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Mexico's low carbon futures: An integrated assessment for energy planning and climate change mitigation by 2050

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A R T I C L E I N F O

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A B S T R A C T

This paper shows an integrated assessment for energy planning and climate change mitigation in Mexico, as an international case study. The Mexico 2050 Calculator was used to run a number of low carbon future scenarios by 2050. The calculator consists of a whole-systems model, which combines the main sectors of the Mexican economy into a single visual tool. By integrating energy and carbon dynamics across all sectors and carrying out a sensitivity analysis of the entire model, we compare four low carbon energy scenarios to assess current energy policy strategies in the country. The methodology proposed in this paper can also be applied to any other nation, particularly to those with similar models already available. Our findings show the relative impact of each sector and their various interactions for achieving Mexico's ratified climate commitments. The paper also includes policy recommendations and highlights the need for scaling-up energy efficiency policy efforts in industry and transport, for having a higher focus on agricultural and land use policies, and for promoting integrated renewable energy policies.

1. Introduction

National Governments agreed by consensus in the 21st Conference of the Parties (COP21) of the United Nations Framework Convention on Climate Change, held in Paris, December 2015, to limit the increase of the global mean surface temperature below 2 °C above pre-industrial levels, with an ambition to stay below 1.5 °C. This target requires that both developed and developing countries substantially reduce their greenhouse gas (GHG) emissions in the next decades. According to the Intergovernmental Panel on Climate Change (IPCC, 2014), this transition requires substantial sectorial transformations prior 2020, imposing important challenges for reducing carbon emissions, particularly in the energy sector.

Climate change mitigation involves a large number of complex variables, requiring the use of integrated models in order to have a comprehensive systems view of the problem, viable solutions and tradeoffs to develop new policy strategies. Integrated as assessment models in climate change are often used to inform policy decisions on preventing and adapting to climate change, and allocating funds for climate research, as discussed by the International Institute for Applied Systems Analysis – IIASA (Dowlatadabi, 1994),

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usually including tradeoffs between conflicting goals. The combination of scientific, socioeconomic and technological aspects of climate change mitigation in these models, support the analysis of GHG emissions, considering the impact of climate policies on the rest of the system. These models usually aim at a) assessing climate control policies, b) forcing multiple dimensions of the problem into the same framework, and c) quantifying the relevance of climate change with respect to other challenges (Kelly & Kolstad, 1998). Thus, for the purpose of this paper, an integrated model compiles variables from different sectors of the economy, such as transport, power, agriculture, industry, residential and commercial sectors, into a single interconnected modelling structure, as a broad system, addressing issues such as energy and carbon dynamics over time.

The energy sector has a long-track record of energy models underpinning major energy policies (Strachan, Pye, & Kannan, 2009) and there is often a tension between policy answers and alternative energy models (Smil, 2000). Evaluation of alternative energy scenarios has usually focused on the difficult issues of defining the baseline, technological change rates, and the substitution mechanisms of the model itself (Ockwell, Watson, McKerron, Pal, & Yamin, 2008; Söderholm, Hildingsson, Johansson, Khan, & Wilhelmsson, 2011; Strachan et al., 2009). Also, energy scenarios involve a substantial amount of uncertainty, arising frequently from variations in data sources and classification (Devezas, LePoire, Matias, & Silva, 2008). As more comparable information exists about data, and change assumptions, better decisions can be made at the local, national and global levels (Devezas et al., 2008). Thus, the use of integrated systems tools with common data classifications and assumptions can become highly informative for policy-makers. Moreover, acknowledging the fact that point long-term projections involving complex issues usually fail at meeting their own forecasts afterwards, it is decision analysis or contingency planning under a range of alternative scenarios what should be pursued more diligently, particularly normative scenarios which outline alternative paths to achieve a desired goal (Smil, 2000).

This paper offers a comparative assessment of four alternative reference scenarios for carbon mitigation in Mexico, as an international case-study, by using a whole-systems model called the Mexico 2050 Calculator[1] (SENER & Centro Mario Molina, 2016). Additionally, it provides a sensitivity analysis of the entire calculator's model in order to understand the role of the energy sector to reduce greenhouse gas emissions and guide further policies to gradually decarbonize the Mexican economy by 2050. The paper also presents an overview of the main ongoing energy and climate change policies in Mexico in order to contextualize the subsequent discussions and offer a critical review of the Mexican experiences, which may also be useful for improving policies in other nations. The methodology proposed in this paper can be applied for similar assessments not only in countries with national calculators already available, but also for countries with valuable studies whose methodologies are not comparable from the onset, and for those who may want to develop comparative platforms. This is the first time that a national calculator has been subject to this type of assessment worldwide in a scientific publication.

The use of calculators has become relatively popular in the last years, given to their simplicity, transparency, and the possibility of running different scenarios interactively with a broad audience, including non-experts in modelling or energy issues. Some nations have even used their national calculators to help prepare their own Intended Nationally Determined Contributions (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC), for example. In Mexico, its national calculator has been used mostly for policy discussions and as an educational tool to date. Further upgrades in the Mexican version could include other types of simulation, for example, land use and soil carbon dynamics. Besides, the model could be adapted to city-level calculators, for example Mexico City, as already done for Beijing in China.

2. Energy and climate policy environment in Mexico

Mexico is one of the most diverse and largest economies of Latin America with a high potential for deployment of renewable energies, particularly solar and wind power, with relevant potentials for bioenergy, hydropower and geothermal as well. Nevertheless, the Mexican energy mix is still highly reliant on fossil fuels. Moreover, Business as Usual (BaU) prospects project Mexico doubling its energy consumption before 2050 (IRENA, 2015). On September 14, 2016, the Mexican Congress ratified Mexicós commitment to reduce its greenhouse gas emissions by 50% compared to emissions in year 2000 by 2050, as described in Mexico's INDC (México - Gobierno de la República, 2015) submitted to COP21. Goals include the commitment of reducing unconditionally its GHG emissions 22% below baseline by 2030, a conditional reduction of 36% below baseline also by 2030, and a maximum of 320 $MtCO_2eq\ y^{-1}$ by 2050. Achieving these goals will require fundamental sectorial and societal changes as well as a substantial amount of policy planning.

2.1. Federal policy initiatives

One of Mexico's important benchmarks on the legal front is the publication of the General Climate Change Law (GCCL), in 2012, which mandates the creation of targets, strategies and plans, and suggests an institutional framework for climate policy implementation, as well as the aspirational goal to reduce its emissions by 50% with respect to 2000 levels by 2050.

In the context of the Constitutional Energy Reform, the Energy Transition Law (ETL) was enacted in December 2015 to regulate the sustainable use of energy and articulate the electric industry's obligations to comply with standards established in Mexico's General Climate Change Law and the Electric Industry Law. This law is particularly relevant since it surpasses any other previously enacted piece of legislation on energy transition and sustainable electric production in Mexico. The implementation of the Energy Transition Law is based on three main instruments, namely: (i) the Transition Strategy to Promote the Use of Cleaner Technologies

[1] The Mexico 2050 Calculator is available at: www.calculadoramexico2050.org.

and Fuels, with 15- and 30-year horizons; (ii) The Special Program for Energy Transition, with clean energy targets, actions, instruments, and financial and regulatory mechanisms; and (iii) the National Program for the Sustainable Use of Energy (PRONASE, for its Spanish acronym). PRONASE states that in 2018, energy intensity in Mexico must be at least equal to that in 2012, and that an additional 5% of final energy consumption must have energy efficiency regulations (from 46% in 2012 to 51% in 2018). The Program mandates the creation of Energy Commissions in the states by 2018, when the current federal administration ends.

In addition, a step forward under the Energy Transition Law is the energy mix diversification, through the Program for the Development of the National Electric System 2016–2030 (PRODESEN for its Spanish acronym). The Program requires companies to generate clean energy with specific national goals of 25% of clean energy production by 2018, 30% by 2021, and 35% by 2024. This implies short term goals of additional 5% of clean generation in 2018, and an additional 5.8% in 2019.

The Special Program on Climate Change 2014–2018 (PECC for its Spanish acronym) probably encompasses the most direct intra and inter-sectorial measures for climate mitigation. It includes 30 mitigation-geared measures estimating an abatement of 83.2 $MtCO_2eq\ y^{-1}$ by 2018 (SEMARNAT, 2014). The Program reflects a relative balance in its sectoral policy focus, except for waste where most of the initiatives are centered on the sustainable management and use of agricultural waste. No integral performance evaluation of the program could be found to date.

2.1.1. Carbon tax

A carbon tax was introduced in 2014 as part of the special tax for products and services (IEPS, for its Spanish acronym). The tax applies to fossil fuels and initially was set to vary according to the carbon content. However, its final design contains different implicit prices, an exemption for natural gas, and a cap that limits its impact on coal and coke. Carbon tax prices may vary from Mex$ 6–10 tCO_2eq^{-1} (approximately US$ 0.30–0.50 tCO_2eq^{-1}, respectively) for petroleum coke, coal coke and mineral coke, to up to Mex $ 50 tCO_2eq^{-1} (approximately US$ 2.70 tCO_2eq^{-1}) for gasoline, diesel and fuel oil. This tax has generated about Mex$ 18.759 billion (around US$ 1 billion) in revenues, cumulatively, since its implementation in 2014. It is expected to create incentives for a carbon market in the future through tax rebates in exchange of certified emission reductions under the Clean Development Mechanism and other markets.

2.1.2. Sectorial initiatives

In addition to the carbon tax, some sectors have complementary direct and indirect policy initiatives to reduce their greenhouse gas emissions, as following described:

2.1.2.1. Cities and transport. In terms of mobility, two federal initiatives include actions for transport: the Strategy for Sustainable Urban Mobility, and the Federal Program to Support Massive Transportation. A step towards a more efficient transport system is the gasoline subsidy elimination suggested in the Energy Reform. Currently, fuel prices are based on a formula according to production, distribution and retailing costs. Since 2010, gasoline price at the pump station has increased nationally and kept closer to its total production cost and sometimes even higher. The Reform establishes that the government should continue to regulate maximum prices of gasoline and diesel until 31 December 2017, and that from 2018 on the market should determine prices (DOF, 2013).

In addition, there are fuel efficiency standards for light vehicles, with a scheme that will likely be further harmonized with US standards in the coming years. No similar regulation exists for heavy duty vehicles. Other initiatives at the city level include the National Project for Energy Efficiency in Municipal Public Lighting, and actions to increase efficiency in water pump systems.

2.1.2.2. Households and buildings. At the household level, emphasis is made on energy efficiency norms for domestic appliances, such as refrigerators, washing machines, air conditioning, and lightning. These norms are designed and implemented by the National Commission for the Efficient Use of Energy (CONUEE for its acronym in Spanish). Also, a standardized building code is currently being discussed to harmonize existing instruments and standards (CASEDI & ICC, 2016), and to make them progressively stringent. In the public sector, the Program for Energy Efficiency in the Federal Government promotes actions to decrease the use of energy in more than 1000 public buildings.

2.1.2.3. Industry. The National Program for Energy Management Systems (2014) works with large energy users (e.g. chemical industry, car manufacturing, food industry and metal industry), small and medium enterprises, state and local governments, and the public sector. For large users, the program focuses on best cases (including ISO-50001 certification), whereas for small and medium enterprises it focuses on the diffusion of information about new technologies and best practices.

Efficiency norms for the industry concentrate in appliances with significant energy savings potential according to energy demand and number of units. There are norms regulating pumps and motors, thermal insulation systems, air conditioning, commercial cooling systems, and lamps, among others. Also, a Mexican Nationally Appropriate Mitigation Action (NAMA) under the UNFCCC is currently in preparation for clean certificates in industry.

2.1.2.4. Electricity. A promising action in the electricity sector is the design and implementation of a Smart Grid Program, which is currently under preparation. Moreover, the Electricity Federal Commission (CFE, for its Spanish acronym) has a Program for the Reduction of Electricity Losses to decrease the percentage of technical and non-technical losses in the grid (currently estimated by CFE at 13.11%).

2.1.2.5. Clean energy certificates. In order to achieve the compulsory targets for clean energy generation, the new legislation requires companies to acquire Clean Energy Certificates (CELs for their acronym in Spanish). Certificates can be bought in auctions or through contracts. The first long-term auction for the basic supply was held in March 2016, with fixed premiums/penalties by location known to bidders. On average, the price for each certificate was lower than expected, and probably one of the lowest worldwide for auctions of similar characteristics.

2.1.2.6. Forestry. Mexico's GCCL calls for strategies to be implemented to halt the loss of original forests as part of mitigation actions, while it's INDC commits to end net deforestation by 2030 as an adaptation measure. Recognizing the cross-sectoral and the multiple factors behind deforestation, the mitigation actions comprise multiple policies aimed at promoting sustainable rural development. The strategy has focused on "early action areas" and is broadly anchored in promoting sustainable use of forests − including agroforestry and silvopastoral systems, payments for environmental services, and enhancing forest governance at community and landscape levels. It is anticipated that a fraction of the funds for these activities will come from the international community through the international REDD+ mechanism. In addition, there has been a significant emphasis on reforestation and restoration of degraded forest lands.

Concerning federal spending in mitigation, 2013 was the first time that the federal budget included a specific Annex (Annex 16) identifying the budget associated with climate change action. Currently, total spending amounts to about 40 billion pesos (approximately USD$ 2.1 billion in 2015), which corresponds to about 0.9% of the public federal budget (GFLAC, 2015).

2.2. State initiatives

Since the publication of Mexico's GCCL and mandated by it, Mexican States have ramped-up climate change planning and its institutional framework. The main instruments being developed include: state-level climate change laws, emissions inventories, the establishment of state-level climate change commissions, and the publication of state climate action programs, aimed at identifying the most cost-effective mitigation measures. With almost half of the national states having finalized their State Climate Action Program, important progress in planning seems to have taken place. Yet, implementation is still incipient.

Existing analyses of state-level budgets for climate change found that stateś investments in mitigation initiatives in 2013 ranged from 0.12% to 4.57% of state-level budget, with a total investment of about Mex$ 6456 million in 2012 (approximately US$ 344 million) (IMCO, 2013). In terms of allocation, state investments in 2013 were mostly allocated in forestry (35% of total mitigation budget) and transport (28% of total mitigation budget).

3. Methods

The methodology consists of a comparative assessment of carbon mitigation pathways, using the Mexico 2050 Calculator, followed by a sensitivity analysis of its entire model. This calculator was developed based on similar modelling approaches also available for other countries. The United Kingdom was the first nation to deploy a national 2050 calculator (DECC, 2016a), inspiring several other countries to prepare their own national calculators, including Mexico. Other countries with completed calculators to date are Australia, Austria, Belgium, Bangladesh, China, Colombia, Ecuador, India, Indonesia, Japan, Mauritius, New Zealand, Nigeria, South Africa, South East Europe, South Korea, Switzerland, Taiwan, Thailand and Vietnam (DECC, 2016b). A full list of all national calculators, their respective models and technical documentations are publicly available online.[2] Therefore, given that calculators share similar methodological approaches, the methodology applied in this article could also be taken as a reference to assess existing scenarios of other national calculators or other similar approaches worldwide. In addition to these national calculators, a Global Calculator[3] (DECC, 2016c) was launched in 2015, led by the former UK Department of Energy and Climate Change (DECC), in collaboration with the EU Climate Knowledge and Innovation Community (Climate-KIC) and other international partners. The European Union also has a calculator under preparation and a preliminary modelling approach to land use dynamics, food and bioenergy, called EU Land Use Futures model (EULUF) was recently launched. The EULUF model and the Global Calculator Land Use Change (GCLUC) model demonstrate that changes in dietary patterns, bioenergy and land use, including soil carbon dynamics, can have a very significant impact on GHG emissions (Strapasson, Woods, & Mbuk, 2016; Strapasson et al., 2017), and this issue is not entirely covered by the Mexico 2050 Calculator yet, at least not in its current version 1.5.0. Also, recently, the Financial Times (FT, 2016) made available an emissions footprint calculator[4] prepared by Imperial College London for helping visualize the impact from the implementation of major economies' INDCs on global GHG emissions, and inform the negotiations at the UNFCCC. The FT calculator is based on the Global Calculator and can also be used to compare carbon mitigation pathways generated by the Mexico 2050 Calculator, against the implementation of INDCs by highly emitting countries, such as China, United States, India, Brazil, Japan, Canada, Russia, Australia, and the European Union member states.

It is worth noting that these calculators work as an engineering model, based on "system dynamics" i.e. on stock-and-flow structures (Forrester, 2013; Voinov, 2008), rather than an econometric model using economic variables such as price and market interactions. The calculator is a free simulation tool, which allows the user to run a large number of technically possible scenarios and

[2] See all national 2050 calculators at: www.2050.org.uk/calculators.
[3] For playing the Global Calculator access: www.globalcalculator.org.
[4] The FT calculator is available at: http://ig.ft.com/sites/climate-change-calculator.

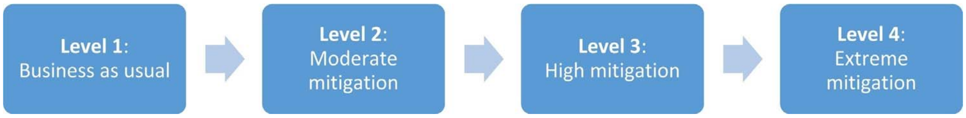

Fig. 1. Levels of growing carbon mitigation effort applied for each lever of the Mexico 2050 Calculator.
Source: Prepared by the authors, using the Mexico 2050 Calculator.

visualize their potential impacts in terms of energy balance and carbon emissions over time, regardless of their costs. The calculator also differs from story-driven modelling (Ulrich, Zündorf, & Jubeh, 2013) and other types of object-oriented approaches. Therefore, the approach used in the Mexico 2050 Calculator is rather different to models commonly used by the energy sector, such as the International Energy Agency's MARKAL model, TIMES, IKARUS, Message, and the U.S. National Energy Modeling System (NEMS). These distinct approaches should not be seen in competition, but instead as complementary tools with different purposes. These models can also be potentially integrated in some cases. The Global Calculator, for example, uses the University College London's TIAM model for making some consequential cost simulations, which are not available in the Mexico 2050 Calculator and other national calculators yet.

3.1. Mexico 2050 calculator

The Mexican calculator was used to compare the impact of policy initiatives on a sectoral level. Similarly to other national calculators worldwide, it works as a system dynamics model of carbon stocks and flows, interconnecting the main sources of energy and greenhouse gas emissions from the demand to supply sides across all sectors. The sectors considered in the calculator from the demand side are: cities and transport, households, industry and the commercial sector, and from the energy supply side: nuclear energy, biomass, renewables (small and large scale), and electricity from fossil fuels, agriculture, waste management, fossil fuels production, and forestry. The model also includes potential changes in the Mexican population growth and economic activity. The three main greenhouse gases (CO_2, CH_4 and N_2O) responsible for anthropogenic climate change are accounted for in the model.

Each sector comprises a number of representative levers. For example, the renewable energy sector has five levers: wind power (onshore and offshore), hydroelectricity, marine renewable energy, geothermic, photovoltaic and solar thermal, being bioenergy estimated in the agricultural sector. For each lever, there are four levels of mitigation effort by 2050, as illustrated in Fig. 1. Level 1 represents a no mitigation effort, similar to a Business-as-Usual (BaU) scenario. Level 2 represents a moderate ambition, with mitigation efforts following today's trends; and level 3 a very high yet plausible mitigation effort. Finally, level 4 represents an extreme mitigation effort, in which just few experts may agree, but still technically possible to achieve, although it may require in some cases a rapid deployment of emerging technologies. Therefore, the calculator can generate a large number of scenarios for greenhouse gas emissions and energy balances from present to 2050, as a result of the many interactions possible among all levers' levels available in the calculator.

The calculator was calibrated based on an extensive literature review and stakeholder consultation led by the Mexican Ministry of Energy and Centro Mario Molina. The model was also subject to external review and several improvements until its final publication online in 2016, as a webtool available in public domain. It is worth noting, however, that there are several uncertainties involved in the calculator model, due to the need for simplifying all sectors into a reduced number of key levers in order to have an operational model working as a whole system.

The entire model used for generating the web interface of the Mexico 2050 Calculator is available as a Supplementary file to this article (Appendix A). This file includes the equations and modelling caveats, and shows how all variables were calibrated and interconnected as a system dynamics model. The way levers' levels were set within the model for each assessed scenario is available in Appendix B, and a brief explanation about their main assumptions is following described. Thus, all simulations and scenarios here shown can be repeated.

3.2. Scenarios

To develop the scenarios, we first selected three methodologically different studies recently prepared for Mexico, as well as a scenario developed by the Global Calculator team. We also considered the experiences provided by the UK Calculator and other countries' calculators, and some supplementary modelling initiatives for climate change mitigation. We then adapted these scenarios and ran new simulations using the Mexico Calculator with the policy objective of reaching Mexico's 2050 greenhouse gas reduction target. These simulations resulted in the proposition of four comparative scenarios: *High-Tech Pathway, Distributed Effort, Full Renewables, Nuclear + Renewables.*

The preparation of these comparative scenarios into the calculator comprised four main steps: (i) selecting parameters for basic assumptions regarding population, GDP and industrial growth for the assessment; (ii) selecting the levers' levels (from 1 to 4) that best matched the respective study of reference; (iii) adapting levers to keep them also approximately aligned to the premises of the study with a leeway of ± 10%; with respect to the target. Then, using the results, we developed inter-sectorial comparisons in terms of their greenhouse gas abatement potentials by 2050, complementing them with a comprehensive sensitivity analysis of the entire Mexico Calculator's model. Afterwards, we contrasted the results obtained from the four proposed scenarios against the ongoing energy and climate change policies in Mexico. The next section offers a brief description of their main propositions. Further details about the scenarios assessed in this paper can be found directly in the online version of both calculators used in our simulations, i.e. the Mexico 2050 Calculator (SENER & Centro Mario Molina, 2016) and the Global Calculator (DECC, 2016c).

3.2.1. High-tech pathway

This scenario was based on the study developed for Mexico and 15 other high GHG emitting countries under the project “Deep Decarbonization Pathways” (Tovilla, Buira, Barthélemy, & Spinazzé, 2015). The analysis emphasizes that policy decisions and investments must be made in the next 5–10 years in order to avoid lock-in effects in technology. In this scenario, energy efficiency efforts are adopted across all sectors; there is a fast deployment of CCS, zero emission vehicles, energy storage technologies, and smart transmission and distribution. The scenario generated in the calculator assumed population to reach 150 million by 2050. GDP growth is estimated at an annual rate of 2.6%, while industry grows at 1.5% annually.

3.2.2. Distributed effort

This scenario was prepared by the authors by applying a similar scenario developed by the Global Calculator team, called “Distributed Effort”, to the Mexico 2050 Calculator. It explores ways in which efforts are balanced across all sectors of the economy (mainly level 2 policies), including better uses of land resources and transforming technologies and fuels, while also maintaining a good lifestyle in terms of food and energy consumption. Cities undergo transformations that lead to fewer km travelled and a swap in transportation modes, buildings are better insulated, consume less gas for heating, and have more efficient lighting systems. Improved soil management leads to a halt in emissions and more than half of agroforestry residues are collected and used. People consume less milk and meat, leaving unoccupied areas for bioenergy production. Energy intensity decreases by making industrial processes more efficient, and by increasing the share of electricity and gas in the fuel mix. Alternative technologies, specifically nuclear and power generation with CCS, also play an important role in providing low carbon energy. Population is considered to reach 150 million by 2050 and GDP and industry grows moderately (below 2.5%).

3.2.3. Full renewables

This scenario is based on a study developed in 2013 by the World Wildlife Fund Mexico chapter (WWF-México, 2013). It rests on moving all sectors towards their technological frontier within economic constraints, first on the demand side and then on the supply side, with a focus on renewables, placing only a very marginal role for oil, gas and nuclear and, no space for Carbon Capture and Storage (CCS) technologies. The scenario assumes a moderate population growth from the current 121 million people (SEGOB, 2016) to about 130 million by 2050, a 3.5% growth in GDP and a similar industrial growth to that of GDP.

3.2.4. Nuclear + Renewable

This scenario is based on the levers identified by an energy forecast developed by the Mexican Government in collaboration with *Fundación IDEA*, focused on an intensive introduction of new technologies and then introduced into the TIMES model. The TIMES model (Loulou, Remne, Kanudia, Lehtila, & Goldstein, 2005), uses linear-programming to produce a least-cost energy system, optimized according to a number of user constraints and assumptions, over medium to long-term time horizons. As such, the options used in this scenario rely more on introduction of new technologies rather than on changes in behavior or land use measures. The scenario ran in the calculator assumes a moderate population growth (130 million by 2050); moderate economic growth (below 3%) and that industry will grow 2% approximately.

3.3. Sensitivity analysis

In addition to the comparative assessment of reference scenarios, we carried out a sensitivity analysis of the entire model. The purpose of carrying out a sensitivity analysis as such was to identify quantitatively the approximate impact of each lever of a certain sector on mitigating climate change and its effects in the energy mix. It provides a different perspective, given that the previous scenarios show other interactions between variables. It is worth noting that the sensitivity analysis does not overcome the several modelling uncertainties, particularly those associated with the necessary simplification of highly complex sectors, and with issues not directly covered by the model, such as economic variables (e.g., oil price, taxes, feed-in tariffs, GDP growth), and the potential emergence of unexpected technologies ahead through disruptive innovation.

Once opening the Mexico 2050 Calculator web-tool, it shows all levers' levels set as level 1 by default, which represents an approximate BaU scenario. Thus, the sensitivity analysis was made by changing a single lever's level from 1 to 2 (moderate effort), then from 2 to 3 (ambitious effort), and finally from 3 to 4 (extremely ambitious), whilst keeping all the remaining levers' levels as BaU in order to determine isolated effect of a single lever (i.e. an area or technology of a certain sector) on the total greenhouse gas emissions and energy balance by 2030 and 2050. This process was then repeated for all levers' levels. The order of the changes does not affect the results, because each lever is independently evaluated, one by one, keeping all the remaining levers as BaU.

4. Results

Our results show that industry and transport are likely to remain as the leaders in energy consumption by 2050 regardless of the scenario. Around 80% of the energy demand comes from these two sectors combined (See Fig. 2) in all scenarios assessed with industry demanding the largest share. Energy demand from buildings for heating, cooling and cooking purposes add up to 15–20% of energy, while the remaining 3–7% of the energy would be used for lighting. All energy values are presented in terms of primary

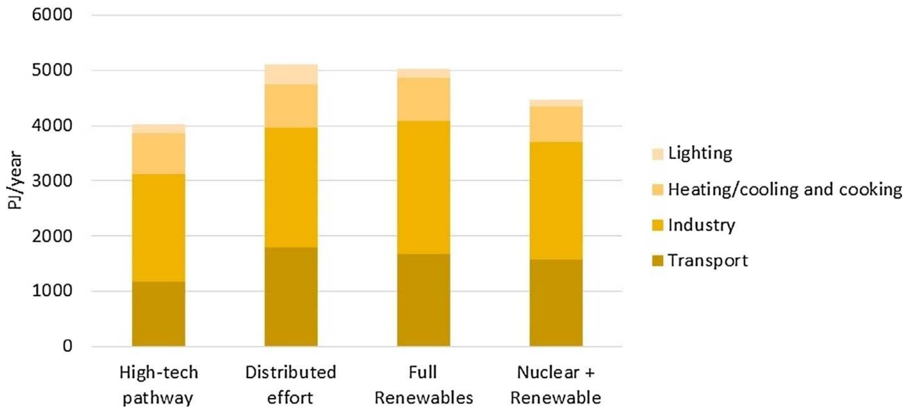

Fig. 2. Final energy demand by sector (2050).
Source: Prepared by the authors, using the Mexico 2050 Calculator.

energy.

In three of the scenarios (*High Tech Pathway, Distributed Effort, and Full Renewables*) half of the 2050 energy generated would come from fossil fuels, i.e. oil and gas (Fig. 3). The share of energy coming from fossil fuels decreases only when allowing nuclear energy to enter the formula in a significant way as well as renewable energy sources. The lower share of fossil fuels (15 and 20%) is observed in the *Nuclear + Renewable* and the *Distributed Effort* scenarios. The role of bioenergy is also worth noting in all scenarios, since it contributes to around 15% of total supply. This share deviates sharply from the BAU trend, where the calculator envisions a bioenergy contribution of less than 4% of energy supply by 2050.

The relevance of renewables supplying energy varies from 15% to almost 30% (Fig. 3). The lower bound (15% and 20%) is observed in the *Nuclear + Renewable* and the *Distributed Effort* scenarios, and can be explained again with the use of additional nuclear energy in the mix. As for the remaining scenarios (*High Tech Pathway and Full Renewables*) energy coming from clean and renewable sources contributes with 20% and 28% respectively. Both scenarios reveal the need of fossil fuels mainly for the industrial and the transport sectors, which dominate energy demand. Differences between energy supply (Fig. 3) and demand (Fig. 2) for each simulated pathway are related to energy losses in the transportation and distribution of electricity in Mexico. These differences may vary according to the scenario and may also include potential energy surpluses due to an over generation and/or exports to other countries. This surplus was particularly high for the *Nuclear + Renewable* pathway, given to an extreme expansion of nuclear energy by 2050 in this specific scenario. Further details on energy flows, from primary energy to the final consumption, and potential over generation/exports, can be seen either in the spreadsheet model or in the Sankey diagram available on the Mexico 2050 Calculator's webtool (Appendix A).

In terms of electricity, demand is largely driven by the industry (Fig. 4). In the *Distributed Effort* scenario, industry accounts for 54% of the demand. In the rest, it involves between 60% (*High Tech Pathway*) and 67% (*Nuclear + Renewable*) of the electricity delivered in Mexico in 2050. The rest of the demand is shared among other sectors with emphasis in lighting, and electricity for heating and cooling.

The main outcome from all the scenarios in terms of electricity supply is that by 2050 Mexico could rely mainly on clean energy to supply electricity. Our simulations show that it would be technically possible to achieve even 100% of electricity coming from renewable sources, although the mix of clean energy sources changes among scenarios. For instance, in *High Tech Pathway* and

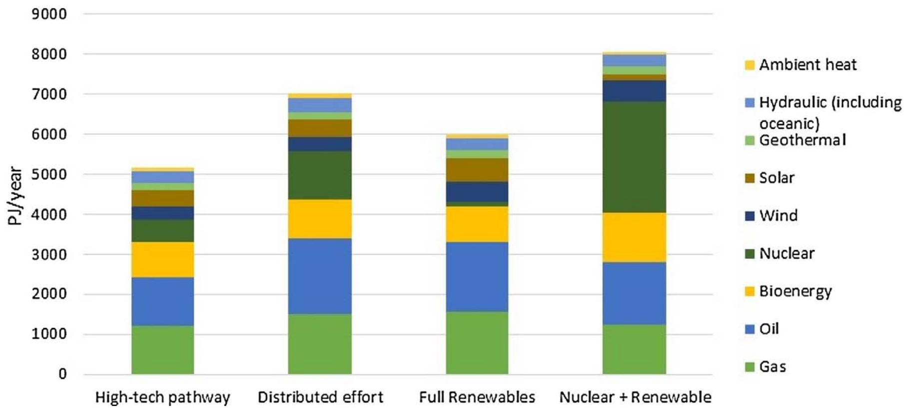

Fig. 3. Primary energy supply by source (2050).
Source: Prepared by the authors, using the Mexico 2050 Calculator.

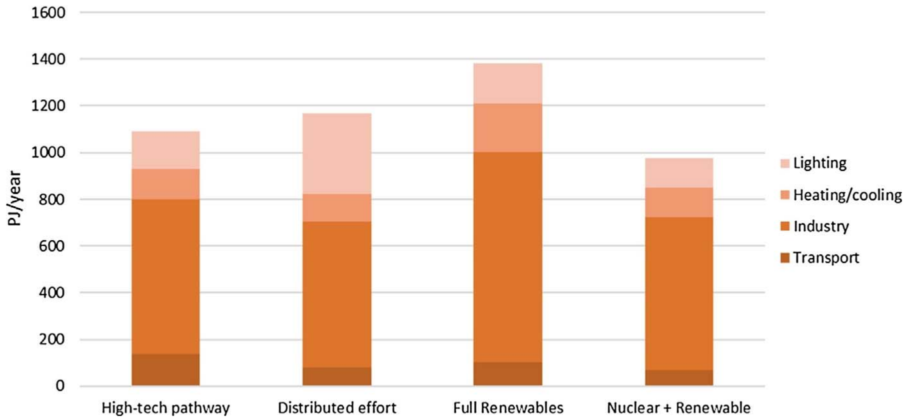

Fig. 4. Electricity Demand (2050).
Source: Prepared by the authors, using the Mexico 2050 Calculator.

Distributed Effort we can observe a balance among solar, geothermal, hydraulic, wind and nuclear energy. *Full Renewables* has a larger contribution from wind and solar energy, while *Nuclear + Renewable* relies mainly on nuclear power, followed by wind and hydropower. The *Full Renewables* scenario observes a small share of conventional sources, and the *High Tech Pathway* scenario contemplates having a very limited amount of electricity based on CCS (Fig. 5), but the amount of fossil sources is not significant.

At the end of the period analyzed (2050), most emissions from economic activities come from combustion processes in all assessed scenarios, which account for 50–84% of all greenhouse gas emissions (Fig. 6). Other sources of emissions are agriculture and industry, with relative weights that depend on each scenario. The first two scenarios (*High Tech Pathway and Distributed Effort*) give more weight to emissions coming from agricultural activities, while the last two (*Full Renewables and Nuclear + Renewable*) are slightly shifted towards industry.

The results reveal that all economic sectors combined should contribute to reach the climate change goals. All scenarios depend on various sectors and subsectors both from the demand and the supply side of the economy to reach the targets (Table 1). Therefore, the Mexican ambitious climate change goals require immediate actions from all agents, either consuming or producing energy, and to stimulate them to innovate processes towards a low carbon economy. From the demand side, actions in cities and transport are likely to have the most significant impact on mitigation, closely followed by actions taken in industry. In *Full Renewables*, industry even surpasses cities and transport in its contribution to reach the 2050 targets. In contrast, no substantial impacts on mitigation at a national level were noted from actions in commerce and public buildings.

From the supply side, climate change policies are spread among agriculture, waste, fossil fuel production and forests. There is a common effort to produce energy from biomass and waste management, whilst also continuing afforestation and reforestation policies. An increase in forestlands could play a major role to attain the Mexican climate goals, which was specially noted in the *Distributed Effort* and *Full Renewables* scenarios. By the end of the assessed period, bioenergy is also able to contribute more significantly to lower emissions.

Power generation from renewables also has a contribution to reduce greenhouse gas emissions, but in a lesser extent, at least in the proposed simulations, except for the Full Renewables Scenario (Table 1). However, renewable energies need to be part of a sustainable long-term strategy. Small-scale renewables, for example, can also help bringing electricity access for all the Mexican

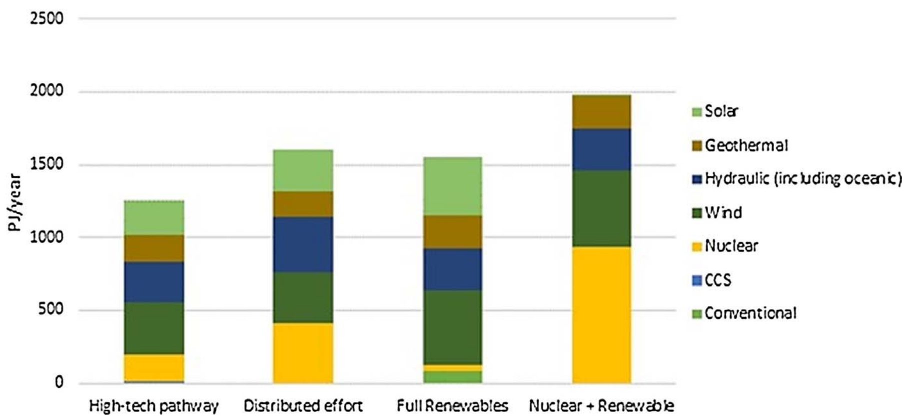

Fig. 5. Electricity Supply (2050).
Source: Prepared by the authors, using the Mexico 2050 Calculator.

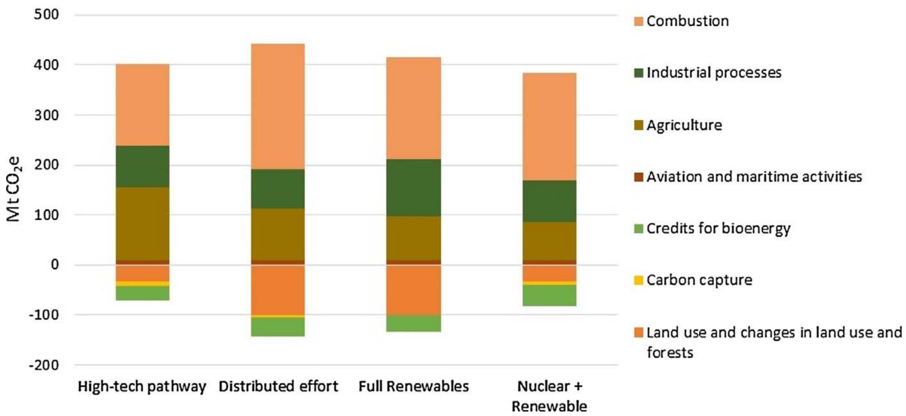

Fig. 6. Greenhouse Gas Emissions (2050).
Source: Prepared by the authors, using the Mexico 2050 Calculator.

Table 1
Sectorial Mitigation Contribution by Scenario.

Scenario	Demand			Supply							
	Cities and transport	Residential	Industry	Nuclear	Fossil electricity	Renewables	Small scale renewables	Agriculture	Waste	Fossil production	Forests
High-tech pathway	20%	9%	14%	2%	6%	6%	0%	8%	13%	13%	9%
Full Renewables	15%	7%	16%	0%	0%	12%	2%	11%	10%	11%	15%
Nuclear + Renewable	15%	9%	14%	12%	0%	0%	0%	17%	12%	11%	9%
Distributed effort	13%	5%	10%	5%	6%	3%	0%	13%	13%	11%	20%
Average	16%	8%	14%	5%	3%	5%	1%	12%	12%	12%	13%

population. With regards to nuclear energy, it could add up to 12% of the mitigation in one of the scenarios (*Nuclear + Renewables*). However, it remains an alternative with low public acceptance.

In summary, the mix of energy sources has to consider a systems plan to maximize the use of different energy forms across all sectors, including heat and electricity, by increasing energy efficiencies not only of equipment and conversion processes, but also of the efficiency provided by a more rational interconnection among different sectors and end uses.

4.1. Sensitivity analysis

Figs. 7 and 8 show the results from the sensitivity analysis for all sectors that have obtained significant reductions in GHG by 2030 and 2050, respectively. Sectors are grouped per color as they were originally grouped into the Mexico 2050 Calculator: cities and transport (blue); residential (purple); industry, public and commercial sector (dark green); nuclear (yellow); carbon capture and storage (black); fossil fuel production (grey); renewable energies (amber); small scale renewables (dark blue); agriculture, bioenergy and food (pink-brown); forests (green) and waste/residues (red). The shades of color shown in each column represent cumulative changes in mitigation potential, from a moderate effort (level 1 to 2, dark shade), to an ambitious effort (level 2 to 3, medium shade) and then to an extremely ambitious effort (level 3 to 4, light shade). Therefore, the full size of each column represents the total potential for an extremely ambitious effort, from level 1 to 4, of a certain lever.

Industrial intensity was revealed to have the largest mitigation impact by both 2030 and 2050, followed by afforestation and waste management in cities, even under a moderate effort. The short-term deployment of solar photovoltaic could have substantial mitigation impact already by 2030, but only if launching very ambitious policies. City and transport altogether also present a substantial potential for reducing greenhouse gas emissions, particularly urban transport systems.

The results from the sensitivity analysis are relatively consistent with the results obtained from the scenarios' assessment, although it shows isolated effects of certain areas and technologies, instead of combined results. Emissions from energy use in different sectors are the main source of greenhouse gas emissions in Mexico and, therefore, the mitigation potential derives mostly from them. However, the results also show a large potential for reducing emissions by adopting more sustainable land use, particularly through afforestation/reforestation policies, as well as by improving waste and sewage treatment nationwide. Waste management affects methane emissions, which has a much higher greenhouse warming potential (GWP) than carbon dioxide, so that its effect is exacerbated in terms of CO_2 equivalent.

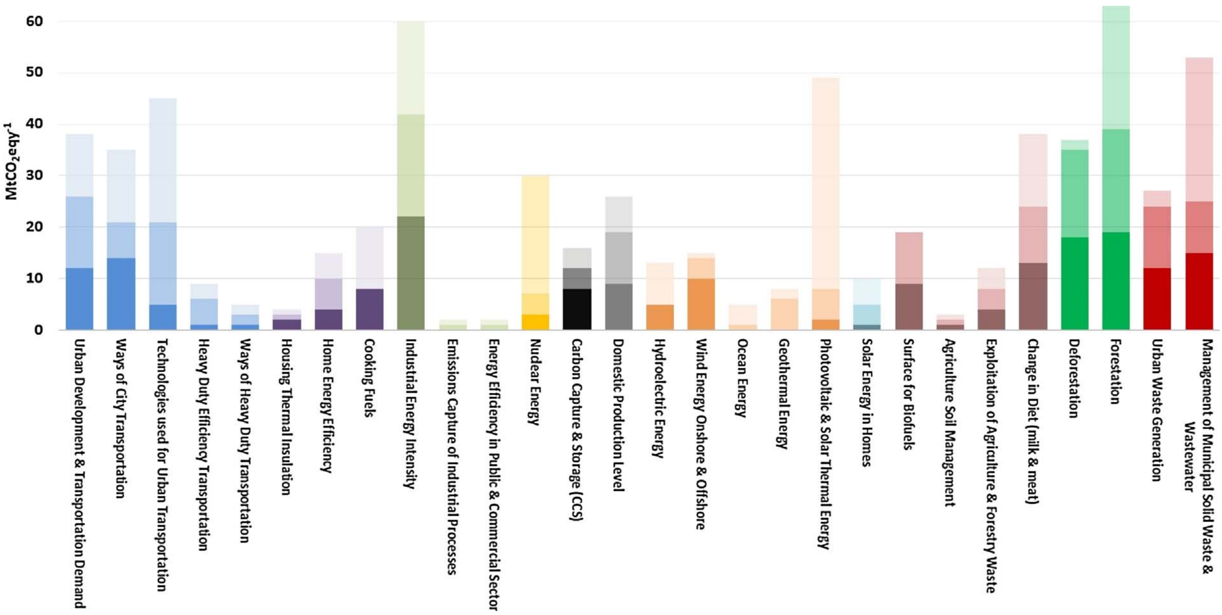

Fig. 7. 2030 GHG mitigation potential per sector in Mexico (sensitivity analysis). (For interpretation of the references to color in the text, the reader is referred to the web version of this article.)
Source: Prepared by the authors, using the Mexico 2050 Calculator.

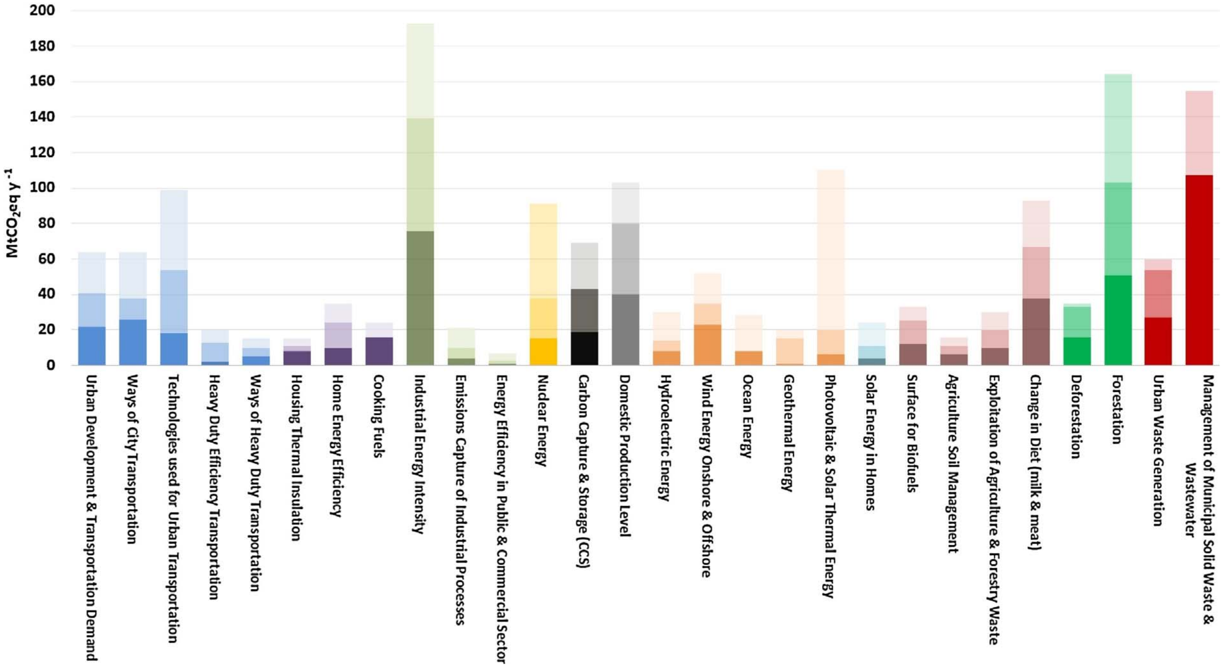

Fig. 8. 2050 GHG mitigation potential per sector in Mexico (sensitivity analysis). (For interpretation of the references to color in the text, the reader is referred to the web version of this article.)
Source: Prepared by the authors, using the Mexico 2050 Calculator.

5. Discussion and policy implications

In recent years, several studies have investigated the feasibility and pathways for medium and long-term CO_2 reduction targets. However, analyses of the policy usefulness of such scenarios have shown that given in-built assumptions and alternative modelling structures, policy-makers are not receiving a sufficiently accurate depiction of available options and trade-offs. Considering the many uncertainties involved in long-term forecasts of energy and carbon dynamics within different sectors of the economy combined, contingency planning under a range of alternative scenarios, particularly under a common goal, become particularly useful for policy-making (Börjeson, Höjer, Dreborg, Ekvall, & Finnveden, 2006; Smil, 2000), specially the identification of trends that appear robust despite scenarios variation.

This paper adopts Mexico 2050 Calculator model as a platform for comparing four alternative 2050 low-carbon energy scenarios for meeting Mexico's 2050 climate commitment recently ratified by the Mexican congress to keep emissions under 320 $MtCO_2eq\ y^{-1}$ by 2050 (a 50% reduction with respect to 2000 levels). Although we recognize the uncertainties of the model, and potential methodological differences for simulating different Mexican energy and climate policies, using the calculator to compare four low-carbon energy 2050 scenarios of reference allowed us to constrain discrepancies of data classification, technological change rates and baseline trajectories and identify commonalities and robust trends.

Our comparative assessment showed that energy demand in 2050 is driven primarily by industry and transport, and that energy from fossil fuels decreases in absolute terms only when including nuclear in a significant way in energy supply. However, 2050 electricity supply can rely almost solely on clean energy sources with the largest share coming from renewables, and electricity demand coming mostly from the industrial sector.

In terms of GHG mitigation, most 2050 emissions will come from combustion processes and all sectors have a role in achieving the mitigation target. From the demand side, industrial efficiency and actions in cities and transport have the most significant impact. From the supply side, mitigation impact is shared between agricultural waste management and forests. Renewable energies could play a key role for heating purposes as well as ending energy poverty in the country. Nuclear plays a limited role in mitigation except for one scenario. Overall findings of the sensitivity analysis show consistency with scenario assessment.

Given that the current energy mix in Mexico is still highly reliant on fossil fuels, and that BAU prospects project Mexico doubling its energy consumption by 2050, achieving the country's 2050 climate commitment would require a substantial ramp-up in renewable energies, energy efficiency, and further legal enforcement. Amongst the most evident needs are the establishment of medium-term energy intensity goals, the development of specific policy instruments and investments in the transport sector, with an emphasis on massive public transportation as well as regulatory policies for power generation and the disposal of municipal solid wastes. Ambitious climate change action would require strong commitment from all economic agents, as well as to rethink production and consumption processes with an increased at-scale implementation starting today. As to existing policies in the country, a higher emphasis should be given to demand-based policy-solutions. In the transport sector, particularly, greater involvement from federal and local authorities is needed. In the industrial sector, policies should go beyond best practices and voluntary agreements. The implementation of an improved version of carbon tax, eliminating distortionary tax rates, or the introduction of a broad and efficient emissions trading system has the advantage of including all major GHG emitters.

Existing low-carbon pathways for countries, in general, include a combination of these three "sine qua non" elements: (i) the ramping-up of energy efficiency in industry; (ii) a new energy system with a higher share of renewable energies in the national primary energy mix, and (iii) further investments on energy efficiency reducing energy consumption at the individual level. Improvements in the transport system, efforts to ensure forest conservation and waste management for climate mitigation, must be included in this formula for the Mexican case.

As to future low-carbon energy scenario assessments in the country, it would be desirable that further assessments analyze specific policy alternatives in regard to viability and cost-effectiveness, considering the political environment and existing institutions, as well as the distributions of benefits and costs amongst societal groups, industrial sectors and geographical regions. The methodology advanced by this paper can be applied, with some adaptations, to countries with similar calculators available, and it may also help inform them to take appropriate policy decisions based on integrated system models and alternative mitigation studies.

The results presented in this paper are subject to many modelling uncertainties that are inherent in the Mexico 2050 Calculator and, therefore, should not be taken as conclusive. On the other hand, the results point out relevant policy directions for climate change mitigation actions, and signalize orders of magnitude of potential carbon emission scenarios and energy trajectories by 2050. For business investments and policy decisions, complementary models should also be considered, as well as market trends, public perception and local environmental constraints. Future updates of the databased used in the calculator and upgrades in the modelling structure and its visual approach could be beneficial to keep increasing its accuracy and reliability, and its contribution to climate policy.

Acknowledgements

The authors acknowledge SENER, Centro Mario Molina, the British Embassy in Mexico, and the former UK Department of Energy and Climate Change (DECC, currently Department of Business, Energy & Industrial Strategies – BEIS) for the availability in public domain of the Mexico 2050 Calculator. Also appreciated were the kind support of Nayeli Mayorga from the British Embassy in Mexico, and Edward Hogg and Laura Aylett from the UK BEIS. Alexandre Strapasson also thanks Jeremy Woods from Imperial College London, Henry Lee, Pinar De Neve and the Giorgio Ruffolo Fellowship program at Harvard University.

Note: Although the Mexico 2050 Calculator was used as an external part of this research, it is worth informing that José Carlos Fernández, co-author of this article, was one of its lead modelers, working in collaboration with Centro Mario Molina and SENER. In addition, Alexandre Strapasson, also co-author of this article, was one of the lead modelers of the Global Calculator and the EULUF model, and also contributed for the development of the FT Calculator, in collaboration with Imperial College London.

Appendix A

The entire Mexico 2050 Calculator model (version 1.5.0), including all calculations for the assessed scenarios, is available online as a Supplementary material. It consists of a MS Excel file made available in public domain by SENER and Centro Mario Molina in full open access. This model is the basis of the calculator's web interface, which is available at: www.calculadoramexico2050.org.

Appendix B

Table B1 includes the description of the levers included in the different categories of the calculator as well as the level selected by the authors under each of the different scenarios.

Table B1
Sector levers and selected levels for the assessed scenarios in the Mexico 2050 Calculator.

Sector	Levers	Levels chosen for each scenario			
		High-tech pathway	Distributed effort	Full renewables	Nuclear + Renewable
Cities and transport	Urban Development & Transport	3	3	4	4
	Ways of City Transportation	4	3	4	3
	Technologies for Urban Transportation	4	3	4	3
	Interurban Passenger Transportation Efficiency	4	3	4	3
	Modal Shift of Interurban Passenger Transportation	4	3	4	3
	Heavy Duty Efficiency Transportation	4	2	3	3
	Ways of Heavy Duty Transportation	4	2	2	2
Residential	Housing Thermal Insulation	3	3	3	4
	Cooling & Heating Efficiency	3	2	4	4
	Residential Energy Efficiency	4	2	4	4
	Cooking Fuels	4	2	4	4
	Firewood Sustainability	4	2	4	3
Industry	Industrial Growth	2	1	2	2
	Industrial Energy Intensity	4	3	4	4
	Emissions Capture of Industrial Processes	4	3	1	4
Commerce, Services & Public Sector	Acclimatization in Commercial & Public Sector	3	3	4	4
	Energy Efficiency in Public & Commercial Sector	3	3	3	4
Nuclear Energy	Nuclear Energy	2	3	1	4
Mitigation for Fossil-Based Power Generation	Electricity from Biomass	1	1	1	1
	Carbon Capture & Storage (CCS)	3	3	1	1
Small-Scale Renewables	Solar Energy in Residences	2	3	4	1
	Solar Water Heaters in Residences	2	3	3	1
Residues	Urban Waste Generation	2	3	2	2
	Management of Municipal Solid Waste & Wastewater	2	3	3	2
Production of Fossil fuels	Domestic Production Level	4	3	4	3
Forestry	Deforestation	2	3	3	2
	Afforestation/Reforestation	2	3	3	2
Energy Balance & Storage	Storage, Distribution Demand & Interconnection	3	3	3	2
Renewable Energies	Wind Energy Onshore & Offshore	3	3	4	4
	Hydroelectricity	3	3	3	3
	Ocean Energy	1	3	1	1
	Geothermal Energy	3	3	4	4
	Photovoltaic & Solar Thermal Energy	3	3	3	1
Agriculture, Bioenergy & Food Consumption	Land for Biofuels	3	3	3	4
	Agriculture Soil Management	2	3	2	4
	Exploitation of Agriculture & Forestry Waste	3	3	4	4
	Change in Diet (milk & meat)	2	3	4	4
	Biofuels from Seaweed	3	3	1	4
General Parameters	Population Growth	3	1	1	1
	Economic Growth	1	1	2	1

References

Börjeson, L., Höjer, M., Dreborg, K. H., Ekvall, T., & Finnveden, G. (2006). Scenario types and techniques: Towards a user's guide. *Futures, 38*(7), 723–739.

CASEDI, & ICC (2016). *Código de Conservación de Energía para las Edificaciones de México 2016*.

DECC–Department of Energy and Climate Change (2016a). *The UK 2050 Calculator. Webtool and supporting documents*. London, UK: DECC Available at: http://classic.2050.org.uk (8 August 2016).

DECC (2016b). *The 2050 Calculators: A fresh approach to modelling energy and emissions–Completed calculators.* Available at: http://www.2050.org.uk (22 October 2016).

DECC (2016c). *The 2050 Calculator: A fresh approach to modelling energy and emissions.* London, UK: DECC Available at: http://www.2050.org.uk (8 August 2016).

Devezas, T., LePoire, D., Matias, J. C., & Silva, A. M. (2008). Energy scenarios: Toward a new energy paradigm. *Futures, 40*(1), 1–16.

DOF (2013). DECRETO por el que se reforman y adicionan diversas disposiciones de la Constitución Política de los Estados Unidos Mexicanos, en Materia de Energía. Diario Oficial de la Federación. 20 de diciembre de 2013. México. Available at: http://www.dof.gob.mx/nota_detalle.php?codigo=5327463&fecha=20/12/2013.

Dowlatadabi, H. (1994). Integrated assessment of climate change: An incomplete overview. In N. Nakicenovic, W. D. Dordhaus, R. Richels, & F. L. Toth (Eds.). *Integrative assessment of mitigation, impacts, and adaptation to climate change* [IASA Collaborative Paper.

FT–Financial Times (2016). *What is at stake at the Paris climate change conference? FT calculator's webtool* Available at: http://ig.ft.com/sites/climate-change-calculator (8 August 2016).

Forrester, J. W. (2013). *Industrial dynamics. Reprint of 1961 first edition. Martino fine books* Eastford, CT, United States. 482 p.

GFLAC (2015). *Transparencia presupuestaria: Clave para una política efectiva de adaptación y mitigación del cambio climático. Presupuesto Climático 2015.* Grupo de Financiamiento Climático de América Latina y el Caribe. México, D.F.

IPCC–Intergovernmental Panel on Climate Change (2014). *Climate change 2014 mitigation of climate change. Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. New York, NY: Cambridge University Pres.

IRENA (2015). Renewable Energy Capacity Statistics. Available at: http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Capacity_Statistics_2015.pdf.

IMCO (2013). Índice de Presupuestos Verdes. Instituto Mexicano para la Competitividad, funded by the United States Agency for International Development. Mexico City, Mexico. Available at: http://imco.org.mx/wp-content/uploads/2013/06/IPV-Informe-Final-USAID.pdf.

Kelly, D. L., & Kolstad, C. D. (1998). *Integrated assessment models for climate change control.* Working paper.

Loulou, R., Remne, U., Kanudia, A., Lehtila, A., & Goldstein, G. (2005). *Documentation for the TIMES model – PART I.* 1–78.

México - Gobierno de la República (2015). *Intended Nationally Determined Contribution. Official document of the mexican government submitted to the UNFCCC on 30th march 2015* Available at: http://www4.unfccc.int/submissions/INDC (22 October 2016).

Ockwell, D. G., Watson, J., McKerron, G., Pal, P., & Yamin, F. (2008). Key policy considerations for facilitating low carbon technology transfer to developing countries. *Energy Policy, 36*(11), 4104–4115.

SEGOB–Secretaría de Gobernación (2016). *Proyecciones de la Población 2010–2050: Datos de Proyecciones.* Mexico City, Mexico: SEOB Available at: http://www.conapo.gob.mx/es/CONAPO/Proyecciones_Datos (22 October 2016).

SENER–Secretaría de Energía, & Centro Mario Molina (2016). *Calculadora México 2050: Futuros energéticos y climáticos. Webtool and supporting documents* Available at: http://www.calculadoramexico2050.org (8 August 2016).

Smil, V. (2000). Perils of long-range energy forecasting: Reflections on looking far ahead. *Technological Forecasting and Social Change, 65*(3), 251–264.

Söderholm, P., Hildingsson, R., Johansson, B., Khan, J., & Wilhelmsson, B. (2011). Governing the transition to low-carbon futures: A critical survey of energy scenarios for 2050. *Futures, 43*(10), 1105–1116.

Strachan, N., Pye, S., & Kannan, R. (2009). The iterative contribution and relevance of modelling to UK energy policy. *Energy Policy, 37/3*, 850–860.

Strapasson, A., Woods, J., & Mbuk, K. (2016). *Land Use Futures in Europe: How changes in diet, agricultural practices, and forestlands could help reduce greenhouse gas emissions. Grantham institute's briefing Paper no. 17*. UK: Imperial College London 16p. Available at: https://www.imperial.ac.uk/grantham/publications [8 Aug 2016].

Strapasson, A., Woods, J., Chum, H., Kalas, N., Shah, N., & Rosillo-Calle, F. (2017). On the global limits of bioenergy and land use for climate change mitigation. *Global Change Biology Bioenergy*. http://dx.doi.org/10.1111/gcbb.12456.

Tovilla, J., Buira, D., Barthélemy, P., & Spinazzé, L. (2015). *Pathways to deep decarbonization in Mexico. Sustainable Development Solutions Network (SDSN) and Institute for Sustainable Development and International Relations (IDDRI)* Available at: https://www.deepdecarbonization.orhttp://deepdecarbonization.org/countries/#mexico (18 August 2016).

Ulrich, N., Zündorf, A., & Jubeh, R. (2013). *Story driven modeling* (1st ed.). United States: CreateSpace Independent Publishing Platform 348 p.

Voinov, A. (2008). *Systems science and modeling for ecological economics.* San Diego, CA, United States: Elsevier, Academic Press 416 p.

WWF-México (2013). Reporte México sobre las Energías Renovables 2050. WWF-México.