Stuck in the Jam:
CO_2 Emissions, Growth and Technical Change in Mexico

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Abstract

Decoupling economic growth from emissions of green-house gases is a major challenge for global sustainability. This relationship, mediated by product composition and the state of technology, is however a complex one. In this paper we examine critically the notion of an Environmental Kuznets curve relating economic growth and emissions, and assess the role of technical change operating at lower levels of aggregation. With the example of a large, middle-income developing country, we show that long periods of economic stagnation reinforce "carbon lock-in" despite significant improvements in energy efficiency.

1. Introduction

Global emissions of greenhouse gases (GHG) have been accelerating in recent decades. According to the last report of the IPCC, during the period 1970 to 2004 global emissions have risen as the combined effect of global income growth (77%) and global population growth (69%), which have surpassed the general decrease in energy intensity of income

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(-33%) and the practically null reduction in carbon intensity of energy (-2%) (Rogner, et al., 2007; see also Sun, 1999). However, since the year 2000 global emissions increased far more rapidly than the worst scenarios projected by the Intergovernmental Panel on Climate Change (IPCC) (see for example Rogner et al., 2007, Raupach, et al., 2007). If the trend of the last 20 years' continues, human GHG emissions would increase between 40% and 60% from 2000 to 2050, which will very likely produce an increase of between 2.5 and 4.5°C in the Earth's mean temperature with respect to the year 2000 (Rogner, et al. 2007). Such apparently small changes in the mean global surface temperature will provoke profound and irreversible changes in climate patterns. Even though there is no scientific consensus, many observers argue that even an additional 2°C increase in global temperature (with respect to the 2000 level) is enough to trigger irreversible changes in the fundamental physical conditions of the biosphere.[1] For avoiding dangerous warming levels, global emissions must be reduced between 60% and 80% by 2050, with respect to 2000 emissions, peaking between 2000 and 2015 (IPCC, Fourth Assessment Report, WGIII, 2007).

Recent emissions' growth has been driven by expansion of the world economy combined with the reversal of earlier declining trends in the energy intensity of economic activity and the carbon intensity of energy. One of the reasons behind these trends is that at the same time that GHG emissions from the developed world have continued to grow, the impact from developing countries is on the rise. Developing countries are responsible of 23% of global cumulative emissions since 1750 (Raupach, et al., 2007; Hansen, et al., 2007), but their share in global emissions is large and growing (up to 70% of emissions growth in 2004).

According to the Environmental Kuznets Curve Hypothesis (EKCH), which we discuss in the following section, it is plausible to expect that under certain conditions the emission intensity of individual economies would start declining after reaching certain

[1] See on this point Lenton et al (2008). The European Union definition of dangerous global surface temperature increase is 2°C with respect to the year 2000. Hansen et al. (2008) argue that a 1°C increase above 2000 levels would already constitute dangerous human interference with climate.

level income. Moreover, if international technology transfer receives effective support, technological leap-frogging could allow developing countries to reach that level earlier on. Assuming that both mechanisms work, the probability of keeping GHG concentration levels below the line of dangerous climate change would then depend on the ability of all major economies to reach in a coordinated way their respective emissions-turning-point income levels and start reducing their absolute emissions before reaching dangerous levels of GHG concentrations. In other words, the spreading of economic growth would make things worst before they get better, but they would eventually get better. As a corollary, the hypothesis reinforces the notion that a GHG mitigation strategy is secondary to economic growth.

Prospects for this type of worldwide adjustment driven by economic growth are obscured by the relative irreversibility of both economic dynamics and their environmental impact. First, the physical processes resulting from GHG emissions entail autonomous feedback with long-term consequences; second, many economic choices relevant for climate change have such long-lasting effects that they can be treated as irreversible (Schmalensee, 1998). As suggested by recent trends, the pervasiveness of high-carbon energy technologies has offset energy efficiency gains. The surge of GHG emissions in large developing economies like China and India reflects the extent to which declining energy intensities have been offset by increasing carbon intensities, due to the acceleration of coal-based electricity generation and a rapidly growing transport sector fueled by oil (Rogner, et al., 2007). These examples illustrate the rigidities posed by technological inertia even in the presence of fast economic growth. Current prospects of global economic downturn only make this worst. For if growth is not a sufficient condition for reducing the carbon content of energy, it still remains a necessary condition for keeping emissions low by means of energy efficieny gains. Slow growth within a high-carbon, energy-intensive system will most probably yield a steady contribution to GHG accumulation, just as a running engine in a traffic jam.

This paper examines the patterns of GHG emissions in Mexico as an example of a large, middle-income developing country experiencing low growth rates. In the first section, it reviews the literature on the so-called Environmental Kuznets Curve Hypothesis (EKCH) as applied to the relationship between economic growth and GHG emissions. In section 2, we describe Mexico's CO_2 emission's historical path and its constituent factors. In section 3, trends and features of energy intensity at the sector level are analyzed and explained. Section 4 focuses on emissions derived from energy use in the energy-producing and industrial sectors, and section 5 concludes.

2. EKC and GHG emission paths

The relationship between economic growth and GHG emissions has been examined by relying on the Environmental Kusnetz Curve hypothesis (Holtz-Eakin and Selden, 1992; Moomaw and Tullis, 1994; Cole et al., 1997; Moomaw and Unruh, 1997 and 1998; Schmalensee et al. 1998; de Bruyn et al., 1998; Sun, 1999; Dijkgraaf and Vollebergh, 2001; Harbaugh, et al. 2002; Matrínez-Zarzoso and Bengochea-Morancho, 2004). It was originally formulated by Grossman and Krueger (1991) in the context of the discussion on trade and the environment (see also Grossman and Krueger, 1995). The Environmental Kuznets Curve (EKC) hypothesis predicts (or, more rigourosly, assumes) an inverted U-shaped curve relating environmental impact to economic growth. Simply stated, it asserts that the environmental impact of economic growth increases with income up to a maximum level and then declines afterwards. As societies satisfy their basic needs, and education and health standards rise, they become more willing to spend parts of their income in protecting the environment. At the same time, and due to technological leapfrogging and imitation, developing countries should exhibit "lower" EKC curves and smaller income thresholds (Dasgupta, et al. 2003).

As argued in Dasgupta et al (2003), an environmental Kuznets curve (EKC) can result as income increases in a society if four conditions are satisfied: 1) the marginal utility of consumption is constant or falling; 2) the dis-utility of pollution is rising; 3) the marginal damage of pollution is rising; and 4) the marginal cost of abating pollution is rising. Applications of this framework have focused on estimating income levels at which "turning points" for different pollutants and other indicators of environmental impact take place. Evidence on such a relationship has been argued, perhaps far too quickly, for promoting trade and investment liberalization (see Baker, 2003).

Despite punctual warnings by the original authors, the hypothesis has sometimes been argued to encompass income effects on aggregated environmental impact. This, however, would imply building a consistent measure of multidimensional environmental impact, an obstacle that impedes consistent testing of the hypothesis in general (Nadal, 2006). There are also problems with aggregation at the spatial level: environmental damage could be curbing at some location while increasing somewhere else, due to a “passing the buck” mechanism (Rothman, 1998). But the main drawback in the EKC hypothesis is the implicit assumption that environmental damage is not cumulative and their impact is reversible (Tisdell, 2001). Rising temperatures and GHG concentration are subjected to strong positive-feedback effects, and may not decline after a critical pollution threshold is exceeded. In such cases, the marginal damage of pollution would increase autonomously after some value, independently of economic growth. Finally, even if the hypothesis holds, it is not granted that there would be enough “atmospheric space” for all countries to curbe their emissions before producing irreversible climate damage.

There is no empirical evidence supporting an EKC for GHG emissions. Both Moomaw and Tullis (1994) and Schmalensee et al. (1998) found that CO_2 rises cross-sectionally with income per capita without strong evidence of a turning point. Both studies show as well that, even when some countries' trajectories present an inverted-U shape, results are highly heterogeneous. Individual country heterogeneity has been confirmed in de Bruyn, van den Bergh and Opschoor (1998), Dijkgraaf and Vollebergh (2001), Roca and Alcantara (2001), Friedl and Getzner (2002), and Huang et al. (2008). More specifically, Cole et al (1997) found that “EKCs exist only for local air pollutants, whilst indicators with a more global, or indirect, environmental impact either increase monotonically with income or else have high turning points with large standard errors.” The encompassing review by Stern (1998) noted that the evidence on an inverted-U relationship between emissions and growth applies only to a small group of measures of environmental impact ,like suspended particles and SO_2. In general, thorough panel data analysis has shown that rebound effects and N-shaped relationships are ubiquitous (Moomaw and Unruh, 1997; Martínez-Zarzoso and Bengochea-Morancho, 2004), and that good “curve fitting” does not necessarily imply future behaviour (Moomaw and Unruh, 1997).

Despite its deterministic flavour, it is nowhere implied in the EKC hypothesis that a reduction of environmental impact would be an automatic consequence of growth (Arrow et. al. 1995). Moomaw and Unruh (1998) argue that while the notion that economic growth proceeds by stages is a key notion behind EKC, it is not certain that it “is a deterministic process that all countries must pass through” (p. 222). But in practice, the EKC approach normally compares countries with very different resource endowments, different income levels, and different patterns of product-technology specialization relying on the key assumption of income determinism. In contrast, Moomaw and Unruh use a simple non-linear dynamic analysis to track down the evidence on the transition to lower levels of CO_2 per capita in a set of countries. Their findings show that “these transitions occur over a broad range of income levels and, somewhat surprisingly, the transitions are found to occur abruptly and co-temporally. They do not appear to be the result of endogenous changes in income growth, but instead result from rapid, co-temporal historical events and responses to external shocks.” Trajectories of CO_2 emissions can thus be better described as “punctuated equilibria,” rather than smooth, continuous change. To the light of current trends in GHG emissions, this conclusion is actually more optimistic that the EKC, and can be handed out as an evidence of both dis countinuous technical change and policy effectiveness.

The literature on technological change provides explanations for the type of punctuated shifts and qualitative discontinuities like those suggested above. A critical issue is the distinction between incremental and radical technological change highlighted by Schumpeter (1947), as well as the notion of technological trajectories (Sahal, 1981; Rosenberg, 1982; Dosi, 1982). Under this nomenclature, it is plausible to associate energy efficiency improvements with relatively easier changes along a given technological trajectory, that is, with technical change derived from small step improvements in patterns of use in existing energy systems. Changing the carbon content of energy, on the contrary, implies technological replacement for qualitatively different energy systems. The observed rigidity in the carbon content of energy at a global scale (Sun, 1999; Rogner, et al., 2007) is a result, of the high sunken costs of substituting highly interrelated systems and the resistance to adopt new energy sources even when they are cost-effective at the margin.

In the presence of a carbon lock-in (Unruh, 2002), there is then a higher probability for individual economies to get trapped in low-growth traps with high carbon intensity. This conclusion has been suggested in an important study on the relationship between trade and the environment in Mexico (Gallagher, 2004). This author found that the hypothetical "turning point" of an emissions Kuznets curve for Mexico would be sliding away beyond the $5,000 1995-USD per capita threshold level found in cross-sectional studies. Trade liberalization would had been related to small income rise, while environmental degradation had advanced persistently. In the following we show how the interplay between components of GHG emissions in Mexico characterize a low-growth, high emissions trap.

3. Mexico's path of CO_2 emissions

Mexico's pattern of CO_2 emissions from energy-use in the second half of the 20th century shows the footprint of industrialization and urbanization processes, an abrupt transition into emission-intensive uses of energy. According to Marland, et al. (2007) emissions intensity in per capita terms in this country progressed geometrically during the 20th century, doubling between 1950 and 1970 (from 0.3 to 0.58 tons of CO_2 per habitant) and then doubling again between 1970 and 1982 (from 0.58 to 1.82 tons of CO_2 per habitant).[2]

The increase in the volume of emissions in Mexico from 1970 surpassed those of

[2] The series by Marland, Boden, and Andres (2007) only account for a handful of GHG emissions' sources. Sheinbaum, Rodríguez and Robles (1999) estimated much higher GHG emissions derived from energy use, but the growth trend in their series is slower. Despite the point-accuracy of this latter estimate, the time-consistency of Marland et al (2007) makes it more suitable for analyzing the long-term trend.

population and income by a factor of two.[3] Currently, Mexico contributes with 1.8% of the global GHG emissions, about 670 million tons of carbon equivalent every year. Examining the most recent trends show that energy and emission intensities decreased between 1989 and 2000 but then rebound in 2003 and 2004 (INE-SEMARNAT, 2006; SENER, 2006). If economic growth continues at current GDP growth rates, the level of emissions will double by 2030; but if more desirable growth rates were attained (5-6% a year) the volume of emissions could easily double in only 10 years (Masera and Sheinbaum, 2004).

Graph 1 shows the historical trend of Mexico's emissions factors as index numbers based in 1971. Decomposition of emissions factors follows the Kaya identity.[4] As noted above, the volume of emissions doubled between 1971 and 1981, expressing the impact of the surge in crude oil production (following the discoveries of large oil-fields in 1976) on the fossil content of energy. During this period, an increase of 50% in income per capita increased the level of emissions by a factor close to 3. Population growth diminished steadily from average annual rates of 3.2% and 3.4% in the 1960's and 1970's to 2.2 and 1.6 in the 1980's and 1990's. CO_2 intensity of the energy mix remained more or less constant during the whole period, and income per capita remained stagnated from 1982 to 1997, growing slowly afterwards, while energy intensity of the economy clearly curbed

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[3] Though impressive, this volume increase was not strongly different from the increase in OECD countries with similar income levels in the early 1970's. As a means of comparison, consider that the index for the volume of total emissions in 2004: Mexico, 385.6; Turkey, 497.6; Portugal, 400; Spain, 272; and 186 in Ireland (1971=100).

[4] This type of analysis has been used in IPCC studies and others for decomposing historical trends in emission's factors (Kaya, 1990). It is based on the following identity:

$$CO2 = \frac{CO2}{Energy} \times \frac{Energy}{GDP} \times \frac{GDP}{Population} \times Population$$

The Kaya identity entails a gross simplification of a complex factors. It aggregates data coming from highly heterogeneous phenomena, separates functions which pertain together, and conceals the nature of relationships among factors. For example, while there is undoubtedly a tight relationship between the carbon content of energy and energy efficiency, this relationship may not be constant in time due to a combination of strictly technical issues in the relative importance of activities. More straightforwardly, there may a clear relationship between energy efficiency and the scale of activity that escapes to be detected by this identity. This drawbacks should be kept present in interpreting the results.

about 1989. In consequence, the slightly curbing trend in total emissions is driven by diminishing energy intensity and, to a much smaller degree, by slower population and economic growth. This result matches those of Sun (1999), who showed that in most countries relative changes in energy intensity are much stronger than changes in the CO_2 intensity of primary energy, for the period 1971-1995.

[insert Graph 1 about here]

Mexico's income trajectory oscillated back and forth within a narrow range during the period 1981-1999. However, during the economic downturn of the "lost decades," the per capita emission rate in Mexico did not diminish proportionately. With fairly steady emission rates and population increasing, total emission volume accumulated at inertial speed while income per capita oscillated around a short range of income levels. As shown in Huang et al. (2008), the relative CO_2 emissions' path ex-socialist countries exhibits a "hockey-stick" shape, as a result of the economic collapse they experienced during the early 1990's. Graph 2 shows that such a path occurred as well in Mexico during the crisis period 1982-1987, but then per capita emissions grew again when income recovered.

[Graph 2 about here]

Despite the strong structural adjustment that took place in Mexico during the "lost decades," it did not provide much improvement in terms of carbon intensity of economic activity. The growth in the total volume of annual emissions did slowed down, mainly driven by energy efficiency and the significant reduction in the pace of population growth.

4. Energy Use

Graph 3 shows the long-term trend of energy-intensity in Mexico. In general terms, this curve exhibits an inverted-U shape along the period 1965-2004, peaking in 1989 and with a weak rebound in the last 2 years of the series. Total energy consumption in the country rise 6-fold in the period from 1,200 to 7,000 Petajoules. According to OECD data, primary energy supply per capita increased from 0.87 tones of oil equivalent (t.o.e.) a year in 1971 to 1.65 in 2005, just about the world's average.[5]

The decreasing trend in energy intensity from the 1990's is result of at least four different, overlapping processes. First, between 1965 and 1981 the annual growth rate of energy consumption was slightly above that of GDP (7.6% and 6.7% a year, respectively), expressing the growing importance of energy-intensive industries that characterizes the industrialization process. Growth in both indicators stagnated during the eighties. Between 1989 and 2004, however, economic growth was much slower compared to previous decades (2.7% annual average), but energy demand grew even more slowly (1.8%). By the 1980's most of the energy-intensive industries in mining, energy-producing and manufacturing had already been deployed. This means that energy-demand per additional unit of output in the industrial sector would have started to fall, as activities with smaller energy-output ratios increased their share in new investments. Growth in the weight of the service sector may have also impacted negatively the average energy intensity of the whole economy.

[Graph 3 about here]

Second, after the 1982 crisis the economy shifted gears to a low-speed growth trajectory, compared to that of the previous decades. Growth of per capita GDP fell from 3.2 per cent a year between 1965 and 1982 to 0.7 per cent a year between 1982 and 2004, likely preventing the expansion of demand into more energy-intensive consumption patterns.[6]

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[5] Energy use per capita is 7.91 t.o.e. (Tones of oil equivalent) in the US, 3.89 in the EU-25, 1.24 in China, 1.11 in Brazil and 0.53 in India (OECD, 2007).

[6] Other Latin American countries experienced a similar trend. Between 1982 and 2004, per capita income growth (measured in constant US dollars PPP) in Argentina and Brazil reached 0.7 and 1.0 per cent a year respectively. This figure contrast strongly with countries that held similar wealth levels in the 1960's like Ireland (6.3), Spain (3.3) and Portugal (3.1), and even more with emerging Asian economies like those of India (5.0), Singapore (5.6), South Korea (7.8) and China (11.5). Source: author's calculations based on *UNCTAD Handbook of Statistics*, 2005.

Third, the economy's liberalization process that took place since the 1980's and a context of a constrained domestic demand both increased market competition and financial stringency. This triggered a multitude of structural and technical changes operating at plant and industry levels throughout the productive sector that plausibly induced, both directly and indirectly, rationalization of energy use. Aguayo and Gallagher (2005) showed that most of the reduction in energy intensity since 1989 can be accounted for by changes in the manufacturing sector, and that energy savings in this sector are a combined result of structural, technical, and trade effects. Finally, institutional efforts like the creation of the National Commission for Energy Savings (CONAE, for its name in Spanish) and the Fund for Electric Energy Saving (FIDE) were also instrumental in facilitating energy savings in firms and households.

Graph 4 shows the trends in energy intensity for three different sectors during the same period. Relative energy use in the energy and industrial sectors is defined as the sectors' energy consumption per unit of that sector's GDP. Due to the pervasiveness of transport, its intensity is calculated as the sector's energy use per unit of total GDP.

[Graph 4 about here]

By examining graph 4 we can differentiate two periods in the time-path of energy intensity at the sectoral level. First, in the period that runs from 1965 to the mid 1980's, total energy intensity increased strongly as an effect of industrialization and urbanization, reflecting the incorporation of energy intensive technologies in both industry and transport. This trends are accompanied by a simultaneous increase in the energy efficiency in the energy producing sector. Plausibly, this last effect is a result of all sorts of economies in energy use, development and rationalization of the infrastructure of energy production and distribution, as well as of the faster introduction of more efficient technologies in energy sectors. Thus, energy efficiency in the energy producing sector supported the transition to an energy-intensive development pattern, buffering the impact on energy resources coming from other productive sectors. Upstream efficiency gains in the production of fuels and electricity held down average intensity of the economy, as more energy-intensive activities were being integrated. In a second period, from the mid 1980's, efficiency gains in the energy sector show signs of exhaustion. Energy intensity in the industrial and transport sectors peaks in the mid 1980's and early 1990's respectively. Energy efficiency gains are stronger in industry than in the transport sector. Finally, the three sectors show a slight rebound effect from 2000 on, mainly due to economic stagnation.

As a recent study showed, the transport sector in Mexico was the most energy intensive within OECD countries by 1996, about 50% more intensive than in the US and 100% compared to European countries like Germany (Gómez-Solares, et al, 2007, p. 20; the authors do not specify the units of comparison). However, the use of individual vehicles per 1,000 inhabitants is still much smaller than that of developed countries (op. cit., p. 15). These figures suggest that energy-use by transport in the country can be expected to increase both relatively and absolutely in the longer term. In other words, without major shifts in regulation and technology, the likely trend of energy efficiency in the transport sector will not contribute positively to improve overall energy efficiency in Mexico. In what follows we examine more closely the contribution of the energy generation and industrial sectors.

5. Sectoral emissions

In order to account for "structural" differences between sectors we map the trends of the components of the Kaya equation for both energy producing and industry sectors. The following analysis is different from the one in section 1 in two aspects. First, it omits the population factor. With population growing at less that 2% in this short period of time, the population effect can plausibly be assumed as constant. Second, unlike the decomposition analysis of section 1, greenhouse gas (GHG) emissions in this section refer to CO_2, CH_4, and SO_2 sectoral aggregates in units of CO_2 equivalent.[7] Data comes

[7] CO_2 equivalents for CH_4 and NO_2 were set according to their potential warming up to 100 years, converted by equivalence factors of 21 and 310 respectively (see UNFCCC, 2004).

from the National Inventory of GHG Emissions (INE-SEMARNAT, 2002). The above-mentioned caveats on this type of analysis must again be recalled.

[Graph 5 about here]

The calculation of emission factors for the energy sector includes both oil extraction and refining as electricity generation. According to Graph 5 above, GHG emissions in the energy-producing sector surged during the period, driven by expansion of scale without any significant reduction in either the carbon content of energy nor in the energy intensity of GDP. This occurred in spite of experienced important changes in technology and fuel-mix that took place in electricity generation during the period (substituting combined cycle plants for conventional thermal generation) that should have translated into reduced carbon contents of fuels and increased energy efficiency. The share of major fuels in the energy sector as a whole changed substantially, with fuel-oil (*combustóleo*) decreasing from 53% to 33%, and natural gas and coal increasing from 29.9 to 49.6% and 5.0 to 13.4% respectively (see SENER, 2007). However, according to GHG emission data, between 1990 and 2003 such changes yielded only minor reductions in emissions volumes. Direct emissions derived from energy consumption in the energy sector increased 49.8% between 1990 and 2003.[8] Changes in the fuel mix would only have yielded a reduction of 2.79% in emission volumes. That is, if the fuel mix of 1990 had remained constant throughout the period, total emissions from energy use in the energy sector would have been about 3% higher. Considering electricity generation alone, direct emissions from energy use increased 75.14% between 1990 and 2003. Changes in the fuel mix in electricity generation would have barely saved 3.7% of electricity GHG emissions.

Further technical change projected for the next decade in electricity generation will not

[8] Emission values were calculated simply by adding up the volume of fuel consumption scaled by the corresponding emission factors by type of fuel, as specified in IPCC (1996), Table 1-1, p. 1.13. Figures of energy consumption come from the National Inventory of Emissions of Greenhouse gases (INE, 2006). Due to lack of information, we omit additional differences among technologies using the same fuels.

provide significant direct reductions of emissions from changes in the fuel mix. According to planned investment of the Federal Commission of Electricity (CFE), the substitution of natural gas for fuel-oil will deepen between 2003 and 2013, changing their share in the industry's fuel mix from 37.6 to 52.2% and 36.2 to 17.5%, while keeping the relative consumption of coal constant. These changes will generate around 5% of emission abatement at each level of emissions. Clearly, since our estimation misses additional differences in emission factors between specific technologies, the ongoing changes in the technological profile of electricity generation will provide additional emission reductions both directly and indirectly (through energy efficiency). But these additional changes will most likely be insufficient, given that gross electricity generation will increase 70% between 2003 and 2013, and that an additional 30 to 40% increase in supply will be needed by 2030.[9]

It seems clear that the ongoing phase of technical change in electricity generation in Mexico, characterized by the penetration of natural gas as a main fuel is insufficient to draw the industry much closer to a level of emission stabilization by 2030. Of course, new combined cycle plants also deliver important emissions savings through increased generation efficiency. But these efficiency savings, coupled with minor changes in absolute emissions per unit of energy produced will be unable to offset the scale effect of growing energy supply. Change along the broader technological trajectory of GHG-intensive energy sources will not flow towards lower-carbon patterns of energy generation. Without major efforts to adopt and deploy renewable energy sources, the energy sector will not be able to disengage growing emissions from economic growth in the next two or three decades in any significant way.

There are other signs that the current technological trajectory is reaching maturity and decreasing efficiency gains. Graph 6 below shows the evolution of the physical and economic efficiency-ratio of the energy sector, measured respectively as the amount of energy consumed per unit of energy produced and as units of energy consumed per unit

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[9] See IEA (2002)

of economic output (in turn, measured as the energy sector's gross domestic product). Both ratios are expressed as index numbers with base in 1965, the first year available in the time series.

[Graph 6 about here]

The story behind the graph can be told, again, by differentiating two different periods. The first period starts in 1965 and ends between 1981-1983, and follows the predictable effects of the process of deployment of a modern energy infrastructure based on oil and electricity and its development. Both measures of efficiency follow twin trajectories along a full cycle of energy-intensity growth and rationalization. Expansion and reduction of relative energy use expresses, first, an energy-consuming phase of construction of a modern energy base and, second, a subsequent phase when energy-saving opportunities are seized and learning by doing delivers improvement of practices and technologies. While the effect of increasing international oil prices from 1973 on surely affects the economic efficiency ratio (as energy GDP includes a strong component of crude exports), this was firmly accompanied by increasing physical efficiency by about 30% from 1965, cutting relative energy use by a half from 1973-1983.

The second period expresses important shifts in the structure of the energy use base, with diverging trends in the coefficients. Exhaustion of possibilities for improving physical efficiency coincides with stagnant levels of economic efficiency. High international prices of oil would have allowed Mexico to subsidized an increasingly inefficient pattern of exploitation and consumption of energy through surging crude-oil exports. This pattern is clearly not sustainable as the fossil-fuel reserves approach exhaustion: the country will be left out to grab whatever resources there are to finance heavy amounts of energy to be consumed in very inefficient ways, and without the "cash cow" of cheap crude exports.

Graph 7 shows that the trends in GHG emissions and their factors in the industrial sector follow a significantly different, and moderately more optimistic, pattern of change. Emissions in the industrial sector include all CO_2, CH_4, and NO_2 emissions derived from energy use as well as emissions from industrial processes. The total volume of sectoral emissions in the industry sector increased around 18% between 1990 and 2000, with a 10% decrease between that last year and 2003 due mainly to economic stagnation. Provided that the carbon content of the energy supply shows a slightly increasing trend, it seems clear that improvements in energy efficiency of about 30% during the period buffered the impact of activity growth (40 to 50%).

[Graph 7 about here]

The emissions' trend of this sector is then one of a moderate increase in the GHG intensity of industrial activity. This trend expresses a technical pattern of development in which growing energy efficiency almost compensates the emissions' effect of economic growth, holding the carbon content of energy rather constant. Such a technical pattern suggests no major technological changes occurring at the level of the carbon intensity of core industrial production technologies. Unlike energy generation, the manufacturing sector seems to have been able to achieve significant energy savings through incremental technical change. But, was efficiency indeed a result of technical advance or the outcome of other factors like changes in the relative importance of energy-intensive industries? We can assert that technical factors dominated those derived form structural change during the period.

[Graph 8 about here]

Graph 8 shows that the evolution of energy efficiency at the sectoral level is a combination of both industry level efficiency gains and changes in the relative shares of individual industries. Total changes in energy intensity during the period 1988-2004 would have a technology component of about 75%, and a scale component of about 20%. That is, about a fifth of the reduction of energy efficiency comes from more intensive industries loosing relative importance in favor of less energy intensive ones. A more detailed analysis shows that most of the scale or composition effect can be attributed to the collapse of the petrochemical industry in Mexico since the late eighties (confirming the results by Aguayo and Gallagher, 2005).

Finally, comparing these two latter graphs, it seems evident that efficiency gains are also closely related to cycles of investment and capacity expansion. Technical progress along the technological trajectory would tend to respond to the investment cycle and to market barriers to growth capacity, since the absorption of new core technologies depend on capital turnover rates. Accordingly, the slowing down of economic growth between the year 2000 and 2003 would have prevented Mexican industry from attaining subsequent gains in energy efficiency.

6. Discussion

We have argued that the EKC approach can be misleading, both theoretically and empirically, for assessing barriers to disengage emissions from economic growth. We showed that the trajectory of increasing GHG emissions in Mexico slowed down from 1982 onwards, as a combined result of reduced population growth, economic stagnation, and moderate gains in energy efficiency. But unlike the experience of ex-socialist countries, growth stagnation during the two "lost decades" and the derived effort of structural adjustment did not yield a corresponding reduction of per capita GHG emissions. Lack of economic dynamism would have reduced opportunities for "shifting down" the EKC for GHG emissions. This shows that without major economic disruptions (that is, when income per capita contracts within small ranges) there is an inertial trend of environmental impact that is simply not reversible. Environmental effects simply tend to accumulate during periods of economic stagnation.

Secondly, we argued that a distinction between incremental and radical technical change is necessary for understanding major shifts in the relationship between growth and GHG emissions. By breaking down the long term emission paths into different factors for different sectors in the Mexican economy, we showed what seems to be a general trend of exhausting opportunities for emissions-saving incremental technical change in the form of energy efficiency within the industrial, energy and transport sectors. Energy efficiency gains in these sectors seem to have slowed down, reaching a level where further gains can only be attained through more profound technological and structural changes. On the other hand, radical technical change in the form of shifts in the carbon intensity cannot be detected at sectoral levels, despite evidence in individual industries. In particular, important changes in the technological base and fuel mixes of electricity generation have not delivered significant reductions in the sectoral level of emissions.

Our findings for the case of Mexico, suggests that lack of economic dynamism would tend to reinforce the exploitation of high-carbon technological alternatives and delay the introduction of low-carbon technologies. Even when energy-saving effects can be attained in a slow-growth context, these type of incremental effects would tend to be small in capital intensive sectors, and will sooner or later lead to exhaustion. This poses important challenges for a successful strategy of mitigation at the international level. It implies that, for reducing the growing impact of developing countries on global emissions, fast growth is a necessary condition, but in no ways a sufficient one. This undoubtedly rises sever concerns about the likely climate effects of the ongoing economic downturn.

Clearly, the technological rigidity of past decades is also permeated by higher relative costs of energy alternatives, the lack of certainty about the impacts of GHG emissions, and the legitimacy of GHG mitigation. Moreover, reduced opportunities to improve old systems also favor innovation. In other words, technological rigidities tend to soften out with the relative improvement of alternatives. But it is important to recognize that there is large segments of economic activity are locked-in to high-carbon technical choices, and face large costs and weak opportunities for switching investment flows into low-carbon energy technologies. The existing technological platform of many industries has to a large extent crystalized investments into high-carbon technological systems, generating multiple sources of lock-in and vested interests (including, but maybe not among the largest, the type of organizational inertia suggested by Unruh, 2000).

Any mitigation strategy in Mexico will have to device solutions for relieving the existing systemic barriers to reduce the carbon content of energy sources. This must emphatically include a shift in the current pattern of exploitation of fossil-energy, which is displaying signs of technological exhaustion. However, both radical change in fuel mixes and new opportunities for energy efficiency will depend on consolidating a new strategy for overall sustained growth.

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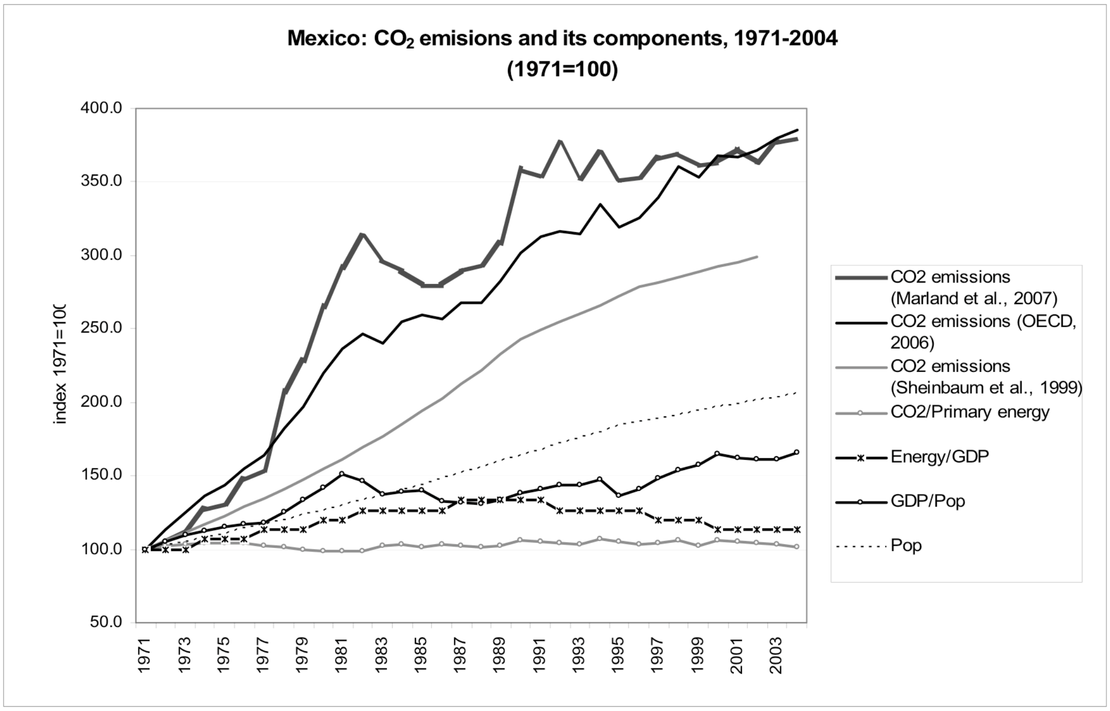
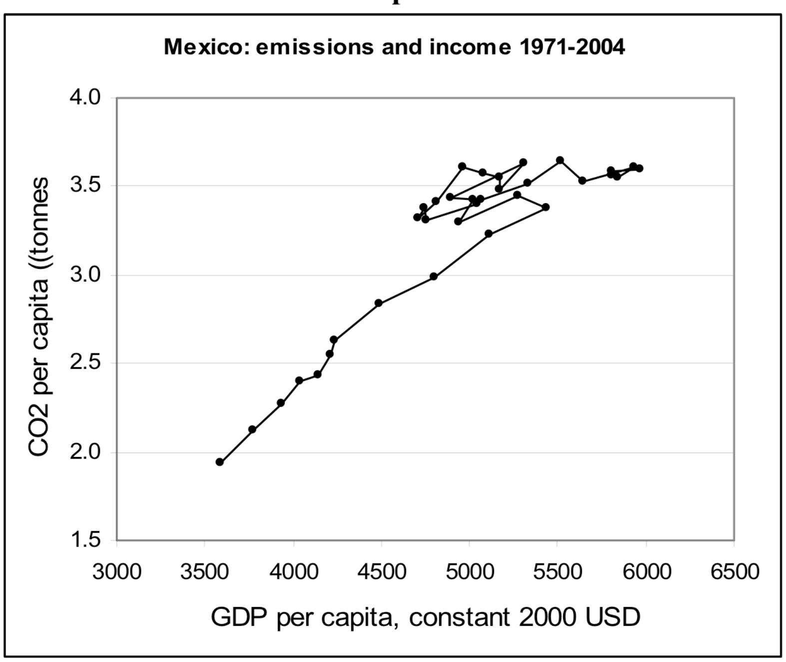
Graph 1



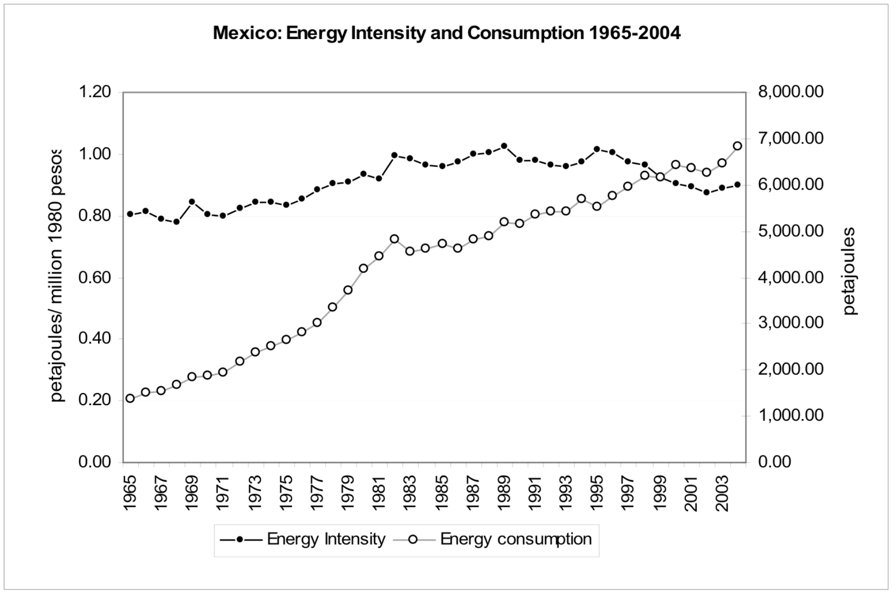
Source: Author's calculations. CO_2 emissions derived from energy use, indicated sources. Energy, GDP/Pop, and Pop: OECD (2007).

Graph 2



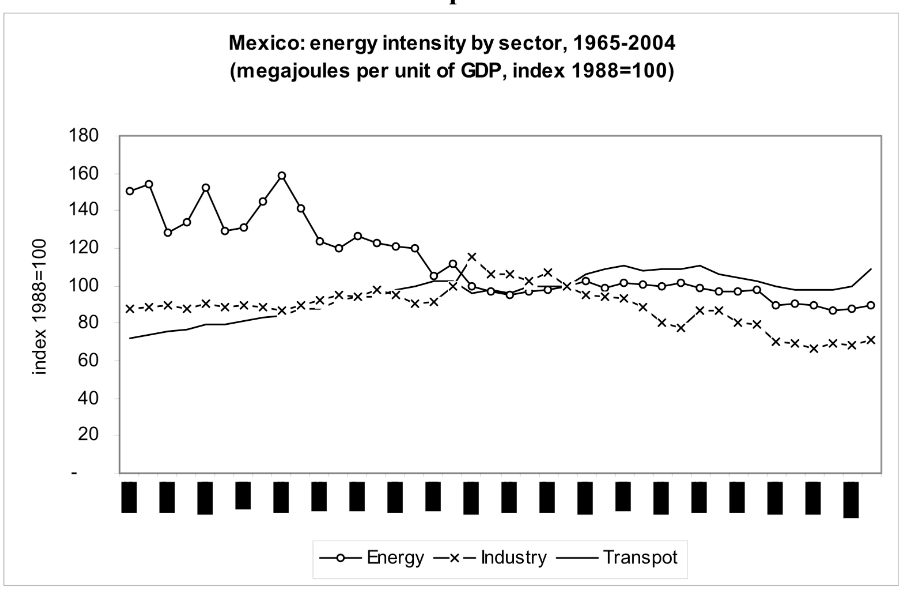
Source: Author's calculations, based on OECD (2007).

Graph 3



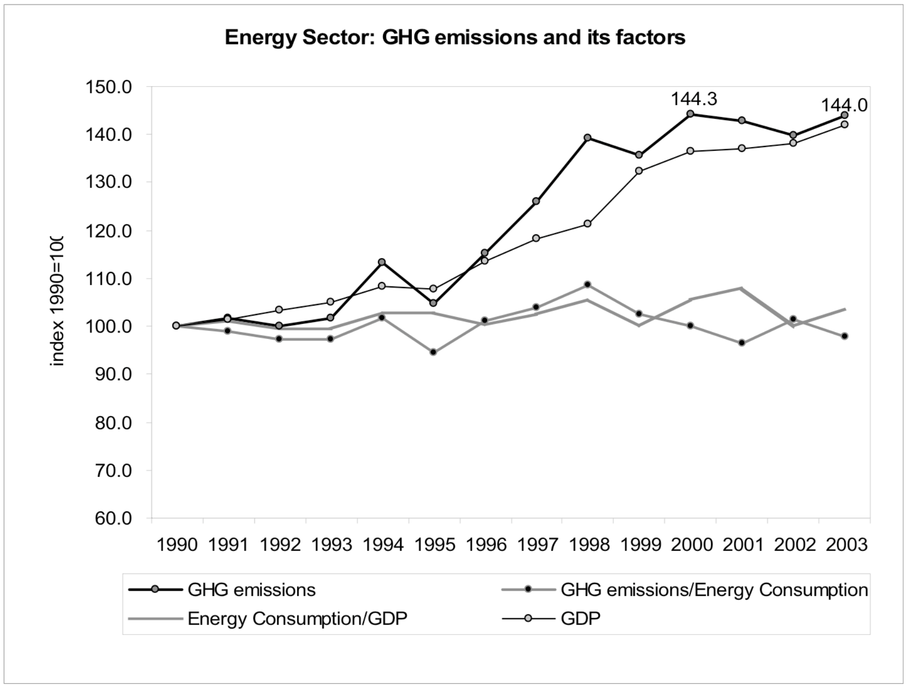
Source: OECD (2007)

Graph 4



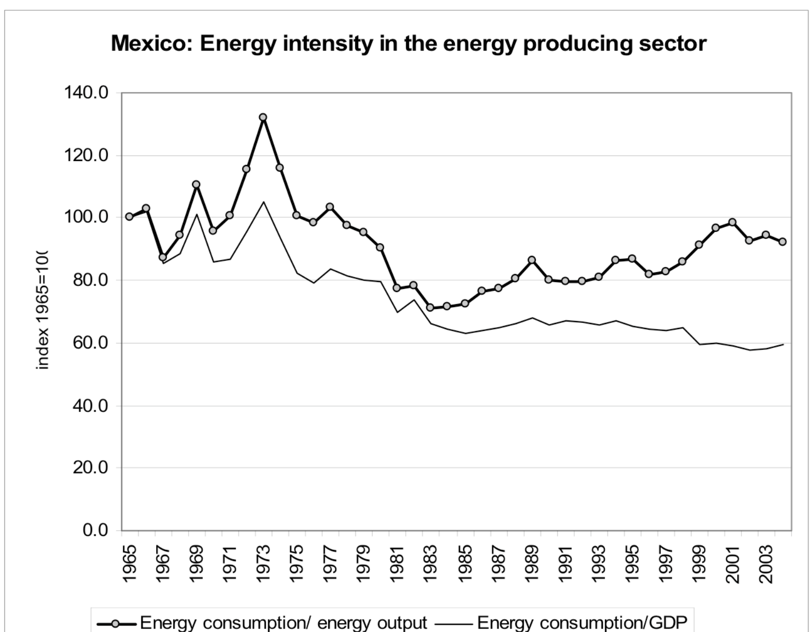
Source: Author's own calculations. Based on INEGI, National Accounts (GDP); SENER, Energy Balances (energy consumption).

Graph 5



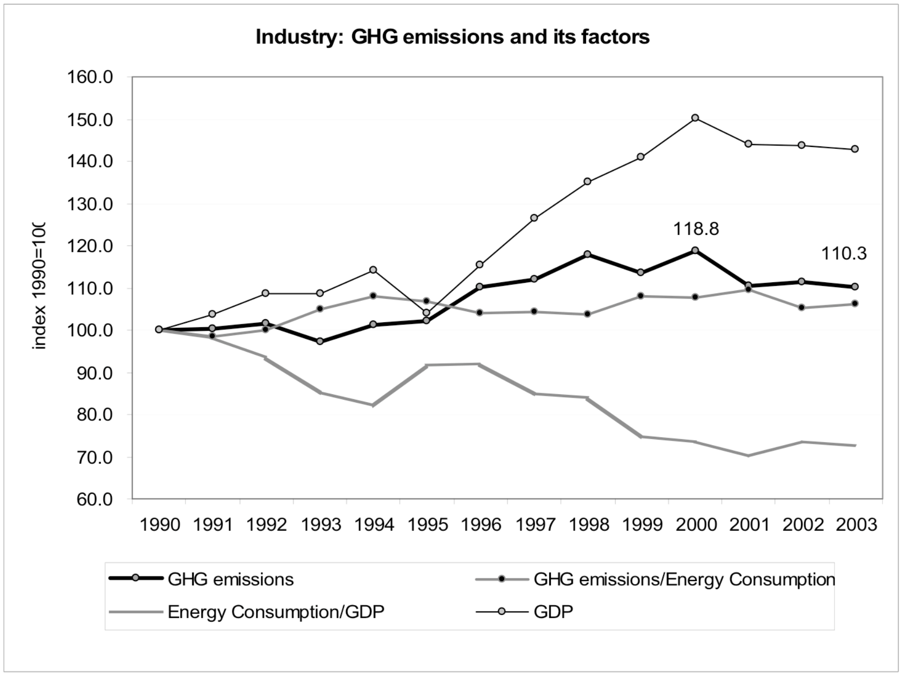
Source: Author's own calculations. Based on INEGI, National Accounts (GDP); SENER, Energy Balances (energy consumption); INE-SEMARNAT, Emissions Inventory (GHG emissions).

Graph 6



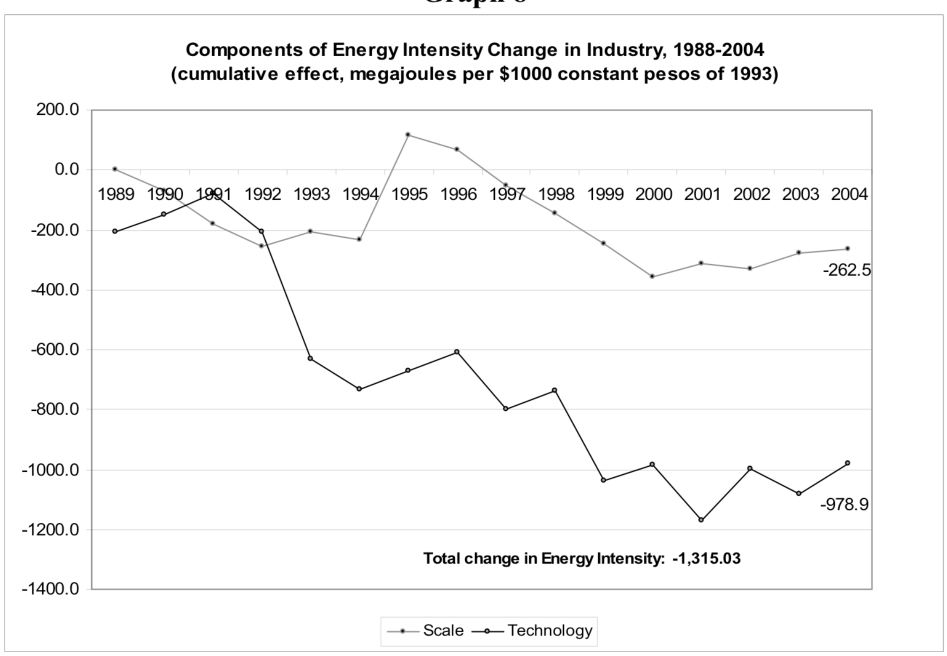
Source: Energy Balances, SENER 2007; National Accounts, INEGI.

Graph 7



Source: Author's own calculations. Based on: National Accounts, INEGI (GDP); Energy Balances, SENER (energy consumption); National Inventory of Emissions, INE-SEMARNAT (2002) (GHG emissions). GHG emissions include

Graph 8



Source: Author's calculations, following Aguayo and Gallagher (2005). Data is from: National Accounts, INEGI (GDP); Energy Balances, SENER (energy consumption)