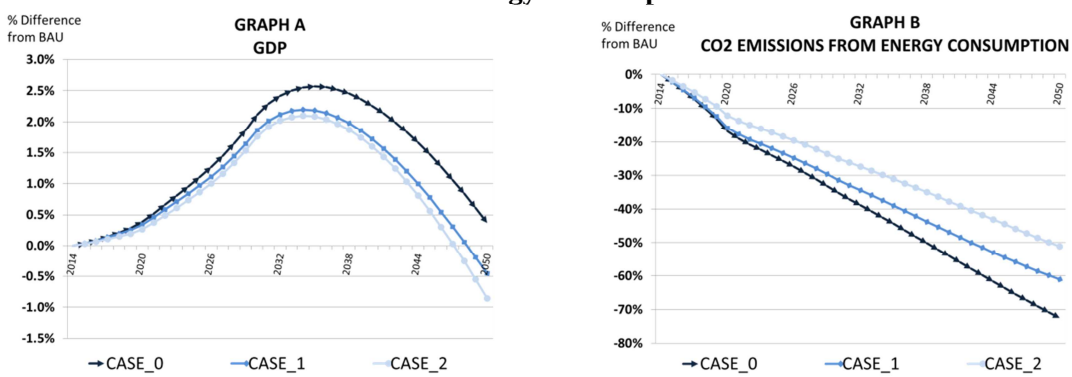
e. Sensitivity Analysis

For the sensitivity analysis, we examine the scenario S2 in all the cases shown in Table 7. The base case (Case 0) considers assumptions and parameters taken into account in section b, 0 and 0. In case 1, the assumption on endogenous energy efficiency is removed. The elasticity 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 remains therefore constant over all the 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 elasticity of substitution between domestic and foreign goods for each type of uses (such 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 wage to unemployment rate. Case 5 adopts an elasticity of 0.3 whereas case 0 assumes 0.1.

Table 7. 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 consumptions goods	1	0.5
Case 3	The Armington elasticity of substitution between domestic and foreign goods	0.8	1
Case 4	Exports Elasticity	0.6	0.8
Case 5	Wage elasticity, sensitivity to unemployment rate	0.1	0.3

Figure 14. GDP and CO2 Emissions from Energy Consumption

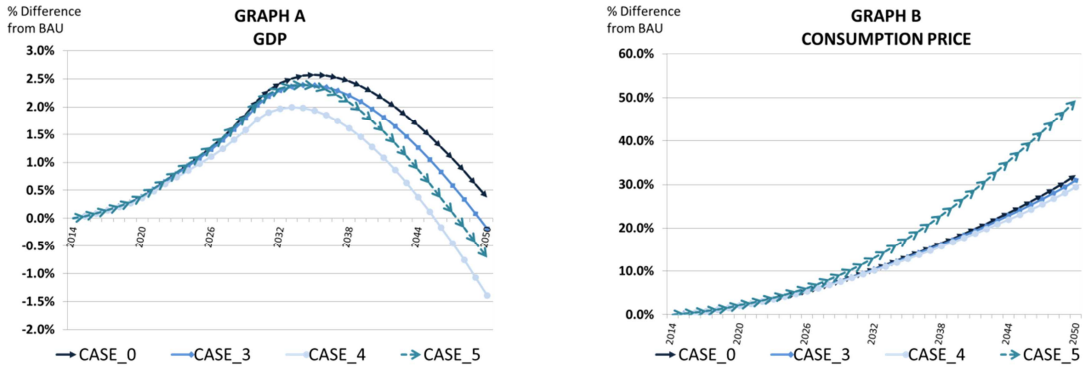


Results in Figure 14 shows that changes in assumptions of elasticities between capital and energy and between consumption goods affect the double dividend in the medium and long term. In particular, removing

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 14.B). The whole economy is less flexible, sectors and households struggle to adapt to higher energy prices. The impact on GDP is limited until 2045, after which we observe a negative effect caused by the higher cost in terms of energy bills because of low flexibility. Agents are unable to further reduce their energy consumption. This implies that investment choices made by them forbid in-depth 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 accompanied with a lower environmental dividend (See Figure 14.A). In the above illustration, we have tested the effect of a less flexible economy. We get the inverse results (not shown for brevity) if we assume a more flexible economy: the GDP and the emission reduction are higher.

Figure 15. GDP and Consumption Price



Case 3, 4 and 5 have no impact on the environmental dividend, reductions in CO_2 emissions from energy consumption remaining at the same level as in the base case (not shown). The explanation is the same as previously mentioned: the substitution effects due to the changes in relative prices have more effect on energy consumption than the revenue effect (here a lower GDP); in other words, rebounds 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 barriers to trade. Because foreign prices are lower[21] than domestic ones, agents import more, which penalizes the national activity. However this negative effect is lower than case 4 and case 5. In case 4, the impact of the relative price between export prices[22] and world prices on the external demand[23] is increased. Since export prices are higher than world prices, external demand decreases more compared to case 0, affecting GDP negatively (See Figure 15.A). In Case 5, wages are more strongly related to the unemployment rate than in case 0. In the event of less unemployment, the bargaining power of trade unions is reinforced, leading to higher wage increases that affect production costs and therefore inflation. This explains why consumption price is higher is case 5 than in the base case (See Figure 15.B). Consequently, the inflationary pressure resulting from the taxation policy reverses the economic gain because the Mexican economy is less competitive externally.

[21] Recall that we assume that the rest of the world does not follow a carbon tax policy.
[22] It depends on the production cost and reflects the price competitiveness of domestic products.
[23] Under the assumption of a « small open economy » the external demand and the export price are negatively related for a given world price.

Conclusions

The main objective of this paper was to evaluate the impact of climate policy in Mexico using the Three-ME model. Our study supports the idea that a double (environmental and economic) dividend is possible. A carbon tax would provide an incentive for a low emission development of the Mexican economy, achieving at the same time higher levels of social welfare through an appropriate distribution policies of the carbon tax revenues. The magnitude and the speed of these benefits depend on the flexibility of the production and consumption structures. Recalling that no price of carbon is implemented in the rest of the world, this result contradicts the argument according to which a price of carbon would necessarily have a negative impact on the economy, when implemented unilaterally.

It is important to remember that this result is obtained despite several pessimistic hypotheses. Firstly, we assumed that the price of renewable technology would remain constant over the entire simulation period. Including a decreasing price would increase further the economic benefits; and meeting the CO2 target would be achieved with a lower carbon tax level. Secondly, we assumed that no other countries would introduce a price of carbon over the whole simulation period. These tend to exaggerate the loss of competitiveness of the Mexican economy. Assuming a certain degree of commitment of the rest of world would increase the benefit of introducing a carbon tax.

A follow-up of this analysis would be to investigate further distributional effects. The redistribution of the tax appeared as a key element to get a double dividend at the aggregate level. Whereas this compensation seems enough when considering an average consumer, it could be different when considering heterogeneity. Disaggregating households by income level could provide a useful insight in this respect.

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