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Environmental implications of decarbonising electricity supply in large economies: The case of Mexico

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ABSTRACT

Driven by the security of supply and climate change concerns, decarbonisation of energy supply has become a priority for many countries. This study focuses on Mexico, the world's 14th largest economy, and considers the environmental implications of decarbonising its electricity supply. Eleven scenarios are considered for the year 2050 with different technology mixes and GHG reduction targets, ranging from stabilisation at the year 2000 level to a reduction of 60–85%. Unlike most energy scenario analyses which focus mainly on direct CO_2 or GHG emissions, this paper presents the full life cycle impacts of electricity generation in 2050 considering ten environmental impacts which, in addition to global warming, include resource and ozone layer depletion, acidification, eutrophication, summer smog, human and eco-toxicity. The results indicate that continuing with business as usual (BAU) would double the current life cycle GHG emissions, even if annual electricity demand growth was reduced to 2.25% from the current 2.8%. Switching from the current fossil fuel mix to a higher contribution of renewables (55–86%) and nuclear power (up to 30%) would lead to a significant reduction of all ten life cycle impacts compared to the current situation and up to an 80% reduction compared to BAU.

1. Introduction

Driven by the security of supply and climate change concerns, decarbonisation of energy supply has become a priority for many countries. As global energy demand continues to grow together with dependence on fossil fuels, the need to decarbonise as well as diversify energy supply is becoming ever more pressing. For example, energy consumption in 2010 increased by 5.6% compared to 2009 and 87% of the total (primary) energy demand was met by fossil fuels [1]. Many countries, including Mexico, are seeking to develop future energy systems that would improve the self-sufficiency of supply but also contribute towards their GHG reduction targets. A signatory to the Kyoto Protocol, Mexico aims to reduce GHG emissions by 30% by 2020 (relative to business-as-usual) and by 50% by 2050 (relative to year 2000 emissions) [2]. If achieved, this would contribute to the stabilisation of CO_2 concentrations in the atmosphere below 450 ppm, required to limit the global average temperature increase between 2 and 2.4 °C [3].

Mexico is the 14th largest economy [4] and 6th largest oil producer in the world [5]. It is also rich in other natural resources including gas, coal and renewable energy sources such as hydro, geothermal, wind, solar and marine [6–10]. However, its economy and energy supply are highly dependent on fossil fuels, which together with a lack of sustainable energy planning has led to serious concerns [11–13]. One of these is that domestic production of fuels is starting to decrease owing to declining reserves [5,14] while at the same time a significant amount of crude oil continues to be exported to generate revenue [5,15]. Consequently, Mexico is becoming more dependent on imports of petrol, natural gas and other high-value secondary energy sources. In addition, little increase has been observed in the use of renewable energies despite the large potential.

Furthermore, the energy sector, and particularly electricity, is one of the most significant contributors to national GHG emissions because of its heavy reliance on fossil fuels. For instance, in 2006, 79% of electricity was generated from fossil fuels [16], contributing 27% of the total energy-related GHG emissions [2]. At the same time, electricity demand has been growing at an annual rate of 2.8% [17]. Meeting the target of 50% reduction of GHG emissions by 2050 would require cutting the emissions from electricity generation by 85% on 2000 levels (110.7 Mt CO_2 eq.), emitting only 16.2 Mt CO_2 eq. by 2050 [2]. This is a very challenging task and will necessitate significant reductions in the short and medium terms, particularly as electricity demand is projected to grow [18].

While the Mexican Government has made an effort to reduce GHG emissions in the short term by substituting heavy fuel oil

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with combined cycle gas power plants [17,19], this cannot be a long-term solution for mitigating climate change and improving the security of supply. Similarly, little consideration has been given to environmental impacts other than climate change. Therefore, more sustainable options must be identified and implemented. Given that Mexico is one of the world's largest economies, this is not only important for Mexico but also globally.

Thus far, little work has been carried out considering sustainable future electricity mixes for Mexico. A limited number of scenario analyses have been conducted [e.g. 18,20,21] but these have focused solely on direct CO_2 or GHG emissions, ignoring other impacts and life cycle stages. In order to identify environmentally sustainable options it is necessary to expand the scope of such assessments both vertically and horizontally: firstly, all life cycle stages should be accounted for to ensure that environmental burdens are not simply transferred from the point of electricity generation to another point up- or downstream; secondly, impacts other than climate change should be addressed to ensure that one environmental impact is not mitigated at the expense of another [22].

Regarding the need to address other environmental impacts for Mexican power plants, most previous work is limited to specific plants and contexts: for instance, an assessment of the cross-border health impacts induced by aerial emissions from Mexican power-exporting plants on recipients in the USA [23].

As for the need to cover all life cycle stages, life cycle assessment (LCA) studies of present-day electricity mixes are available in literature for several countries including Mexico [24] and the UK [25]. However, these only address the present day; combining LCA and scenario analysis is a novel area of research that provides a much more comprehensive information for sustainable development policy.

In the energy sector, such an approach has been partially demonstrated for four European countries by the NEEDS project (see [26]) and, independently, for Belgium [27] and Denmark [28]; however, these cannot be used for other countries with their own unique electricity mixes, resource bases and climate targets, such as Mexico. Moreover, these studies address highly developed European economies with typical carbon reduction targets of up to 80% by 2050 (compared to a 1990 baseline). These are some of the most ambitious targets in the world and therefore the analyses are not congruous with the requirements of other regions, particularly developing countries. Many developing countries have only stated a reduction target for 2020 relative to business-as-usual (BAU): Chile, for instance, targets emissions 20% lower than BAU by

Table 1
Main drivers and characteristics of different scenarios for electricity production in Mexico in 2050.

Scenario	Source	GHG reduction target for 2050 on the 2000 levels[a]	Scenario description
BAU	Based on IEA [30] and Greenpeace and EREC [18]	None	Current energy trend based on fossil fuels (mainly gas and coal power together contributing 87% to the total by 2050); small, or no support for the development of other low carbon technologies such as renewable energies and nuclear power, which only contribute 12% and 1% to the total by 2050, respectively; the use of CCS is not considered in this scenario
Green	Based on Greenpeace and EREC [18]	70%	Energy policy supporting the development of renewable energies which contribute 86% to the total electricity mix by 2050; other sources such as gas and coal power together contribute 14% of the total energy mix by 2050; due to energy security and environmental concerns, nuclear power, oil and CCS are not considered
A-1	This study	Stabilisation (no increase)	Energy policy supporting diversification of electricity supply and encouraging investment in low-carbon options with emphasis on renewable energies; wind, solar and hydro power contribute 49% of the total by 2050; gas, coal and nuclear power contribute 26%, 15% and 10% to the total; CCS and oil power plants are not considered
B-1	This study	Stabilisation (no increase)	Energy policy supporting diversification of electricity supply, and investment in low-carbon options, with strong support for fossil fuels: gas, and coal with and without CCS, representing 70% of the total by 2050; renewable energies (wind and solar), and nuclear power contribute 25%, and 10% to the total, respectively. No contribution from oil power
C-1	This study	Stabilisation (no increase)	Energy policy supporting diversification of electricity supply, and investment in low-carbon options, with strong support for nuclear power and renewable energies (wind and solar) contributing 20%, and 39% to the total by 2050, respectively; gas and coal together contribute 41%; CCS and oil power plants are not considered
A-2	This study	60%	Energy policy supporting diversification of electricity supply and encouraging investment in low-carbon options with emphasis on renewable energies; wind, solar and hydro power contribute 62% of the total by 2050; gas, coal with CCS and nuclear power contribute 17.6%, 10% and 10% to the total; no contribution from oil power plants.
B-2	This study	60%	Energy policy supporting diversification of electricity supply, and investment in low-carbon options, with strong support for fossil fuels: gas with and without CCS, and coal with CCS representing 70% of the total by 2050; renewable energies (wind and solar), and nuclear power contribute 25%, and 10% to the total, respectively. No contribution from oil power
C-2	This study	60%	Energy policy supporting diversification of electricity supply, and investment in low-carbon options, with strong support for nuclear power and renewable energies (wind and solar) contributing 25%, and 47% to the total by 2050, respectively; gas, and coal with CCS together contribute 28%; no contribution from oil power plants
A-3	This study	85%	Energy policy supporting diversification of electricity supply and encouraging investment in low-carbon options with emphasis on renewable energies; wind, solar and hydro power contribute 75% of the total by 2050; gas with and without CCS, coal with CCS and nuclear power contribute 10%, 5% and 10% to the total; no contribution from oil power plants
B-3	This study	85%	Energy policy supporting diversification of electricity supply, and investment in low-carbon options, with strong support for fossil fuels: gas and coal with CCS, representing 47% of the total by 2050; renewable energies (wind and solar), and nuclear power contribute 43%, and 10% to the total, respectively. No contribution from oil power
C-3	This study	85%	Energy policy supporting diversification of electricity supply, and investment in low-carbon options, with strong support for nuclear power and renewable energies (wind and solar) contributing 30%, and 55% to the total by 2050, respectively; gas with and without CCS, and coal with CCS together contribute 15%; no contribution from oil power plants

[a] All reduction targets refer to direct rather than life cycle emissions. GHG considered: carbon dioxide, methane and nitrous oxide.