



EVALUATING PEMEX'S DRILLING EXPANSION TO COMBAT DECLINING OIL RESERVES



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ABSTRACT

Mexico's Federal Government receives over 40% of its revenue from selling oil but faces an economic crisis if the country becomes a net importer of oil by 2020 as forecasted by the U.S. Energy Information Administration. Since 2000 the Mexican national oil company, PEMEX, has made a concerted effort to expand drilling in order to reverse the trend of declining oil reserves and improve the performance of Mexico's energy sector. Statistical models and a cost-benefit analysis show the drilling expansion has been partially successful through 2008 but concerns exist over the sustainability of PEMEX's current policy. Of particular concern are a steep decline in oil production since 2004 and a 300% increase in operating costs since 2000. Using correlations and econometric models, the analysis confirms a diminishing rate of return for each new well drilled and an increasing marginal cost per barrel of oil extracted. Reforms in operations and international partnerships can alleviate these problems to improve PEMEX's access to capital and ability to increase oil reserves in the long term.

EXECUTIVE SUMMARY

With the world's 16th largest source of proven oil reserves, Mexico is an important supplier to the global oil market. Through high taxes on its sales, PEMEX supplies over 40% of the revenue to the Mexican government. This considerable dependency on oil for revenue creates an incentive for political involvement in PEMEX's operations. PEMEX underinvested in exploration since oil was easy to extract, which led to a decline in oil reserves beginning in the mid-1980s. In 2000, PEMEX made a concerted effort to expand drilling in hopes of reversing this trend at the order of Mexican President Vicente Fox. From 2000-2008, the drilling expansion was the largest attempt to increase exploration and production in the company's history. Despite these efforts, oil production has been declining since 2004 and the U.S. Energy Information Administration estimates that Mexico could become a net importer of oil by 2020.

MEXICO NATIONALIZED THE HYDROCARBON SECTOR IN A MOVE THAT THE MEXICAN PEOPLE CELEBRATE ANNUALLY AS THE EXPROPIACION PETROLERA (OIL EXPROPRIATION)

No publications incorporate historical data and the present trends using quantitative methods to determine the effectiveness of PEMEX's concerted effort to reverse declining oil reserves since the year 2000. This report assesses PEMEX's drilling expansion to combat declining oil reserves to determine the likelihood of an economic crisis in Mexico within the next decade.

ANALYSIS OVERVIEW

The comprehensive analysis contained in this report includes:

1. An evaluation of PEMEX's competitiveness compared to other national oil companies and international oil companies
2. An analysis of the likelihood that Mexico has reached peak oil production
3. Updating a well-respected analysis done on the oil industry in Mexico
4. A sustainability evaluation consisting of statistical correlations, econometric models, and a cost-benefit assessment
5. Comparisons of actual oil production and reserve levels versus expected levels had the drilling expansion not occurred

The analysis shows the drilling expansion has been partially successful through 2008 but concerns exist over the sustainability of PEMEX's current policy including a steep decline in oil production since 2004, which appears to indicate Mexico has surpassed peak oil production. In addition, a 300% increase in operating costs since 2000 highlight the need to control costs as PEMEX extracts oil from more remote and expensive areas. Using correlations and econometric models, the analysis confirms a diminishing rate of return for each new well drilled and an increasing marginal cost per barrel of oil extracted. Reforms in operations and international partnerships can alleviate these problems to improve PEMEX's access to capital and ability to increase oil reserves in the long term.

This report considered several policy criteria that provided a framework for the analysis and recommendations. These criteria included political feasibility, the circumstances leading to Mexico's energy reform in 2008, economic and technological limitations, energy forecasts for Mexico, the historical perspective of other petro-states, and recent changes in U.S. energy policy.

RECOMMENDATIONS

1. Mexico and PEMEX should undertake a public campaign to highlight international partnerships with the governments and national oil companies of Norway and Brazil in order to change political will in Mexico
2. PEMEX's drilling expansion has been partially successful and should continue depending on operating costs and access to capital

1. OIL IN MEXICO OVERVIEW

On March 18 1938, Mexico nationalized the hydrocarbon sector in a move that the Mexican people celebrate annually as the *Expropiación Petrolera* (Oil Expropriation). The nationalized oil company, Petroleos Mexicanos or PEMEX is Latin America's largest company based on revenue (Fortune Magazine). It maintains a monopoly over the entire hydrocarbon sector for exploration and development, oil refining, marketing, and distribution. Like other National Oil Companies (NOCs), PEMEX is a great source of pride for the Mexican people. For some time, analysts have suggested that PEMEX privatize more aspects of its business to increase operating efficiency. However, the Mexican Congress has consistently defended the monopoly PEMEX has over the hydrocarbon sector. This resistance to change is one of the primary motivations to perform an analysis of PEMEX's operations in order to determine the sustainability of the oil sector in Mexico.

PROBLEM STATEMENT

An assessment of PEMEX's drilling expansion to combat declining oil reserves is necessary to determine the likelihood of an economic crisis in Mexico within the next decade. The following facts highlight the importance of this evaluation:

- The U.S. Energy Information Administration estimates Mexico could be a net importer of oil by 2020
- Mexico's Federal Government depends on PEMEX for over 40% of its revenue
- Oil reserves have been in decline since the mid 1980s
- PEMEX instituted a significant drilling expansion in 2000 to reverse the trend of declining oil reserves
- Oil production has been declining sharply since 2004 despite the increase in drilling
- Contentious energy reform in 2008 did not address core issues related to PEMEX's operation

The scope of this report is limited to assessing the drilling expansion by PEMEX from 2000 to 2008 to determine the sustainability of the oil sector in Mexico.

GOVERNMENT DEPENDENCY ON PEMEX REVENUE

For decades, the Federal Government has taxed the revenue of PEMEX and not its profits. This strategy allows the government to control the money flowing into PEMEX through high taxes. Figure 1-1 depicts the Federal Government's significant dependency on revenue from PEMEX. Thus, the government largely relies on the ability to extract and produce oil in a cost-efficient manner to function.

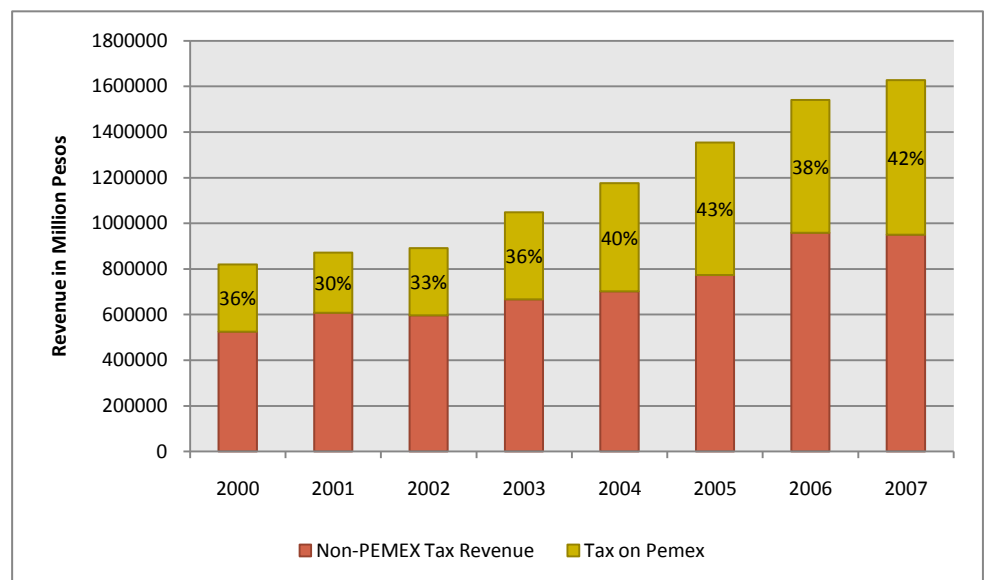


Figure 1-1: Mexico's government depends on revenue from PEMEX

IMPACT OF THE OIL RESERVE DECLINE

Historically, PEMEX benefited from highly productive oil wells. Figure 1-2 depicts PEMEX's high return per well drilled before 2000. Although the consistent devaluation of the peso and the financial crisis of 1994 negatively affected PEMEX's cash flow, oil production steadily increased during the 1980s and 1990s. This is mostly due to the highly productive Cantarell oil field, which provided a major part of oil production for PEMEX during this period (Peschard-Sverdrup, 2008, p. 12).

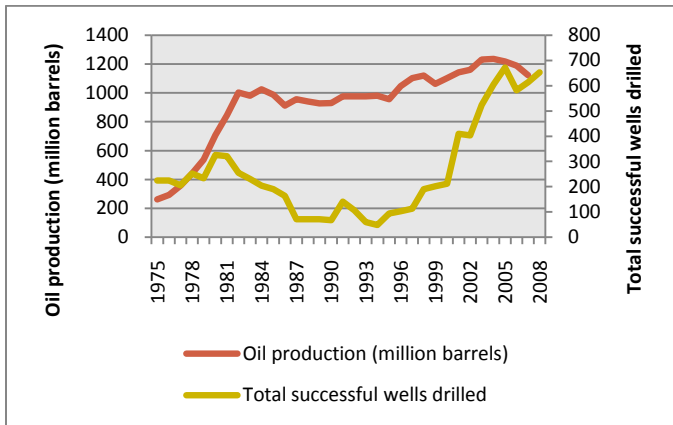


Figure 1-2: Oil came easily for PEMEX until 2000 (PEMEX, 2004-2008; Moroney & Dieck-Assad, 2005)

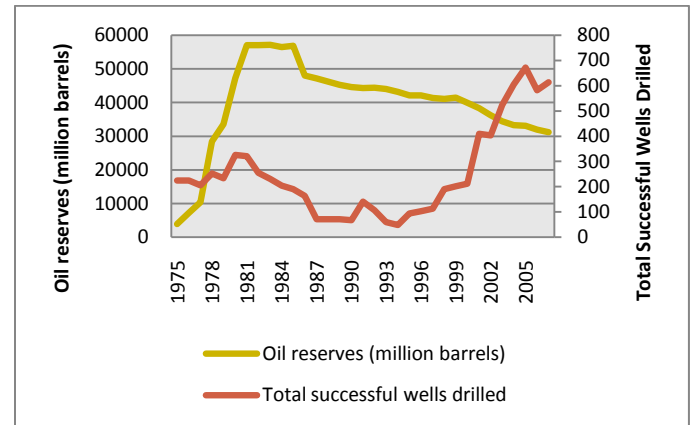


Figure 1-3: Mexico's oil reserves have steadily declined since the mid 1980s (PEMEX, 2004-2008; Moroney & Dieck-Assad, 2005)

In 1999, Mexico was the world's fifth largest oil producer (U.S. Energy Information Administration). Large tax revenues for the Federal Government came from exporting oil to the United States and the government's dependency on oil grew. Despite the price of oil being under US\$ 20 per barrel, PEMEX accounted for over 30% of the tax revenue for the Federal Government.

While oil production increased steadily during the 1980s and 1990s, Mexico's oil reserves headed in the opposite direction. From its peak in the early 1980s, the reserves lost a third of its value by the year 2000. Since oil reserves are a predictor of future production levels (and therefore revenue for the Federal Government), Mexicans were rightly concerned over this decline. This concern revealed itself during the Presidential election in 2000 as oil exploration and production became an important issue.

The Dallas Morning News polled Mexicans one week before the election and found that 72% supported radical change (Camp, Roderic Ai, 2007, p. 220). If Mexicans were going to elect their first President from an opposition party since 1910, a radical change would be necessary. Furthermore, significant reforms were needed if Mexico's national oil company was to reverse the trend of the country's declining oil reserves. Such a turnaround would require significant capital investment, which was previously difficult to come by. PEMEX would also need technological expertise not available within the company to extract oil from hard to reach locations on and off shore. The world oil market was growing rapidly and Mexico would need reform if it were to remain a key player.

THE DRILLING EXPANSION POLICY

When Mexicans elected Vicente Fox President in 2000, he gave PEMEX a clear objective: increase production of oil (Moroney & Dieck-Assad, 2005, p. 3). Figure 1-5 and Figure 1-6 depict the marked growth in well drilling by PEMEX after the year 2000. The trend of increased drilling has continued under the leadership of President Felipe Calderon. Unfortunately, oil reserves are still declining and oil production has been declining since 2004. The decline in production is primarily due to the significant decrease in

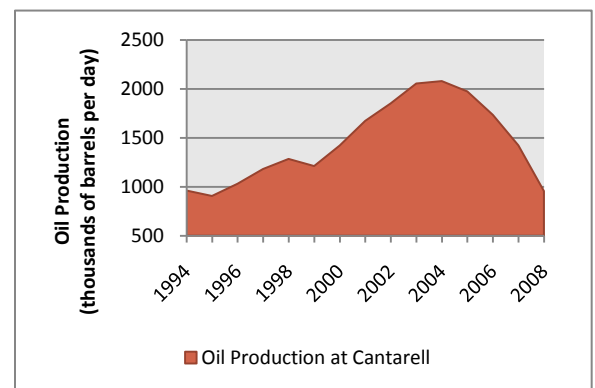


Figure 1-4: Declining production at Cantarell has accounted for much of the total decline in production (Sistema de Información Energética)

production at Cantarell (see Figure 1-4) and PEMEX's lack of technology capable of extracting oil from remote areas. PEMEX uses debt financing to fund most investments including exploration and production activities. PEMEX's access to capital may be at risk due to the tightening of credit markets and a lessening of its own capacity to borrow.

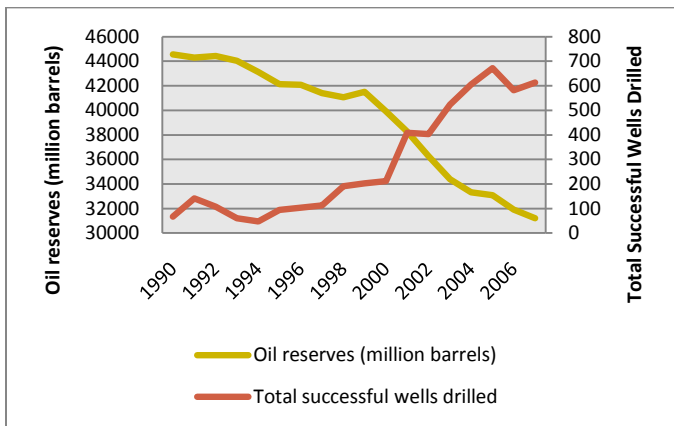


Figure 1-5: The 2000s are a stark contrast from the 1990s

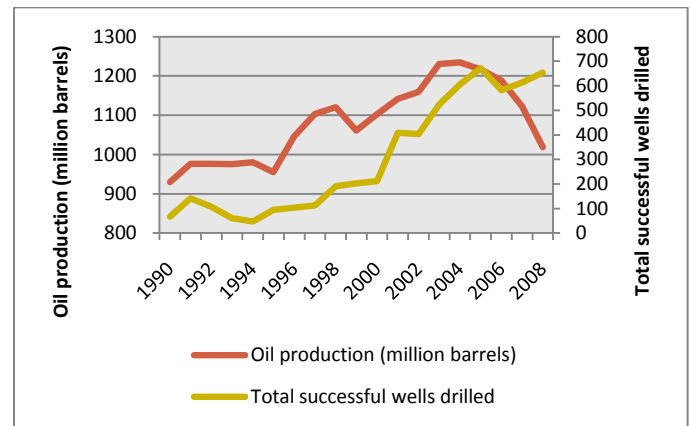


Figure 1-6: Production is declining despite PEMEX's recent efforts

ENERGY REFORM IN 2008

In 2007, it was clear that PEMEX required further reforms to improve the drilling expansion effort due to continued declines in oil reserves and recent and significant declines in oil production. Subsequently in April of 2008, President Felipe Calderon proposed reform at PEMEX including autonomy with its budget and greater private partnership in exploration. These reforms did not address some of PEMEX's core issues. The likely barrier to further reform is political in nature due to the strife during 2008's energy reform debates. The leader of the opposition party at the time, the Party of the Democratic Revolution (PRD), claimed President Calderon's reform was attempting to privatize PEMEX (The Economist, 2008). One can expect attacks like these in the future unless political will changes. Meanwhile, the nationalization of the hydrocarbon sector continues to be a source of pride for the Mexican people.

REPORT MOTIVATION

This report is part of a larger effort by Global EESE (Energy and Environment Strategic Ecosystem), a globally collaborative, distributed foresight network initiated by the U.S. Department of Energy. Global EESE's goal is to address energy and environmental security challenges in the public sphere in order to provide an international and comprehensive approach to analyses of these issues. In *The Wealth of Networks*, Yockai Benkler states the public sphere must be "susceptible to perceiving and considering the issues of anyone who believes that their condition is a matter appropriate for political consideration and collective action" (Benkler, 2006, p. 182). In this way, Global EESE hopes a collective approach to addressing energy and environmental security problems captures issues often missed in traditional intelligence gathering for national security.

In 2008, Global EESE initiated several pilot projects to investigate energy and environmental security issues including a project focused on North America's changing oil relationships including causes and consequences. Many have assessed Mexico's oil industry throughout the last decade but no publications incorporate historical data and the present trends using quantitative methods to determine the effectiveness of PEMEX's concerted effort to reverse declining oil reserves since the year 2000. This analysis is necessary to evaluate the likelihood that PEMEX will reverse this trend given its technological capabilities and access to capital. Thus, this report attempts to provide an assessment of PEMEX's effort to combat declining oil reserves in order to provide an input to the evaluation of North America's changing oil relationships.

2. BACKGROUND RESEARCH

In order to perform an assessment of PEMEX's drilling expansion and provide useful recommendations, significant background research was necessary. An understanding of Mexican politics, the operations at PEMEX, international factors effecting PEMEX, and the risks unique to "petro" states provided a foundation for the analysis.

OVERVIEW OF MEXICO

PEMEX provides the Federal Government over 40% of its tax revenue creating a significant dependency on the country's NOC. This reliance results in significant influence in the operation of PEMEX by the Federal Government in hopes of improving social welfare through revenue from oil. As a result, the political model of Mexico is paramount since its citizenry can attach economic growth to the political system (Camp, Roderic Ai, 2007, p. 4). This was evident with the election of Vicente Fox as President in 2000, the first victory for an opposition party since 1910. Mexicans demanded change and part of that transformation involved the operation of PEMEX. Combine the Federal Government's dependency on PEMEX with the fact that 25% of Mexicans in 1998 believed that redistribution of wealth is the second most important task of democracy and one can see the relationship between revenue at PEMEX and the interconnections with the political system (Camp, Roderic Ai, 2007, p. 5).

NATIONAL PRIDE IN PEMEX

The nationalization of the hydrocarbon sector is a great source of pride for the Mexican people. Celebrated annually as *Expropiacion Petrolera* (Oil Expropriation), it is one of the major national holidays or Fiestas Patrias. This pride has led to a stiff resistance to change for fear of international involvement in what many believe to be Mexico's strongest asset. While it was easy to perpetuate this sense of national pride with one party rule by the PRI, the election of President Vicente Fox created the opportunity for debate. However, this debate has been limited to minor changes at PEMEX as evident in the energy reform of 2008.

U.S.-MEXICAN RELATIONS

A tense history wrought by war and cultural differences, the distrust of U.S. intentions by Mexico is born from past events. From the capturing of half its land in the Treaty of Guadalupe Hidalgo in 1848 to the expelling of U.S. oil companies with the nationalization of the hydrocarbon sector in 1938, Mexico has a history of nationalism partially because of anti-Americanism (Camp, Roderic Ai, 2007, pp. 49-51). The mere proximity of Mexico to the U.S. when combined with the fear of territorial loss may have encouraged the political stability provided by early authoritarian regimes in the country (Camp, Roderic Ai, 2007, p. 51).

POLITICAL BARRIERS AND THE ENERGY REFORM OF 2008

The Mexican political system is vastly different from the U.S. system. In 2000, only 25% of Mexicans considered political parties legitimate compared with 56% of Americans (Camp, Roderic Ai, 2007, p. 57). While politicians in America typically react to polls and campaign promises, the Mexican government often pursues its own policies because of self-interest or its "interpretation of societal interests" (Camp, Roderic Ai, 2007, p. 167). This political culture is a result of one party rule prior to 2000 and a lack of accountability in the electoral system. The Constitution of Mexico prevents members of the Mexican Congress from serving consecutive terms in the same chamber, which strips much of the accountability provided by representative democracy.

In April of 2008, President Felipe Calderon proposed ambitious energy reform. The contentious debate that followed highlighted the political hurdles present when addressing issues in Mexico related to the hydrocarbon sector. The reforms are a positive step, but further changes are necessary to address core issues related to PEMEX's operation as this report analyzes in *Drilling Expansion Policy Analysis*.

PROGRAM FOR GROWTH AND EMPLOYMENT

On October 8, 2008, Mexico established a new program for PEMEX that included substantial reform to the way PEMEX handles debt. The program included the construction of a new oil refinery using funds from the *Stabilization Fund for Oil Income Investment (FEIIP)*. The law also eliminated the *PIDIREGAS* program for debt financing. Existing *PIDIREGAS* debt is now public debt and future capital expenditures by PEMEX would no longer be included in the Mexican Government's budget.

PETROLEOS MEXICANOS LAW

In November of 2008, the Mexican Congress enacted energy reform in hopes of improving the operation of PEMEX. The reforms included many modifications to PEMEX's operational guidelines. The following are some of the most significant changes (PEMEX, 2009):

Public works and service contracts

- Will always be in cash
- May not be based on a percentage of production, value of hydrocarbon sales or profit percentages
- Should be established when the contract is signed

Corporate Governance

- Board resolutions will require a favorable vote of at least two professional members; if such vote is not received, the vote on the resolution will be postponed until the next meeting

Citizen Bonds

- PEMEX may issue debt securities that grant holders a return linked to its performance
- Bonds may only be acquired by Mexicans (individuals, pension funds, mutual funds, and market makers)

Debt

- PEMEX will be subject to general debt guidelines and authorization from the Ministry of Finance and Public Credit for specific transactions will not be required
- However, the Secretary of Finance and Public Credit may object to specific debt transactions, as justified exceptions

Budget

- PEMEX may, without the authorization of the Ministry of Finance and Public Credit, (i) make budgetary adjustments (as long as it oversees PEMEX's financial balance annual goal and the regular budget for personnel services is not increased) and (ii) increase its expenses as its income increases
- PEMEX investment projects will be subject to a less complicated registration in the Secretary of Finance and Public Credit

National Suppliers

PEMEX must:

- Require minimum percentages of national content in its procurement of certain goods and services
- Establish preference in favor of proposals that employ Mexican human resources, goods or services
- Grant preferences to small-and medium-sized companies during national bidding processes
- Have a specialized area that identifies opportunities for the development of Mexican suppliers and contractors

ENERGY FORECASTS

In 2009, the U.S. Energy Information Administration (EIA) estimated that Mexico could become a net importer of oil due to increasing demand for gasoline combined with decreasing oil production (U.S. Energy Information Administration). This prediction comes despite Mexico's effort to expand drilling since the year 2000. The accuracy of the EIA's prediction is difficult to assess without intricate knowledge of PEMEX's internal strategy to combat declining oil reserves. However, the data available on oil production and oil reserves indicates a dire scenario. Mexico's largest oil field, Cantarell has been in a steep decline since its peak in 2004. Providing over 60% of PEMEX's production in 2004 at over 2 million barrels per day, it provided less than half that production level in 2008 accounting for only 36% of total production (PEMEX, 2004-2008). Efforts to replace Cantarell's lost production have only been marginally successful indicated by the steady decline in overall production since 2004. However, in January 2009, the Ku-Malooob-Zaap (KMZ) field passed Cantarell as Mexico's largest oil field (PEMEX, 2009, p. 2).

Despite being the world's seventh largest producer of crude oil in 2008, Mexico remains a net importer of refined gasoline due to a shortage of oil refineries (U.S. Energy Information Administration). The Mexican government requires that PEMEX absorb any cost for imported gasoline above the price set by the Hacienda, Mexico's Finance Ministry (Stojanovski, 2008, p. 64). The 2008 energy reform includes the construction of a new refinery, but is unclear if this act alone will meet demand for gasoline presently or in the future.

PEMEX OPERATIONS

PEMEX is a great source of pride for the Mexican people. As Latin America's largest company, PEMEX is a juggernaut in Mexico employing over 140,000 people and providing 3% of Mexico's GDP (PEMEX, 2004-2008; U.S. Central Intelligence Agency, 2009).

COMPANY MISSION

PEMEX's mission is to "maximize hydrocarbons and by-products economic value, contributing to the sustainable development of the country" (PEMEX, 2009). The Director General of PEMEX, Jesus Reyes Heroles has laid out the challenges facing PEMEX in order to achieve its goal. These obstacles include labor relations and negotiations, transparency, efficiency, and financial stability (PEMEX, 2009). For PEMEX to address these issues, it must work with labor unions, the Mexican Congress, and its own internal infrastructure. The scope of this report is limited to assessing PEMEX's recent internal efforts related to oil drilling to determine if its *efficiency* is adequate to sustain the oil industry in Mexico.

OPERATIONAL LIMITATIONS

Historically, the Federal Government has maintained tight control over operations at PEMEX including annual budgets, budget modifications, and investments. Like other NOCs, PEMEX lacks complete autonomy but in Mexico, the fragmentation of the control structure prevents any single actor from maintaining strategic oversight. The Federal Government views PEMEX as a source of

revenue for the country and attempts to maximize short-term gains (Stojanovski, 2008, p. 7). While this strategy worked well when oil was easily accessible, recent years have shown that a lack of investment in technology may hinder PEMEX's ability to extract oil from remote sources.

In addition to the Federal Government priorities, the tax burden PEMEX has incurred also hampers the company's ability to invest in exploration and production technology. Taxing revenue at well over 50% has severely restricted PEMEX's capacity to development technological expertise. As a result, PEMEX used debt financing to fund over 95% of all investments in 2007 (PEMEX, 2004-2008).

Table 2-1: 2007 tax regime for PEMEX (PEMEX, 2008, p. 48)

Tax Name	Description
Ordinary Hydrocarbons Duty	The method of calculating this duty is the value of the extracted total production of crude oil and natural gas during the year minus certain permitted deductions (including investments, plus some costs, expenses and duties)
Hydrocarbon Duty for the Oil Revenues Stabilization Fund	Applied at a rate between 1% and 10% of the value of the extracted crude oil production where the yearly weighted average crude oil export price for a certain year exceeds between US\$ 22.00 and US\$ 30.00 per barrel.
Extraordinary Duty on Crude Oil Exports	Applied at a rate of 13.1% on the difference between the value realized for crude oil exports and the budgeted crude oil price of US\$ 42.80, times the annual export volume. This duty is to be credited against the Hydrocarbon Duty for the Oil Revenues Stabilization Fund. The income from this duty is designated to the states of Mexico via the Income of the Federative Entities Stabilization Fund.
Duty for the Fund for Scientific and Technological Research on Energy	Applied at a rate of 0.05% to the value of the extracted production of crude oil and natural gas for the year. The revenues from this tax are designated for the Mexican Petroleum Institute in accordance with the Federal Expenditure Budget.
Duty for the Fiscal Monitoring of Oil Activities	Applied at a rate of 0.003% to the value of extracted production of crude oil and natural gas for the year. The revenues from this tax are designated for the Auditoria Supreme Federal Audit in accordance with the Federal Expenditure Budget.
Additional Duty	Applied if the actual production of crude oil in the years 2006, 2007, and 2008 is less than the target production, but only when the shortfall is not because of force majeure, act of god, or energy policy.
Special Tax on Production and Services	In accordance with the regulations in effect, PEMEX is subject to the Special Tax on Production and Services (IEPS), which applies to the import and sale of gasoline and diesel. The IEPS is paid to Ministry of Finance and Public Credit monthly, after deducting the daily advance payments. The rates applicable to this tax depend on factors such as the type of product, price of reference, the region where one sells, additional freight and applicable commissions.
Hydrocarbon Income Tax ("IRP")	This tax is calculated by applying a 30% rate on the excess of the total revenues minus the authorized deductions pursuant to the specific rules expressed by the Ministry of Finance and Public Credit.
Value Added Tax	For purposes of determining the Value Added Tax (VAT), PEMEX follows the criterion for excluding only the interests paid for institutions of credit and credit unions in accordance with the fraction V of the article 15 of the Regulation of Value Added Tax.
Income and Assets Taxes	Certain Subsidiary Companies are subject to the income tax law and the assets tax law.

The Mexican Constitution requires PEMEX to be the only oil operator in the country. Furthermore, the law prevents PEMEX from entering in any agreements with other companies to share revenue from extracted oil. This requirement removes the strongest incentive for partnerships, which are likely necessary for PEMEX to complete remote exploration due to its technological shortcomings. The only overseas partnership PEMEX possesses is the shared operation of an oil refinery in the United States (Stojanovski, 2008, p. 8). Despite these restrictions, PEMEX has sought cooperation with other NOCs including StatoilHydro (Norway)

and Petrobras (Brazil). PEMEX hopes these partnerships will enhance its technological abilities (PEMEX, 2007). PEMEX has not released any conclusive results from these partnerships so it is unknown if these agreements have been fruitful.

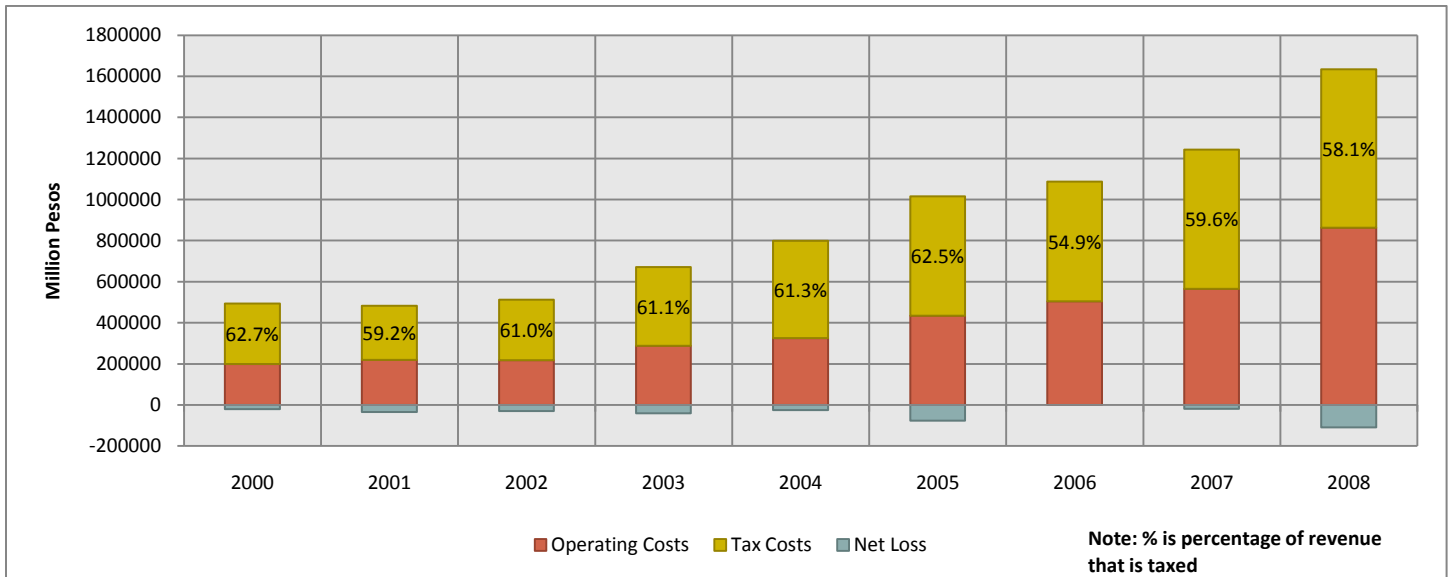


Figure 2-1: PEMEX has trouble making ends meet due to high operating costs and high taxation on its revenues (PEMEX, 2004-2008)

TECHNOLOGICAL LIMITATIONS

Throughout the 1980s and 1990s, PEMEX underinvested in technological development due to financial woes in the country combined with easy to extract oil at Cantarell (Stojanovski, 2008, pp. 61-62; Moroney & Dieck-Assad, 2005, p. 14). As a result, PEMEX must spend considerable time catching up to other NOCs and International Oil Companies (IOCs) in order to extract oil from remote areas, where many of their possible oil reserves exist. Partnerships with experienced exploration companies would make this technological advancement straightforward but the Mexican Constitution prevents incentives necessary for most of private industry.

ECONOMIC LIMITATIONS

The global financial crisis that began in late 2008 has led to steep declines in demand in the international oil market. With crude oil prices falling from US\$ 120 per barrel in September 2008 to US\$ 50 per barrel in April 2009, revenue for oil companies has diminished considerably (U.S. Energy Information Administration). ExxonMobil reported profits in the first quarter of 2009 that were 58% below the previous quarter (Exxon Mobil Corporation, 2009). In 2008, PEMEX made a calculated risk to hedge US\$ 70 per barrel prices for much of their exports in 2009. Thus, PEMEX appears to have shielded itself from the global financial crisis for 2009. If oil remains near US\$ 50 per barrel for 2010, that could mean considerable revenue loss for PEMEX compared to 2008 numbers and lead to serious constraints on the Federal budget. The following calculation provides a rough estimate for how much revenue would be lost if PEMEX could export oil at US\$ 50 per barrel in 2010 assuming 2008 production levels:

$$\text{Revenue Loss} = 1403 \frac{\text{thousand barrels}}{\text{day}} \times (84.14 - 50) \frac{\text{U.S. dollars}}{\text{barrel}} = \text{US\$ 17.5 billion}$$

Note: US\$ 17.5 billion dollars of PEMEX revenue was approximately 7% of the Federal budget in 2007

The other major consideration regarding the financial crisis is PEMEX's access to capital. Other NOCs like Petrobras felt the credit crunch late in 2008 when contractors hired to build offshore drilling rigs could not borrow money to finish construction (Baskin & Flick, 2008). Since PEMEX has operated consistently at a deficit for the past decade, it must borrow funds to finance operations including 95% of all investments for exploration and production in 2007 (see Figure 2-2). Mexico further complicated this process with the energy reform of 2008, which eliminated PEMEX's method for financing debt known as *PIDIREGAS*. PEMEX must now finance its own debt based on its credit rating. The credit rating is a function of the company's ability to retain cash after paying taxes and duties and the size of its long-term liabilities. Given PEMEX's consistent balance deficit and the tight credit markets, its access to capital may diminish in the near future.

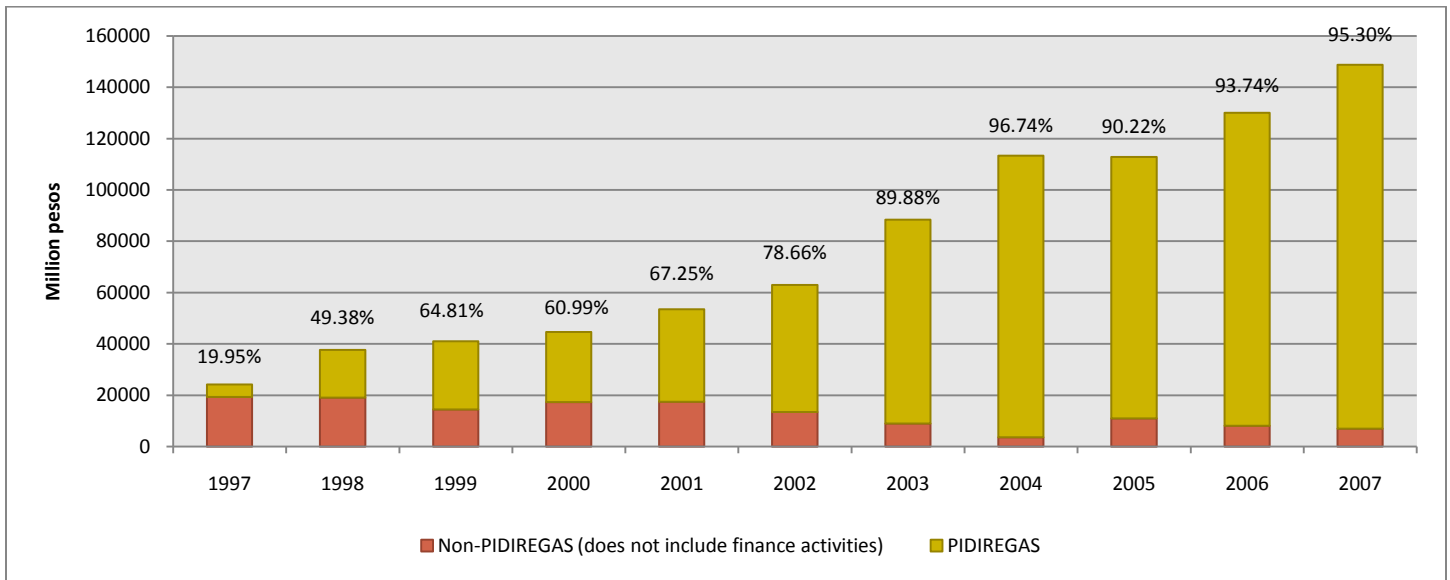


Figure 2-2: PEMEX relies on debt financing to fund investments in production and exploration

HISTORICAL PERSPECTIVE

A look back at recent history in Mexico and other oil-centric (or petro) states provides a necessary framework to assess risk if Mexico does become a net importer of oil by 2020 as the U.S. EIA predicts. The potential revenue shortfall for the Federal Government presents a danger that warrants examination.

PETRO-STATES

Petro-states are nations whose hydrocarbon sector provides a substantial portion of revenue for the government. These nations typically have nationalized hydrocarbon sectors and a National Oil Company (NOC). Iran, Saudi Arabia, Venezuela, Norway, Indonesia, and Mexico are all examples of petro-states.

An economic effect known as Dutch-Disease, where favorable price changes in one sector of the economy (e.g., oil) cause distress in other sectors is a powerful explanation of the poor performance of oil exporters (Karl, 1997, p. 4). This effect is often the outcome of institutional arrangements and not just an explanation for a decline in the economy. The constant interaction between the political environment and this condition fosters the mode of economic development.

Mexico is a good example of a petro-state because the political influence over PEMEX is considerable but the country does not suffer from Dutch Disease since PEMEX comprises less than 5% of GDP. In this way, Mexico is in a relatively unique position to avoid some of the pitfalls that plagued other petro-states with fluctuations in oil prices. However, with 40% of government revenue coming from PEMEX, the EIA's forecast in 2020 could compromise the stability of the state. In fact, Terry Lynn Karl's central argument in *The Paradox of Plenty* fits Mexico well:

Commodity-led growth induces changes in prevailing notions of property rights, the relative power of interest groups and organizations, and the role and character of the state vis-à-vis the market. These institutional changes subsequently define the revenue basis for of the state, especially its tax structure. How these states collect and distribute taxes, in turn, creates incentives that perversely influence the organization of political and economic life and shapes government preferences with respect to public policies. In this manner, long-term efficiency in the allocation of resources is either helped or hindered, and the diverse development trajectories of nations are initiated, modified, or sustained.

(Karl, 1997, p. 7)

Karl argues that how the state collects and spends its revenues define its nature. In this way, a linkage exists between petro-states due to their dependencies on oil exports for revenue. Furthermore, one cannot easily separate economic rationality from political rationality in terms of rent seeking, especially for states with NOCs since they retain tighter controls of company operations. Karl groups petro-states into capital-deficient and capital-surplus countries where capital-deficient nations have larger populations and fewer oil reserves per capita. Karl considers Mexico a capital-deficient country along with Algeria, Indonesia, Nigeria, Venezuela, and Iran. Since Mexico is not a member of OPEC and became an exporter of oil later than others, the boom-bust cycle discussed below is slightly time-shifted from the one experienced by Mexico in the 1980s. (Karl, 1997, pp. 13-19)

THE BOOM-BUST CYCLE IN PETRO-STATES

The boom-bust cycle of the 1970s is a warning of impacts from the latest boom-bust cycle in the oil industry from 2004-2009. In 2009, many petro-state governments planned for oil prices above US\$ 70 per barrel but oil remains a relatively inexpensive US\$ 50 per barrel as of May 2009 (U.S. Energy Information Administration).

The boom for petro-states in the 1970s revealed itself in the form of public spending, economic narrowing, and increased debt due to a spike in oil prices. Between 1973 and 1974, Venezuela's government expenditures increased almost 75% in real terms and Iran's increased almost 60%. By 1977, Algeria's public investment rate reached 75% of non-mining GDP. The boom also affected other exports since the oil sector is the basis for the value of their currencies. Since oil increased in price, the currency became overvalued compared to non-oil activities resulting in cheaper imports and a further narrowing of petro-state economies. Inflation occurred leading to increased subsidies (especially the domestic oil supply), and support for inefficient local industries. Lastly, petro-states leveraged oil in the ground to borrow. The false belief that the product would increase in value led to unprecedented borrowing: five countries accounted for over half of all Less Developed Countries (LDCs) loans and three of them (Mexico, Venezuela, and Algeria) were oil exporters. (Karl, 1997, pp. 25-30).

The bust occurred in the 1980s with the collapse of oil prices from US\$ 32 per barrel in 1981 to US\$ 13 per barrel in 1986. By then, petro-states faced debt, inflation, deficits, inefficiencies in local industries, and a bloated public sector. Most petro-states saw an increase in the oil sector as a percentage of GDP along with a decline in agriculture. Oil revenue dropped substantially, which led to increased borrowing. By 1987, the debt service ratio to exports reached 65% in Venezuela and 113% in Nigeria. While the aggregate GNP of LDCs grew 14% between 1981 and 1986, it fell by 20-50% in Venezuela, Indonesia, and Nigeria. Mexico's GNP dropped 50% during this period. (Karl, 1997, pp. 30-32)

Table 2-2: Variations in macroeconomic performance (Karl, 1997, p. 192)

	Indonesia	Iran	Nigeria	Venezuela	Algeria
Estimated growth/government expenditures 1975-75, %	19.8	35.9	29.9	38.5	Unavailable
Ratio of 1980 to 1986 GNP	0.96	0.88	0.46	0.81	1.51
Percent change in ratio of tradeables to non-tradeables (1965-1982)	-61.8	-1.6	-59.3	-6.9	-5.7
Increase in ratio of total external debt to GDP, 1975-80 as % of 1975 ratio	-26.6	Unavailable	87.7	265.2	41.5
Incremental capital/output ratio (ICOR)	5.2	Unavailable	39.2	8.5	Unavailable

A CAPITAL-INTENSIVE INDUSTRY

Oil and coal are the top manufacturing industries according to their degree of capital-intensity. Karl highlights two effects from this extreme capital intensity:

1. High levels of foreign ownership or control of their main

resource since the country did not possess the capital to develop the industry initially

2. Low employment generation and a skewed wage structure (Karl, 1997, p. 47)

Karl concludes that the economy of petro-states that allow foreign involvement are characterized as foreign-controlled with high-wages, high unemployment, and strong unions (Karl, 1997, p. 48). It is the fear of this outcome that could motivate Mexico's current nationalistic sentiment regarding the oil sector. Mexico avoids foreign ownership through their Constitution, which prohibits any entity from controlling hydrocarbons besides PEMEX. However, many analysts have suggested that Mexico must relinquish this control if they are to extract oil in remote areas since they lack technological capabilities.

Karl sites that the oil sector employs only 1-2 percent of the workforce. The issue of low employment generation at Mexico is not evident as the unemployment level was a low 4.7% in 2008 (OECD). This is likely a result of the oil sector's low percentage of overall GDP as cited earlier.

Although Mexico has avoided some of the drawbacks of the nature of the oil sector, PEMEX still faces a deficient access to capital due to high taxes on its revenue and tight credit markets. Furthermore, PEMEX faces a powerful and influential labor union when attempting any reform.

PETRO-STATE EXCEPTIONS: NORWAY AND INDONESIA

Indonesia and Norway avoided the pitfalls other petro-states succumbed to and an exploration of their policies may provide some insight.

In Indonesia, neither modern state building nor regime formation stemmed from oil's influence on the economy. Suharto, Indonesia's leader during the 1970s and 1980s relied on international expertise to form economic policy including a balanced-budget rule and no quantitative controls on exchange rates. The regime also focused on agricultural development to balance the influence

NORWAY POSSESSED A DIVERSIFIED TAX BASE, A NEAR ZERO UNEMPLOYMENT RATE, AND MINIMAL POVERTY

of the oil sector. This dynamic economic policy set the stage for a different growth trajectory during the boom of the 1970s. In addition, corruption of the Indonesia's oil industry, Pertamina forced the government to send much of the oil windfall to foreign creditors; this blessing in disguise prevented a considerable growth in the public sector that plagued other petro-states. Furthermore, Indonesia protected other exports by devaluing their currency. Lastly, they instituted significant tax reform for the private sector

prior to the sharp decline in oil prices in 1986. (Karl, 1997, pp. 208-212)

The case of Norway highlights the benefits of a democratically elected government to manage the boom-bust cycle. Norway remained relatively unscathed compared with other petro-states during the bust. With a highly educated, merit-based, and ethical public sector, Norway possessed a diversified tax base, a near zero unemployment rate, and minimal poverty. Norway anticipated the problem of the boom-bust cycle by adopting a restricted approach to oil revenue spending based on "caution, state control, moderation, and long-term planning." As a result, Norway capped growth during the boom period of the mid 1970s. Public expenditures rose 17% from 1975 to 1976 and continued at that rate until 1979. However, the government did grow similarly to other petro-states: increased subsidies, social services, and public employment. (Karl, 1997, pp. 213-220)

A political power change occurred in 1981 due to the highest current account deficit of any OECD country besides the United States, the highest external debt of any OECD country, and high labor costs that led to a loss of competitiveness. However, Norway used half of this debt to develop the petroleum sector. By 1983, Norway had paid off most of this foreign debt while other petro-states wallowed in budget crises. The control of the government returned to the Labor Party in 1986 after the oil price plunged. The country then created a "petroleum fund" to share the benefit of oil revenues in the future when Norway depletes its reserves. For all that, Norway's policies created an economic foundation that mitigated the boom-bust cycles experienced by other petro-states. (Karl, 1997, pp. 213-220)

MEXICAN FINANCIAL CRISIS IN 1994

In 1994 and subsequent years, Mexico experienced a financial crisis that affected the entire country including the operations of PEMEX. Foreign exchange reserves dropped from 30 billion in February 1994 to 12 billion in December 1994 because of two political assassinations including Presidential candidate Donaldo Colosio and the Chiapas uprising in response to NAFTA. The fall in reserves resulted from the confluence of the political shocks and the policy response (Kruger & Tornell, 1999, p. 10). The monetary authorities kept the exchange rate fixed and expanded domestic credit to avoid a sharp increase in interest rates after the assassination of Colosio. They also started distributing dollar-denominated bonds called Tesobonos. The total value of Tesobonos increased from around 1.2 billion dollars at the end of 1993 to 29 billion dollars in December 1994. Since Mexico's reserves stood at 12.5 billion dollars in early December, the government had become illiquid (Kruger & Tornell, 1999, p. 11).

All policy programs implemented were aimed at reducing the current account deficit, preventing inflation from getting out of control, and avoiding a meltdown of the banking system. In order to help stabilize financial and foreign exchange markets, international financial institutions and the governments of the United States and Canada assembled a loan guarantee package for Mexico at the end of January, amounting to US\$ 52 billion (Kruger & Tornell, 1999, p. 11). Mexican authorities used these funds for three purposes. They redeemed maturing dollar-indexed Tesobonos (large buy-back program). The funds also helped refinance commercial banks' foreign currency liabilities. Finally, foreign exchange reserves were increased (Kruger & Tornell, 1999, p. 16). An important note is that the Mexican government repaid all the loans at an accelerated pace (Kruger & Tornell, 1999, p. 17).

Privatization and free trade were important components to the recovery policy. However, privatizing the oil and electricity sectors did not advance much between 1995 and 1999 (Kruger & Tornell, 1999, p. 17).

ECONOMIC EVOLUTION

An eighty-five percent depreciation of the peso and an interest rate hike reflected the liquidity crisis that Mexico suffered in early 1995. This resulted in a sharp fall in economic activity. As Figure 2-3 shows, GDP fell 6% in real terms during 1995. However, the economy recovered from the recession quickly and grew in the fourth quarter of 1995. It then achieved a GDP growth rate of 5% in 1996 and 7% in 1997. The recovery was not uniform across the economy (Kruger & Tornell, 1999, p. 20).

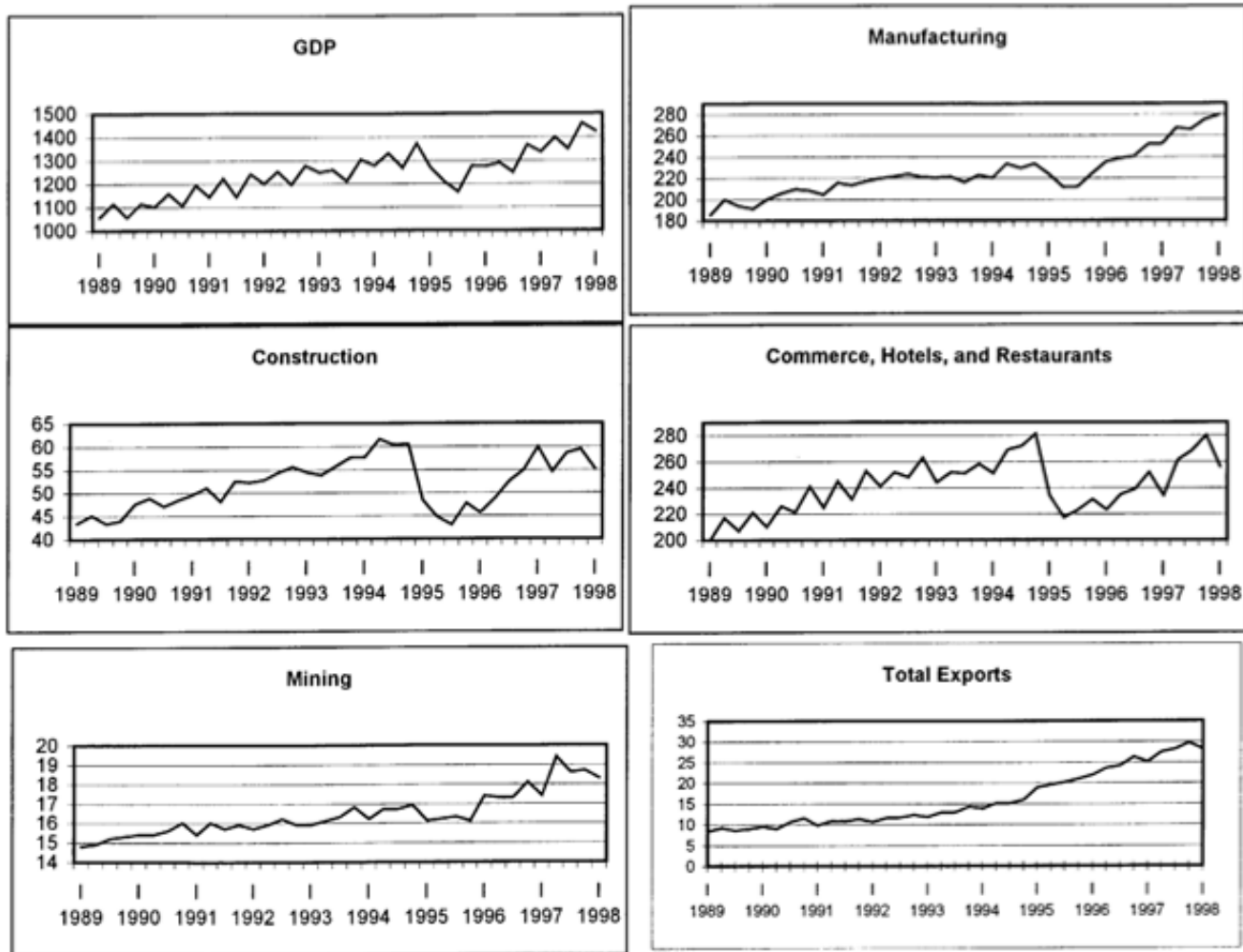


Figure 2-3: Sectoral Real GDP in Mexico (Inegi, Sistema de Cuentas Nacionales, 2009)

The stunning growth of the tradable sector stems from Mexico's substantial real depreciation and the foreign credit readily available to firms in the tradable sector. Other sectors of the economy suffered a credit crunch that resulted in a slow recovery (Kruger & Tornell, 1999, p. 21).

The following three reasons explain why high GDP growth did not reduce the amount of non-performing loans:

1. The lack of transparent and effective bankruptcy procedures in Mexico made it incredibly difficult to take possession of a debtor's assets in case it failed to service its debt
2. While the banks reduced their net lending they were simultaneously saddled with the "evergreen" accounts (where the bank in question lends the debtor the principal and interest that the debtor was supposed to have repaid)
3. Several moral hazard problems existed in the banking system (Kruger & Tornell, 1999, pp. 24-25)

RELATING TO OIL PRODUCTION

The macroeconomic look at the financial crisis of 1994 highlights the following key points:

1. The Mexican government acted swiftly to counteract the financial crisis

2. The policies enacted had significant effects on the Mexican economy (see Figure 2-3 for the effects on trade)
3. International involvement was necessary to stabilize the financial system

PEAK OIL CONCEPT

The United States experienced marked growth in oil production during the early 20th century. In explaining this growth, M. King Hubbert argued in 1956 that “no finite resource can sustain for longer than a brief period such a rate of growth of production; therefore, although production rates tend initially to increase exponentially, physical limits prevent their continuing to do so” (Hubbert, 1956, p. 8). Hubbert used this basic property of finite resources to develop a model to explain oil production. Known as Hubbert's Peak, the theory states that oil production resembles a Gaussian curve over time (see Figure 2-4). Oil production will rise exponentially until the producer

exhausts all proven reserves. The oil production peaks at this point and future discoveries define the limit for the remaining oil produced. Technological capabilities, economic factors, and the resource itself limit the future discoveries.

While many dispute the preciseness of Hubbert's model, oil *is* a finite resource that will expire eventually. Furthermore, it is also inarguable that production will peak at a level that is unreachable in the future. In Mexico's case, assessing this production peak and the resource's expiration is critical to understanding the sustainability of the oil sector in the country. Hubbert concludes his analysis with a stark reminder of the importance of energy to the stability of a nation:

[Access to energy] does pose as a national problem of primary importance, the necessity, both with regard to requirements for domestic purposes and those for national defense, of gradually having to compensate for an increasing disparity between the nation's demands for these fuels and its ability to produce them from naturally occurring accumulations of petroleum and natural gas.

(Hubbert, 1956, p. 27)

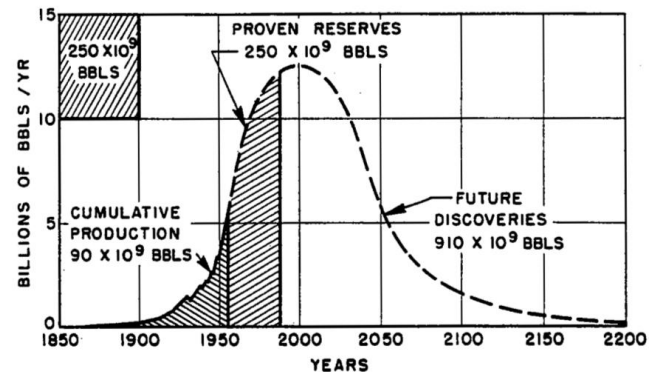


Figure 2-4: Hubbert's estimate for world oil production

3. DRILLING EXPANSION POLICY ANALYSIS

Since the year 2000, PEMEX has undertaken a concerted effort to increase drilling to combat declining oil reserves. This section assesses that effort to determine an economically efficient path forward for the oil company. The approach to complete this task includes a revisiting of the Moroney-Assad analysis in *Energy and Sustainable Development in Mexico*, the creation of econometric models to evaluate the sustainability of the effort, and an overall cost-benefit analysis of the effort. This section only presents the analysis results; the following section entitled *Commentary and Conclusions on Policy Analysis Results* contains any interpretations and conclusions from the analysis.

The Moroney-Assad analysis concluded that PEMEX should explore for more oil in an effort to increase reserves. PEMEX's implementation of many of their recommendations post-2000 warrants an update of this analysis. There are indicators from the Moroney-Assad analysis that still hold true today including the exploratory oil drilling success ratio. However, some models are no longer valid including oil reserve additions. The significance of updating these models is important when considering future policy decisions at PEMEX.

WHILE NATURAL GAS IS A CRITICAL ELEMENT TO ECONOMIC GROWTH IN MEXICO, OIL IS THE PRIMARY PROVIDER OF REVENUE TO PEMEX AND IS THUS THE FOCUS OF THIS ANALYSIS

To evaluate sustainability, the competitiveness of PEMEX and the potential of peak oil in Mexico are useful. Furthermore, econometric models involving marginal costs of extraction along with PEMEX's increasing operating costs are also suitable. Lastly, it is useful to compare the current situation and the hypothetical scenario if PEMEX continued business-as-usual. This comparison is possible using econometric models to forecast the hypothetical scenario in order to calculate benefits and costs associated with PEMEX's drilling activities in the 2000s.

ANALYSIS METHODOLOGY

The data for this analysis is from two sources. Much of the data before 1990 was from *Energy and Sustainable Development in Mexico*. From 1990 to 2008, the data for the analysis was from PEMEX or the [Sistema de Informacion Energética](#). For the models in *Revisiting the Moroney-Assad* analysis and *Sustainability evaluation using econometric models*, the statistical program [STATA](#) provided the results for the regressions and correlations. In addition to the regressions used by Moroney-Assad, the analysis uses the Durbin-Watson test statistic to detect autocorrelation in the residuals. In each appropriate case, the test passed. Crystal Ball within Microsoft Excel provided all forecast results.

POLICY CRITERIA

The following criteria define the context required to determine feasible recommendations and focus the analysis. Research conducted including an extensive literature review provided the foundation for these factors.

PEMEX'S FISCAL STATE

The Mexican government heavily taxes the revenue and not the profits of PEMEX. In addition, PEMEX's internal operating costs are increasing rapidly. Since 2000, PEMEX has operated at a deficit every year except 2006 (see Figure 2-1). Furthermore, the future could consist of a diminished access to capital due to a tightening of the credit markets and financing modifications from the energy reform of 2008.

ENERGY REFORM IN 2008

The energy reform in 2008, though significant, does not address the long-term sustainability of PEMEX as highlighted in the World Bank's Report entitled *Creating the Foundations for Equitable Growth*. In the report, the World Bank highlights some of the critical issues related to the long-term sustainability of PEMEX including:

1. Mobilization of state-of-the-art technology
2. Attraction of private participation
3. Improved access to capital
4. Definitions of performance metrics to improve internal performance (The World Bank, 2007)

The budgetary changes improve accountability and flexibility at PEMEX, but still restrict the control of oil activities to PEMEX preventing any private control. These changes result in inefficiencies in PEMEX's operations since the most cost-effective method to explore and produce oil may not be usable. Furthermore, the restrictions may prevent PEMEX from extracting valuable oil from areas inaccessible to PEMEX due to the technological deficiencies of the company and its partners. Thus, while partnerships are possible, they are unlikely in remote areas since PEMEX cannot contract with firms on a risk-basis (The Economist, 2008).

The absorbing of *PIDIREGAS* debt as public debt provides PEMEX with breathing room to invest more in exploration and drilling. The reform also now allows PEMEX to finance debt outside of the constraints of the Federal fiscal balance. However, the accounting change did not absolve the debt, but instead shifted the borrower from the oil company to the national government. Furthermore, PEMEX's ability to attain capital will depend on the company's credit rating. The credit rating is a function of the company's ability to retain cash after paying taxes and duties and the size of its long-term liabilities. Given PEMEX's consistent balance deficit and its inability to replace depleting reserves, its access to capital may diminish in the near future.

Energy reform also called for the building of a new oil refinery in Mexico to help reduce the country's dependence on imported gasoline. Using nearly the entire balance of the *Stabilization Fund for Oil Income Investment (FEIIP)* to finance an oil refinery may be a sound investment but it disagrees with the funds intended purposes, which is to smooth the government's adjustment to fluctuations in oil prices. If oil prices continue to fall into 2010, the depletion of this fund could be prove critical to other public operations dependent on revenue from oil exports.

The reform allows PEMEX to maintain the monopoly over the upstream and downstream sectors of the oil industry. While important to Mexico's national pride, there is little historical precedence that a monopolistic policy can improve efficiency. For instance, reforms in Brazil, Colombia, and Indonesia removed monopolies on the upstream and downstream sector. In addition, Brazil and Colombia transformed their national oil companies into publicly traded companies in an effort to improve accountability and increase autonomy (Quiroz, 2009). Preventing private investment in PEMEX forces the company to assume all risk and financial obligations for exploration activities. This burden will fall on the Mexican Federal Government's budget to some degree.

MEXICO'S ENERGY FORECAST

According to the U.S. Energy Information Administration, Mexico could become a net oil importer by 2020 (U.S. Energy Information Administration). Since 2000, rising oil prices have increased the Federal Government's dependency on oil. Meanwhile, crude oil

production has been declining since 2004. If present trends continue, a serious economic crisis may occur in Mexico. This problem is despite PEMEX's recent efforts to increase drilling.

U.S. ENERGY POLICY CHANGES

Mexico sells over 80% of its oil to the United States, but the U.S. is undergoing a distinct shift in policy away from fossil fuels (PEMEX, 2004-2008). American President Barack Obama's agenda includes marked shifts in energy policy from previous administrations including support for Plug-in Hybrid Vehicles (PHEVs) and a considerable reduction in economy-wide greenhouse gas emissions. The *American Recovery and Reinvestment Act* passed in 2009 includes tax credits of up to US\$ 7500 on the purchase of PHEVs. In a speech to a joint session of Congress on February 24 2009, President Obama called on Congress to pass legislation that would cap greenhouse gas emissions in the U.S. These public policies identify a new trend in the U.S. that aims to decrease oil consumption considerably in the coming decades (see Figure 3-1). If the U.S. is successful, it may help define the path off fossil fuels for other developed nations to follow.

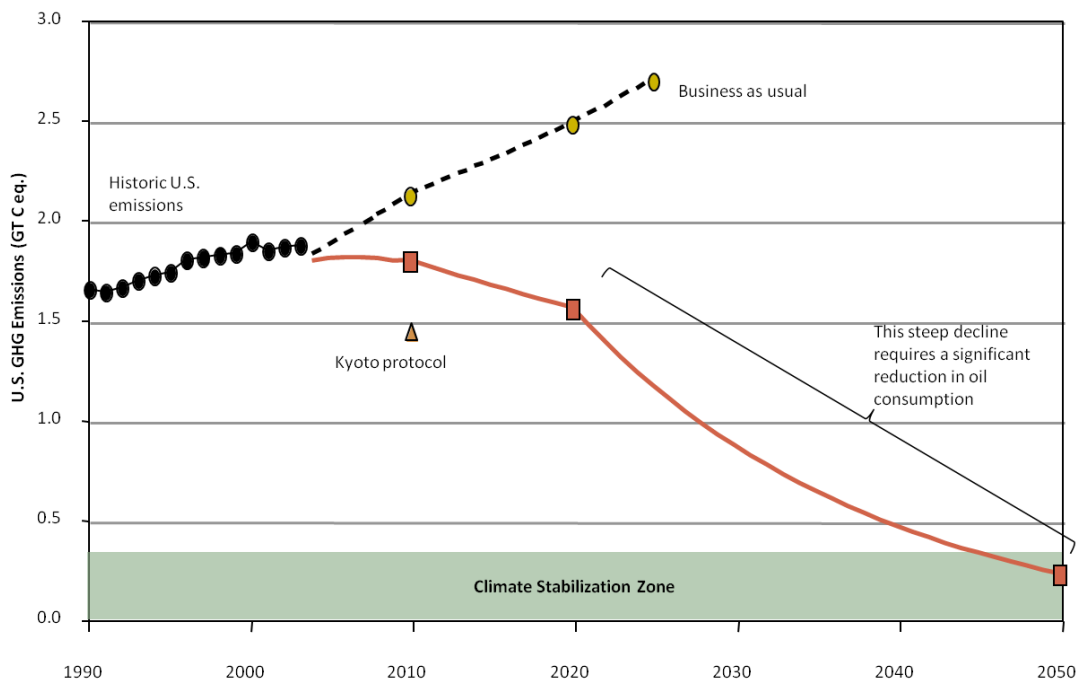


Figure 3-1: Reaching the emission target desired by the Obama Administration will require steep reductions in oil consumption (Kammen, 2008)

POLITICAL BARRIERS

The Mexican Congress passed energy reform in late 2008 after an arduous debate. It is unlikely significant legal reforms related to the structure and operations of PEMEX are possible in the near future. The privatization of exploration, extraction, and shipment of fossil fuels are politically infeasible at this time and the analysis avoided exploring this option. This infeasibility includes collaborating with U.S. private industry due to hesitation of increased American involvement in Mexico's national oil industry.

Another political factor that required consideration was the impact of policy changes on government revenue. Since the government relies so heavily on revenue from PEMEX to fund government programs, stiff political opposition from affected parties will occur if revenues decline.

ECONOMIC LIMITATIONS

The global economic downturn combined with Mexico's limited financial resources makes significant investments difficult. The payback period and likelihood of success were important criterion to that end. Other economic limitations include PEMEX's access to capital, which was mentioned previously.

TECHNOLOGICAL LIMITATIONS

The lack of technology readily available to PEMEX limits exploration and drilling of oil. The low investment in the 1980s and 1990s by PEMEX resulted in a consistent decline in oil reserves. This investment did not occur because oil was easy to extract and the government restricted PEMEX's access to capital with high taxes and tight budgetary controls.

HISTORICAL PERSPECTIVE

Historically, few states have overcome a heavy dependence on oil for revenue. There are many more examples of states that have squandered the additional revenue available during boom times only to suffer recession or worse when the commodity price falls

Table 3-1: Political Instability of Petro-States, 1974-1992 (Karl, 1997, p. 193)

Rank	Change of Government	Change of Regime	Change of State
1. Iran	✓	✓	✓
2. Nigeria	✓	✓	✗
3. Algeria	✓	Threatened	Threatened
4. Venezuela	✓	Threatened	✗
5. Indonesia	✗	✗	✗
6. Norway	✓	✗	✗

(see Table 3-1). The report considered the successful policies of states like Norway, Indonesia, and more recently Brazil, which sustained steady economic growth during turbulent years in the global oil market or have developed policies that mostly detach politics from oil industry development.

Furthermore, the analysis considered the fiscal climate in Mexico that helped lead to the financial crisis in 1994. Policies recommended in this report could not recreate the fiscal climate that led to a significant current account deficit.

PEMEX'S COMPETITIVENESS

In an effort to define a path forward, it is useful to understand how PEMEX compares to other National Oil Companies (NOCs) and International Oil Companies (IOCs). Figure 3-2 and Figure 3-3 use data from 2004 to show PEMEX's operating efficiency compared to other companies. PEMEX takes in some of the highest revenues of any oil company but operates less efficiently than many of other NOCs including Saudi Aramco, Petroleos de Venezuela, StatoilHydro, and Petrobras. Since 2004, production has declined steeply at PEMEX while the number of employees has increased; this occurrence should further reduce PEMEX's competitiveness. However, the sales per employee have increased from 2000 to 2007 by 41% due to high oil prices. Thus, while operating costs have increased almost 200% since the policy began, sales have increased nearly 100% too.

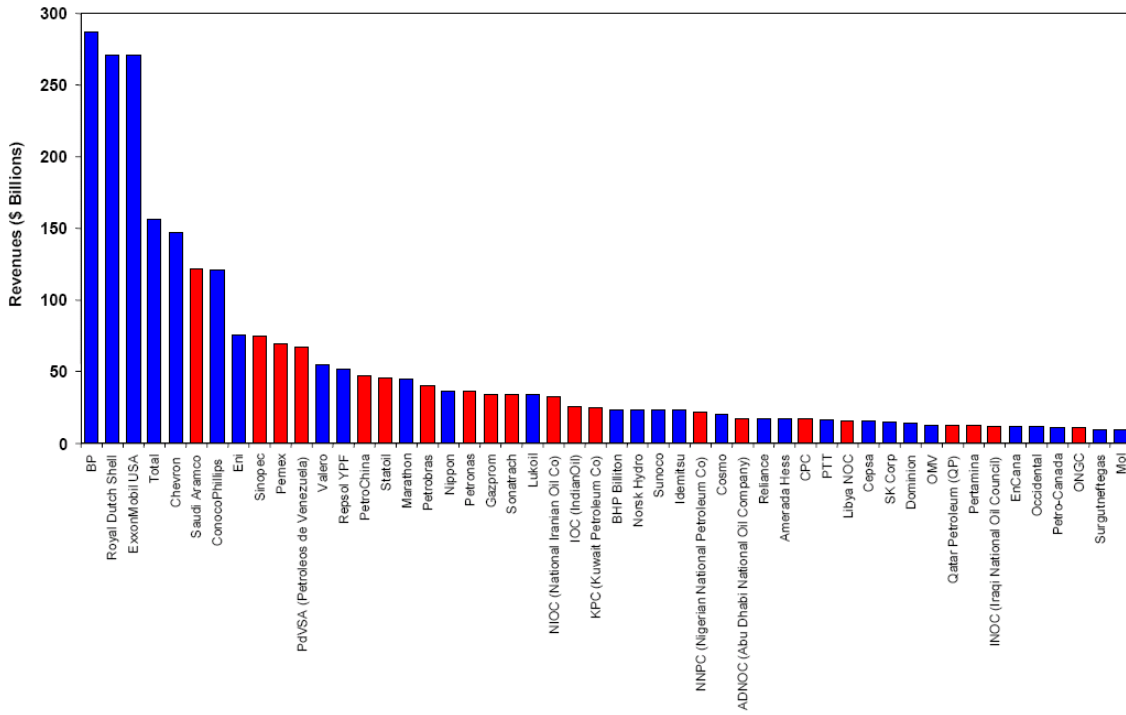


Figure 3-2: PEMEX is near the top compared to other National Oil Companies (Victor, 2007, p. 12)

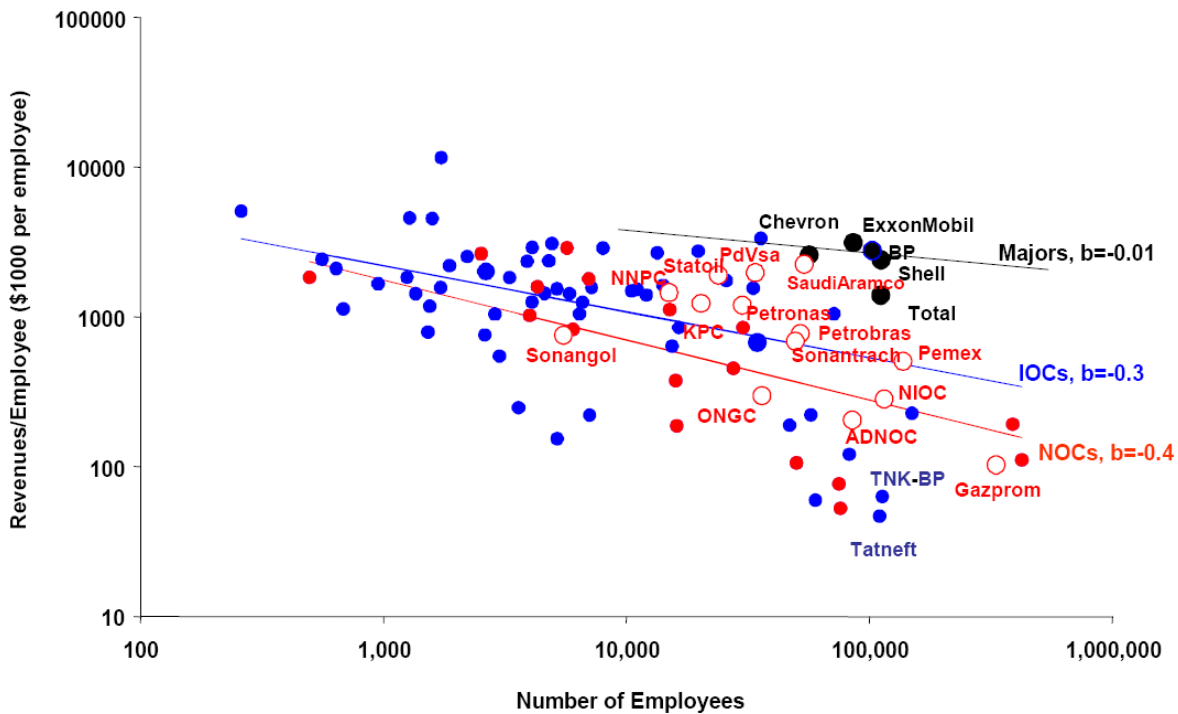


Figure 3-3: PEMEX is not as efficient as other National Oil Companies (Victor, 2007, p. 13)

PEAK OIL EVALUATION

As mentioned in *Background Research*, peak oil is a concept developed by M. King Hubbert in 1956. Determining if Mexico has experienced peak oil helps in assessing the sustainability of the oil sector. This analysis uses two methods to determine cumulative oil production: the Hubbert Linearization and the Hubbert Parabola. In addition, the results from the Hubbert Linearization provided the input to create a Hubbert's Peak curve. The models assume geological constraints are the only factors that limit production. Thus, one issue with these methods is that they do not control for external factors related to production levels including politics, natural disasters, and economic fluctuations.

MODEL METHODS

Both models require oil production and cumulative production data. This analysis used data from 1938 to 2008; data from 1900-1938 skewed results since the oil sector was not government controlled during that period. In addition, the Hubbert Linearization model begins in 1946 once cumulative production had increased by 1/100 of a billion barrels. This helps to filter out the learning curve the government incurred after it began operating the oil sector in Mexico.

HUBBERT LINEARIZATION

The Hubbert Linearization is a common approach to determining estimated cumulative production by first graphing the ratio of oil production and cumulative oil production on the vertical axis and cumulative oil production on the horizontal axis (see Figure 3-4). The next step is to estimate a line to determine where the ratio crosses the horizontal axis. The Hubbert Linearization uses actual oil production and cumulative oil production data.

$$\frac{\text{AnnualOilProduction}}{\text{CumulativeOilProduction}} = m \times \text{CumulativeOilProduction} + a$$

a = ratio of annual oil production and cumulative oil production when cumulative production is zero

m = slope of the line

Equation 3-1: Hubbert Linearization

The Hubbert Linearization provides two inputs for a Hubbert's Peak curve: the total cumulative production and the ratio of production to cumulative production when cumulative production is zero. Solving the linear equation for zero determines the estimated cumulative production. In this case, the estimation is 54.81 billion barrels of oil, which is 2.96% lower than Mexico's cumulative oil production plus the *probable reserves (2P)* for Mexico or 56.48 billion barrels through 2008 (PEMEX, 2004-2008). The ratio of production to cumulative production when cumulative production is zero is 0.0877.

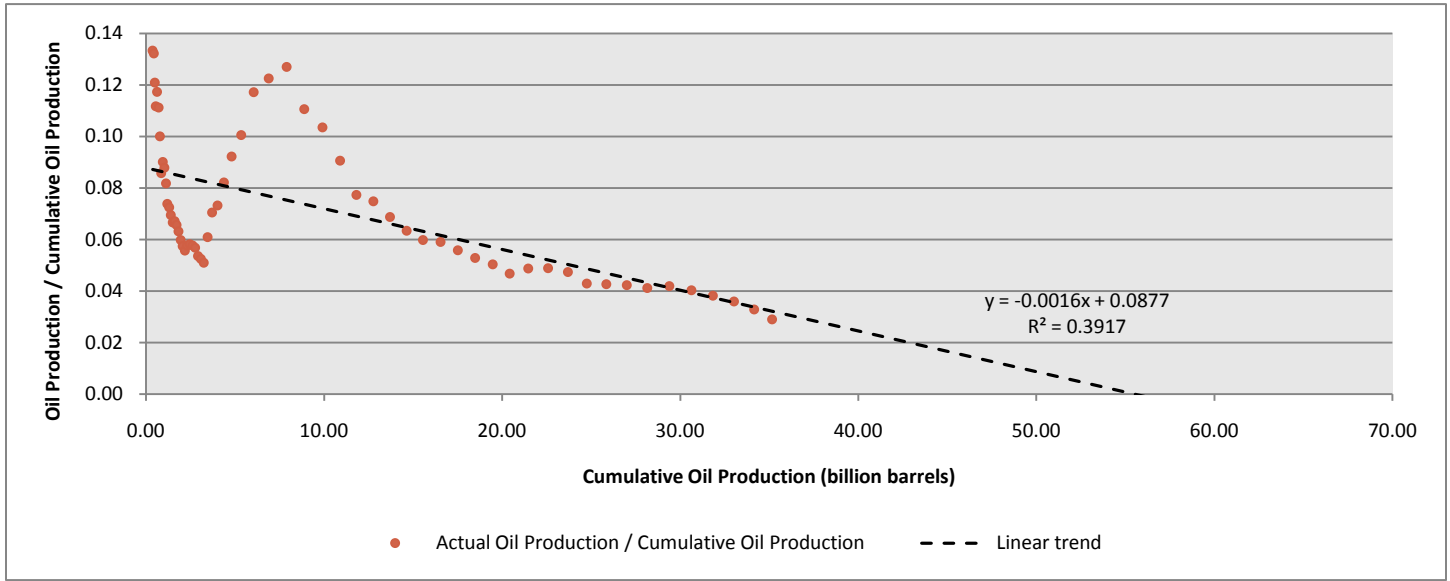


Figure 3-4: Hubbert's Linearization for Mexico

HUBBERT'S PARABOLA

The Hubbert Parabola is an alternative approach to determining cumulative oil production developed in 2006 by Roberto Canogar (Canogar, 2006). This technique uses the least squares method to estimate a parabola (second order polynomial) for the plot of cumulative oil production and annual oil production (see Figure 3-5).

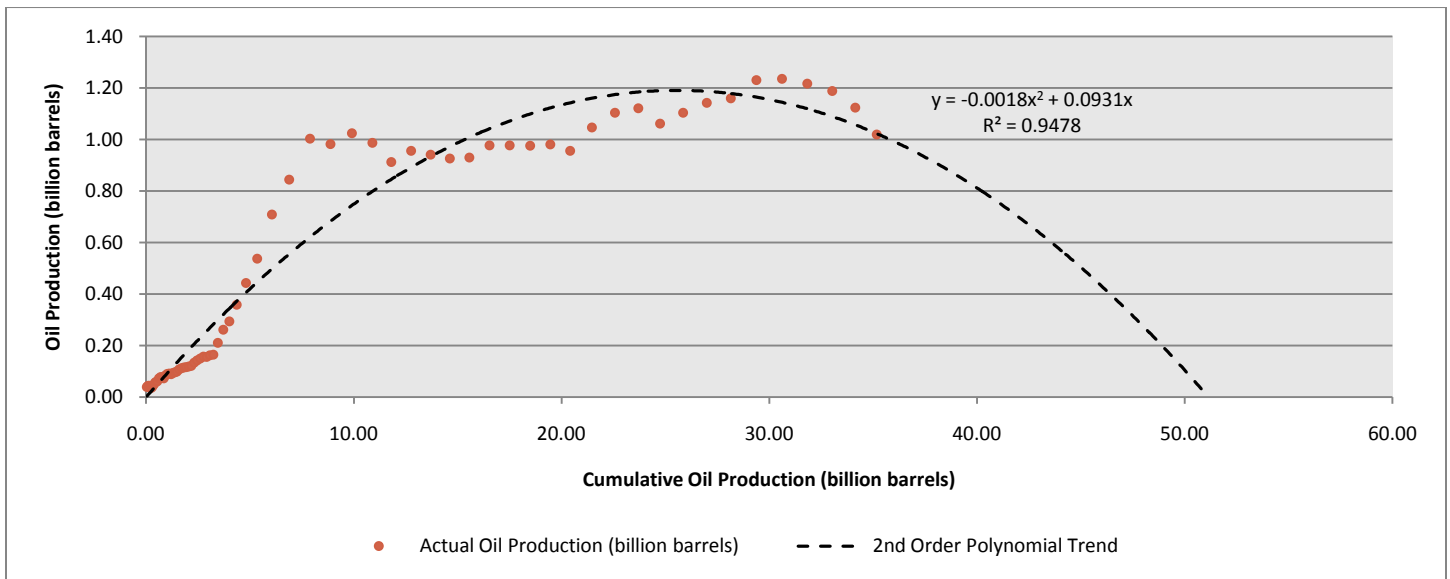


Figure 3-5: Hubbert's Parabola for Mexico

Solving the parabola's equation for zero determines the estimated cumulative production. In this case, the estimation is 51.72 billion barrels of oil, which is 8.44% lower than Mexico's cumulative oil production plus the *probable reserves (2P)* for Mexico or 56.48 billion barrels through 2008 (PEMEX, 2004-2008).

HUBBERT'S PEAK

The results from the Hubbert Linearization provide the input to construct the Hubbert's Peak curve. First, Equation 3-2 provided the annual oil production levels for all years in a table. Next, a new column in the table was added for a time estimate. The time estimate was created based on the inverse of the estimated oil production levels and a known cumulative production level in Mexico. In 2006, cumulative oil production was approximately 33 billion barrels. The time estimate was calculated by assigning 2006 to the row when cumulative oil production was 33 billion barrels. For other rows of this new column, the inverse of the estimated oil production levels was added or subtracted (see Table 3-2). Figure 3-6 shows the results of the Hubbert's Peak curve for Mexico.

$$EstimatedAnnualOilProduction_t = \left(1 - \frac{CumulativeOilProduction_t}{TotalCumulativeOilProduction}\right) \times a \times CumulativeOilProduction_t$$

$EstimatedAnnualOilProduction_t$ = Estimated annual oil production in year t

$CumulativeOilProduction_t$ = Cumulative oil production baseline starting at 1 and incrementing by 1 for each year t

$TotalCumulativeOilProduction$ = Estimated total cumulative production from Hubbert Linearization

a = ratio of annual oil production and cumulative oil production when cumulative production is zero from Hubbert Linearization

Equation 3-2: Estimated oil production for Hubbert's Peak

Table 3-2: Sample of Hubbert's Peak data

Cumulative Oil Production Baseline	Hubbert's Peak Oil Production (billion barrels)	Scaled time (2006 baseline)
26	1.35	2000.77
27	1.35	2001.51
28	1.35	2002.25
29	1.35	2002.99
30	1.34	2003.74
31	1.33	2004.48
32	1.31	2005.24
33	1.29	2006.000
34	1.27	2006.786
35	1.25	2007.589
36	1.22	2008.411
37	1.18	2009.255

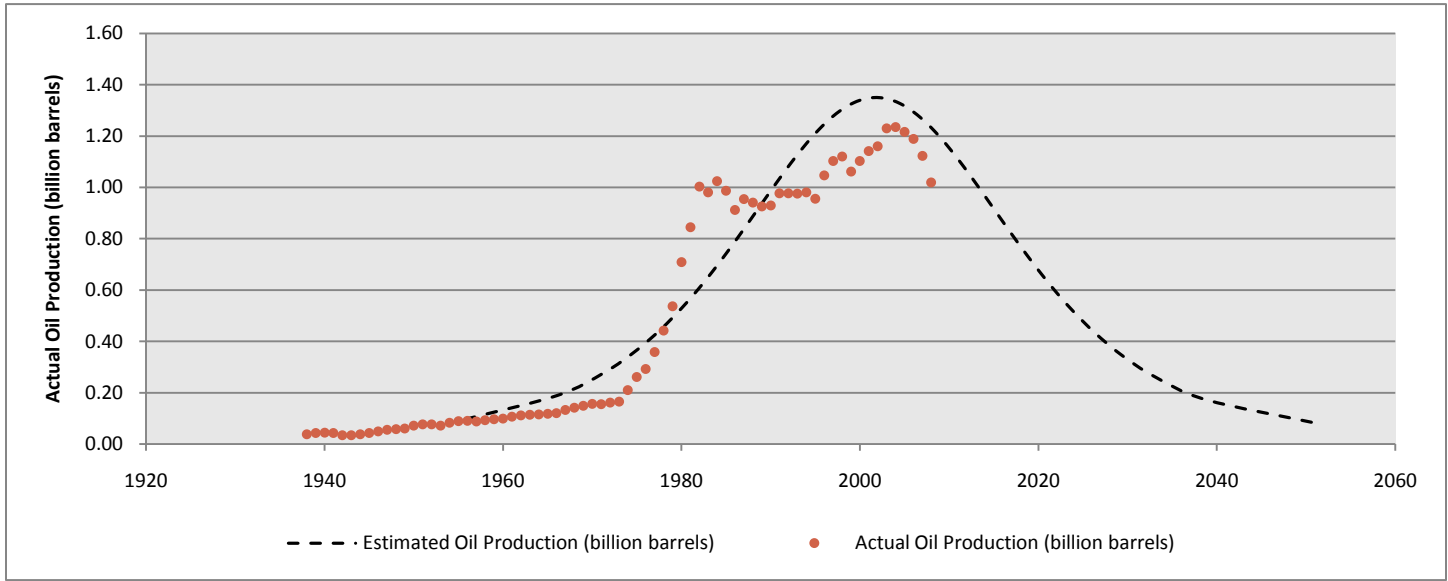


Figure 3-6: Hubbert's Peak for Mexico

REVISITING THE MORONEY-ASSAD ANALYSIS

The Moroney-Assad analysis from *Energy and Sustainable Development in Mexico* concluded that increasing drilling would add to Mexico's oil reserves. The authors argued that more drilling would increase the drilling success rate and thus, push reserves and production higher. The Moroney-Assad analysis used data from 1975 to 2000. They used econometric models with data from this period to provide evidence for their recommendations. After 2000, PEMEX implemented these recommendations and increased drilling substantially. This section revisits the Moroney-Assad analysis to follow-up on their models by including data from 2000 to 2007 or 2008 where possible.

For clarity purposes, the section titles below are the actual chapter titles from the book *Energy and Sustainable Development in Mexico*.

CHAPTER 4: EXPLORATION AND DEVELOPMENTAL DRILLING

This chapter dealt with exploration and developmental drilling using the following models:

$$TEWD_t = \beta_1 + \beta_2 NMOP_t + \beta_3 TEWD_{t-1} + \varepsilon_{1t}$$

$TEWD_t$: Total exploratory wells drilled

$NMOP_t$: Net Mexican oil-export price

ε_t : The disturbance term

Equation 3-3: Exploratory wells drilled model

$$TDWD_t = \beta_1 + \beta_2 NMOP_t + \beta_3 TDWD_{t-1} + \varepsilon_{2t}$$

$TDWD_t$: Total development wells drilled

$NMOP_t$: Net Mexican oil-export price

ε_t : The disturbance term

Equation 3-4: Developmental wells drilled model

The purpose of these models was to predict the number of wells drilled by PEMEX depending on the previous years' drilling (TEWD or TDWD) and the net Mexican oil-export price (NMOP). The NMOP represents the amount of capital available to Mexico in a given year and the number of wells drilled the previous year accounts for trends over time.

Unfortunately, the results published in *Energy and Sustainable Development in Mexico* for these models could not be reproduced. The authors were unable to assist in resolving the discrepancy. The analysis results indicate the models from the Moroney-Assad analysis are not statistically significant from 1975 to 2000, which contradicts conclusions from the book.

CHAPTER 5: SUCCESSFUL EXPLORATION AND DEVELOPMENT

The Moroney-Assad analysis created a model to incorporate learning-by-doing, which yielded a strong correlation between the oil well success ratio and the number of cumulative wells drilled previously. This correlation existed for both exploration and development wells indicating PEMEX could expect a higher ratio of success for developing and discovering oil in the future.

The Moroney-Assad analysis used the following equations to model the rate of success for drilling exploratory and developmental wells (Moroney & Dieck-Assad, 2005, p. 57):

$$OSRE_t = \beta_0 + \beta_1 OSRE_{t-1} + \delta_1 DUM78 + \beta_2 CUMEW_{t-1} + \varepsilon_t$$

$OSRE_t$: Exploration well success ratio

$DUM78$: Dummy variable to factor out unusual success ratio in 1978

$CUMEW_{t-1}$: Cumulative successful wells drilled from 1975 onward

ε_t : The disturbance term

Equation 3-5: Exploration success ratio model

$$OSRD_t = \alpha_0 + \alpha_1 OSRD_{t-1} + \alpha_2 CUMDW_{t-1} + v_t$$

$OSRD_t$: Development well success ratio

$CUMDW_{t-1}$: Cumulative successful wells drilled from 1975 onward

v_t : The disturbance term

Equation 3-6: Development success ratio model

The analysis showed similar results by extending the Moroney-Assad model to 2008. The exploratory drilling success ratio had a strong correlation with the cumulative wells drilled. However, the developmental drilling success ratio did not correlate with cumulative wells drilled since it had a p-value of greater than 0.1. Thus, learning-by-doing provides some benefit to PEMEX in oil drilling. This result is especially significant when one considers the rapid increase in drilling since 2000.

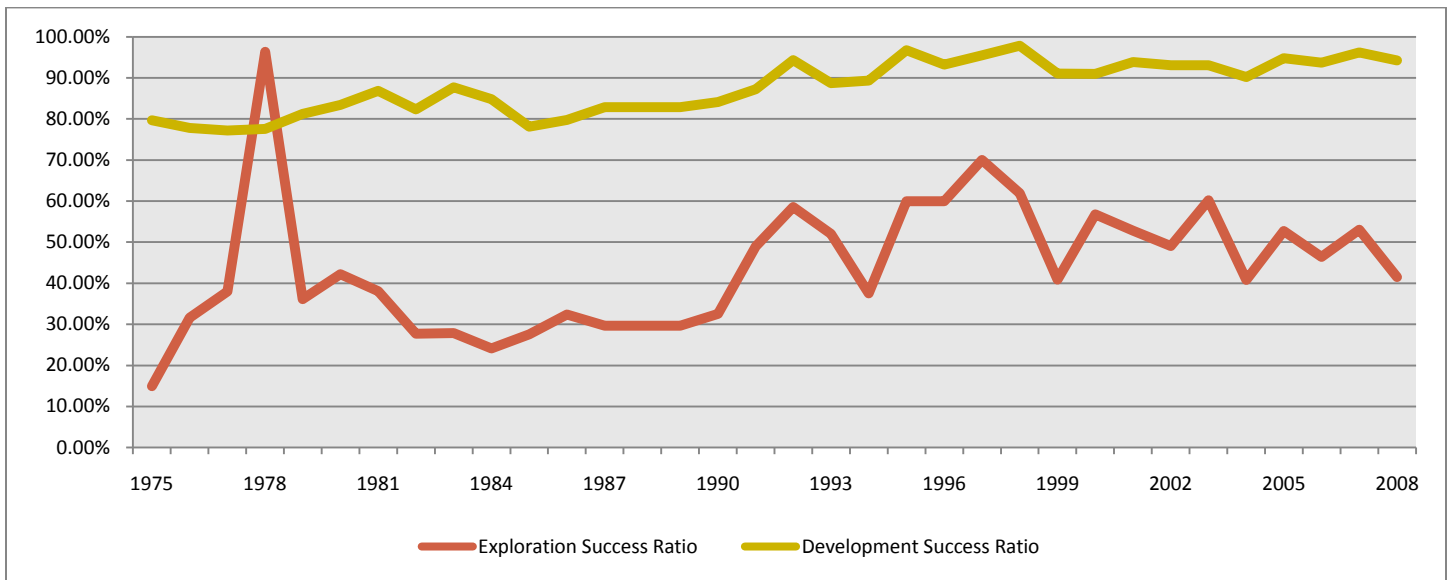


Figure 3-7: The ratio of success for exploratory well drilling is improving with more drilling while the ratio of success for developmental drilling is leveling off (Moroney & Dieck-Assad, 2005; PEMEX, 2004-2008)

CHAPTER 6: ADDITION TO OIL AND GAS RESERVES

The Moroney-Assad analysis created a model to predict oil reserves using total successful wells drilled per year. Through 2000, the results were statistically significant that drilling wells added to oil reserves with a coefficient of 18.9 million barrels per well. Running the same model through 2007 yields a statistically *insignificant* result. Thus, it is no longer possible to correlate increases in drilling with increases in oil reserves. The result of this regression test is significant for efforts by PEMEX to expand oil reserves.

Note: The natural gas reserve model is not included, but is also no longer statistically significant.

The Moroney-Assad analysis used the following equations to model gross additions to oil reserves (Moroney & Dieck-Assad, 2005, pp. 73-74):

$$GORA_t = b_0 + b_1 TSWD_t + b_2 ODUM2H + b_3 ODUM1 + u_{1t}$$

$GORA_t$: gross oil reserve additions in year t

$TSWD_t$: total successful wells drilled in year t

$ODUM2H$: dummy = -1 for 1978 and 1980

$ODUM1$: dummy = 1 for 1986

u_{1t} : the disturbance term

Equation 3-7: Model for gross oil reserves additions

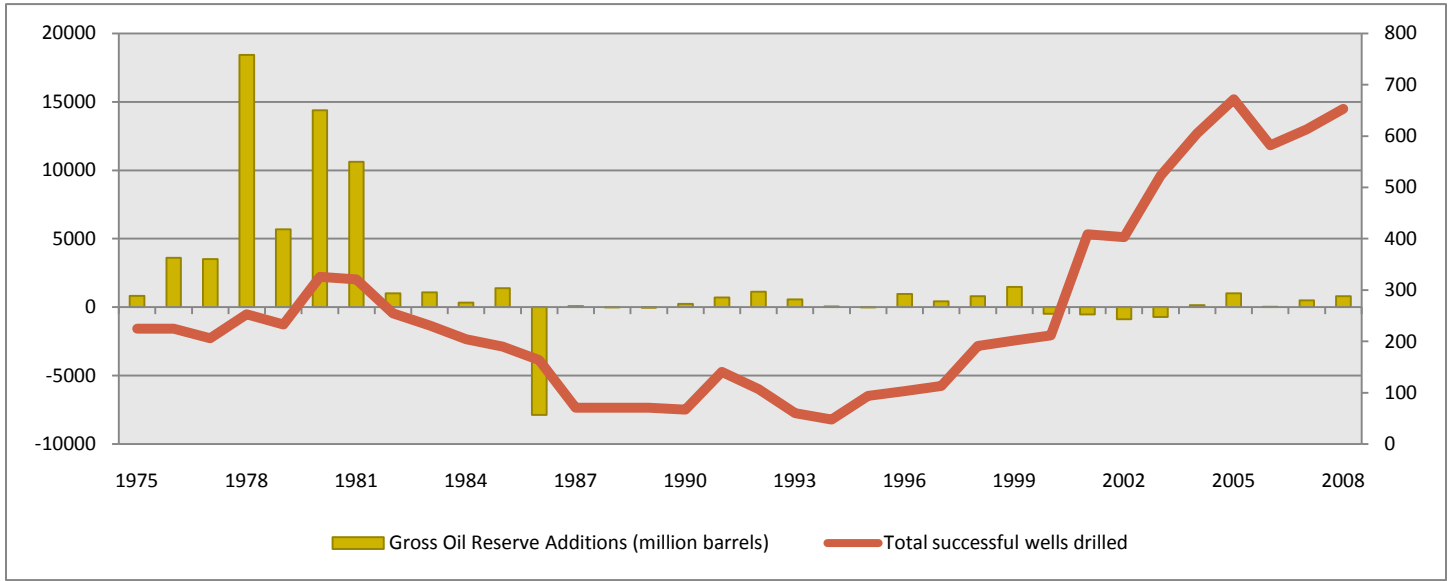


Figure 3-8: Gross oil reserve additions and total successful wells drilled from 1975-2008 (Moroney & Dieck-Assad, 2005; PEMEX, 2004-2008)

CHAPTER 7: PRODUCTION MODELS

The oil production model in this chapter predicted oil production based on oil reserves. The Moroney-Assad analysis shows that oil reserves are the ultimate constraint on oil production. However, the model also highlights that politics can play a role with the use of a dummy variable to account for mandates to increase oil production by the Mexican government. It was not possible to recreate the model precisely including the Dickey-Fuller tests and the exact results for the regression model (see *Appendix A: Analysis Results*). However, the coefficients for oil reserves and political dummy variable were statistically significant.

Through 2008, the model is also statistically significant. In fact, one explanatory variable that was insignificant in the Moroney-Assad analysis, oil production lagged one year, is now statistically significant. The Moroney-Assad analysis used the following equations to model gross additions to oil reserves (Moroney & Dieck-Assad, 2005, p. 84):

$$OPRO_t = \beta_1 + \beta_2 ORES_{t-1} + \beta_3 OPRO_{t-1} + \beta_4 ODUM6 + \varepsilon_{1t}$$

$OPRO_t$: oil production in million barrels for year t

$ORES_{t-1}$: end-of-year oil reserves in million barrels for year $t-1$

$OPRO_{t-1}$: oil production in million barrels lagged one year

$ODUM6$: a binary variable equal to 1 for 1987, 1991, 1996-1998, and 2000 and zero otherwise

ε_{1t} : the disturbance term

Equation 3-8: Model for oil production

SUSTAINABILITY EVALUATION USING ECONOMETRIC MODELS AND CORRELATIONS

In addition to revisiting the Moroney-Assad analysis, econometric models, correlations, and forecasts can provide further insight into the current and future operations at PEMEX. For instance, a negative correlation exists between the number of successful wells drilled and Mexico's oil reserves since 1993. This section examines data from the early 1990s to 2008 to evaluate PEMEX's recent efforts to expand drilling and its long-term implications.

This part of the analysis focuses on three areas to address the sustainability of PEMEX's operations:

1. **Mexico's oil reserves:** without a reversal in the trend since the 1990s, Mexico could become a net importer of oil by 2020 (U.S. Energy Information Administration).
2. **Employee count:** PEMEX has increased its employee count in production and exploration by 25% since 1996 to fund the substantial increase in drilling. The size of the company represents the increasing operating costs, which have rose by almost 300% since 2000. In 2007, PEMEX attributed the reserve for retirement payment as the primary factor to rising operating costs (PEMEX, 2008, p. 28).
3. **Marginal cost per barrel of oil:** Since 2000, the marginal cost for each barrel of oil has increased 100% when accounting for inflation. This marginal cost increase is favorable to the cost of oil, which has jumped more than 320% since 2000.

In each case, the results warrant further evaluation of PEMEX's operations including the cost-benefit analysis of the drilling expansion found in *Cost-benefit analysis of drilling expansion*.

OIL RESERVES AND NEGATIVE CORRELATION WITH DRILLING

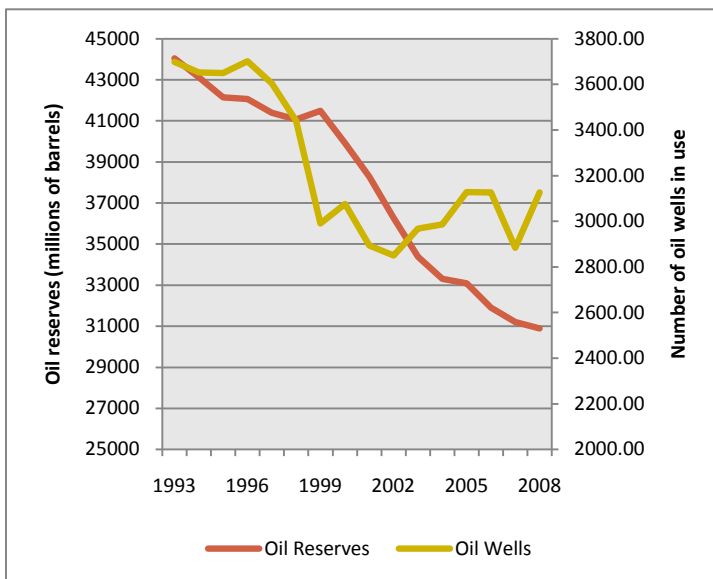


Figure 3-9: The relationship between oil reserves and oil-only wells breaks down in the mid-1990s (PEMEX, 2004-2008; Sistema de Información Energética)

Figure 3-9). This indicates oil wells are less productive than were previously.

TEST RESULTS

The statistical test shows that a strong negative correlation exists between the total successful wells drilled and the oil reserves using data from 1993 to 2008. The correlation coefficient for this test is -0.98. These results indicate for every well drilled in a year, the number of oil reserves decreases.

OIL RESERVES AND NEGATIVE CORRELATION WITH EMPLOYEE COUNT

Oil reserves are the critical factor for a sustainable oil industry in Mexico. If the recent trend regarding oil reserves continues, Mexico could become a net importer of oil by 2020 according to the U.S. EIA. PEMEX undertook a considerable effort to expand exploratory and developmental drilling since 2000. While it takes approximately two years for drilling to pay dividends, it is appropriate to look at the data to determine the relationship between drilling and oil reserves.

TEST ASSUMPTIONS

This test assumes that the increased non-associated gas drilling at PEMEX is mostly a result of oil exploration and development. The number of non-associated gas wells has increased 300% since 1996 and it is unlikely that PEMEX is exploring exclusively for natural gas since the return on investment is considerably lower than oil. Thus, one should consider the costs with drilling all wells, not just oil wells. Furthermore, while the relationship between oil reserves and oil-only wells is strong in the early 1990s, the relationship breaks down by the mid-1990s (see

With a recent spike in oil drilling, PEMEX has committed to exploring for oil to reverse the trend of declining oil reserves. Determining the efforts' effects on the company's operating costs is one of the critical factors in a sustainability assessment. Total

employee count is a suitable metric to measure this effect since PEMEX attributed much of their rising costs to retirement payments and other employment expenses in 2007.

TEST ASSUMPTIONS

This test assumes the focus of the additional employees in exploration and production is on increasing oil reserves and oil production. This does not account for the use of PEMEX as a repository for political hiring favors. One can consider this effect on employee count to be minimal in comparison to legitimate labor expansion.

TEST RESULTS

The statistical test shows there is a strong negative correlation between the number of employees at PEMEX within the

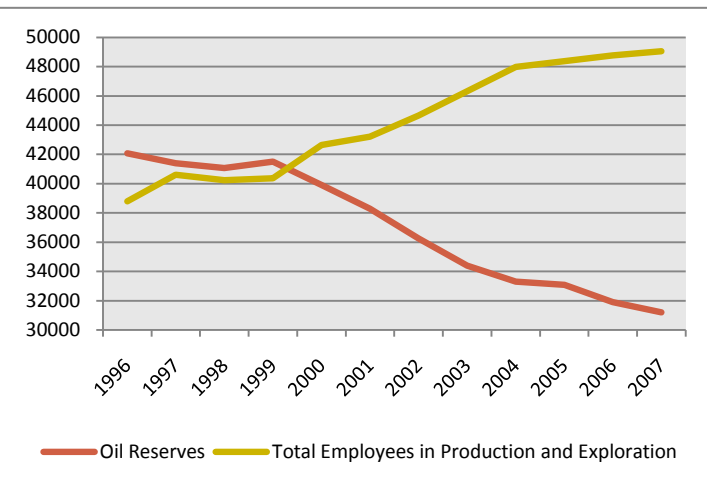


Figure 3-10: Oil reserves are decreasing at almost the same rate that total employees in exploration and drilling are increasing (PEMEX, 2004-2008)

production and exploration subsidiary and the total oil reserves using data from 1996 to 2007. The correlation coefficient in this case is -0.99. These results show that for every new employee hired in the production and exploration subsidiary at PEMEX, the oil reserves decreases.

Note: The lack of employee data available from PEMEX limited the range of years used in this correlation test

OPERATING COST RATE AND EMPLOYEE COUNT

Investigating PEMEX's rising marginal cost per barrel of oil is another metric to evaluate PEMEX's recent drilling expansion and the effort's long-term sustainability. Over time, the companies marginal cost per barrel of oil has increased considerably. This model attempts to help explain at least part of that reason.

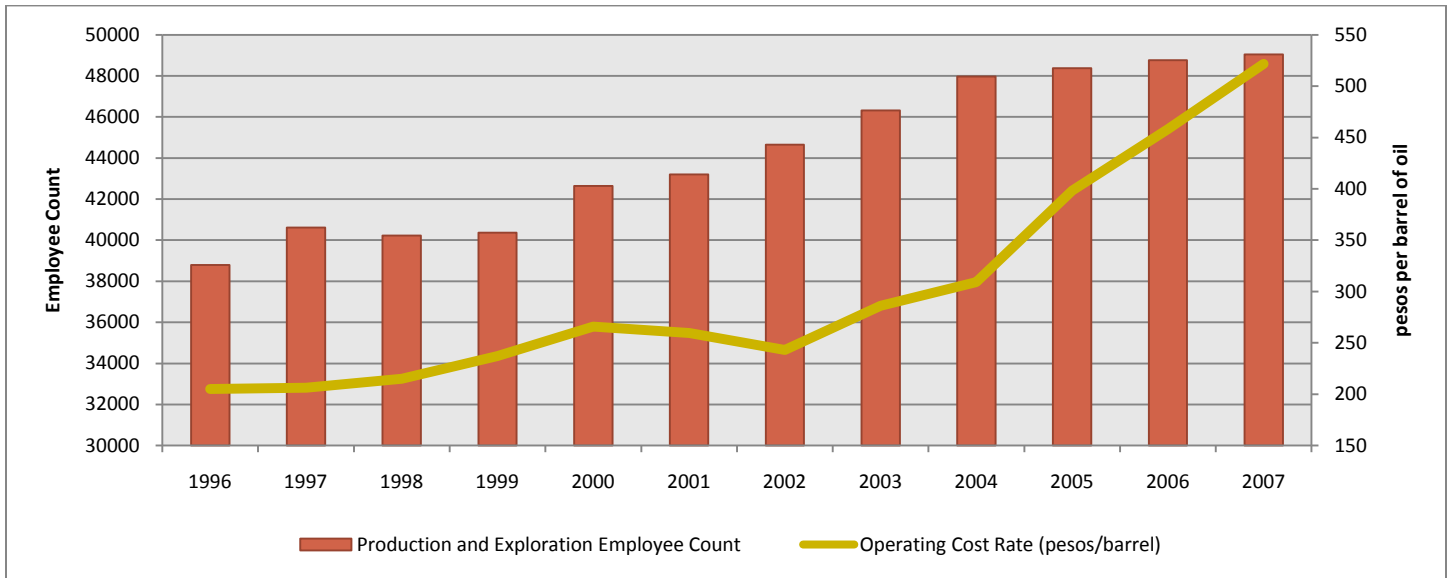


Figure 3-11: Operating costs have risen with the number of employees in production and exploration (PEMEX, 2004-2008)

MODEL ASSUMPTIONS

In this model, the total number of employees in production and exploration represents PEMEX's efforts to expand drilling. It is likely that PEMEX has already extracted the oil that is easy to access. This model associates that level of difficulty with labor instead of pure capital costs.

MODEL RESULTS

The model results indicate a strong positive correlation between the total production and exploration employee count and the marginal cost per barrel of oil. For each new employee hired in the production and exploration subsidiary at PEMEX, the marginal cost increases by 0.02 pesos.

$$\text{OperatingCostRate}_t = -719.2521 - 0.02 \times \text{Employees}_t$$

$\text{OperatingCostRate}_t$ = Cost per barrel of oil in pesos

Employees_t = Total number of employees in PEMEX Production and Exploration Subsidiary in year t

Equation 3-9: Operating cost rate and employee count model

OIL RESERVES EVALUATION

The oil reserve model conveys the amount of oil reserves gained from PEMEX's increased drilling effort from 2000 to 2008. The gain is the actual oil reserves minus the expected oil reserves had PEMEX not increased drilling. This difference is useful in determining the effectiveness of the drilling program. Figure 3-12 conveys the actual and estimated oil reserves along with the percentage gained by drilling. It is clear the actual oil reserves are declining at a slower rate than the estimated oil reserves, which would indicate the drilling effort is successfully finding more oil reserves.

Note: Since it takes approximately 2 years for drilling to yield results (i.e., oil reserves), the model begins forecasting in 2002 even though PEMEX drilling increased significantly in 2000.

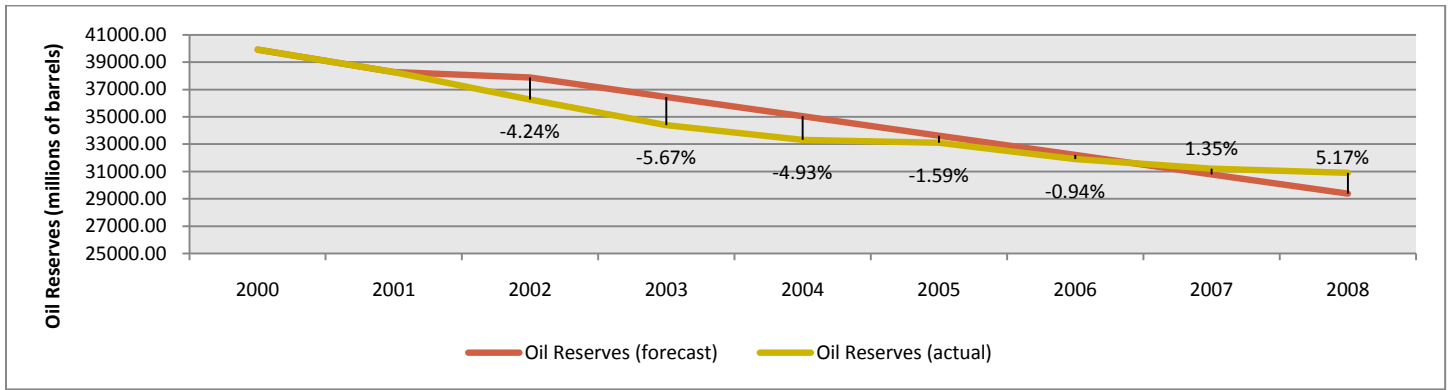


Figure 3-12: PEMEX lessened the trend in decline in reserves by increasing drilling

The regression model defined below defines the forecast for expected oil reserves.

$$OilReserves_t = 41932 - 16.683 \times TotalWellsDrilledCentered_t + \varepsilon_t$$

$OilReserves_t$: oil reserves in million barrels in year t

$TotalWellsDrilledCentered_t$: difference of total successful wells drilled from average (1990-2001) in year t

ε_t : the disturbance term

Equation 3-10: Oil reserve model

Table 3-3: Detailed results from oil reserve model

Year	Total Successful Wells Drilled (centered, forecast)	Total Successful Wells Drilled (centered, actual)	Total Successful Wells Drilled	Oil Reserves (forecast, million barrels)	Oil Reserves (actual, million barrels)	% Gain
1990	N/A	-77.67	67	N/A	44,560.0	N/A
1991	N/A	-3.67	141	N/A	44,295.0	N/A
1992	N/A	-37.67	107	N/A	44,439.0	N/A
1993	N/A	-84.67	60	N/A	44,043.0	N/A
1994	N/A	-96.67	48	N/A	43,127.0	N/A
1995	N/A	-50.67	94	N/A	42,146.0	N/A
1996	N/A	-41.67	103	N/A	42,072.0	N/A
1997	N/A	-31.67	113	N/A	41,392.0	N/A
1998	N/A	46.33	191	N/A	41,064.0	N/A
1999	N/A	57.33	202	N/A	41,495.0	N/A
2000	N/A	67.33	212	N/A	39,918.0	N/A
2001	N/A	253.33	398	N/A	38,286.1	N/A
2002	261.61	N/A	382	37,871.94	36,265.9	-4.24%
2003	346.44	N/A	508	36,456.71	34,388.9	-5.67%
2004	431.27	N/A	626	35,041.49	33,312.2	-4.93%
2005	516.10	N/A	652	33,626.26	33,093.0	-1.59%
2006	600.93	N/A	573	32,211.04	31,908.8	-0.94%

2007	685.76	N/A	600	30,795.81	31,211.6	1.35%
2008	770.59	N/A	641	29,380.59	30,900.0	5.17%

The explanatory variable for this model is the difference from the average drilling from 1990 to 2001 calculated as follows:

$$TotalWellsDrilledCentered_t = TotalWellsDrilled_t - AverageWellsDrilled_{1990-2001}$$

$TotalWellsDrilledCentered_t$: difference of total successful wells drilled from average (1990-2001) in year t

$TotalWellsDrilled_t$: number of successful wells drilled in year t

ε_t : the disturbance term

Equation 3-11: Centering of wells drilled from 1990-2001

The following calculation estimates the amount of oil reserves gained since 2000 using the oil reserve model. To account for deficiencies in the forecasted oil reserves and to improve the accuracy of the calculation, it ignores any negative differential.

$$\sum_{t=2002}^{2008} OilReserveGain_t = maximum(0, \%OilReserveGain_t) \times ActualOilReserves_t$$

Equation 3-12: Oil reserve gain

Note: the maximum() decision function allows the calculation to ignore negative sales gains, e.g., if the gain in 2000 was -5%, then the calculation would use zero for the gain in the year 2000.

The calculation from Equation 3-10 resulted in a net gain of **2019.38** million barrels of oil from 2002-2008.

OIL PRODUCTION EVALUATION

The oil production model compares the expected production levels had PEMEX not increased drilling in 2000 versus the actual oil production. Each barrel of oil sold more than the business-as-usual scenario is additional revenue for the company. The oil production model runs from 2000 to 2008 using data from 1990 to 1999 to forecast the expected production levels. The gain in oil production is the actual oil production minus the expected oil production had PEMEX not increased drilling. Figure 3-13 depicts the two scenarios. Oil production was mostly steady from 1990 to 1999. Thus, the forecasted business-as-usual model predicts oil production to increase only slightly to 2008. PEMEX's actual drilling increased considerably over business-as-usual until 2004. However, PEMEX's oil production has decreased considerably since then, primarily due to steep decline in production at Cantarell (see Figure 1-4).

The regression model defined below defines the forecast for expected oil production:

$$OilProduction_t = 1012.6 + 0.8428 \times TotalWellsDrilledCentered_t + \varepsilon_t$$

$OilProduction_t$: oil production in million barrels in year t

$TotalWellsDrilledCentered_t$: difference of total successful wells drilled from average (1990-1999) in year t

ε_t : the disturbance term

Equation 3-13: Oil production model

The explanatory variable for this model is the difference from the average drilling from 1990 to 1999 calculated as follows:

$$TotalWellsDrilledCentered_t = TotalWellsDrilled_t - AverageWellsDrilled_{1990-1999}$$

$TotalWellsDrilledCentered_t$: difference of total successful wells drilled from average (1990-1999) in year t

$TotalWellsDrilled_t$: number of successful wells drilled in year t
 ϵ_t : the disturbance term

Equation 3-14: Centering of wells drilled from 1990 to 1999

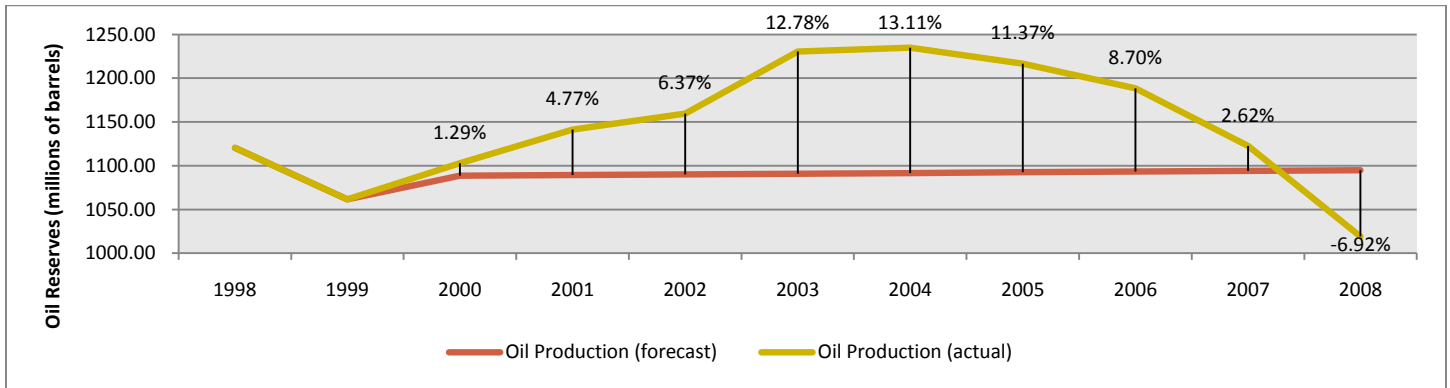


Figure 3-13: Until 2004, the drilling expansion appeared to be very successful compared to business-as-usual

Table 3-4: Results from oil production model

Year	Total Successful Wells Drilled (centered, forecast)	Total Successful Wells Drilled (centered, actual)	Total Successful Wells Drilled	Oil Production (forecast, million barrels)	Oil Production (actual, million barrels)	% Gain
1990	N/A	-45.60	67	N/A	930.02	N/A
1991	N/A	28.40	141	N/A	976.68	N/A
1992	N/A	-5.60	107	N/A	976.38	N/A
1993	N/A	-52.60	60	N/A	975.79	N/A
1994	N/A	-64.60	48	N/A	980.08	N/A
1995	N/A	-18.60	94	N/A	955.21	N/A
1996	N/A	-9.60	103	N/A	1046.39	N/A
1997	N/A	0.40	113	N/A	1103.40	N/A
1998	N/A	78.40	191	N/A	1120.55	N/A
1999	N/A	89.40	202	N/A	1061.42	N/A
2000	90.28	N/A	212	1088.68	1102.76	1.29%
2001	91.18	N/A	398	1089.43	1141.37	4.77%
2002	92.07	N/A	382	1090.19	1159.64	6.37%
2003	92.96	N/A	508	1090.94	1230.38	12.78%
2004	93.85	N/A	626	1091.69	1234.76	13.11%
2005	94.75	N/A	652	1092.44	1216.67	11.37%
2006	95.64	N/A	573	1093.20	1188.29	8.70%
2007	96.53	N/A	600	1093.95	1122.63	2.62%
2008	97.42	N/A	641	1094.70	1018.93	-6.92%

The following calculation estimates the amount of oil production gained since 2000 using the oil production model. To account for deficiencies in the forecasted oil production and to improve the accuracy of the calculation, it ignores any negative differential.

$$\sum_{t=2000}^{2008} OilProductionGain_t = \text{maximum}(0, \%OilProductionGain_t) \times ActualOilProduction_t$$

Equation 3-15: Oil production gain

Note: the maximum() decision function allows the calculation to ignore negative sales gains, e.g., if the gain in 2000 was -5%, then the calculation would use zero for the gain in the year 2000.

The calculation from Equation 3-15 resulted in a net gain of **733** million barrels of oil from 2000-2008.

COST-BENEFIT ANALYSIS OF DRILLING EXPANSION

This section details the statistical models used to predict the benefits and costs of the drilling expansion at PEMEX since 2000. Building off the econometric models defined in *Sustainability evaluation using econometric models*, the models use forecasts to determine the benefits and costs of the policy. Because PEMEX does not release operating costs by subsidiary, it is not possible to determine the total operating costs for the production and exploration subsidiary. Thus, the analysis must use company-wide sales and operating costs. Since the vast majority of PEMEX's revenue comes from exporting oil or selling refined products, it is suitable to use company-wide sales.

MODEL FOR TOTAL SALES

The total sales model provides the source for the benefit of the drilling expansion at PEMEX. The sales projections include both domestic and foreign sales giving an accurate representation of the benefit from the drilling expansion. The cumulative wells drilled since 1975 provide the baseline for projecting the expected sales had the drilling expansion not taken place. The projections run from 2000 to 2008 and use cumulative wells drilled from 1990 to 1999. With sales slowly increasing throughout the 1990s, the business-as-usual case predicts a steady increase in sales during the 2000s. The actual sales for PEMEX were considerably higher even after 2004 due to the steep increase in world oil prices.

The regression model defined below defines the forecast for expected oil production:

$$TotalSales_t = 5552.6 + 132.39 \times CumulativeWellsDrilled_t + 196209 \times Dummy_{FinancialCrisis} + \varepsilon_t$$

OperatingCosts_t: Total costs for PEMEX operations in year t

CumulativeWellsDrilled_t: Total wells drilled since 1975 in year t

Dummy_{FinancialCrisis}: True when t=1995 or t=1996 to account for Financial Crisis of 1994

Equation 3-16: Total sales model

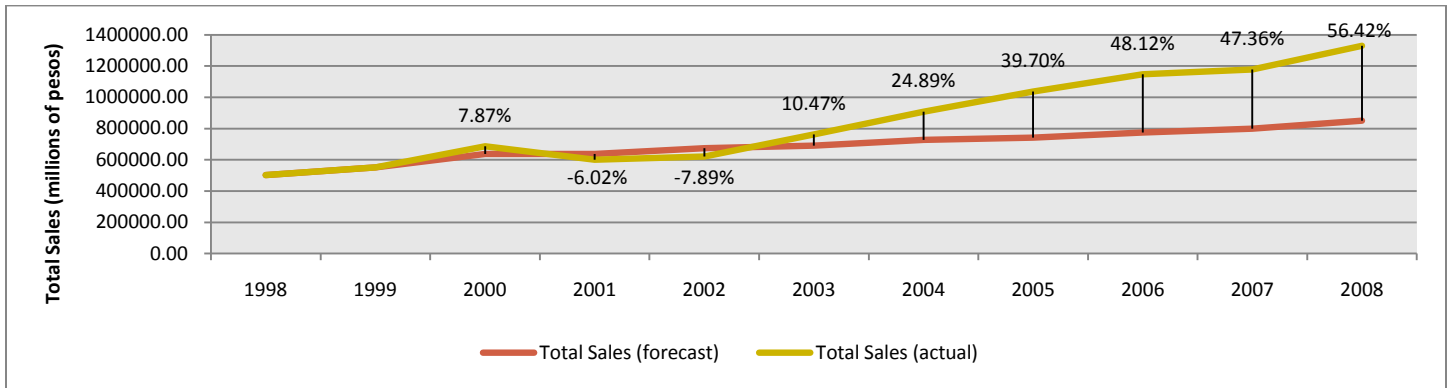


Figure 3-14: Total sales model shows a much stronger than expected growth in revenue for PEMEX

Table 3-5: Total sales model data (forecasted sales data adjusted for inflation)

Year	Total Cumulative Wells Drilled since 1975 (forecast)	Total Cumulative Wells Drilled since 1975 (actual)	Dummy for 1994 Financial Crisis	Total Sales (forecast, million pesos)	Total Sales (actual, million pesos)	% Gain
1990	N/A	3113	0	N/A	476,709.22	0.00%
1991	N/A	3254	0	N/A	389,930.10	0.00%
1992	N/A	3361	0	N/A	437,466.19	0.00%
1993	N/A	3421	0	N/A	420,179.32	0.00%
1994	N/A	3469	0	N/A	447,138.45	0.00%
1995	N/A	3563	1	N/A	690,485.37	0.00%
1996	N/A	3666	1	N/A	670,066.54	0.00%
1997	N/A	3779	0	N/A	597,180.24	0.00%
1998	N/A	3970	0	N/A	502,290.40	0.00%
1999	N/A	4172	0	N/A	551,729.28	0.00%
2000	4373.12	4384	0	636,881.67	687,004.86	7.87%
2001	4574.25	4782	0	638,027.72	599,625.62	-6.02%
2002	4775.38	5164	0	674,118.37	620,922.21	-7.89%
2003	4976.52	5672	0	690,836.65	763,133.92	10.47%
2004	5177.65	6298	0	726,885.86	907,783.10	24.89%
2005	5378.78	6950	0	741,547.62	1,035,970.21	39.70%
2006	5579.92	7523	0	774,421.19	1,147,093.83	48.12%
2007	5781.05	8123	0	799,892.05	1,178,750.95	47.36%
2008	5982.18	8764	0	849,613.01	1,328,950.00	56.42%

MODEL FOR OPERATING COSTS

The operating costs model provides the source for the costs of the drilling expansion at PEMEX. The model compares the actual costs from 2000 to 2008 and the expected costs had PEMEX not expanded drilling. Although the benefit from the drilling expansion mostly began in 2003, it is important to start the forecast in 2000 since the drilling expansion costs began accumulating that year.

The regression model defined below defines the forecast for operating costs:

$$\text{OperationalCosts}_t = -61751 + 75.122 \times \text{CumulativeWellsDrilled}_t + 62961 \times \text{Dummy}_{\text{FinancialCrisis}} + \varepsilon_t$$

$\text{OperationalCosts}_t$: Total costs for PEMEX operations in year t

$\text{CumulativeWellsDrilled}_t$: Total wells drilled since 1975 in year t

$\text{Dummy}_{\text{FinancialCrisis}}$: True when t=1995 to account for Financial Crisis of 1994

Equation 3-17: Operating costs model

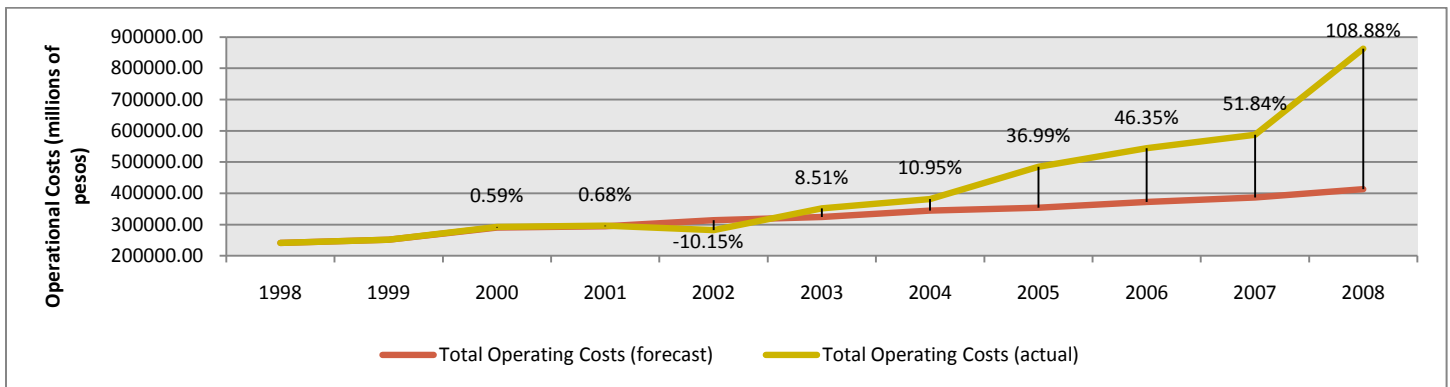


Figure 3-15: Operating costs have increased significantly versus business-as-usual

Table 3-6: Operating costs model data (forecasted cost data adjusted for inflation)

Year	Total Cumulative Wells Drilled since 1975 (forecast)	Total Cumulative Wells Drilled since 1975 (actual)	Dummy for Financial Crisis of 1994	Total Operating Costs (forecast, million pesos)	Total Operating Costs (actual, million pesos)	% Gain
1990	N/A	3113	0	N/A	190,434.66	N/A
1991	N/A	3254	0	N/A	173,966.63	N/A
1992	N/A	3361	0	N/A	186,603.31	N/A
1993	N/A	3421	0	N/A	188,659.71	N/A
1994	N/A	3469	0	N/A	189,921.07	N/A
1995	N/A	3563	1	N/A	268,870.07	N/A
1996	N/A	3666	0	N/A	213,893.43	N/A
1997	N/A	3779	0	N/A	227,540.53	N/A
1998	N/A	3970	0	N/A	241,041.23	N/A
1999	N/A	4172	0	N/A	251,486.08	N/A
2000	4373.12	4384	0	290,669.10	292,388.00	0.59%
2001	4574.25	4782	0	294,278.90	296,267.54	0.68%
2002	4775.38	5164	0	313,914.08	282,037.46	-10.15%
2003	4976.52	5672	0	324,516.83	352,147.89	8.51%
2004	5177.65	6298	0	344,186.91	381,887.86	10.95%
2005	5378.78	6950	0	353,713.59	484,568.64	36.99%
2006	5579.92	7523	0	371,899.74	544,270.24	46.35%

2007	5781.05	8123	0	386,540.87	586,921.55	51.84%
2008	5982.18	8764	0	412,956.25	862,596.00	108.88%

BENEFIT SUMMARY

This section details the benefits of the drilling expansion effort. To account for deficiencies in the forecasted total sales and to improve the accuracy of the benefit calculation, the calculation ignores any negative differential since it is unlikely that the expanded drilling lead to less sales. The following algorithm defines the method to calculate the total benefits:

$$\sum_{t=2000}^{2008} AnnualBenefit_t = maximum(\%TotalSalesGain_t, 0) \times TotalSales_t$$

$AnnualBenefit_t$ = Total benefit in million pesos for year t

$\%TotalSalesGain_t$ = Percentage of sales benefit increase for year t

$TotalSales_t$ = Total sales in million pesos for year t

Equation 3-18: Benefit of drilling expansion

Note: the maximum() decision function allows the calculation to ignore negative sales gains, e.g., if the gain in 2000 was -5%, then the calculation would use zero for the gain in the year 2000.

Table 3-7: Benefits of drilling expansion

Year	Sales Gain %	Total Sales (million pesos)
2000	7.87%	687,004.86
2001	-6.02%	599,625.62
2002	-7.89%	620,922.21
2003	10.47%	763,133.92
2004	24.89%	907,783.10
2005	39.70%	1,035,970.21
2006	48.12%	1,147,093.83
2007	47.36%	1,178,750.95
2008	56.42%	1,328,950.00

COSTS SUMMARY

This section details the costs of the drilling expansion effort. The calculation ignores any negative differentials since they are likely due to a modeling error. The following algorithm defines the method to calculate the total costs:

$$\sum_{t=2000}^{2008} AnnualCost_t = maximum(\%OperatingCostLoss_t, 0) \times TotalOperatingCost_t$$

$AnnualCost_t$ = Total cost in million pesos for year t

$\%OperatingCostLoss_t$ = Percentage of operating cost increase for year t

$TotalOperatingCost_t$ = Total operating costs in million pesos for year t

Equation 3-19: Cost of drilling expansion

Note: the maximum() decision function allows the calculation to ignore negative sales gains, e.g., if the gain in 2000 was -5%, then the calculation would use zero for the gain in the year 2000.

Table 3-8: Costs of drilling expansion

Year	Operating Cost Loss %	Total Operating Cost (million pesos)
2000	0.59%	292,388.00
2001	0.68%	296,267.54
2002	-10.15%	282,037.46
2003	8.51%	352,147.89
2004	10.95%	381,887.86
2005	36.99%	484,568.64
2006	46.35%	544,270.24
2007	51.84%	586,921.55
2008	108.88%	862,596.00

COST-BENEFIT RESULT (2000-2008)

The overall benefit for PEMEX's drilling expansion is considerably positive due to the rise in world oil prices since 2004. Table 3-9 summarizes the benefit-cost calculation. The accumulated benefit of the drilling expansion rose rapidly from 2004-2008. The source for a large percentage of the cost increases is from 2008 alone. PEMEX attributes much of the cost increases to the need for imported products (PEMEX, 2009, p. 21). Furthermore, 2008 was also the first year the actual production level dipped below the forecasted level at the start of the model in 2000.

Table 3-9: Cost-Benefit summary

Year	Benefit (million pesos)	Cost (million pesos)	Accumulated Benefit (million pesos)	Accumulated Benefit (million 2008 dollars)
2000	54,067.92	1,718.90	52,349.02	3,798.81
2001	0.00	1,988.64	50,360.37	3,654.50
2002	0.00	0.00	50,360.37	3,654.50
2003	79,863.32	27,631.06	102,592.63	7,444.83
2004	225,916.43	37,700.95	290,808.11	21,103.04
2005	411,319.54	130,855.04	571,272.61	41,455.48
2006	552,012.89	172,370.50	950,915.00	69,004.94
2007	558,300.70	200,380.68	1,308,835.02	94,978.08
2008	749,770.63	449,639.75	1,608,965.91	116,757.65

The accumulated benefit illustrates the gains from the drilling expansion. One should not assign real value to this benefit beyond the observation that it is considerably positive. *Commentary and Conclusions on Policy Analysis Results* analyzes this cost-benefit assessment in further detail.

4. COMMENTARY AND CONCLUSIONS ON POLICY ANALYSIS RESULTS

The following section provides commentary and conclusions on the policy analysis results presented in *Drilling Expansion Policy Analysis*. This section provides the framework for the report's final recommendations.

COMPETITIVENESS

In 2004, PEMEX appeared less efficient than most major National Oil Companies (NOCs). It is likely this fact only worsened since 2004 due to the steep declines in oil production. However, the rise in oil prices helped hide this issue as the additional revenues more than offset the decline in production. In fact, the revenue per employee at PEMEX has increased since 2004 reaching 4.19 million pesos per employee in 2007. Thus, while PEMEX rate of income per employee has increased, it has grown less competitive compared to other NOCs in recent years due to the decline in oil production. This competitiveness highlights the significance of improving efficiency as oil reserves decline.

PEAK OIL

Mexico's oil production has steadily declined since 2004. The analysis in this report indicates that Mexico has less than 20 billion barrels of oil remaining. Both the Hubbert Parabola and the Hubbert Linearization are within 10% of the current cumulative oil production plus the *probable reserves (2P)* in Mexico as of 2008. However, Mexico has an additional 10 billion barrels of oil in *possible reserves*. Thus, it is feasible that the total oil production remaining is substantially more than the estimate from this analysis. Extracting this oil and finding additional reserves is dependent on PEMEX's access to technology and capital. If PEMEX is unable to access these additional reserves, then it is highly likely that Mexico has already surpassed peak oil. This conclusion is a dire one for the sustainability of the oil sector in the country.

REVISITING THE MORONEY-ASSAD ANALYSIS

EXPLORATION AND DEVELOPMENTAL DRILLING

The Moroney-Assad analysis concluded that net oil export cost predicted the level of exploration and developmental drilling. Although this model could not be recreated, sources for drilling frequency are worth mentioning. *PIDIREGAS* funded nearly all of PEMEX's exploration and developmental drilling from 2000-2008 (see Figure 2-2). Although Mexico eliminated *PIDIREGAS* in the energy reforms of 2008, one can expect debt financing to be a large source of capital for PEMEX's future exploratory and developmental drilling efforts. To that end, the Moroney-Assad model of using oil export revenue to predict future drilling appears to miss the major source of financing for these efforts.

SUCCESSFUL EXPLORATION AND DEVELOPMENT

The exploration and developmental drilling models from the Moroney-Assad analysis are partially valid using data through 2008. The exploration drilling success ratio still increases with more wells drilled, while there is no correlation between the development drilling success ratio and the cumulative number of wells drilled. The high ratio of success in developmental drilling may explain the

developmental drilling model failure. The ratio has been above the 90th percentile since the 1990s. With a tripling of the total development wells drilled since 2000 and a success ratio of 92% in 2008, it is clear PEMEX has learned from its previous experience.

ADDITION TO OIL AND GAS RESERVES

Until 2000, the Moroney-Assad analysis showed each successful well drilled by PEMEX provided an addition of 18.85 million barrels of oil to Mexico's oil reserves. However, the model of using successful wells drilled to predict oil reserves is no longer statistically significant when considering data through 2008. This is largely because the gross oil reserve trend has not reversed since PEMEX expanded drilling. One might attribute this relationship breakdown to the rapid increase in non-associated gas wells in production, which totaled 3120 wells out of 6247 oil and gas wells in 2008. PEMEX's published data does not distinguish between oil and gas wells drilled so it was not possible to investigate this explanation further. However, data available from [Baker-Hughes](#) on rig counts does provide some evidence that new oil wells are the focus of PEMEX.

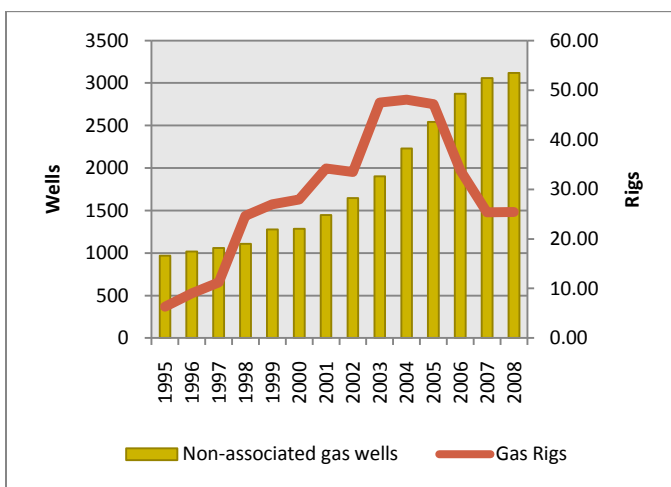


Figure 4-1: There is no correlation between non-associated gas wells in production and the number of active gas rigs since 1995

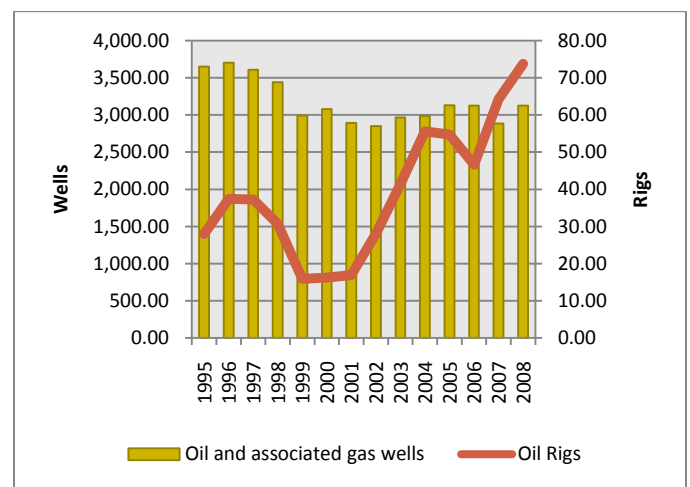


Figure 4-2: There is no correlation between oil and associated gas wells in production and the number of active oil rigs since 1995

Figure 4-1 and Figure 4-2 convey the relationship between wells and rigs. The figures show that the total gas wells have increased substantially since the mid-1990s while the total oil wells have decreased. Furthermore, the number of oil rigs has increased over 400% since 2000 while the number of gas rigs in operation during 2008 was about the same as in 2000. Assuming the reason for the increase in total oil rigs in operation at PEMEX is to drill for new or existing oil, the analysis shows it has been only marginally successful at reversing the decreasing trend of oil reserves and have been unsuccessful at reversing the trend of declining oil production.

PRODUCTION MODELS

The Moroney-Assad model attempts to predict oil production based on reserves and previous production levels. The model is statistically significant through 2008 and highlights a serious problem for PEMEX. Since the mid 1980s, Mexico's oil reserves have steadily declined from its peak of 57 billion barrels. Meanwhile, oil production followed oil reserves precisely until the mid 1980s. From then until 2004, production steadily increased but has since declined sharply. The oil production in 2008 is approximately the same as the peak of oil reserves in 1984 (see Figure 4-3). Since 2004, rising oil prices have helped offset the issue of declining production. Unless PEMEX is able to reverse the trend of declining oil reserves, it will likely face a difficult future.

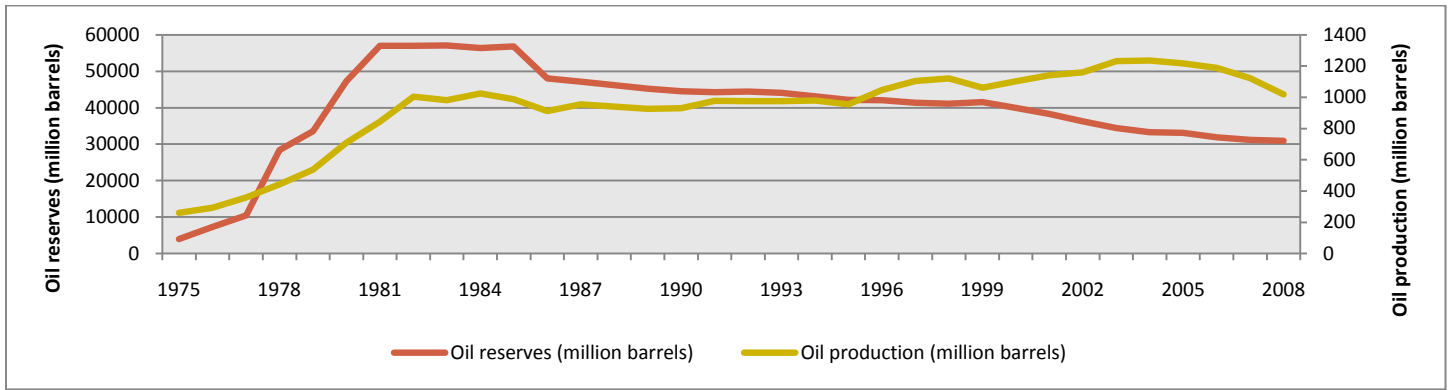


Figure 4-3: The Moroney-Assad analysis showed oil reserves help predict oil production (Moroney & Dieck-Assad, 2005; PEMEX, 2004-2008)

MORONEY-ASSAD ANALYSIS SUMMARY

Table 4-1 conveys the important shifts in oil data at PEMEX since the year 2000. For instance, one can see that there is no longer a correlation between oil reserves and the level of drilling.

Table 4-1: Summary from revisiting of Moroney-Assad analysis

Moroney-Assad Model	Summary (Moroney-Assad Analysis)	Summary (Updated through 2008)	Model Comment
Exploration and Developmental Drilling Model	Drilling is responsive to net price of oil Higher price leads to increase in developmental and exploration wells	Access to capital through debt financing funds 95% of exploration and developmental drilling Political influence may help in predicting drilling levels	Could not reproduce original models
Exploration and Development Success Ratio with Experience Model	Success ratio increased due to technological advances and learning-by-doing	Developmental drilling success may have reached a plateau, while the success ratio for exploration drilling is still increasing	Developmental drilling success ratio model no longer statistically significant
Oil Reserve Model	Mexico has a large endowment of oil and gas since each new well adds significantly to reserves	Drilling expansion has only marginally succeeded at reversing the trend of declining oil reserves	Model no longer statistically significant
Oil Production Model	Oil reserves predict oil production Political influence plays a considerable role in determining production levels	Oil reserves still accurately predict production levels	Previous oil production levels now statistically significant

SUSTAINABILITY EVALUATION USING ECONOMETRIC MODELS AND CORRELATIONS

In assessing sustainability of PEMEX’s operations, econometric models provided strong evidence that PEMEX’s drilling expansion is unsuccessful at reversing the negative trend in oil production and only marginally successful at diminishing the negative trend in oil reserves.

OIL RESERVES AND NEGATIVE CORRELATION WITH DRILLING

This model indicates oil reserves are negatively affected by the number wells added to the inventory available to PEMEX. The reasonable conclusions for this relationship are one of two options:

1. The production from these oil wells is increasing more rapidly than in previous time so the lifetime of each oil well is decreasing. Mexico's oil production has declined since 2004 while the number of wells has consistently increased. Thus, it is difficult to establish a relationship between the production rate of oil wells and the declining oil reserves.
2. The amount of oil extracted from each well is less than previous wells. As a result, there is a diminishing rate of return for each new oil well. PEMEX has increased the number of non-associated gas wells from 942 in 1993 to 3120 in 2008 (PEMEX, 2004-2008). However, PEMEX appears to be focusing much of its exploratory efforts on oil as mentioned previously. Thus, the negative relationship between drilling and oil reserves is still significant. The data suggests this conclusion is valid.

The results from this model strongly suggest that each well added to PEMEX's inventory is producing less and less oil. This diminishing rate of return is a considerable warning for the long-term viability of the drilling efforts at PEMEX.

OIL RESERVES AND NEGATIVE CORRELATION WITH EMPLOYEE COUNT

This model highlights another negative correlation between oil reserves and a metric that conveys PEMEX's effort to reverse declining oil reserves. In this case, it is clear that additional employees are not decreasing oil reserves. However, it is also clear that the rapid increase in employees in the last decade has not added to Mexico's oil reserves. One explanation for this result is the affect the additional employees had on oil production. There is not a statistical relationship between the increase in employee count and oil production as the employee count has rapidly increased since 2000 while production only began to decline in 2004.

If the metric of success for PEMEX's expansion in exploration and production was the reversal of declining oil reserves, then the results of this model strongly suggest that PEMEX's effort to combat declining oil reserves with increased hiring has been unsuccessful.

OPERATING COST RATE AND EMPLOYEE COUNT

This model conveys one of the sources of rising costs at PEMEX. The positive correlation between production and exploration employee count and the marginal cost per barrel of oil is a critical forward-looking metric. If marginal cost per barrel of oil continues to rise, it may result in some oil being cost-ineffective to extract. In 2009, PEMEX informed members of the Mexican Senate energy committee that costs at deepwater sites like Chicontepec are increasingly expensive approaching US\$ 26 per barrel. Meanwhile, one barrel of oil extracted from Cantarell costs between US\$ 3 and US\$ 6. As a result, the recommendation by a PEMEX board nominee was to reconsider some deepwater projects (Energy Current, 2009). While PEMEX attributed these cost increases to expensive extraction equipment, the report highlights the importance of improving operating efficiency at PEMEX as it begins to extract oil from more remote sources. For instance, PEMEX attributed the reserve for retirement payment as the primary factor to rising operating costs in 2007 (PEMEX, 2008, p. 28).

OIL RESERVES EVALUATION

The oil reserves evaluation attempts to compare Mexico's oil reserves from 2000-2008 if no drilling expansion occurred and the actual oil reserve levels. It is clear from the model that PEMEX has reduced the rate of the decline of oil reserves; Figure 3-12 depicts the decrease. However, there are two factors not accounted for in this model. First, a decline in production after 2004 may account for part of the perceived gain. The estimated reserve additions since 2000 are 2019.38 million barrels. Since the accumulated

production decline since 2004 is only 392.51 million barrels, the reserve additions are more likely attributable to new discoveries. Second, the reserves used in the model are *possible reserves (3P)*, which have a higher degree of uncertainty than the standard reserve estimation used by agencies such as the U.S. Energy Information Administration. PEMEX did not make estimations other than 3P publicly available until after 1999. In fact, possible reserves have steadily increased since 1999 (PEMEX, 2004-2008).

OIL PRODUCTION EVALUATION

The oil production determines the gains of the drilling expansion from 2000-2008 by comparing actual production levels versus expected production levels. The model does not account for the steep and unexpected decline in production at Cantarell since 2004. Despite this fact, the model does show considerable gains in oil production versus business-as-usual through 2007. These gains are attributable to the drilling expansion, which supports the claim that the program has been successful. A more accurate model isolating production in different regions could help account for the production losses at Cantarell and more accurately define the production gains from the drilling expansion.

OVERALL SUMMARY OF ECONOMETRIC MODELS TO EVALUATE SUSTAINABILITY

RESULTS

- Oil reserves are negatively correlated with production and exploration employee count at PEMEX and the total number of successful wells drilled in a year
- The marginal cost per barrel of oil is positively correlated with the production and exploration employee count at PEMEX
- The drilling expansion helped decrease the rate of decline in oil reserves
- The drilling expansion produced additional oil beyond business-as-usual, which generated a considerable benefit for PEMEX

CONCLUSIONS

- Each well added to PEMEX's inventory is producing less and less oil. This diminishing rate of return is a considerable warning for the long-term viability of the drilling efforts at PEMEX.
- If the metric of success for expansion in exploration and production was the reversal of declining oil reserves, then the results of this model strongly suggest that PEMEX's effort to combat declining oil reserves with increased hiring has been unsuccessful. However, if the metric is simply to decrease the rate of decline, then the effort has resulted in marginal success since 2007.
- If the marginal cost per barrel of oil continues to rise, it may result in some oil being cost-ineffective to extract since oil from remote sources is already expensive for PEMEX to produce.

COST-BENEFIT ANALYSIS OF DRILLING EXPANSION

PEMEX's drilling expansion from 2000-2008 has increased revenue significantly over business-as-usual. The vast majority of these additional revenues came from after 2004 despite the decline in oil production. This revenue gain was due to a significant rise in oil

prices from 348 pesos in 2004 to 1159 pesos in 2008. At a gain of over 300%, it is clear any additional oil above business-as-usual would have provided ample compensation for PEMEX.

The financial crisis that swept the globe in late 2008 has affected nearly all industries including the global oil market. The price of oil has crashed from a high US\$ 133 per barrel in July to US\$ 41 per barrel in December of 2008 (U.S. Energy Information Administration). PEMEX shrewdly hedged US\$ 70 per barrel oil for 2009, but it is unclear what 2010 will bring to the global oil market, as much will depend on economic recovery ongoing in the United States and elsewhere. Thus, the increasing operating costs at PEMEX may hurt the company's bottom line and its ability to extract oil from remote areas.

5. RECOMMENDATIONS FOR PEMEX AND MEXICAN FEDERAL GOVERNMENT

PEMEX undertook an unprecedented expansion of drilling in the year 2000. The ultimate goal of this effort was to increase oil production and reverse the trend of declining oil reserves. Oil production initially rose but has been declining steadily since 2004 and is now lower than it was when the program began. Furthermore, the rate of decline of oil reserves has lessened but remains negative. PEMEX may have reached the peak of its oil production and must take action to improve operating efficiency to stay competitive as oil becomes more difficult to extract. Thus, the recommendations presented attempt to improve operating efficiency while considering the policy criteria outlined previously especially political feasibility.

RECOMMENDATION 1: PARTNERSHIPS TO CHANGE POLITICAL WILL

MEXICO AND PEMEX SHOULD UNDERTAKE A PUBLIC CAMPAIGN TO HIGHLIGHT INTERNATIONAL PARTNERSHIPS WITH THE GOVERNMENTS AND NATIONAL OIL COMPANIES OF NORWAY AND BRAZIL IN ORDER TO CHANGE POLITICAL WILL IN MEXICO.



Figure 5-1: Proposed timeline

PROBLEM

Mexico has resisted any public policies that share revenues from oil discoveries with partners. This mindset is born from political considerations by the Mexican Congress to resist any foreign control over hydrocarbons since nationalization occurred in 1938. The energy reform of 2008 renewed the debate over hydrocarbon control in the country. Despite the best intentions, the reforms may actually hinder PEMEX's future access to capital and prevent them from operating in the most efficient manner. The arduous debate in the country highlighted the political infeasibility of significant change in Mexico's tight control over the oil sector. For real change to occur, a lengthy and informative public campaign must take place about the dangers of the present trends in Mexico and the opportunities available to mitigate the problems. Essentially, Mexico must look at adopting policies of other successful National Oil Companies (NOCs) before it is too late.

BACKGROUND

In 2007, PEMEX reached out to fellow NOCs Petrobras and StatoilHydro (PEMEX, 2007). These two NOCs in particular have developed policies to manage the oil sector in an efficient manner to maximize social welfare in their nations without maintaining strict control over oil in the ground. The *Background Research* section of this report highlights the policies in Norway that have diminished its susceptibility to the boom-bust nature of the global oil market. Brazil implemented its reforms more recently, but has reaped the benefits quickly. Mexico would receive a considerable benefit from expanding these partnerships. For PEMEX to succeed on its own, it must increase its technological capabilities and develop more economically efficient policies since oil will become more difficult to extract in the future.

In the late 1990s, Brazil opened its oil market to private industry and many consider the process a model of transparency (The Economist, 2009). The country has found its two largest oil deposits in its history since 2007. Private companies including British Gas and Anadarko Petroleum have assisted in discoveries, but Petrobras retains a sizeable stake in oil revenues for the benefit of the Brazilian people. Since the 1980s, Petrobras has developed considerable expertise in deepwater exploration. Many consider the company the world's best-known producer of deepwater oil (The Economist, 2009). It would be worthwhile for Mexico to consider Brazil's policies on oil revenue sharing and for PEMEX to attain (or use) some of Petrobras' knowledge of deepwater exploration.

Norway has maintained a stable and successful oil sector for decades. Norway's public policies have benefited the Norwegian people with consistently low unemployment and minimal poverty. Norway's smart and long-term view for public expenditures has prevented it from experiencing the same hardships felt in other petro-states. They capped the growth of the government during the boom years of the 1970s and created an oil fund for future generations to share the wealth of their natural resource. Mexico would benefit from public policies similar to Norway's to reduce its dependency on revenue from oil for the government budget.

PHASE 1: PEMEX UNDERTAKES MASSIVE PUBLIC ADVERTISING CAMPAIGN HIGHLIGHTING PARTNERSHIPS WITH PETROBRAS AND STATOILHYDRO

PEMEX partnered with Petrobras and StatoilHydro in 2007 in order to share technology and work together. These partnerships are an opportunity for PEMEX to inform the Mexican people of the efficiency and success of these companies with a massive public advertising campaign. This campaign should include highlighting the recent oil discoveries by Petrobras along with the historic success of StatoilHydro.

PHASE 2: MEXICAN GOVERNMENT HOLDS JOINT CONFERENCE WITH BRAZIL AND NORWAY TO DISCUSS PUBLIC POLICES RELATED TO THE HYDROCARBON SECTOR

Following the advertising campaign, the Mexican government should hold a joint conference in Mexico with members of the Brazilian and Norwegian governments. The purpose of this conference should be to discuss the public policies related to the hydrocarbon sector in all three nations in order to highlight the potential benefit of further reforms in Mexico. The conference should highlight the benefits of private partnerships in oil exploration to the Brazilian people along with the stable and successful management of oil revenues in Norway.

PHASE 3: ASSESSMENT OF POLITICAL WILL FOR FURTHER REFORM OF HYDROCARBON SECTOR INCLUDING LAW CHANGES TO ALLOW PEMEX TO OPERATE MORE EFFICIENTLY

Changing political will in Mexico to encourage further reforms in the hydrocarbon sector is the goal of the first two phases of this program. The final phase is to assess the likelihood of change before enacting policy debates that will allow PEMEX to operate more efficiently.

RECOMMENDATION 2: CONTINUE DRILLING EXPANSION**PEMEX'S DRILLING EXPANSION HAS BEEN PARTIALLY SUCCESSFUL AND SHOULD CONTINUE DEPENDING ON OPERATING COSTS AND ACCESS TO CAPITAL****PROBLEM**

PEMEX faces declining oil reserves and production. The company undertook a significant effort to combat declining oil reserves in 2000 with only marginal success. In addition, oil production at the country's largest oil field, Cantarell has been in steep decline since 2004 leading to an overall production decline that could make Mexico a net importer of oil by 2020.

BACKGROUND

This report provided substantial justification for the drilling expansion policy begun in 2000. Although the ultimate goals of increasing oil production and reversing the decreasing trend in oil reserves have not succeeded, the program has been marginally successful.

The rate of decline for oil reserves is less than it was in the year 2000 and the effort has resulted in a net benefit for PEMEX due to increased production from 2000-2004 compared to business-as-usual. The cost-benefit analysis showed the increased sales at PEMEX far outweighed any increases in costs from 2000-2008. Although this increase is largely due to the rise of global oil prices, the analysis also showed that the program increased oil production above business-as-usual. The decrease in the rate of decline in oil reserves has also helped prolong the year when Mexico could become a net importer of oil. However, the effort has not diminished the likelihood of the U.S. EIA's forecast of a switchover in 2020 since they released their report in 2009.

PEMEX faces an increasing marginal cost per barrel of oil and the potential of not being able to extract some oil due to economic constraints. In 2007, PEMEX attributed much of their rising costs to retirement payments and other employment expenses. PEMEX attributed rising costs in 2008 to rising equipment costs. This mix of sources for cost increases highlights the importance of improved efficiency at the company. As a result, the recommendation by a PEMEX board nominee was to reconsider some deepwater projects in 2009.

CONTINUE DRILLING EXPANSION AS LONG AS POSSIBLE

PEMEX should continue the drilling expansion as long as it remains economically efficient to do so. PEMEX should consider factors including long-term operating cost increases (labor expansion) as well as risk of access to capital. PEMEX should avoid significant debt financing if possible to maintain a credit rating that will allow it to finance necessary operations. The company should also consider cost-cutting options that will lower long-term effects on the marginal cost per barrel as it extracts oil from more expensive and remote areas. One option to lower this growth is to use temporary contractors and part-time workers to limit the expansion of the full-time employee base in the production and exploration subsidiary. While PEMEX has been a solid provider of employment for the Mexican people in the past, it must consider the difficulties ahead in extracting oil at increased cost.

6. FUTURE WORK

This report focused on evaluating PEMEX's effort to increase the supply of oil in Mexico. The U.S. EIA estimates that Mexico could become a net importer of oil by 2020 if present trends continue due to declining oil reserves and increased demand for gasoline. Future work could evaluate other significant aspects of this problem including:

- **Perform regional analysis of exploration and production of oil by PEMEX:** Regional data is available but this report did not consider it for the analysis. The regional data may provide useful insights into the priorities of PEMEX's exploration and production efforts. For instance, the vast majority of exploratory wells drilled by PEMEX between 2000 and 2008 were in the North region but oil production has only increased 12% in that region since 2000 and it provides only 3% of total production as of 2008 (see *Appendix B: Regional Data*).
- **Identify demand side opportunities in Mexico to help prevent the 2020 switchover to a net importer of oil:** Organizations like the [International Council on Clean Transportation](#) are looking at ways to reduce the rising demand for fuels in Mexico without hampering economic growth.
- **Investigate potential for partnerships between PEMEX and universities in the U.S. including Texas A&M and University of Texas at Austin:** PEMEX must learn advanced drilling techniques. In Brazil, Petrobras began work on deepwater exploration in the 1980s and many now consider it a world leader in this activity. PEMEX will need to improve the knowledgebase of its workforce in order to turn possible oil reserves into proven oil reserves.
- **Evaluate ballooning retirement costs at PEMEX and its affect on long-term financial stability:** The reserve for retirement benefits increased by 36.9% from 2007 to 2008 to over 112 billion pesos (PEMEX, 2009). According to PEMEX, the cost increases in 2007 were primarily due to higher cost of the reserve for retirement payments (PEMEX, 2008, p. 28).
- **Investigate potential for alternative energy infrastructure in Mexico to allow PEMEX to transition to an energy market without fossil fuels:** Partnerships like the [Mexico Renewable Energy Program \(MREP\)](#) are useful. This program ran from 1994-2004 and combined the resources of the U.S. DOE, USAID, and the Sandia National Laboratories to increase the use of renewable energy in Mexico.

APPENDIX A: ANALYSIS RESULTS

REVISITING THE MORONEY-ASSAD ANALYSIS

CHAPTER 4: EXPLORATION AND DEVELOPMENTAL DRILLING

The following output from STATA is for the Exploratory Drilling Model. The p-value below indicates the regression is statistically *insignificant*.

```
. regress tewd nmop L.tewd if year < 2001
```

Source	SS	df	MS	Number of obs = 25		
Model	13132.7435	2	6566.37177	F(2, 22)	=	50.96
Residual	2834.69646	22	128.849839	Prob > F	=	0.0000
-----				R-squared	=	0.8225
-----				Adj R-squared	=	0.8063
Total	15967.44	24	665.31	Root MSE	=	11.351

tewd	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
nmop	1.014983	.8489376	1.20	0.245	-.7456057	2.775572
tewd						
L1.	.7611896	.1202835	6.33	0.000	.5117369	1.010642
_cons	.8733942	5.704405	0.15	0.880	-10.95682	12.70361

The following output from STATA is for the Developmental Drilling Model. The p-value below indicates the regression is statistically *insignificant*.

```
. regress tdwd nmop L.tdwd if year < 2001
```

Source	SS	df	MS	Number of obs = 25		
Model	160969.494	2	80484.7471	F(2, 22)	=	46.83
Residual	37813.4658	22	1718.7939	Prob > F	=	0.0000
-----				R-squared	=	0.8098
-----				Adj R-squared	=	0.7925
Total	198782.96	24	8282.62333	Root MSE	=	41.458

tdwd	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
nmop	6.374808	4.141145	1.54	0.138	-2.213401	14.96302
tdwd						
L1.	.6508223	.170724	3.81	0.001	.2967624	1.004882
_cons	4.507815	20.65721	0.22	0.829	-38.33262	47.34825

CHAPTER 5: SUCCESSFUL EXPLORATION AND DEVELOPMENT

Exploration Success Ratio with Experience Model

```
. regress osre L.osre dum78 cumew1 if year > 1975 & year < 2001
```

Source	SS	df	MS			
Model	.475136831	3	.158378944	Number of obs =	25	
Residual	.237923476	21	.011329689	F(3, 21) =	13.98	
				Prob > F	= 0.0000	
				R-squared	= 0.6663	
				Adj R-squared	= 0.6187	
Total	.713060307	24	.029710846	Root MSE	= .10644	

osre	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
osre						
L1.	.2683542	.1282135	2.09	0.049	.0017197	.5349888
dum78	.6782233	.11713	5.79	0.000	.4346382	.9218085
cumew1	.0004715	.0001817	2.60	0.017	.0000937	.0008493
_cons	.1516626	.0685114	2.21	0.038	.0091852	.2941399

Development Success Ratio with Experience Model

```
. regress osrd L.osrd cumdw1 if year > 1975 & year < 2001
```

Source	SS	df	MS			
Model	.06505048	2	.03252524	Number of obs =	25	
Residual	.028257247	22	.00128442	F(2, 22) =	25.32	
				Prob > F	= 0.0000	
				R-squared	= 0.6972	
				Adj R-squared	= 0.6696	
Total	.093307727	24	.003887822	Root MSE	= .03584	

osrd	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
osrd						
L1.	.5650552	.1765154	3.20	0.004	.1989846	.9311258
cumdw1	.0000163	9.10e-06	1.79	0.088	-2.60e-06	.0000351
_cons	.3330385	.1338831	2.49	0.021	.0553818	.6106951

Exploration Success Ratio with Experience Model (updated)

```
. regress osre L.osre dum78 cumew1 if year > 1975 & year < 2009
```

Source	SS	df	MS			
Model	.455464424	3	.151821475	Number of obs =	33	
Residual	.309060593	29	.010657262	F(3, 29) =	14.25	
				Prob > F	= 0.0000	
				R-squared	= 0.5957	
				Adj R-squared	= 0.5539	
Total	.764525018	32	.023891407	Root MSE	= .10323	

osre	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
osre						
L1.	.2706922	.1203347	2.25	0.032	.0245801	.5168042
dum78	.6347731	.1102262	5.76	0.000	.4093353	.860211
cumew1	.0002707	.0001112	2.43	0.021	.0000433	.0004982
_cons	.2078774	.0583391	3.56	0.001	.0885604	.3271943

Development Success Ratio with Experience Model (updated)

```
. regress osrd L.osrd cumdw1 if year > 1975 & year < 2009
```

Source	SS	df	MS	Number of obs = 33		
Model	.081211906	2	.040605953	F(2, 30)	=	36.88
Residual	.033030777	30	.001101026	Prob > F	=	0.0000
				R-squared	=	0.7109
				Adj R-squared	=	0.6916
Total	.114242683	32	.003570084	Root MSE	=	.03318

osrd	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
osrd						
L1.	.6577454	.1380212	4.77	0.000	.3758686	.9396222
cumdw1	6.76e-06	4.17e-06	1.62	0.116	-1.77e-06	.0000153
_cons	.2776773	.1101811	2.52	0.017	.0526575	.5026971

CHAPTER 6: ADDITION TO OIL AND GAS RESERVES

Addition to Oil and Gas Reserves

```
. regress gora tswd odum2h odum1 if year > 1974 & year < 2001
```

Source	SS	df	MS	Number of obs = 26		
Model	563993294	3	187997765	F(3, 22)	=	45.03
Residual	91850255	22	4175011.59	Prob > F	=	0.0000
				R-squared	=	0.8600
				Adj R-squared	=	0.8409
Total	655843549	25	26233742	Root MSE	=	2043.3

gora	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
tswd	18.85483	5.567608	3.39	0.003	7.308318	30.40134
odum2h	12445.21	1674.091	7.43	0.000	8973.361	15917.06
odum1	-9441.968	2087.472	-4.52	0.000	-13771.12	-5112.816
_cons	-1506.585	978.9519	-1.54	0.138	-3536.807	523.6367


```
. estat dwatson
```

Durbin-Watson d-statistic(4, 26) = 2.190175

Addition to Oil and Gas Reserves (Updated)

```
. regress gora tswd odum2h odum1 if year > 1974 & year < 2009
```

Source	SS	df	MS	Number of obs = 34		
Model	534172296	3	178057432	F(3, 30)	=	34.39
Residual	155311583	30	5177052.76	Prob > F	=	0.0000
				R-squared	=	0.7747
				Adj R-squared	=	0.7522
Total	689483879	33	20893450.9	Root MSE	=	2275.3

gora	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
tswd	-.2624929	2.155476	-0.12	0.904	-4.664563	4.139577


```
.
. dfuller opro if year > 1974 & year < 2001

Dickey-Fuller test for unit root                Number of obs   =           25

                ----- Interpolated Dickey-Fuller -----
                Test          1% Critical    5% Critical    10% Critical
                Statistic     Value         Value         Value
-----
Z(t)            -2.924         -3.750         -3.000         -2.630
-----
MacKinnon approximate p-value for Z(t) = 0.0426

.
. dfuller dopro if year > 1974 & year < 2001

Dickey-Fuller test for unit root                Number of obs   =           25

                ----- Interpolated Dickey-Fuller -----
                Test          1% Critical    5% Critical    10% Critical
                Statistic     Value         Value         Value
-----
Z(t)            -3.010         -3.750         -3.000         -2.630
-----
MacKinnon approximate p-value for Z(t) = 0.0340
```

Oil Production (updated)

```
. regress dopro dores1 L.dopro odum6 if year > 1974 & year < 2009

                Source |           SS           df           MS           Number of obs =           33
-----+-----
                Model | 65320.4925           3 21773.4975           F( 3, 29) =           9.56
                Residual | 66042.0667          29 2277.31265           Prob > F           =           0.0001
-----+-----
                Total | 131362.559          32 4105.07997           R-squared           =           0.4973
                                           Adj R-squared       =           0.4452
                                           Root MSE           =           47.721

                dopro |           Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-----+-----
                dores1 |   .0061328   .0022189     2.76  0.010   .0015947   .0106709
                dopro |
                L1. |   .3490679   .174777    2.00  0.055  -.0083911   .7065269
                odum6 |   64.27888  22.44347    2.86  0.008   18.37683  110.1809
                _cons |  -3.645902  10.28276   -0.35  0.725  -24.67651  17.38471
-----+-----
```

Dickey-Fuller tests (updated)

```
. dfuller ores if year > 1974 & year < 2009

Dickey-Fuller test for unit root                Number of obs   =           33

                ----- Interpolated Dickey-Fuller -----
                Test          1% Critical    5% Critical    10% Critical
                Statistic     Value         Value         Value
-----
Z(t)            -3.118         -3.696         -2.978         -2.620
-----
MacKinnon approximate p-value for Z(t) = 0.0252
```

```
.
. dfuller dores if year > 1974 & year < 2009

Dickey-Fuller test for unit root                Number of obs   =           33

                ----- Interpolated Dickey-Fuller -----
                Test          1% Critical    5% Critical    10% Critical
                Statistic      Value         Value         Value
-----
Z(t)            -3.218         -3.696         -2.978         -2.620
-----
MacKinnon approximate p-value for Z(t) = 0.0189

.
. dfuller opro if year > 1974 & year < 2009

Dickey-Fuller test for unit root                Number of obs   =           33

                ----- Interpolated Dickey-Fuller -----
                Test          1% Critical    5% Critical    10% Critical
                Statistic      Value         Value         Value
-----
Z(t)            -3.577         -3.696         -2.978         -2.620
-----
MacKinnon approximate p-value for Z(t) = 0.0062

.
. dfuller dopro if year > 1974 & year < 2009

Dickey-Fuller test for unit root                Number of obs   =           33

                ----- Interpolated Dickey-Fuller -----
                Test          1% Critical    5% Critical    10% Critical
                Statistic      Value         Value         Value
-----
Z(t)            -2.745         -3.696         -2.978         -2.620
-----
MacKinnon approximate p-value for Z(t) = 0.0665
```

SUSTAINABILITY EVALUATION USING ECONOMETRIC MODELS AND CORRELATIONS

OIL RESERVES AND NEGATIVE CORRELATION WITH DRILLING

- tswd: Total successful wells drilled
- ores: Total oil reserves

```
. corr ores tswd if year > 1992
(obs=16)

            |      ores      tswd
-----+-----
ores |      1.0000
tswd |     -0.9778      1.0000
```

OIL RESERVES AND NEGATIVE CORRELATION WITH EMPLOYEE COUNT

- peec: Production and exploration employee count
- ores: Total oil reserves

```
. corr ores peec if year > 1995
(obs=12)

      |      ores      peec
-----+-----
ores |      1.0000
peec |     -0.9906      1.0000
```

OPERATING COST RATE AND EMPLOYEE COUNT

- opercostrate: Marginal cost per barrel of oil
- peec: Production and exploration employee count

```
. regress opercostrate peec if year > 1995 & year < 2008, robust

Linear regression                               Number of obs =      12
                                                F( 1, 10) =      24.16
                                                Prob > F      =      0.0006
                                                R-squared     =      0.7366
                                                Root MSE     =      53.969

-----+-----
opercostrate |      Coef.      Robust      t      P>|t|      [95% Conf. Interval]
-----+-----
peec |      .0227993      .0046389      4.91      0.001      .0124631      .0331355
_cons |     -719.2521     193.9671     -3.71      0.004     -1151.438     -287.0664
```

OIL RESERVE MODEL

Statistical results from forecast using Crystal Ball:

- R-squared: 0.682
- Adjusted R-squared: 0.6504
- SSE: 1.34E+7
- F Statistic: 21.467
- F Probability: 9.31E-4
- Durbin-Watson: 0.712
- No. of Values: 12

A double exponential smoothing method was used to forecast the oil reserves from 2002-2008 with an Alpha of 0.402 and a Beta of 0.895.

OIL PRODUCTION MODEL

Statistical results from forecast using Crystal Ball:

- R-squared: 0.450
- Adjusted R-squared: 0.3815
- SSE: 21195
- F Statistic: 6.5508
- F Probability: 0.03368
- Durbin-Watson: 1.095
- No. of Values: 10

A double exponential smoothing method was used to forecast the oil reserves from 2000-2008 with an Alpha of 0.999 and a Beta of 0.007.

COST-BENEFIT ANALYSIS OF DRILLING EXPANSION

MODEL FOR TOTAL SALES

Statistical results for forecast using Crystal Ball:

- R-squared: 0.826
- Adjusted R-squared: 0.7759
- SSE: 1.73E+10
- F Statistic: 16.583
- F Probability: 0.002210
- Durbin-Watson: 2.437
- No. of Values: 10

A double exponential smoothing method was used to forecast the oil reserves from 2000-2008 with an Alpha of 0.999 and a Beta of 0.941.

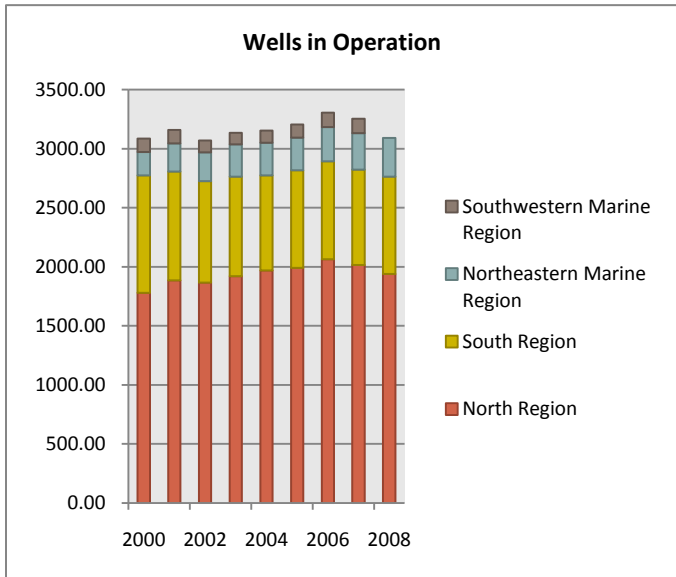
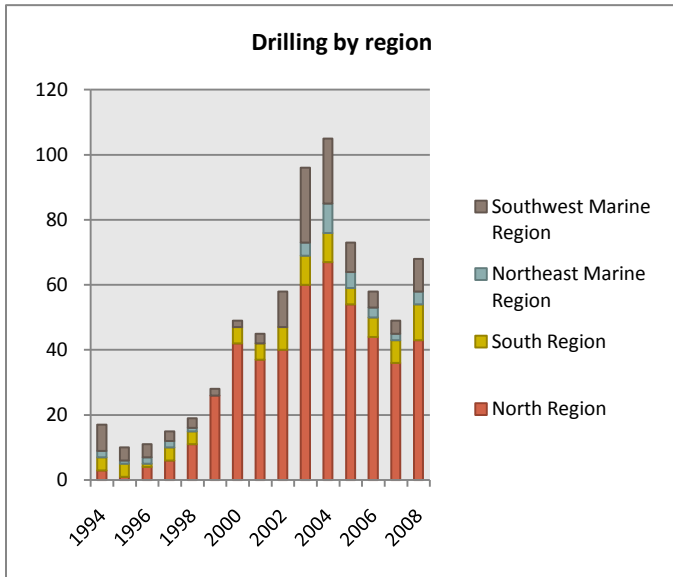
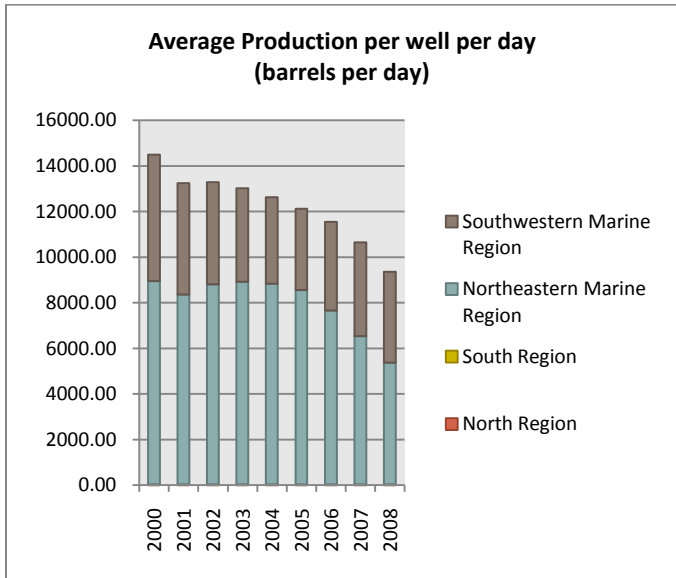
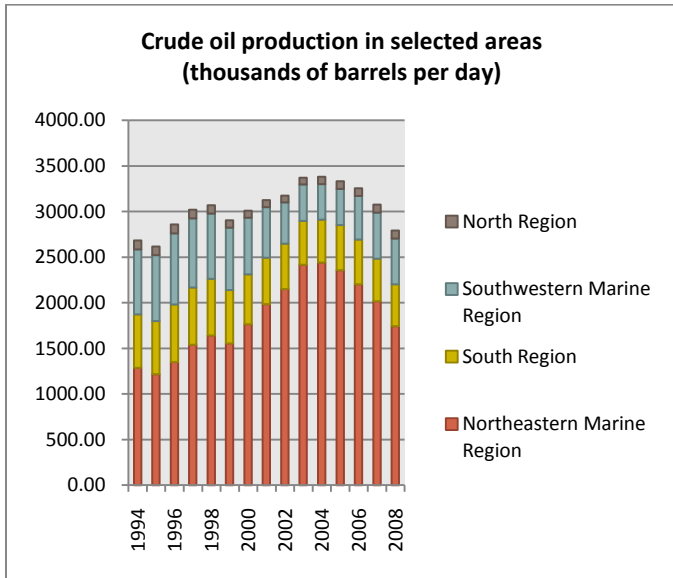
MODEL FOR OPERATING COSTS

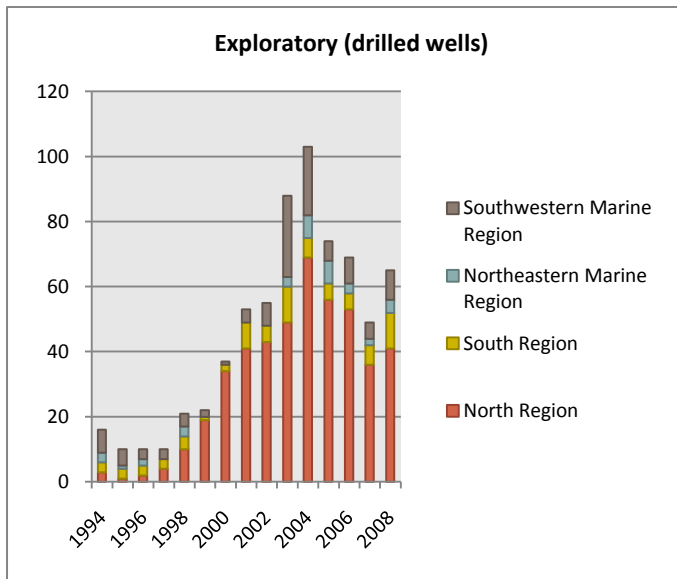
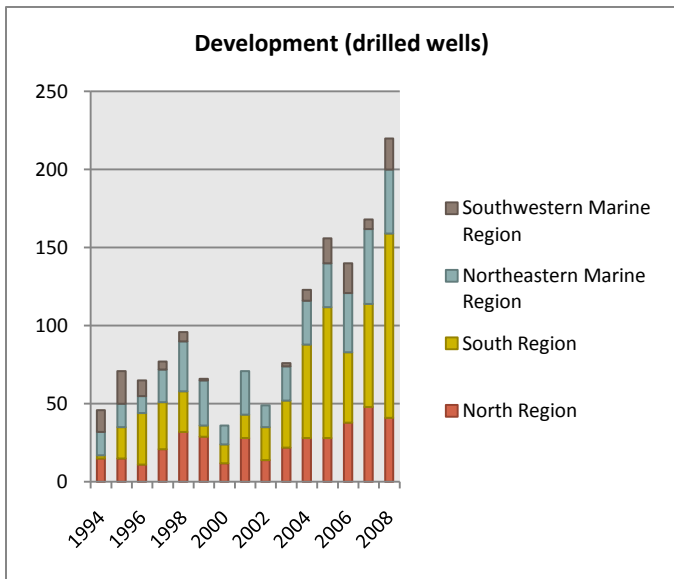
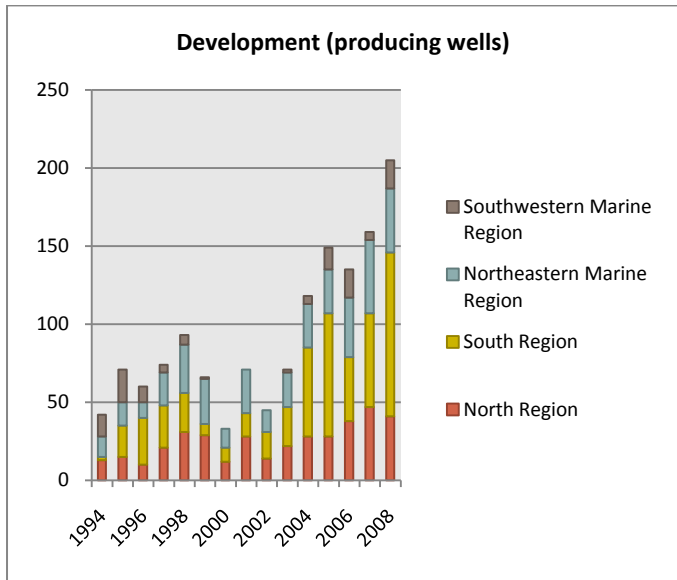
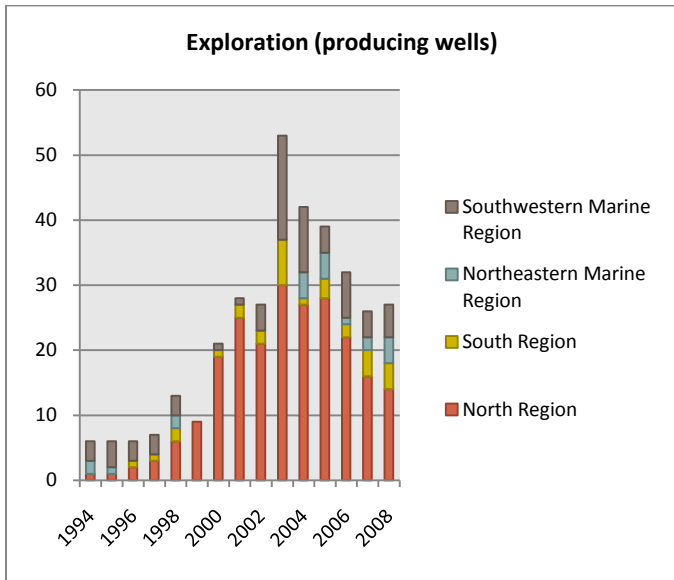
Statistical results from forecast using Crystal Ball:

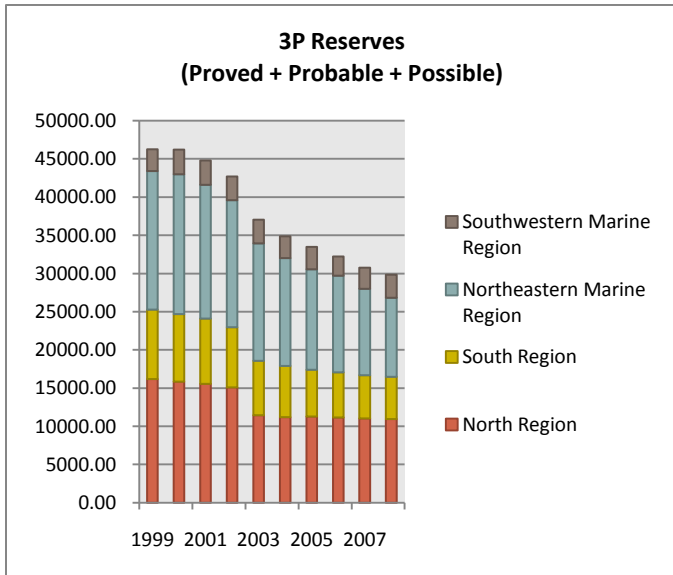
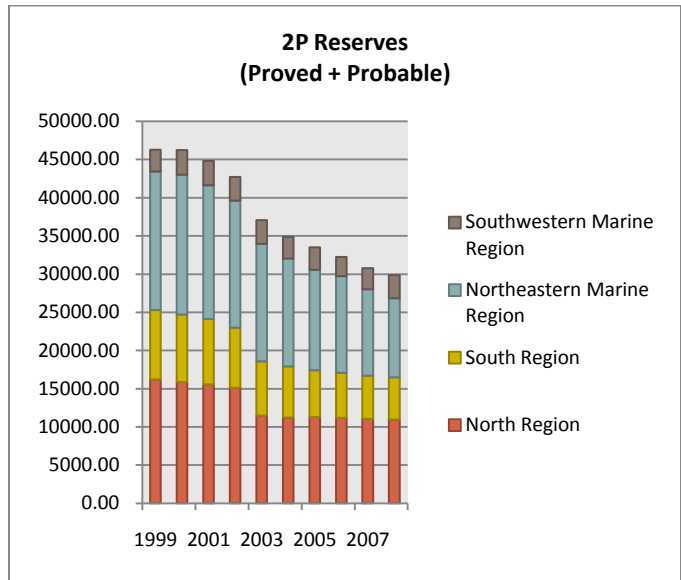
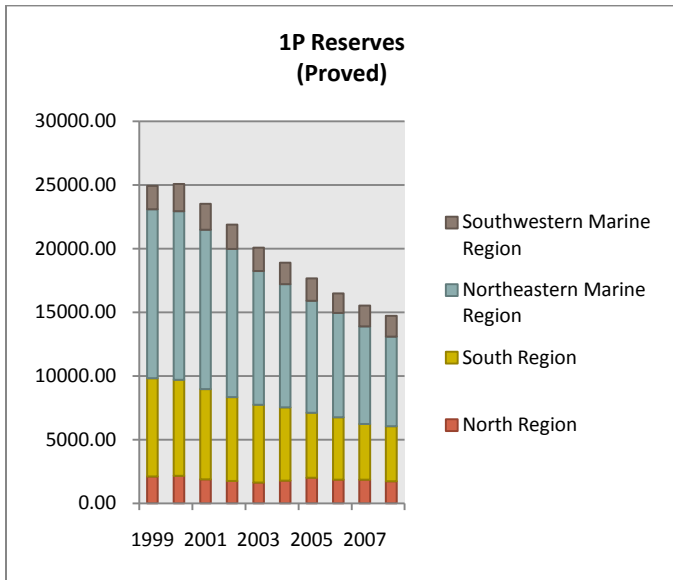
- R-squared: 0.673
- Adjusted R-squared: 0.5797
- SSE: 3.09x10⁹
- F Statistic: 7.2058
- F Probability: 0.01998
- Durbin-Watson: 2.633
- No. of Values: 10

A double exponential smoothing method was used to forecast the oil reserves from 2000-2008 with an Alpha of 0.999 and a Beta of 0.941.

APPENDIX B: REGIONAL DATA







GLOSSARY

PIDIREGAS: The investment in long-term productive infrastructure projects (“PIDIREGAS”) and related liabilities are initially recorded in accordance with NG-09-B, applicable to Entidades Paraestatales de la Administración Pública Federal (“State-owned Entities of the Federal Public Administration”), which requires recording only those liabilities maturing in less than two years (PEMEX, 2008, p. 41). Mexico eliminated this program in 2008.

probable reserves (2P): Estimated amount of hydrocarbons at a specific date, in perforated and not perforated formations, defined by geological and geophysical methods, located in adjacent areas to producing deposits where it is considered that probabilities exist of obtaining technical and economically production of hydrocarbons, at the same stratigraphic level where proven reserves exist (PEMEX, 2004-2008).

proved reserves (1P): Volume of hydrocarbons measured at atmospheric conditions that can be yielded economically with the methods and applicable exploitation systems in the moment of the evaluation, as much primary as secondary (PEMEX, 2004-2008).

possible reserves (3P): Estimated amount of hydrocarbons at a specific date in not perforated formations, defined by geological and geophysical methods, located in areas far from producing fields, but inside the same producing geological province, with possibilities of obtaining technical and economically production of hydrocarbons, at the same stratigraphic level where proven reserves exist (PEMEX, 2004-2008).

Stabilization Fund for Oil Income Investment (FEIIP): This fund is available to help smooth the government's adjustment to fluctuations in world oil prices.

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