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Mexican Power System to 2050: Sustainability Assessment with an Energy Model

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Renewable energies have converted one of the most viable option to promote development and growth in a sustainable way. Mexico is considered as a diverse country, has abundant renewable energy resources that support the country's ambitions to decarbonize its power system. In particular, electricity generation in Mexico is dominated by natural gas, which has gradually replaced by fuel oil as the main fuel. At the end of 2017, 329,162 GWh of electricity were generated, of which 78.9% produced with conventional technologies (fossil fuel) and the remaining 21.1% with clean technologies. According to the Mexican National Inventory of Gas Emissions and Greenhouse Compounds, electricity production contributes with 25.9% of national emissions due to the burning of fossil fuels. Mexico has made commitments that it will face in order to move towards a low-carbon economy, both the inclusion of clean energy and the adaptation and mitigation of climate change.
Due to the current situation, there is a need for a tool that allows flexible evaluation of the evolution of the Mexican Power System (MPS). In the present work, an MPS-energy model from 2017 to 2050 (SEN-50) is developed which was structured in the Low Emissions Analysis Platform (LEAP) program. The SEN-50 is a computational tool that allows evaluating scenarios considering energy policies, economic development, population growth, new technologies and greenhouse gases (GHG) emissions impact. The SEN-50 model optimizes and estimates the growth in electricity demand by sector (residential, agricultural, industrial, services, commerce, and transportation) and shows a mix of technologies to reduce CO_2 emissions from the power sector to 50% by 2050 considering the potential of renewable resources, technological advance and future costs. The SEN-50 results it also shows that is possible the GHG reduction, renewables penetration and economic growth of power system for sustainable development in Mexico to 2050.

1. Introduction

Human influence on climate change is unequivocal, anthropogenic GHG emissions are becoming higher due economic and demographic growth (IPCC, 2014). According to the International Energy Agency (IEA), energy sector represents more than 80% of carbon dioxide (CO_2e) emissions worldwide and these emissions will continue increasing every year. It means that electricity sector generates almost two thirds of total world growth. According to IEA, in 2016, global CO_2 emissions from burning fossil fuels reached 32 Gt CO_2 (IEA, 2018).
The United Nations 2030 Agenda for Sustainable Development and its Sustainable Development Goals (SDGs) convoke all countries to take urgent actions to combat climate change and its effects. Guarantee access to affordable, safe, sustainable and modern energy are fundamental in the SDGs. In the Conference of the Parties (COP 21) held in Paris in 2015, several countries committed to significantly reduce their GHG emissions to a level of not increasing the planet's temperature above 2°C. The parties should adopt internal mitigation measures, in order to achieve the objectives (UN, 2015).
As part of efforts to regulate emissions of GHG and compounds (its precursors and particles that absorb and emit infrared radiation in the atmosphere), the General Law on Climate Change (GLCC) entered into force in

2012, with the aim of establishing the basis for Mexico to contribute to compliance with the Paris Agreement. The function of the GLCC is to regulate, promote and incorporate adaptation and mitigation actions with a long-term focus, it also defines the obligations of the authorities as well as establishes institutional mechanisms to face the challenge (SEGOB, 2012). It is essential to design and implement public policy instruments to strengthen the GLCC to meet the objectives. One of the planning instruments is the National Climate Change Strategy (NCCS) vision 10-20-40 (SEMARNAT, 2013) which describes the lines of action to be followed based on the available information of the present and future environment, to meet national priorities and achieve the country's long-term goals. The general objective of this reform was to provide a more sustainable, efficient, transparent and productive energy sector, to increase the benefits obtained from the country's resources, while promoting the growth of low-carbon energy sources (IEA, 2016). The Mexican electricity system change from monopoly model (handled by Federal Electricity Commission) to opened private investment, allowing competition in the generation and marketing segments. Mexico has made an international commitment to reduce 22% of its GHG emissions by 2030, which could rise to 36% in the case of receives international support (SEGOB, 2014).

At the National Autonomous University of Mexico (UNAM) a study was carried out to evaluate the environmental future of Mexico until the year 2025 in terms of GHG through three scenarios. The first scenario emphasizes the use of petroleum derivatives, mainly fuel oil; in the second, the use of natural gas predominates; and the third scenario evaluates the high participation of renewable energies, mainly considering the technical and economic feasibility. Among their results, they were able to forecast, through the Low Emissions Analysis Platform (LEAP) tool, that the scenario that prioritizes renewable energies is the most favorable, since emissions reduce 32% compared to the first scenario and 19% compared with scenario two (Manzini, Islas, & Martínez, 2001).

Years later, it was used in a mathematical model developed at the Electrical Research Institute in collaboration with specialists from UNAM and the National Institute of Ecology, with the purpose of evaluating technological options to mitigate GHG emissions in the SEN through two scenarios: one using nuclear energy and fossil fuels with CO2 capture and storage technologies and the other using renewable energy sources. In the first scenario, emissions were reduced, however, the risk from the use of nuclear energy and dependence on fossil fuels must be considered. In the second scenario, an electricity sector with zero emissions and without dependence on fossil fuels was achieved, however, the large areas of land for solar and wind power plants must be taken into account, as well as the intermittency of renewable energies (Castrejón, 2012).

The paper objective is to evaluate technological scenarios to reduce GHG emissions in the power sector to 2050, based on GLCC targets and renewable technologies deployment, involving all participants in the new organization scheme, as well as considering the measures of mitigation actions and adaptation to climate change.

1.1 Mexican Power System

The National Power System (SEN, in Spanish) is a key component of the energy sector that involves the generation, transmission, distribution and commercialization of electricity. Today in Mexico, only the electricity could be produced from public and private sectors. The electricity demand has grown more than doubled in the last twenty years, but consumption per capita is relatively low, compared with world demand. According to data from the National Electric System Development Program, in 2017 per capita electricity consumption was 2,295 kilowatt-hours per person (kWh/p) (SENER, 2018a). The electricity generation is dominated by natural gas, which has replaced fuel oil as the main fuel (IEA, 2016).
According to the National Inventory of Gas Emissions and Greenhouse Compounds (INEGyCEI, in Spanish), electricity production contributes with 25.9% of national emissions due to the burning of fossil fuels, which mainly release carbon dioxide (CO_2), as well as methane (CH_4) and nitrous oxide (N_2O) depending of the characteristics of the fuels, the technology used and the reduction measures. In this sense, there is a great challenge in the electricity sector (INECC, 2018).

1.2 GHG emission commitments

The Mexico government goal due international agreements was to reduce GHG emissions by 22% by 2030 against a baseline; this mitigation is equivalent to 210 Mt CO_2e. Specifically, the electricity generation sector could contribute a reduction of 63 Mt CO_2e, that is, 31% of its emissions, around a third of the unconditional national goal (INECC, 2018).
The GLCC recognizes the potential of the electricity sector to contribute to the mitigation of climate change. Therefore, it promotes energy efficiency practices and the use of renewable energy sources for electricity

generation. It also points out the importance of developing incentives for both public and private investment in the generation of electrical energy from renewable sources and the inclusion of the costs of social and environmental externalities. The NCCS aims to accelerate the energy transition towards clean energy sources, by replacing fossil fuels, strengthening regulatory, institutional and economic schemes and minimizing environmental and social impacts (SEMARNAT, 2013). The Energy Transition Law promotes and generates incentive planning instruments for the execution of renewable energy projects in Mexico (SEGOB, 2015)

2. Materials and Methods

The Mexican Power System Energy Model (SEN-50) proposed was developed using the software Low Emissions Analysis Platform (LEAP), a computational tool that allows evaluating scenarios of energy policy, economic development, population growth, technological progress and GHG emissions impact. The model was developed using historical data (2013 to 2017) of the Mexican electricity demands per capita and it can be used to evaluate the behaviour of the SEN from 2017 to 2050. The SEN-50 operates under a hierarchical structure of the country's final energy consumption according to the National Energy Balance (SENER, 2017). The model structure consists of four main modules: user variables, demand, transformation, and resources, which represent the integration of the transformation and electricity consumption sectors. Optimization calculations in LEAP work through integration with the Open Source Energy Modelling System (OSeMOSYS) (Figure 1).

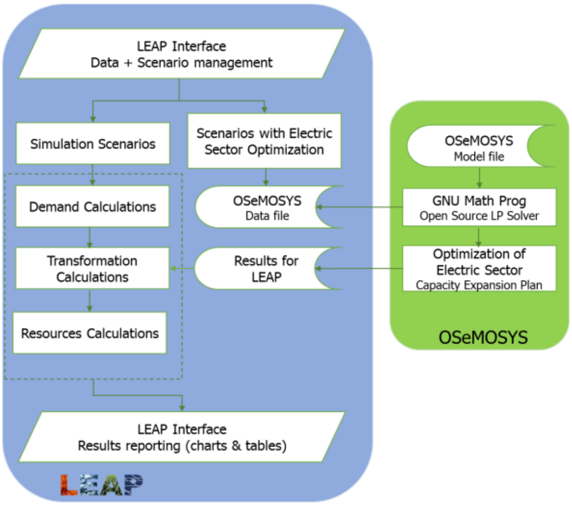

Figure 1: Interface LEAP – OSeMOSYS (Howells, et al., 2011).

The SEN-50 considers the electricity demand as a function of population growth based on electricity generation technologies (Table 1). The electricity generation processes include 13 different technologies; these technologies can be classified in two main groups: clean and fossils.

The electricity generation considers historical information on installed capacity and electricity production by type of technology in accordance with the PRODESEN reports (SENER, 2018a) and the prospects for the electricity sector published annually (SENER, 2018b). The technologies were characterized according to its lifetime, maximum availability, efficiency, the investment cost, and the fixed and variable operation and maintenance costs (CFE, 2015).

The SEN-50 model considers population growth as a function to determine electricity demand. Official sources from the National Population Council (CONAPO) (CONAPO, 2016) and United Nations (UN) World Population Prospects were used, based on probabilistic projections of total fertility and life expectancy at birth (UN, 2017). The UN methodology for estimating the population and its prospects presents a low fertility model (LVF) and another with constant growth (CVF). Two per capita consumption scenarios are considered: 1) 2.0 MWh, based on the average consumption of the period 2000 to 2015 in Mexico and 2) 4.0 MWh, considering the consumption of some developed countries during 2015 (according to data reported by the IEA (IEA, 2016)).

Table 1: Power technologies. (Adapted from SENER, 2018a).

Technology	Efficiency	Maximum availability	Capital cost	O&M fixed cost	O&M variable cost	Life time
	%	%	US$/kW	US$/kW	US$/kW	years
Combine cycle	46	56	1,013.2	19.0	3.3	40
Thermoelectric	30	33	2,045.1	35.8	3.0	30
Carboelectric	39	61	1,425.5	33.8	2.4	40
Gas turbine	23	23	813.2	5.1	4.8	30
Internal combustion	31	10	2,877.3	46.4	5.2	25
Fluidized bed	38	85	1,438.0	35.0	3.0	40
Hydro	-	40	1,931.2	24.4	-	60
Wind	-	27	1,423.0	38.1	-	25
Geothermal	-	73	1,889.6	105.1	0.1	30
Solar	-	16	1,197.5	10.7	-	30
Bioenergy	13	21	2,810.0	34.0	3.0	30
Nuclear	34	77	3,988.5	101.1	2.4	60

3. Results and Discussion

According to the selected population models, CONAPO estimates that the population in Mexico will be 148,134,871 people in 2050. The projections of the world population of the UN under the LVF scenario estimates that by 2050 the population will be 134,123,000 people, while the CVF scenario will be 180,776,000 inhabitants (Figure 2).

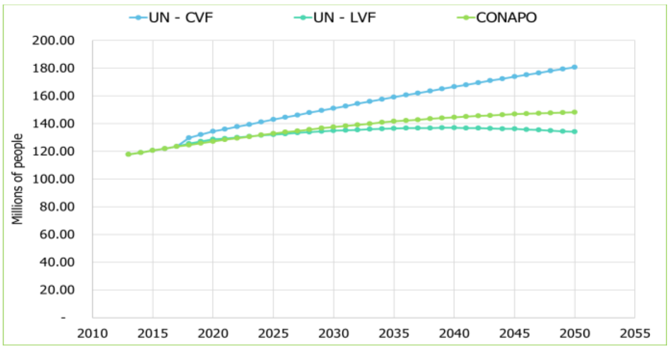

Figure 2: Population growth projections in Mexico.

According to the population models of CONAPO and the UN described above, and the per capita consumption taken from the IEA, it was possible to estimate the expected demand for electrical energy by 2050 (Figure 3). According to the IEA, electricity demand in Mexico will grow at an annual rate of 2.4% in 2040, reaching 459 TWh (IEA, 2016). The IEA projections are within the range of the expected demands of the SEN-50 model.

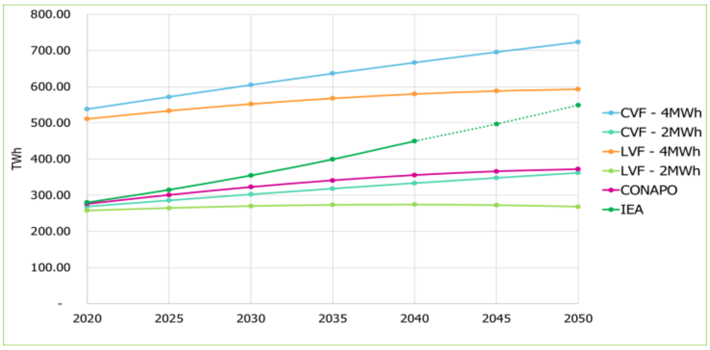

Figure 3: Projections of electricity demand to 2050 in Mexico.

The Figure 4 and 5 show the projection of installed capacity and electricity generation. The IEA forecasts that the installed capacity for electricity generation in Mexico will be 161 GW in 2040 (Figure 4). It also makes an evaluation of electricity generation; its results show that to satisfy demand it will be necessary to produce 518 TWh in 2040 (Figure 5).

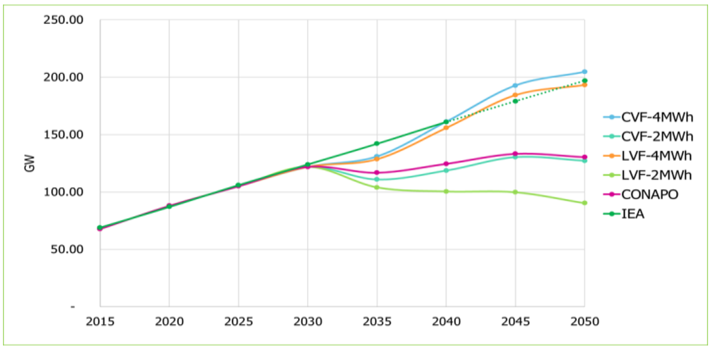

Figure 4: Projections of installed capacity to the year 2050 in Mexico.

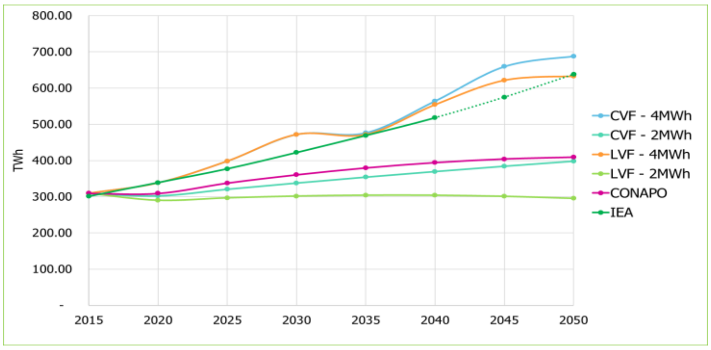

Figure 5: Electric power generation projections for the year 2050 in Mexico.

The results of the SEN-50 model and making a comparison with the IEA model, it can be seen that its estimates approximate the values obtained in the scenarios with high electricity consumption per capita. Regarding the analysis of emissions, the baseline of the annual report of GHG mitigation potential in the electricity sector was considered. This trend scenario is a reasonable projection of the emissions that would occur in the absence of climate change mitigation actions. According to the NCCS, mitigation actions seek to transform the electrical matrix, increase the participation of clean technologies and use fossil resources more efficiently. The NCCS scenario (Figure 6) reflects the fulfillment of the GHG reduction goals of 30% by 2030 and 50% by 2050.

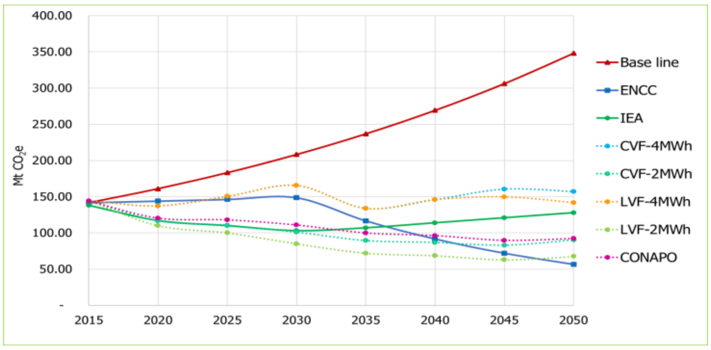

Figure 6: GHG mitigation in the SEN by 2050 in Mexico.

It is important to mention that, according to the SEN-50 model, the scenario that managed to mitigate the most GHG emissions was the LVF-2MWh scenario, in which mitigation reduced 280 Mt CO_2e, followed by CVF-2Wh with a decrease of 258 Mt CO_2e, while the high consumption scenarios (4MWh/per capita) only managed to reduce 190 Mt CO_2e with constant population growth and 206 Mt CO_2e with low population growth.

4. Conclusions

The model developed in this study is a contribution to the energy analysis and planning capabilities in Mexico to 2050. Proposed model satisfactory defines energy scenarios to satisfy electricity demand. In each analysed scenario, it was possible to estimate the expected electricity demand to 2050, by analysing the behaviour of population growth as an indicator of the evolution of electricity consumption and technologies including GHG emissions obtained from each scenario. Also, the GLCC proposals are met, which in turn comply with international agreements on climate change mitigation.

These details make the SEN-50 model a novel and useful energy tool that represents the electricity generation sector in Mexico. The model will continue to be developed to broaden its analytical capabilities, evaluate macroeconomic values, disaggregate demand by sector, add new technologies, and evaluate the social impact of the sector.

Acknowledgments

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