Mexico's Transition to a Net-Zero Emissions Energy System: Near Term Implications of Long Term Stringent Climate Targets

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Key messages

- Our modelling suggests that deep decarbonisation of Mexico's power system to 2050 is techno-economically feasible and cost-optimal through renewables
- An over-investment in gas infrastructure in the next 15 years may delay the power sector's transition to lower carbon sources and put at risk either meeting carbon targets cost-effectively or leaving some gas assets stranded
- A novel TIMES energy systems model for Mexico has been used to explore the implications of a whole energy system decarbonisation on the power sector, considering energy efficient technologies in end-use sectors; these results have been used as input to the Balmorel-Mexico model to simulate our scenarios.

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1 Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) 21st Conference of the Parties (COP), celebrated in Paris in 2015, resulted in a climate change agreement to achieve global emission reductions in order to keep climate change well below 2 °C above pre-industrial levels, with the aim of limiting it to as close to 1.5 °C as possible (UNFCCC 2015). The agreement also pledges a ‘net-zero’ emissions energy system by 2100. While the long-term aim is highly ambitious, the current short-term pledges are less demanding up to 2030. There has been a small number of analyses on the Intended Nationally Determined Contributions (INDCs), mostly conducted in the months prior to the Paris agreement, using the commitments of the major emitters and those who had already submitted their INDCs (IPCC 2014; Fawcett et al. 2015; Boyd et al. 2015; Admiraal et al. 2015; Ekholm and Lindroos 2015). These analyses suggest the INDCs effort puts the average global temperature increase on a course to somewhere between 2.7 and 3.7 °C by the end of the century. While the INDCs are a useful interim step towards decarbonisation, the international community recognises the need to increase these ambitions in order to achieve Paris long-term goals. Mexico’s contribution to global GHG emissions is below 2% (Federal Government of Mexico 2015); however, Mexico is considered to be highly vulnerable to the negative impacts of climate change (Federal Government of Mexico 2013a, b). It is therefore in Mexico’s interest to show leadership and commitment towards climate change mitigation targets. This is a significant challenge, since Mexico is an emerging country and reducing emissions without jeopardizing socio-economic growth and competitiveness will require international collaboration, political commitment, a broad consensus across sectors and significant capital investments in order to transform energy production and consumption; including increased electrification in end-use sectors, and for this electricity to be supplied by clean sources. All these goals also have implications on the way electricity is transmitted. According to the National Electric System Development Programme (PRODESEN) (Secretaría de Energía 2017) developed by Mexico’s Ministry of Energy (SENER), in Mexico 79.7% of the electricity is generated by fossil fuel power plants, and about 54.2% of the total electricity in 2016 is based on natural gas. The projections in PRODESEN (2017) suggest that the investment required in the power sector for generation, transmission and distribution projects over the next 15 years is USD 105 billion. Most of this investment (81%) will be allocated to power generation projects, of which 37.8% will come from conventional technologies (21.6 GW) and 62.2% from clean technologies (35.5 GW). There is a global debate around the role of natural gas as a fuel bridge to a cleaner energy system. Natural gas may replace more polluting fossil fuels-based generation and provide support to an increasing share of variable renewables; however, the emission factor of any gas technology is higher than the average carbon intensity of the grid needed, for a well below 2 °C global target to be reached, unless carbon capture and storage becomes commercially available. The risk of stranded natural gas assets may increase further under deep decarbonisation policies without the commercial availability of CCS, or if energy system end-use sectors, fall short in their contribution to decarbonisation. Therefore, public decision makers and private sector investors would do well to consider the consequences of ambitious long-term decarbonisation pathways to increase the carbon risk resilience of their natural gas-based assets. Making investment decisions based on moderate INDC ambitions to 2030, that reflect an inadequate long-term ambition, could lead to poor investment choices in energy infrastructure (Pye et al. 2017). In this chapter, we explore the near-term implications of increasing climate policy ambitions in 2050 to better understand the extent to which power sector investments may lead to technological lock-in, or remain consistent with long-term stringent climate targets. This study will consider the whole energy system but focus on the electricity sector implications since, after transport, this is the largest contributor to emissions in Mexico; and given its key role as enabler for the decarbonisation of end-use sectors, which are considered to be more difficult to decarbonise than the power sector.

2 Mexico's Climate Policies and Energy Reform

Mexico was the first developing country to publish a Climate Change Law with stringent mitigation targets to 2050. Mexico's GHG emissions targets are stated in the General Law on Climate Change (DOF 2012), in the National Strategy on Climate Change (Federal Government of Mexico 2013a, b) and in the Intended Nationally Determined Contributions (INDC) (Federal Government of Mexico 2015) presented to the United Nations Framework Convention on Climate Change (UNFCCC) as part of the preparations for the Paris Agreement (UNFCCC 2015). To achieve these ambitious targets, the transformation of the electricity sector and an increase in renewables in the system are crucial. The renewable energy market in Mexico is shaped by the General Climate Change Law, which published Mexico's intent to increase electricity generated from clean energy sources, including efficient co-generation and nuclear energy, to 35% by 2024 and to 50% by 2050. The country approved in 2014 an Energy Reform bill whose main drivers are to boost domestic oil and gas production and to decrease electricity production costs (Federal Government of Mexico 2013a, b). However, the energy reform was not only designed for the oil and gas sector; it was also created to liberalise the electricity generation market and open future development to private firms, thereby creating competition among energy producers. The reform package created an independent grid operator (CENACE), which controls a new, wholesale market and enables customers to purchase power directly from generators. The creation of CENACE has established an independent power producer (IPP) market for the first time in Mexico. In order to comply with national goals of sustainable development and emissions reduction outlined in Mexico's General Climate Change Law, the Mexican Government created Clean Energy Certificates (CELs). Mexico's Energy Regulatory Commission (CRE) administers the system known as DECLARACEL, which grants a CEL per each MWh of electricity produced by a generator using clean energy technologies. Large consumers of electricity, mainly industrial and commercial, also known as Qualified Consumers, are required to consume electricity generated from clean energy sources. The requirements will begin in 2018 with a five percent share gradually increasing over the next few years to 30% by 2021 and 35% by 2024. Large consumers of electricity will obtain the CELs they need to comply with this requirement from Qualified Service Suppliers and they will apply the DECLARACEL system to submit these certificates and thereby avoid sanctions. The Mexican Government has also introduced long-term auctions to provide new and existing clean electricity generation projects with a certain return on investment for 15–20 years. The main objectives of the long-term auctions are to attract investment, promote competition amongst all technologies, and ensure efficiency for the buyer. This new regulatory environment has resulted in increased investment during the second power auction held in Mexico in 2016, contracting 8.9 TWh of power, mostly wind and solar (CENACE 2016) at an average tender price of $33.5/MWh, a wind price of $32/MWh and a solar price of $27/MWh. These prices compare favourably with results from auctions which took place in other countries over the past few years, in particular on solar prices. A decline can also be observed in onshore wind auction prices, although not as steeply as for solar PV. According to the IEA (2017), over the period 2017–22 global average generation costs are expected to further decline for solar PV by 25 and 15% for onshore wind.

3 Decarbonisation Pathways to 2050: What Do Other Studies Say?

In recent years, there have been a number of studies that explored different decarbonisation pathways for Mexico using a wide range of models. Studies point to an important mitigation potential in the country, with a wide variety of pathways available for Mexico's energy system transition. Tovilla and Buira (2015) explored deep decarbonisation pathways towards 2050 based on the 2050 Energy and Emissions Calculator model for Mexico. This study explored three scenarios: central, no CCS and limited CCS, concluding that deep decarbonisation pathways are feasible with increased energy efficiency in all sectors, CCS, zero emission vehicles, energy storage technologies and smart grids. Elizondo et al. (2017) modelled a number of low-carbon scenarios using the same tool to assess current energy policy strategies. The assessment found that industrial efficiency, cities and transport have the largest GHG emissions mitigation impact. In Mexico's Climate Change Mid-Century Strategy (2016) the Government carried out a modelling exercise using the EPPA Model and Balmorel to evaluate two scenarios; one considering unconditioned NDC emissions reduction goal of 22% reductions from baseline by 2030, with the goal of 50% reduction by 2050. The second scenario explores a more ambitious policy of 36% reduction by 2030 with additional policies agreed at the regional level with USA and Canada. In both models renewable energy plays an important role as well as cogeneration and natural gas technologies. The CLIMACAP-LAMP project (Veysey et al. 2016) undertook a cross-modelling exercise which included a wide-range of modelling techniques such as general equilibrium models, energy systems models and market equilibrium models. This exercise involved three scenarios: current energy and climate policies, 50% GHG emissions abatement by 2050 and 50% abatement of fossil fuels and industry. Results from the six models involved, showed different decarbonisation pathways, but shared common decarbonised electricity supply and mitigation actions in the transport sector. Using IEA's World Energy model, Mexico's Energy Outlook (IEA 2016) also shows a strong reduction in the GHG emissions intensity of the power sector in their new policies scenario, with solar PV and wind accounting for half of capacity additions over the period to 2040. As far as we are aware, the only study that has explored increased climate ambition scenarios to 2050 beyond targets existing in current national policy using an optimisation model is the Balmorel model-based analysis carried out by Togeby and Dupont (2016). Three high CO_2 price scenarios where modelled in myopic mode, resulting in decreased emissions (20–50%) from the electricity sector at an additional cost of up to 11% in the most ambitious scenario. It is worth noting that some of the tools used in these studies may not have a detailed enough representation of Mexico's energy system due to their global or top-down nature, and some of the pathways described in the studies may not necessarily be cost-optimal, given the accounting nature of some of the tools used. However, these exercises are indicative of the size of the challenge and contribute to our understanding of the trade-offs and energy-economy-environment dynamics of different pathways. These studies are also in general agreement with the proposed short-term steps to limit warming to 1.5 °C (Climate Action Tracker 2016). In terms of the electricity sector, this study highlights the need to develop a power system consisting largely of renewables and other zero and low carbon sources, with rapid and sustained growth in the coming decade. It also suggests that no new coal-fired power plant can be built and that fossil fuels should incur externalities and these ought to be included in the cost/price of electricity. Additionally, it recommends higher electrification in the transport, industrial and residential sectors to reduce GHG emissions.

4 Methodology and Scenarios

We have used two soft-linked models in this chapter: an energy systems optimisation model (TIMES MX-Regional) and a power systems model (Balmorel-Mexico), both commissioned by SENER; the former was developed in collaboration with University College London (UCL) and the latter with the Technical University of Denmark (DTU). While the energy systems optimisation model includes a representation of the power sector, it does not have the spatial and temporal disaggregation of a power systems model which is better placed to find the optimal dispatch of variable renewable sources such as wind and solar. On the other hand, the power systems model does not have the bottom-up, technology-rich sectorial detail of an energy systems model to better understand how different decarbonisation pathways and their related uptake of low-carbon technologies may impact electricity generation. TIMES (an acronym for The Integrated MARKAL-EFOM System) is a bottom-up, least cost optimisation, techno-economic, partial equilibrium model generator for local, national or multi-regional energy systems (Loulou et al. 2005). The TIMES MX-Regional model (TMXR) (Solano-Rodriguez 2017) represents Mexico's energy system tracking energy flows, greenhouse gas emissions (carbon dioxide, methane and nitrous oxide) and related costs from resource supply through conversion and distribution to end-use demands. As a partial equilibrium energy system and technologically detailed model, it is well suited to investigate the techno-economic, trade-offs between long-term divergent decarbonisation scenarios. The model represents the energy systems of 5 Mexican regions; each region is described and modelled to include its supply sector (fuel mining, primary and secondary production, exogenous import and export), its power generation sector and its demand sectors (residential, commercial, industrial, agriculture and transport). Balmorel-Mexico is a partial equilibrium model, with perfectly competitive markets, that allows the simultaneous optimisation of investments and power dispatch, including transmission capacity, with a high detail of spatial and temporal resolution (more information on the Balmorel platform at www.balmorel.com). Technologies are modelled as unique plants, without any aggregation. The model is deterministic and assumes full foresight, and refurbishments or shutdown of existing capacity can be part of the investment options. All information is available for the optimisation in Balmorel, e.g. hourly demand, hydro inflow, wind and solar profiles. Also, the availability of power plants is known. The Balmorel-Mexico model includes 53 regions, which are interconnected through power transmission lines (Fig. 1).

The soft-link approach is summarised as follows:

(1) The total electricity demand, as well as consumption of fossil fuels and biomass for power generation are endogenously calculated by the TMXR model under different decarbonisation scenarios.
(2) The consumption of fossil fuels and biomass calculated from TMXR is set as an upper boundary limit in the Balmorel model; this consumption is consistent with the contribution of the power sector to achieve the decarbonisation target imposed on the whole energy system.
(3) The electricity demand in Balmorel is exogenously defined as the electricity demand calculated by TMXR but disaggregated geographically to the 53 regions of Balmorel, according to the allocation factors defined in PRODESEN (2017), which evolve between years.
(4) Resulting from this approach, Balmorel shows the optimal investment made in the power system portfolio subject to the same emission constraints as TMXR.

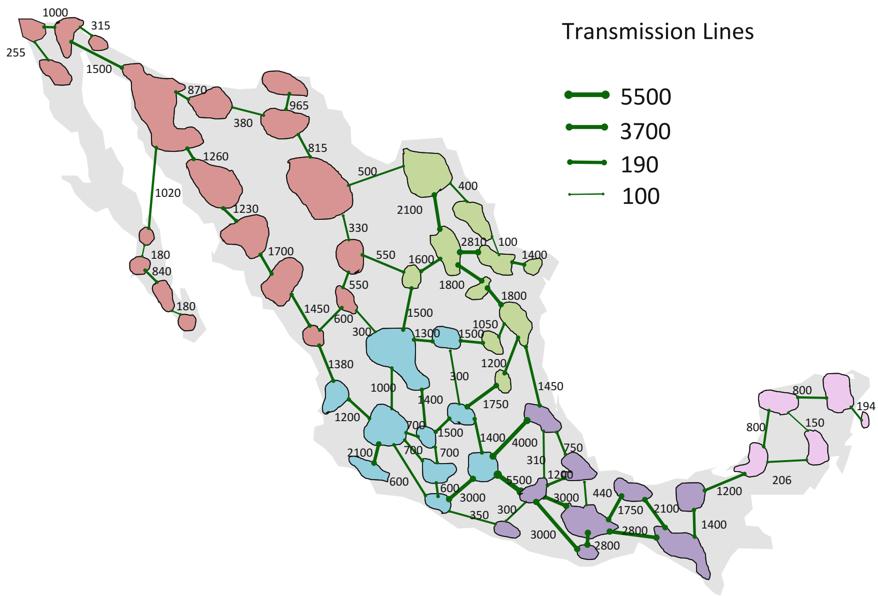


Fig. 1 Power transmission lines in Balmorel-Mexico (the colours represent the 5 regions in TMXR)

We have applied this soft-link approach to three reduction scenarios using an assessment horizon of 2014–2050. The trajectory of the key drivers of GDP, population growth, and number of households, which influence energy service demand in the economy, is the same in each scenario.

The scenarios modelled include:

- **Current Policy (CP)**: The clean energy goals as formulated in the Mexican energy and climate laws are fulfilled, including a 50% reduction in GHG emissions relative to the year 2000 by 2050. New coal-based capacity cannot be added, as this is not in line with current policy.
- **Deep Decarbonisation (DD)**: This is a hypothetical scenario with a 75% reduction in GHG emissions relative to the year 2000, used to find the implications of a 2050 emissions target consistent with a well below 2 °C scenario.
- **Net-zero (NZ)**: This scenario has the same GHG targets as the Current Policy scenario up to 2030, but increases its decarbonisation ambition towards a net-zero GHG emission energy system by 2050.

5 Decarbonisation Pathways to 2050: What Does Our Study Say?

5.1 End-Use Sectors Electrification and the Role of Natural Gas

Our TMXR results show that electricity demand is largely driven by the industrial sector towards 2050, followed by the transport and residential sectors. As expected, there is larger electrification in the NZ scenario than in the other two (Fig. 2). Even with this growth, the electricity sector GHG emissions are reduced in all scenarios thanks to a significant penetration of wind and solar in new generation capacity, at the expense of natural gas. The consumption of natural gas for electricity generation decreases under stringent emission targets (Fig. 3); over 40% less in the NZ scenario compared to the current policy scenario by 2050.

5.2 Renewables in the Power Sector: Techno-Economically Feasible and Cost-Optimal

Results from the CP scenario in Balmorel, with the restrictions given by TMXR, concerning the availability of resources, including the natural gas consumption, and the limits associated with the contribution of the electricity sector to the Mexican decarbonisation goals (Figs. 4 and 5). Investments in renewable energy such as hydropower, geothermal, wind and solar in areas with high capacity factors are

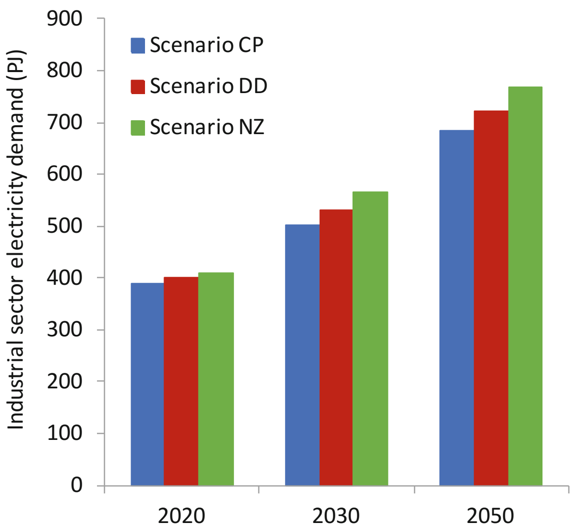
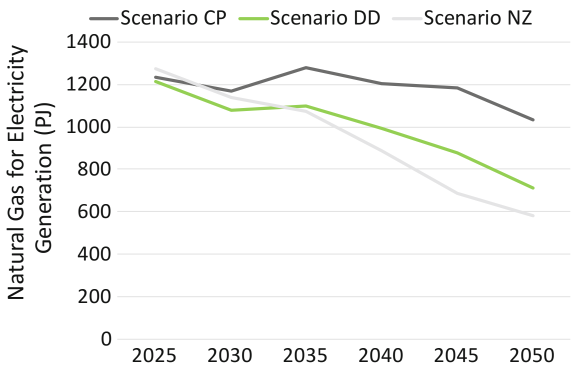


Fig. 2 Industrial sector electricity demand under scenarios CP, DD and NZ

Fig. 3 Natural gas consumption for electricity generation



economically preferable to the use of existing gas plants. However, once the integration of renewables is high, a larger share of them in the energy matrix would require significant expansions of the infrastructure for power transmission and/or of storage technologies, such as pumped-hydro or batteries, which are more costly than the use of natural gas; therefore, the use of natural gas for electricity generation is favoured from an economic perspective, unless there are decarbonisation targets that limit its consumption.

5.3 *Continued Investment in Gas Risks Stranded Assets*

Stranding assets might not be a feasible or cost-effective solution for an optimal power sector transition. At present, a more secure framework for energy investments might be a preferred option, even if long-term decarbonisation targets should be considered when planning the future energy system. Therefore, in order to ensure that the existing capacity is not stranded, a constraint associated with a

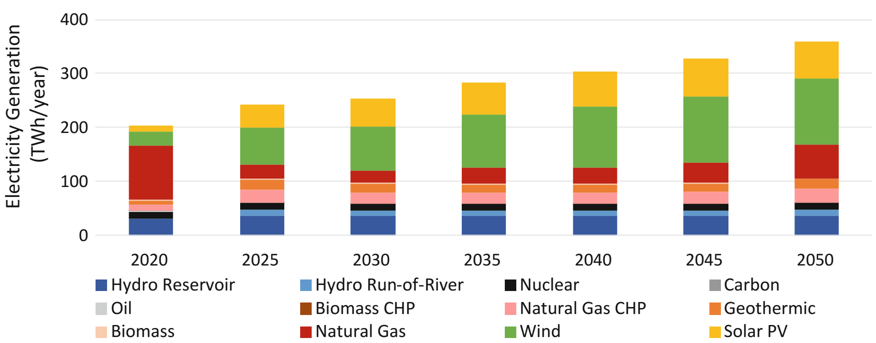


Fig. 4 Electricity generation in Mexico–CP scenario

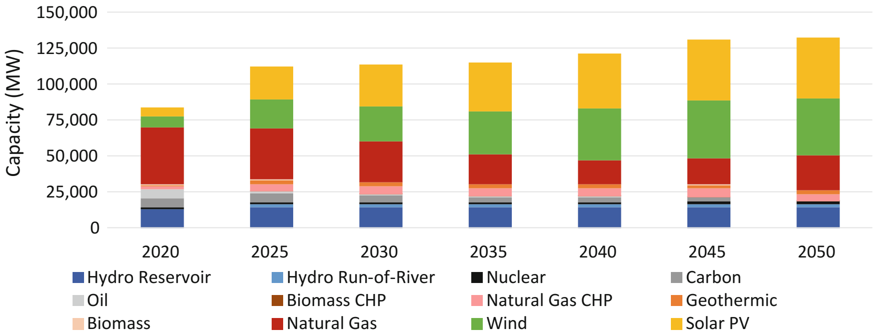


Fig. 5 Installed capacity for electricity generation in Mexico—CP scenario

minimum use of 40% of each natural gas combined cycle plant is defined (Figs. 6 and 7). Investments in renewable energy technology are postponed, compared to the CP scenario (Figs. 4 and 5), but from 2035 onward, when a large capacity of the existing combined cycle (CC) plants achieves the end of their lifetime, investments in renewable energy are similar to the ones without any limitation about the use of existing CC plants. By 2050, the integration of renewable energy and the level of GHG emissions are almost equal in both approaches; however, an early retirement of some CC plants could allow for a faster decrease in GHG emissions in a cost-efficient way, although if they remain in the system they would not hinder the accomplishment of the decarbonisation targets.

The NZ scenario, which has the most ambitious decarbonisation targets with the constraints that avoids having stranded assets for existing CC natural gas plants (minimum use of 40% of each natural gas CC plant) has a higher electricity demand, due to a larger electrification of the transport and industrial sectors, and a lower natural gas consumption allocated to the power sector (Fig. 8). In NZ scenarios the power sector is not fully decarbonised by 2050 (over 80% of electricity generation has zero emissions, with most of the remaining generation being

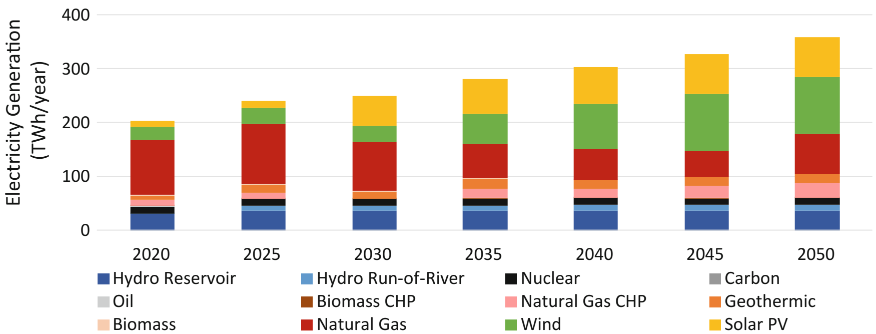


Fig. 6 Electricity generation in Mexico—CP Scenario, no stranded assets

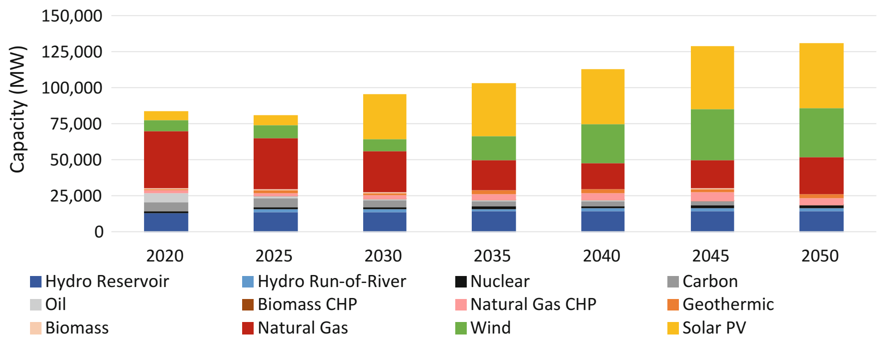


Fig. 7 Installed capacity for electricity generation in Mexico—CP scenario, no stranded assets

gas-based), since we are allowing some energy system emissions to be sequestered through removal options such as afforestation.

5.4 *The Electricity System Can Operate with High Levels of Variable Renewable Energy*

A large integration of renewable technologies is observed: the feasible potential defined in the scenarios for hydropower and geothermal plants is reached, and there are investments in wind and solar technologies in areas with high potential (AZEL 2017) (Figs. 9 and 10).

In the NZ scenario for 2050, there are also some investments in natural gas plants with CCS, because they play a very important role in providing flexibility and ensuring the stability of the system (Fig. 11). Unless the generation from hydropower from reservoirs or from biomass increases, storage is integrated in the

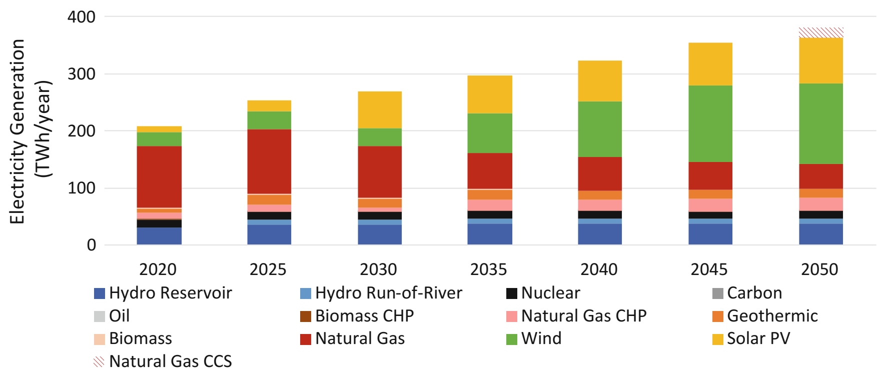


Fig. 8 Electricity generation in Mexico—NZ scenario, no stranded assets

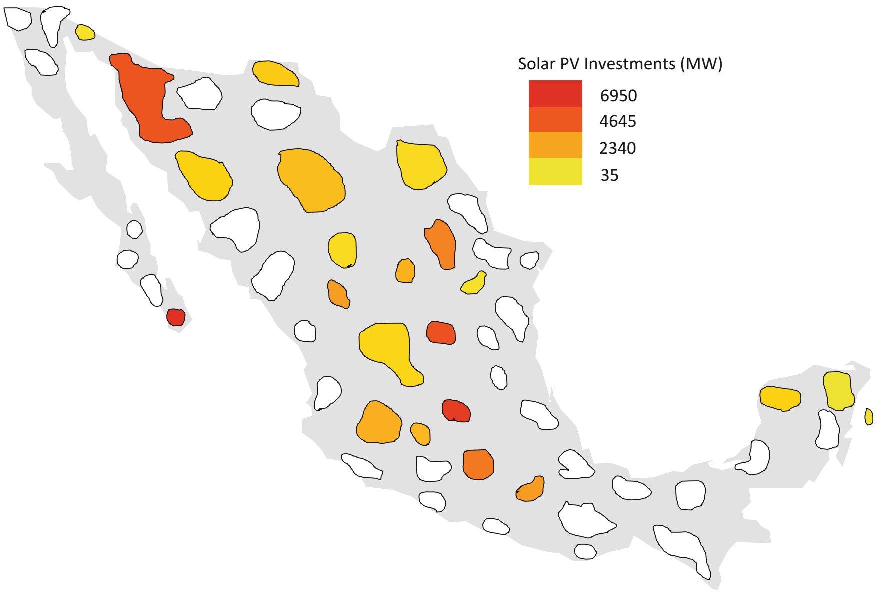


Fig. 9 Cumulative investments in solar PV plants from 2020 to 2050—NZ scenario

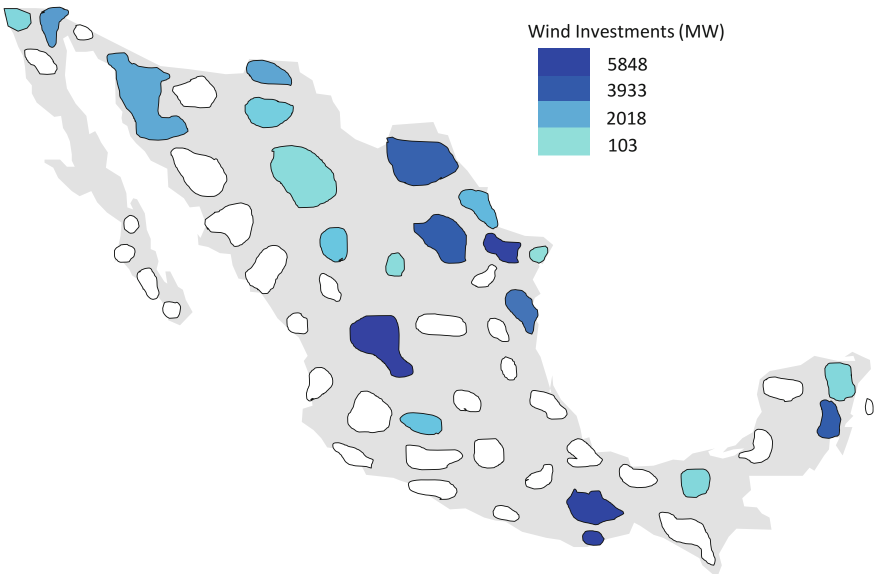


Fig. 10 Cumulative investments in wind plants from 2020 to 2050—NZ scenario

energy system, or there are some measurements that promote demand side management, it is not possible to satisfy the total energy demand without the use of natural gas in periods where the generation from variable energy sources is low and the electricity demand is high.

Mexico's power system is highly flexible due to geographical (spatial) differences, wind and solar patterns, the existence of hydropower and a strong transmission grid. Nonetheless, due to the limitations provided by the GHG emissions target, carbon capture and storage technologies are required for achieving the decarbonisation targets of the NZ scenario. Therefore, the integration of shares higher to 86% of clean energy in the system (clean energy as defined by the Mexican government in the Energy Transition Law), and of 61% of variable renewable energy for power generation (wind, solar and hydropower run-of-river) would require larger investments in storage (e.g. pumped-hydro or batteries) and a higher degree of flexible electricity demand if CCS technologies are not to be implemented in the electricity sector.

5.5 *Investment Versus Fuel Costs*

As would be expected, the total power generation system costs for generating electricity will increase when the GHG emissions are reduced; Balmorel-Mexico shows that both the DD and NZ scenarios are more costly than the CP scenario in terms of total costs. Compared to the CP scenario, the DD scenario is between 125–312 Million USD/year more expensive over the 2020–2050 time period

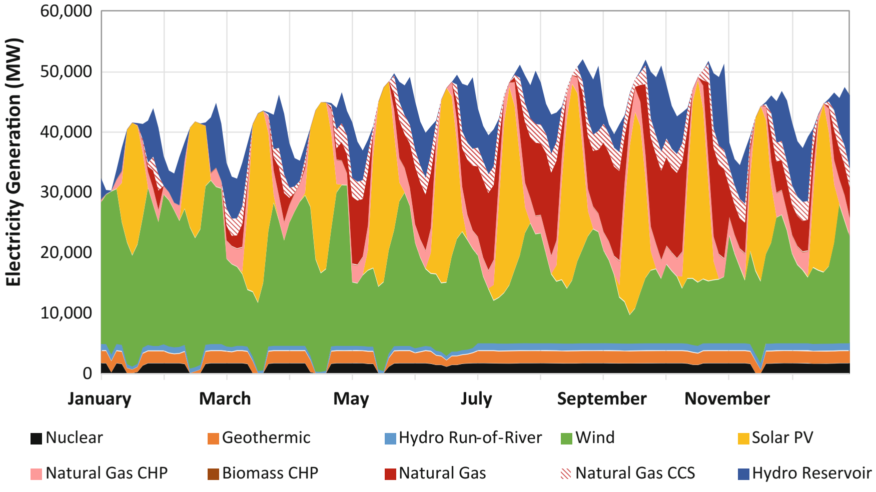


Fig. 11 Electricity generation balance—scenario NZ, 2050 (Each month is depicted selecting a representative day for graphical purposes)

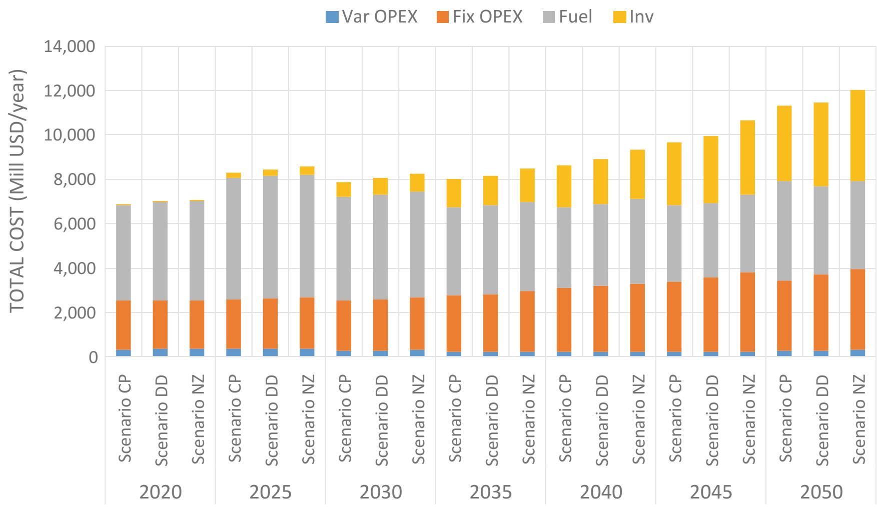


Fig. 12 Electricity sector costs by component—CP, DD and NZ "no stranded assets" scenarios

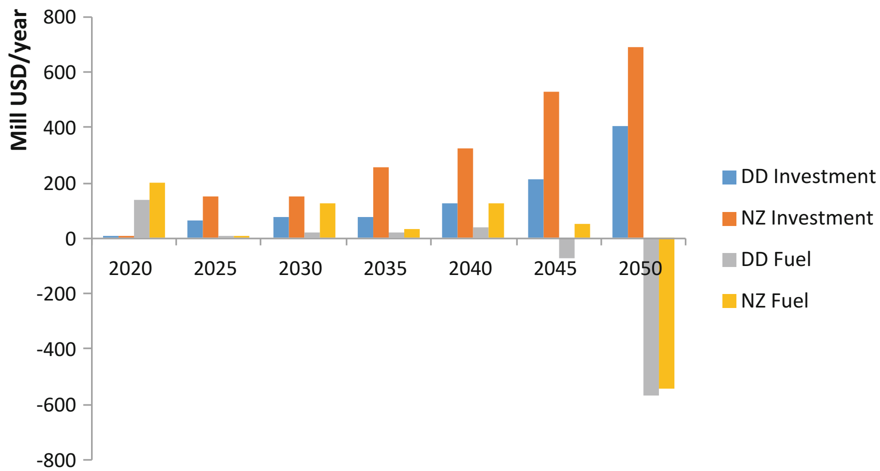


Fig. 13 Relative difference in investment and fuel costs of DD and NZ scenarios versus the CP scenario

(1.5–3.2% of total costs), while the NZ scenario is between 216 and 980 Million USD/year more costly (3.2–10.2% of total costs) (Fig. 12).

However, there are significant differences in the cost components of these scenarios, in particular the investment and fuel-related costs. Investment costs are up to 405 million USD/year higher in the DD scenario and up to 687 million USD/year in the NZ scenario, both compared to the CP scenario (12–20% higher respectively) (Fig. 13). In contrast, both CP and DD scenarios are up to half a billion USD/year more economical than the NZ scenario towards 2050, as more natural gas capacity is replaced by renewables; hence having higher fuel costs but lower investment costs.

6 Conclusion

This chapter focuses on the near-term implications of a deep decarbonisation of the energy system in the electricity sector, exploring the potential future role of natural gas in Mexico's power sector. Our modelled scenarios suggest that a higher ambition in the decarbonisation of the electricity system is possible through a significant growth post-2030 in renewable electricity generation as well as investment in hydro reservoirs, storage (e.g. pumped-hydro or batteries) or flexible electricity demand if CCS technologies are not available or adopted. The modelled scenarios considered only clean energy and GHG emission targets; further reduction of emissions could be achieved by combining these mechanisms with CO_2 prices. While the three decarbonisation scenarios modelled are feasible, there are caveats that should be taken into consideration. Firstly, the electricity demand levels used in this study are lower than those projected in PRODESEN largely due to the optimal use of energy efficient technologies in end-use sectors, not accounted for in these Government projections; higher electricity growth would likely be more costly, as it may require additional investment in CCS or for some renewable capacity to be installed in areas of lower potential. This is also true in the NZ scenario if no removal options were available to decarbonise the energy system. Secondly, if other sectors fail to decarbonise timely, the carbon budget for the electricity sector would need to be reduced accordingly. A historical analysis of Mexico's electricity system makes it clear that coal-to-gas and fuel oil-to-gas substitution has already played a major role in reducing the sector's emissions. Therefore, the potential of natural gas as a fuel bridge to further decarbonise the electricity system is limited. Investors in new gas-based power plants will expect to maximise the use of their assets throughout their lifetime. Hence, it could be argued that the "no stranded assets" scenarios represent a more realistic variant of the modelled decarbonisation targets; otherwise special payments would need to be made by regulators in order for gas-based capacity to be used solely as back up to renewables, or to run at low load factors post-2030 unless they are retrofitted with CCS. This would likely discourage private investment in new gas-based power plants. Our "no stranded assets" scenarios show a delay in significant renewables growth until post-2030, while our "stranded assets" scenarios consider it more cost-effective to invest in renewables 5–10 years earlier. Our study suggests that short-term gains through low-priced natural gas generation may delay renewables penetration into the system and result in a more costly electricity system, as global renewables growth trends are expected to continue decreasing their capital cost. Our results show that investments in renewable electricity generation in areas with high capacity factors are economically preferable than the use of existing gas plants.

They also suggest that the decarbonisation path of the electricity system post-2030 is largely dependent on the investment decisions made in the 2020s; it is therefore essential that Mexico's energy planning decision-makers avoid a natural gas "lock-in" that would either cause carbon targets to be missed or risk leaving some natural gas infrastructure stranded.

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