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International Seminar on Bioenergy & Sustainable Rural Development

WORKING GROUP 2: GENERATION OF ELECTRICITY

International Seminar on Bioenergy and Sustainable Rural Development
- 5th LAMNET Project Workshop – Mexico 2003

FUTURE PARTICIPATION OF BIOENERGY IN THE MEXICAN ENERGY MIX FOR POWER GENERATION

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ABSTRACT

Three scenarios relating to the environmental futures of electricity generation in Mexico up to the year 2025 are presented. The first scenario emphasises the use of fueloil fuelled steam turbine plants, and represents the historic path of Mexico's energy policy mid-90's. The second scenario prioritises the use of natural gas fuelled combined cycle plants, reflecting the energy consumption pattern that arose in the mid-90's as a result of reforms in the energy sector. The third scenario takes into account the present and medium term use of natural gas technologies that the energy reform has produced, but after 2007 a high and feasible participation of renewable sources of energy is considered. The participation of bioenergy in the form of firewood and bagasse is emphasized The energy consumption of the three scenarios are calculated up to the year 2025 with its corresponding CO_2 emissions.

INTRODUCTION

In January 2001 the Intergovernmental Panel on Climate Change (IPCC) Working Group I [WGI, 2001] reported: 1. The Earth's average surface temperature has increased by 0.6 ± 0.2 ^{o}C during the last 100 years; 2. Snow cover and ice extent have decreased and global average sea level rose between 10 cm and 20 cm during the 20th century; 3. Concentrations of atmospheric greenhouse gases (GHG) (CO_2, N_2O and CH_4) have continued to increase as a result of human activities; 4. There is a positive radiative forcing produced by increased concentrations of GHGs that tends to warm the Earth's surface; 5. There is a negative radiative forcing due to natural causes (changes in solar radiation output, explosive volcanic activity) and from anthropogenic aerosols (biomass and fossil fuel organic carbon combustion) that tends to cool the surface on a regional scale, and 6. The balance between the atmospheric mixture of long lived GHGs and short lived anthropogenic aerosols results in a net positive radiative forcing that tends to global warming.

Mexico is one of the countries that have signed and ratified the Kyoto Protocol. The Kyoto Protocol calls for reducing the GHG emissions to a lower level than 1990. In that year Mexico emitted 444 million tons of CO_2 or 2% of world emissions [INE, 2003]. These reductions would have to be accomplished between 2008 and 2012.

Mexico has one of the highest levels of CO_2 emissions per unit of GDP in the Americas. Due to its international commitments it is of utmost interest for us to analyse which technological trends for energy generation and use, particularly in the power sector, can reduce these emissions without distressing the rapid economic growth that Mexico needs.

In this paper the possibilities of technological restructuring of the electricity generation sector, particularly with renewable sources are explored, and how these changes affect CO_2 emissions by the year 2025. In 1996, the total generating capacity was 34733 PJ, from which 31% were renewables, mainly hydropower. See Table 1. In our base or BAU scenario the most likely path is to fulfil the electric sector expansion using fossil fuelled plants, decreasing renewables' participation down to 13%.

Table 1. Energy technologies mix including new renewables [Islas, 2001].

POWER PLANTS	BASE YEAR 1996 %	TREND 2025 %	OFFICIAL 2025 %	TRANSITION 2025 %
NON RENEWABLES				
COMBINED CYCLE - NG	5.6%	2.1%	61.3%	16.1%
STEAM TURBINE - OIL	41.1%	74.6%	15.4%	15.4%
INTERNAL COMBUSTION - OIL	4.8%	4.2%	4.2%	2.9%
COAL	7.5%	2.8%	2.8%	2.8%
FUEL OIL AND DIESEL FIRED	6.0%	2.3%	2.3%	2.3%
NUCLEAR	3.8%	1.4%	1.4%	1.4%
RENEWABLES				
HYDROELECTRIC	28.8%	11.5%	11.5%	23.5%
WIND	0.0%	0.1%	0.1%	13.8%
SOLAR PHOTOVOLTAICS	0.03%	0.01%	0.01%	5.9%
GEOTHERMAL	2.2%	1.0%	1.0%	4.7%
MICRO-HYDRO	0.12%	0.05%	0.05%	3.2%
FUEL CELLS	0.0%	0.0%	0.0%	1.7%
BAGASSE	0.0%	0.0%	0.0%	1.7%
MUNICIPAL SOLID WASTE	0.0%	0.0%	0.0%	1.5%
FUELWOOD	0.0%	0.0%	0.0%	1.5%
SOLAR THERMAL-ELECTRIC	0.0%	0.0%	0.0%	1.4%
TOTAL GENERATING CAPACITY %	100.0%	100.0%	100.0%	100.0%
TOTAL GENERATING CAPACITY MW	**34733**	**92499**	**92499**	**92499**
NON RENEWABLES	69%	87%	87%	41%
RENEWABLES	31%	13%	13%	59%
TOTAL BIOMASS (BAGASSE+ FUELWOOD)	0.0%	0.0%	0.0%	3.1%

To understand the role that renewable energies can play in reducing the mentioned electricity sector atmospheric emissions are of utmost importance. The purpose of this study is to determine these environmental impacts for three energy scenarios by the year 2025. These scenarios are: 1) the trend or BAU scenario; 2) the official scenario; and 3) the transition scenario with renewable energy sources. The last scenario is a renewable energy mix scenario, based on a thorough review of the economic and technical potential of renewable energies. From which Bioenergy will be considered here in two forms, bagasse and firewood.

The scenarios were built taken into account the following information: the technological change of power plants and considering the available resources in Mexico. We assume that power sector technology will continue to evolve between 1996 and 2025. This evolution is expressed as decreasing capital costs per power unit. (See Table 2)

Table 2. Capital cost evolution for energy technologies in USD 1997/kW. [Islas, 2001].

PLANTS	1997	2000	2005	2010	2015	2020	2025
Combined Cycle	813[1]	428[2]	428[2]	428[2]	428[2]	428[2]	428[2]
Gas Turbine	455[1]	453[2]	453[2]	453[2]	453[2]	453[2]	453[2]
Internal Combustion	455[1]	453[2]	453[2]	453[2]	453[2]	453[2]	453[2]
Geothermal	2030[1]	1372[3]	1250[3]	1194[3]	1147[9]	1100[3]	1100[3]
Carboelectric	1467[1]	1212[2]	1212[2]	1212[2]	1212[2]	1212[2]	1212[2]
Dual	1756[1]	1438[2]	1438[2]	1438[2]	1438[2]	1438[2]	1438[2]
Wind	1232[7]	750[3]	720[3]	675[3]	665[3]	655[3]	655[3]
Nuclear	2559[1]	2116[4]	2116[4]	2116[4]	2116[4]	2116[4]	2116[4]
Hydro	1912[1]	1750[2]	1750[2]	1750[2]	1750[2]	1750[2]	1750[2]
Steam Turbine	933[1]	776[2]	776[2]	776[2]	776[2]	776[2]	776[2]
MicroHydro	3001[5]	3001[5]	3001[5]	3001[5]	3001[5]	3001[5]	3001[5]
Solar Photovoltaic	9300[3]	5300[3]	2900[3]	1500[3]	1305[9]	1110[3]	1110[3]
Solar Thermal	4051[6]	4051[6]	3234[6]	2418[6]	2380[6]	2342[6]	2342[6]
Municipal Solid Waste	5892[6]	5892[6]	5892[6]	5892[6]	5892[6]	5892[6]	5892[6]
Bagasse	2102[3]	1892[3]	1650[3]	1464[3]	1361[9]	1258[3]	1258[3]
Firewood	1965[3]	1745[3]	1510[3]	1346[3]	1380.5[9]	1115[3]	1115[3]
Fuel Cells	3000[8]	1607[6]	1568[6]	1568[6]	1568[6]	1568[6]	1568[6]

1 COPAR 1996 *4 EPRI 1993* [7] *ANES 2000*
[2] *COPAR 2000* [5] *Rand Corporation 1999* [8] *IEA 1997*
[3] *DOE & EPRI 1997* [6] *NEA/IEA 1998* [9] *Interpolated values*

BIOENERGY RESOURCE ESTIMATION FOR FOWER PLANTS

A Mexican energy resources database was prepared in spreadsheet format, it shows availability details of bagasse, firewood and the rest of the renewables for the present, medium and long term.
Firewood is the most used form of bioenergy with 256 PJ, that's 75% participation consumed totally for residential use, followed by bagasse consumed mostly in sugar industry for heat (15%) and electricity generation (10%) [SENER, 2001].

We considered bagasse as the only bioenergy form in use for combined heat and power generation in the sugar industry, in fact 84% of the electrical power needed in the sugar industry is self generated, but with very old technologies, mostly steam turbines, as suggested by (Navia, 1987), we considered a recent technology consisting in bagasse gasification as an input fuel for a gas turbine, which give a much more efficient performance than the previous technology. Details of data entered for the installed capacity estimations for bagasse can be found in Table 3. As seen from that table we chose approximately half of the installed capacity potential, in order to prevent us from being too optimistic, and thinking that just about half of the 68 sugar cane mills existing in Mexico could afford to install a 50 MW power plant.

Table 3: Bagasse installed capacity estimation and firewood area calculations.

ENERGY CROP	BAGASSE		FIREWOOD (SALIX)
AREA [hA]	580,000	in 1986	342,945
PRODUCTION [Mton]	35.7	in 1986	3.4
CROP YIELD [ton/hA]	61.6		10
ENERGY YIELD [kWh/ton]	430	in 2025	4,500
TECHNOLOGY	Gasification + Gas turbine	in 2025	IGCC; EFF=47%; PF=60%
GENERATED ELECTRICITY [GWh]	15,351		15,432
MAXIMUM INSTALLED CAPACITY	3,400		DEPENDING ON AREA
INSTALLED CAPACITY [MW]	**1,529**		**1,380**
SOURCE	Navia, J. et al. ANES proc., p 304 (1987)		Gustavsson, L. And Borjesson, P. En. Pol. 26(9), p 699 (1998)

Firewood was not taken as a participant in the Mexican installed electric capacity initially, but we consider that is a must to include it as an important renewable resource in the near future beginning its participation in 2010, when its capital costs are more competitive as seen on table 2. Also the expected efficiency in firewood technologies is 47% by 2030 [IEA, 1998] contrasting with the actual efficiency of 36%. To calculate the area needed for the energy crops, we started proposing an installed capacity as an educated guesses we decided to take an installed capacity almost equal to the bagasse power plants, thinking also that the same power plant could handle both fuels, in that configuration the storage of bagasse is avoided.

Then, the energy yields values of firewood, were taken from [Gustavsson, 1998], and the technology that would be more likely to be in its mature state, between 2010 and 2015, reaching a 40% efficiency is the Integrated Gasification and Combined Cycle plants (IGCC). Finally the obtained area is smaller than the actual sugar cane fields.

METHOD

The Long Range Energy Alternatives Planning (LEAP) program was used. It is a user-friendly software tool for integrated energy-environment analysis and greenhouse gas mitigation analysis developed by the Stockholm Environment Institute – Boston with support from international organisations. It is a bottom-up accounting model which, when applied to the electricity sector, allows evaluation of different energy policies in electricity generation (such as energy efficient use, fuel substitution and technological changes) and their corresponding emissions.

In this study it was necessary to calculate the electricity demand by the different Mexican end-use sectors. The following sectors were considered: residential, commercial, public, agricultural, industrial, transport and energy sector self-consumption.

ASSUMPTIONS

For all the energy scenarios developed for Mexico from 1996 to the year 2025 the following common hypotheses were considered: 1. Constant economic growth with a 4% GDP average annual increase; 2. Constant average annual population growth of 1.21%, resulting in 130 million people by the year 2025; 3. Constant end-use demand structure; 4. Energy and particularly electricity demand grows 4% per year as the GDP; 5. The installed power capacity increases by 5% up to the year 2007 [Secretaría de Energía 1998]; 6. After 2007, the annual growth rate of the installed capacity is considered constant at 3.4% [Alonso 1994], and 7. Finally, 3% of the new electricity supply is devoted to satisfy the peak power demand by means of internal combustion engines burning diesel and natural gas.

The electricity demand in Mexico grew at an AAGR of 7.7% between 1966 and 1989. During the nineties this rate fell to 5.1%. Up to now, the electricity demand growth rate has always been greater than the GDP's growth rate (4.2% and 3.4% respectively). Due to improvements in energy efficiency of end use technologies and to an effective energy savings programs, this difference is decreasing. We assume that this tendency continues, reaching zero by 2012, and that by the year 2025 the electricity demand rate is 0.8% less than the GDP rate. Based on these assumptions, the electricity demand between 1996 and 2025 is 4%, identical to the assumed GDP growth rate.

SCENARIO BUILDING

Three different paths were considered for the evolution of the energy sector in Mexico.
The Trend scenario was selected to provide a baseline comparison and also to establish an upper limit for the GHG emissions of the Mexican power industry. The most used fuels are oil products. In the power generation sector all new capacity supply is accomplished with technologies that use mainly fueloil.

In this scenario, fueloil consumption increases with an AAGR of 5.8%. The installed capacity of the power sector utilities which use fueloil increases from 14,283 MW to 66,849 MW by the year 2025, representing 70% of the total installed capacity. This scenario is economically feasible only if the fueloil prices are much lower than natural gas prices. Under this conditions the vapour turbine plants would be the most competitive, according to Comision Federal de Electricidad (CFE), the Mexican public utility company [CFE, 1997]. This situation would make it very difficult to introduce renewable sources into the energy mix in the long term.

The Official scenario was chosen because it represents the continuation of the present policy of the Mexican Energy Secretary, in which natural gas (NG) is the privileged fuel. The information to construct this scenario was taken from government publications in which the medium term future planning of the power industry is described. It reflects the new path in fuel consumption in the Mexican power sector, which was established as part of the electrical industry reform in 1992 [Secretaría de Energía, 1998].

All new installed capacity is accomplished using NG technologies, giving preference to combined cycles. Natural gas has an AAGR of 9.9%. In absolute terms this expansion permits an increase from 135 PJ to 2110 PJ in 2025, representing 55% of the total electricity consumption. The installed capacity of combined cycle for power generation increases from 1957 MW to 56, 668 MW, representing 62.3% of the total installed capacity.

In the Transition scenario, natural gas is privileged until 2007 and then renewable energies are preferred between 2007 and 2025. Table 4 shows the specific hypothesis employed in this scenario. It is considered viable from an economic and technological point of view and is fully referenced to the technical and economic feasibility study of a high renewable scenario share made by the [EIA 1998].

The combined cycle plants fuelled with natural gas are considered the most competitive technology for power generation up to the year 2010 [INE 1990, CFE 1997]. After 2010, it is assumed that renewable technologies are technically and economically feasible By 2025, the renewable energies grow at an average annual rate of 5.61% and account for 54% of the installed power capacity.

In this scenario we assume a gradual internalisation of externalities of power generation of current power sources, high fueloil and natural gas prices, and an intensified industrial learning within the electrical power industry regarding the use for energy generation and equipment fabrication..

In this scenario renewable resources are used to satisfy most of the Mexican power demand up to the year 2025. Applying the assumptions made by several authors [IEA 1997, Palz 1994, IEA 1998, Borja 1998, CONAE 2003, Manzini 1999], a strong participation of renewable energies in the power industry is possible from a technical, economic and institutional point of view. Table 4 shows the hypothesis employed.
From Table 4 can be observed that hydroelectricity doesn't need to grow as fast as most of the other "newer" renewables, because most of the actual (and future) installed capacity is still from this source.

Table 4. Specific hypothesis employed in Renewable and Transition scenarios, showing the AAGR of installed electricity capacity for various renewable sources.

SOURCES	TRANSITION SCENARIO AAGR
• Hydroelectricity	5.2%
• Solar Photovoltaics	25.9%
• Municipal Solid Waste	41.7%
• Biomass	42.0%
• Wind	39.2%
• Fuel cells	42.3%

RESULTS

Figure 1 shows the primary energy consumption in the Mexican power sector in each scenario. The different energy paths up to 2025 are due mainly to the different technology efficiencies encountered on each scenario.

In the Official scenario the energy needed to satisfy demand is less than in the other scenarios because of the larger efficiencies of natural gas feed technologies such as combined cycle power plants (up to 50%). Trend and Renewable scenarios have very similar global power efficiencies in 2025. Finally, in the Transition scenario, global power efficiency is intermediate in 2020, but shows a deterioration in 2025.

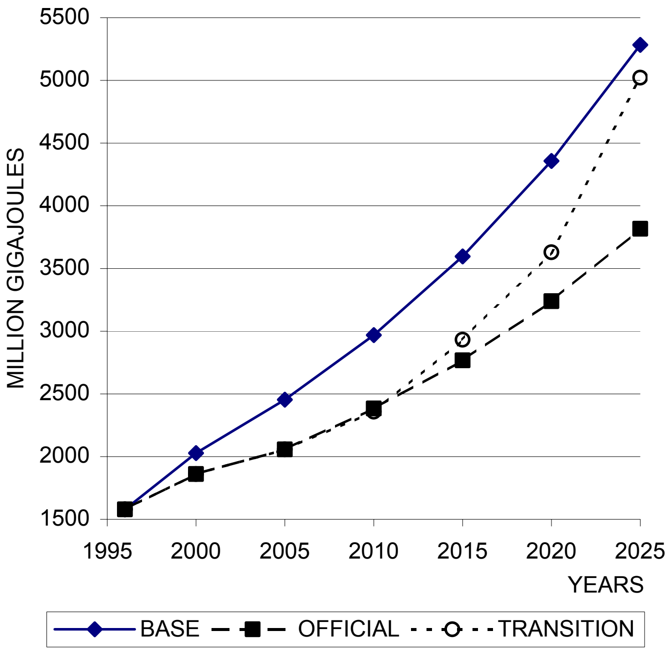

Fig. 1. Primary energy consumption in the Mexican power sector between 1996 and 2025 for three different scenarios.

CO_2 EMISSIONS

Figure 2 shows the predicted evolution of CO_2 emissions for each scenario. The best scenarios for reduction of CO_2 emissions are the ones based on increased use of renewable energies, that is, the Transition scenario. The Transition scenario has 64% fewer emissions than the Trend scenario. The Official scenario consumes less energy and has a 50% reduction in CO_2 emissions. (See Fig. 2).

In the Transition scenario CO_2 emissions are 1.4 times greater than base year emissions with an AAGR of 1.1%. The Official scenario has an AAGR of 2.3%, with 1.9 times more emissions than 1996. The Trend scenario is the worst, having an AAGR of 4.8% and 3.8 times more emissions than the base year. In the Transition scenario, after 2020 the amount of CO_2 starts to drop, unlike either of the other scenarios. This means that using this scenario, it is possible to have, in the long-term, both economic growth and dropping level of CO_2 emissions.

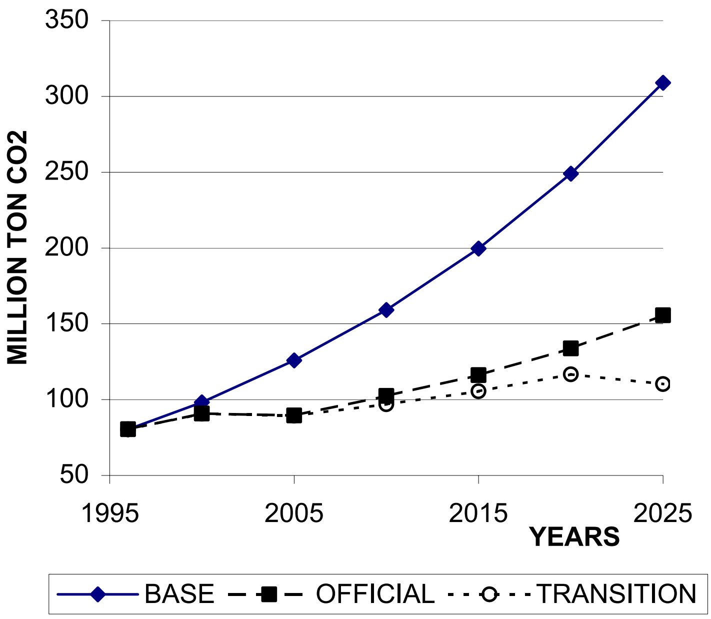

Fig. 2. Carbon dioxide emissions in Mexican power sector between 1996 and 2025 for three different scenarios.

CONCLUSIONS

Regarding CO_2 emissions, the Renewable and Transition scenarios, which prioritise renewable energy sources, are the most favourable. These scenarios produce 69% and 64% fewer CO_2 emissions, respectively, than the Trend scenario in 2025, while the Official scenario has 50% fewer emissions. In relation to CH_4 emissions, the Renewable and Transition scenarios are the second least harmful, producing 177% and 277% more CH_4 emissions than Trend scenario in 2025. The Official scenario is the worst, emitting 1028% more methane than the Trend scenario by the year 2025.

The Official scenario shows important advantages in terms of reductions in energy consumption and CO_2, NOx and SOx emissions. From this point of view, the recent reform in the Mexican power sector has positive environmental results. Nevertheless, it is still not the best scenario in environmental terms, particularly regarding climate change. The favourable results given in the Transition scenario show that **the use of renewable energies is the best energy policy choice to reduce CO_2** emissions. Moreover, our results show that the Transition scenario is the only scenario in which it is possible to have both long-term economic growth and dropping level of **CO_2** emissions.

This study clearly shows that while the current long term trend in the Mexican Electric sector is to reduce renewable sources in the energy supply mix, the possibility exists to dramatically increase their role by 2025. In the Trend scenario the energy produced by renewable sources is only 3%, and in the Official scenario this figure is 7%. In the Renewable and Transition scenarios these numbers are 74% and 68%, respectively.

As our results show, maybe we underestimated the Bioenergy participation in the energy mix, but its presence resulted more important than fuel cells or solar thermal electric, there is room also to consider other forms of Bioenergy as biogas from landfills, or gasification of organic waste from municipal solid waste, etc. Our results suggest that a complete review of the technical and economic potentials of Mexico’s renewable energy resources and of the barriers to realize these potentials is needed in order to make better policy decisions regarding energy and the environment, which in turn can lead to sustainable development.

We need participation from all renewable sources in order to have a sustainable electricity sector, that according to OLADE criteria is a when renewable installed capacity is more than 50%, in order to be able to begin operating firewood power plants in the near future, its just about time to start planting trees for energy crops.

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