ON EFFICIENT UTILIZATION OF EGYPT'S ENERGY RESOURCES: OIL AND GAS

Tarek H. Selim

Working Paper No. 117
December 2006

The author would like to thank Professor Hanaa Kheir-El-Din and Dr. Omneia Helmy for help and encouragement during the time spent in writing this research. Thanks also go to Professor Robert Mabro and Dr. John Salevurakis. In this paper, research assistance was provided by Mr. Amr Al Garhi, MA in Economics, the American University in Cairo. Additional research assistance was provided by Homa Azargoshasb, Abdula Mutualo, and Loubna Olama, MA Candidates in Economics, the American University in Cairo. The author would like to thank them all for valuable assistance.

1. INTRODUCTION

Energy is a prime source of livelihood for many nations and is a cause of affluence for others. In Egypt, energy constitutes one fifth of the country's overall economic activity, a little less than half of the country's export revenues, and is a strategic resource for future growth. Yet, Egypt's energy reserves are quickly depletable, with a risk of over-consumption, production is aging as far as oil is concerned, and at the same time energy reserves are rather new with respect to natural gas. Hence, there are future tradeoffs between oil and natural gas in the Egyptian economy. Specifically, oil and gas should be considered as demand substitutes in addition to possessing future complementary roles in energy supply.

The strategic importance of the energy sector to the Egyptian economy is seen by observing the country's other sources of comparative advantage: (1) cotton, (2) tourism, and (3) the Suez Canal. Exports of cotton have been declining rapidly in the past couple of decades because of more effective world demand for substitutable products to Egyptian long-staple cotton fabrics. In addition, tourism is vulnerable to domestic and external shocks of the Middle East, and the Suez Canal is managed as a fixed income generator of government revenue. Thus, energy is the leading strategic resource on which the Egyptian economy can depend toward a path of sustainable development.

Such a positive statement does not come without reservations. Notably, with the continuing decline in Egyptian crude oil production, Egypt’s hydrocarbon future lies in natural gas. In particular, the country’s gas reserves have increased so substantially over the last decade that it is now feasible to start exporting large volumes of gas as well as catering to growth in domestic demand in the coming decade. Most recent figures estimate Egypt's natural gas reserves, ranked 14^{th} worldwide, at 66 trillion cubic feet (tcf) of proven reserves and up to 140 tcf of probable reserves. However, the recent price hikes in crude oil present an opportunity cost for the economy in terms of hard currency exports. A policy maker is thus faced with the challenge of having to answer the important question of: "What should Egypt do with its energy reserves?" Should the Egyptian economy export a sizeable portion of natural gas and leave oil for domestic consumption, even though such consumption is subsidized and creates a strain on the national budget? Or should Egypt predominantly export its scarce oil resources, leaving domestic consumption to abundant natural gas reserves, even though there are switching costs involved? In either situation, there is an opportunity cost. The first situation creates lost opportunities in terms of oil exports at high prices, coupled with domestic over-consumption at subsidized prices. The second situation creates an opportunity cost of natural gas exports and over-depletion of a strategic resource.

This research will tackle the topic of energy policy in Egypt on several fronts. Analysis of the world energy market (section 2) with reasonable estimates of future prices for oil and natural gas will be conducted, such that the "most likely" scenario from the US Department of Energy's Information Administration database will be utilized (Energy Information Administration 2006). This will be followed by analysis of the energy sector in Egypt including historical production, consumption, and net exports of energy resources (section 3). In addition, the research will tackle when and to what extent Egypt will turn into a net importer of oil, and analyze the trend of such behavior. Derivation of a time path for natural gas resource depletion, based upon proven reserves, and a forecasted timeline of natural gas consumption until 2025 will be conducted. This will be based upon comparative elasticity analysis (section 4) between oil and natural gas including the calculation of price elasticity, income elasticity, and energy/GDP elasticity for both resources, and the calculation of the elasticity of substitution between oil and natural gas. The analysis will also include an energy sustainability constraint (application of Hartwick's model) on resource extraction rates, with the objective of guaranteeing future expected energy demand, conditional upon GDP growth rate targets, which guarantee sustainable development (section 4). Energy sustainability analysis will incorporate alternative energy use including solar and nuclear energy. Policy recommendations will conclude the research (section 5).

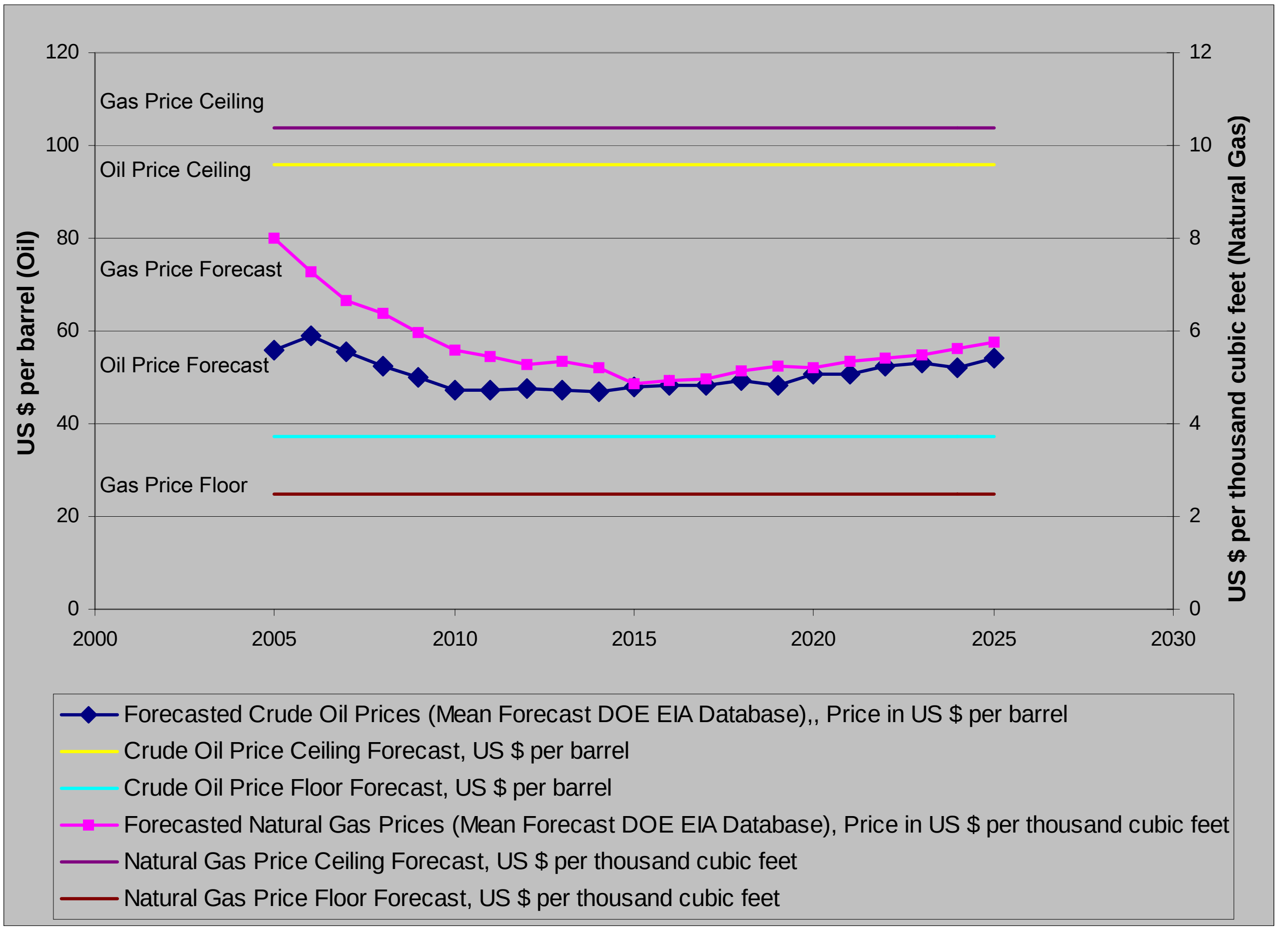
2. The World Energy Market and Future Projections Until 2025

Energy is considered a causal input to economic development, and the performance of the world energy market has a large effect on the quality of life of current and future generations. At the world energy market level, oil and natural gas have very different characteristics. The oil market involves a cartel (OPEC) and has a non-differentiated price element across geographic regions, whereas the natural gas market contains a price advantage within regions, less thermal efficiency, and cleaner emissions than oil. The main future energy challenges are to increase world energy security and to minimize the environmental impact of energy use, especially carbon emissions. Although it is forecasted that world energy demand will increase, due to increasing demand by key developing countries like China and India, it is also expected that world energy supply will expand and overcome such demand. This scenario has been the main drive for forecasted future energy prices by the US Department of Energy, Energy Information Administration in its Energy Modeling System and Forecast Database (World Energy Outlook 2006).

Although prices play a key role in the choice between different sources of energy, oil products are not easily displaced in certain types of use (mainly in transportation). Crude oil behaves much like any other commodity with wide price swings in times of shortage or oversupply. Its prices are driven by supply (mainly OPEC) rather than demand . However, natural gas prices are predominantly demand-driven, and the fundamental drivers are weather, season, and inventory levels. The price of natural gas varies widely between separate regional markets. It tends to settle lower than its oil equivalent, although there are circumstances, such as in East Asian markets, where delivered prices are typically higher than their oil equivalent. Comparing oil with gas reflects the fact that oil deposits tend to be in areas that are not major consumers of oil, but for natural gas the production and consumption regional match is much better. The effect of transportation costs is strongest in the case of natural gas, with crude oil being generally moved via a pipeline because it is the cheapest mode. The thermal efficiency of oil is superior to that of gas as 1 cubic meter of oil has the same energy content as 1,000 cubic meters of natural gas, yet natural gas produces less carbon emissions than oil, and is therefore more environmentally friendly.

Most experts believe that there will be no shortage of international oil and gas reserves over the next few decades, provided sufficient investment is made into new production, transport and refinery capacity. Maintaining robust and transparent international markets for energy, including the free movement of capital, is a key policy objective. But many reserves lie in parts of the world ridden with political instability, or where other barriers to investment exist. This, however, is not considered to be a major impediment to energy supply so long as Middle Eastern political tensions are contained and no new wars break out. Moreover, in terms of oil, non-OPEC production is expected to expand rapidly creating oversupply at future oil prices. For natural gas, reserves are expected to be excessively utilized (or even depleted), especially the abundant natural gas deposits in the former Soviet Union bloc, such as Russia and Ukraine.

Figure 1. World Energy Market Forecasted Price Paths for Oil and Gas Until 2025



Source: Author's Calculations based on World Energy Outlook (2006) and Energy Information Administration (2006).

As seen from figure 1, world energy prices are expected to decrease over time until 2015, due to expanding world supply, expected reserve concessions, and lower growth in China's energy demand. However, analysts predict that oil prices will witness large swings in the future, with an average price of $52 per barrel, with a price floor of $37 per barrel and a ceiling as high as $96 per barrel over the time period of 2005-2025. Thus, oil prices are expected to have a large variance over time, but the average price is expected to be close to the 2004 standards. The assumptions here are that the political turbulence in Iraq will ease with time, the nuclear crisis in Iran will be solved by diplomatic means, and that energy prices will stabilize beyond the Bush Administration in the United States. However, if the current problems in the Middle East intensify, particularly the threat of Iran halting its energy exports to the West, oil prices can reach as high as $96 per barrel. The situation with natural gas is considerably different. Russia and Ukraine, in addition to Qatar and Iran, hold the largest natural gas reserves, with Russian reserves estimated at more than 1,400 tcf at a bare minimum. These world reserves are predominantly unutilized creating relative resource abundance. The average price for natural gas per thousand cubic feet, for the time period 2005-2025, is $5.67 for the Middle East region. The lowest estimate stands at $4.87 and the highest at $6.66 for the Middle East and North Africa region, although price variations are much higher for other regions (see figure 1 for weighted average world price variations for natural gas).[1] Hence, price variation in the Middle East for natural gas is estimated at 15 percent. This runs counter to future expectations of international oil prices, with upper price variation reaching 80 percent and a lower price variation of 27 percent (see figure 1).

An important element of comparison between oil and natural gas in the international energy market is price. Oil prices behave with wide price swings in times of shortage or oversupply, but those price swings are expected to be short in duration (peak or trough phases) in the future time period until 2025. Even though oil prices are predominantly supply-driven, natural gas prices, in contrast, are predominantly demand-driven and vary by region due to pipeline transportation costs. In addition, the expected profit margin for oil through 2025 is 70 percent on average, since the cost of oil production is expected to decrease due to process innovation reaching as low as $3-$7 per barrel (the lower end attributed to Arabian Gulf producers). In contrast, the expected profit margin for natural gas through 2025 is 20 percent, which makes economies of scale in natural gas production more necessary than oil. This runs in line with substantial increases in natural gas production in the future.

[1]The price of natural gas is regional. In the Middle East, the price range is $4.87 to $6.66 per thousand cubic feet. Figure 1 shows the weighted average of international natural gas prices including regions outside the Middle East.

Table 1. World Energy Market for Oil and Natural Gas: Projections Until 2025

	World Oil Market	*Natural Gas Market*
Pricing	$57 mean price (US $ per barrel). Large price swings until 2025: $37 price floor, $96 price ceiling. High end price variation at 80 percent, lower end price variation at 27 percent.	Stable regional prices at $5.7 with $0.8 as standard deviation through 2025 (US $ per thousand cubic feet). Maximum price swings (variation) at 15 percent for Middle East/North Africa region.
Elasticities	Oil is more price inelastic than natural gas, but carries higher income elasticity.	Natural gas has lower income elasticity, but is more price elastic than oil.
Profit margins	There is a uniform world oil price (non-differentiated on a regional level), and profit margin is expected at 70 percent due to cost-reducing process innovations, with least cost estimate at $3 per barrel (Arabian Gulf producers).	Differentiated prices by region, with profit margins expected at 20 percent requiring economies of scale.
Consumption	1.9 percent annual growth rate to 2025. Consumption end use predominantly in transportation with declining power generation demand for oil.	2.2 percent annual growth rate to 2025. Consumption end use in residential, commercial and power generation.
Reserves	1,293 billion barrels (Jan. 2006). Modest expectations of additional reserves.	6,112 trillion cubic feet (Jan 2006). High expectations of probable reserves.
Production	OPEC remaining a key player with declining dominance. Production capacity reaching maturity in 2015 and remaining stable to 2025. Reserves to production ratio of 115 years (Arabian Gulf region)	No OPEC (cartel) equivalent expected. Net production surplus of 16 trillion cubic feet by 2025 in developing countries.
Thermal efficiency	Oil is more thermally efficient than gas. 1 cubic meter of oil has the same energy content as 1,000 cubic meters of natural gas	Gas is less thermally efficient but is a cleaner fuel.
Kyoto Protocol	Kyoto Protocol carbon emissions reduction standards will affect oil market negatively more than gas.	Kyoto Protocol standards will lead to expansion of natural gas market.
Transportation cost	Alternatives to oil pipeline transportation exist, but pipeline is expected to remain the cheapest mode.	There is no expected alternative to pipeline for natural gas transportation except LNG (Liquefied Natural Gas).

Source: Author's comparison analysis based on data from World Energy Outlook (2006), Energy Information Administration (2006), and Clarkson and Deyes (2002).

3. EGYPT'S ENERGY SECTOR: HISTORICAL TRENDS

During the past several years, production of petroleum products constituted around 8 percent of GDP, and was the largest single industrial activity. The export of crude oil and petroleum products constituted 40 percent of Egypt's export returns and around 20 percent of its GDP.[2] By the start of 2006, Egypt's proven oil reserves have been maintained officially at 3.7 billion barrels with no substantial increase in the past decade. However, export of oil is rapidly declining and Egypt is expected to be a net importer of oil in the short run. Natural gas, on the other hand, is abundant with reserves estimated at 66 trillion cubic feet.

The natural gas sector is one of the fastest growing sectors in the Egyptian economy and production increased more than two-fold between 1999 and 2003[3] and almost 1000-fold over the last 20 years by 2005 standards. It is worth mentioning that the substantial increase in the production of natural gas helped to offset some of the negative repercussions of the reduction of crude oil production. The average daily production of natural gas during 2004 was 3.6 billion cubic feet per day (bcf/d).[4] Total gas consumption increased dramatically when thermal power plants were ordered to convert from oil to gas. This was a pivotal and strategic decision made in Egypt's energy policy history. These plants now constitute around 65 percent of total gas consumption.[5] In 2001/2002, Egypt ranked third in worldwide natural gas consumption, with a daily consumption of 2.6 billion cubic feet (bcf).[6] Around 84 percent of Egypt's electric generating capacity is thermal (natural gas), with the remaining 16 percent hydroelectric from the Aswan High Dam. The government has converted all oil-fired plants to run on natural gas as their primary fuel.[7]

Historically, the rate of growth of oil production steadily exceeded that of oil consumption. However, this trend has shifted. With oil production continuously declining and oil consumption increasing due to population growth, oil exports have seen a steep decline. Egypt is thus expected

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[2] Energy Information Administration, *Country Analysis briefs: Egypt*. U.S. Department of Energy, May 2006: www.eia.gov/emeu/cabs/egypenv.html.
[3] Ibid.
[4] Ibid.
[5] Energy Information Administration (2006).
[6] World Energy Council (2002)
[7] Ibid.

to be a net oil importer in the near future. In addition, Egypt is faced with a trade-off between exporting crude oil and exporting refined oil products. On one hand, if Egypt wants to maintain being a crude oil exporter then it would have to decrease the throughput to refineries and hence decrease its refined oil export revenues. The significance of the petrochemicals industry is further accentuated by the fact that natural gas is one of its primary inputs. On the other hand, Egypt's natural gas reserves provide an excellent potential advantage for the production of petrochemicals. Unfortunately, production of petrochemical products only covers a third of domestic demand. This should encourage the government to develop this sector in a bid to improve its deficit situation. Furthermore, petrochemicals are strategic intermediate inputs to many industries, and strengthening that sector would boost Egypt's industrial base and ensure a sustained raw material supply chain (AmCham 2003, P.34). The Egyptian government undertook a long term investment plan to the tune of $10 billion in order to develop the petrochemical industry by the year 2021. The plan is envisaged to take full advantage of Egypt's gas reserves to maximize value added benefits. A by-product of this ambitious plan is the import substitution of the current $3 billion bill that Egypt foots to cover its petrochemical imports.[8]

Oil Reserves

Egypt’s proven oil reserves were estimated at 3.6 billion barrels on average from 1996 to 1999. In January 2000, the government released a revised estimate of probable crude oil reserves, raising the figure to 8.2 billion barrels, based on new finds and increased recovery ratios. Even though the proven crude oil reserves declined and stood at 2.9 billion barrels from 2000 till 2002 (AmCham 2003, p.12), as of 1 January 2006 Egypt’s proven crude oil reserves were estimated at the amount of 3.7 billion barrels (APRC 2003, p.94).

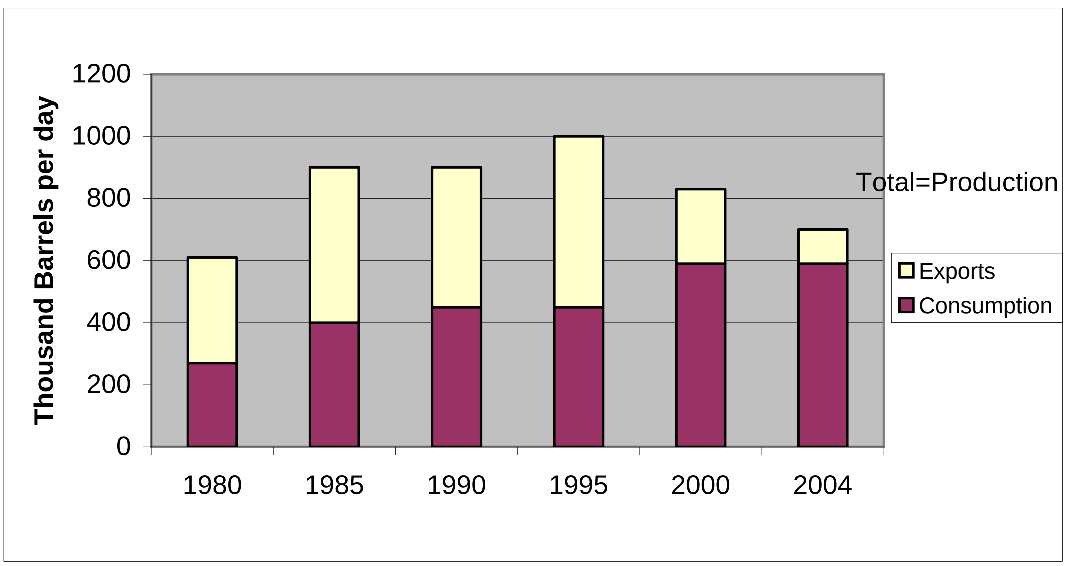
Oil Production and Consumption

Egyptian oil production in 2003 averaged 618,000 barrels per day (bpd), down sharply from a peak in 1996 of 922,000 bpd (AmCham 2003, p12; Energy Information Administration 2006). In contrast, domestic demand for oil has been climbing from 501,000 bpd in 1996 to 566,000 bpd in 2003. The sharp increase in local oil consumption over the past decade can be attributed to two

[8] Middle East Economic Digest, Egypt: Petrochemicals, January 2003.

factors: (1) economic growth in the late 1990s contributed to higher demand for oil and (2) oil subsidies encouraged over-consumption. The prices of most types of fuel have not moved substantially for the past decade, except due to the recent partial lifting of oil subsidies. This policy, even after partial subsidy removal, has encouraged over-consumption. Increased exploration, particularly in new areas, may lead to new discoveries raising production above the 800,000 bpd level. Figure 2 shows the trend of oil production, consumption and exports in Egypt from 1980 until 2004. By breaking down the country's total production into consumption and exports, it is seen that during the last twenty years (1985-2004) Egypt had squeezed its export revenues by over-consumption.

Figure 2. Egypt's Oil Production (Broken down into Exports and Domestic Consumption)

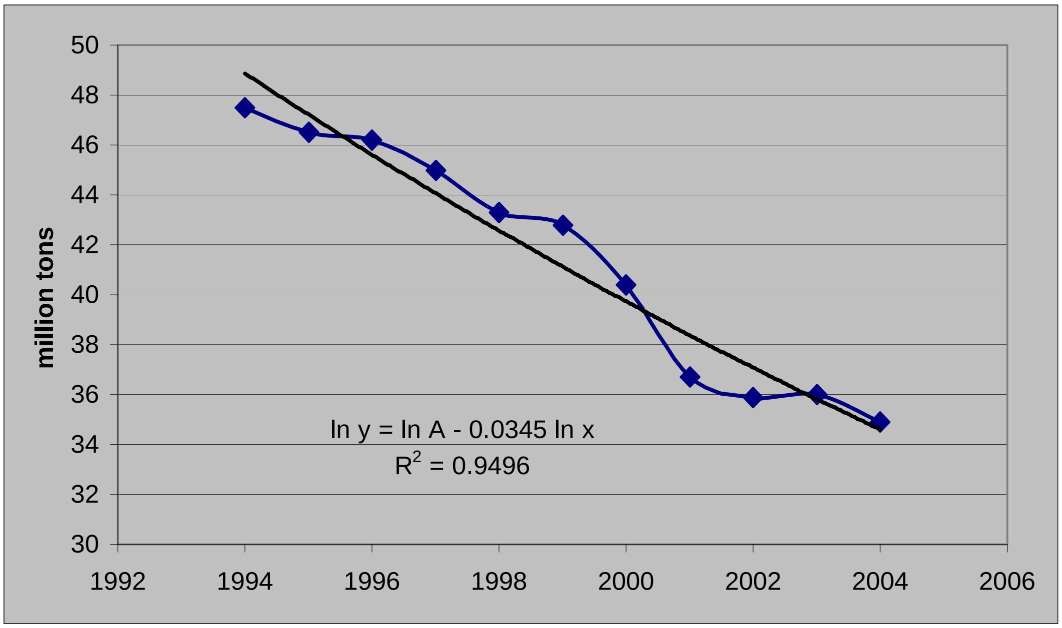


Source: AmCham (2003) and Energy Information Administration (2006)

Moreover, despite the buoyant export activity and the large number of discoveries made each year, which are brought into production as rapidly as possible, there seems little prospect for Egypt to reverse the decline in its crude oil production in the future (see figure 3). Not only is oil production steadily decreasing due to X-inefficiency in production, but proven oil reserves have leveled off, putting a double squeeze on the amount of oil available for export. Some analysts suggest that Egypt could cease to be a net oil exporter sometime between 2007 and 2010 (APRC

2003, p.94). As will be analyzed later, the author estimates that net imports of oil will become a fact in the short run for Egypt, as early as 2007/2008.

Figure 3: Trend of Egypt's Oil Production: 1992-2004



Source: IDSC 2006, Government of Egypt, with declining trend line estimated by the author.

Oil Areas of Production

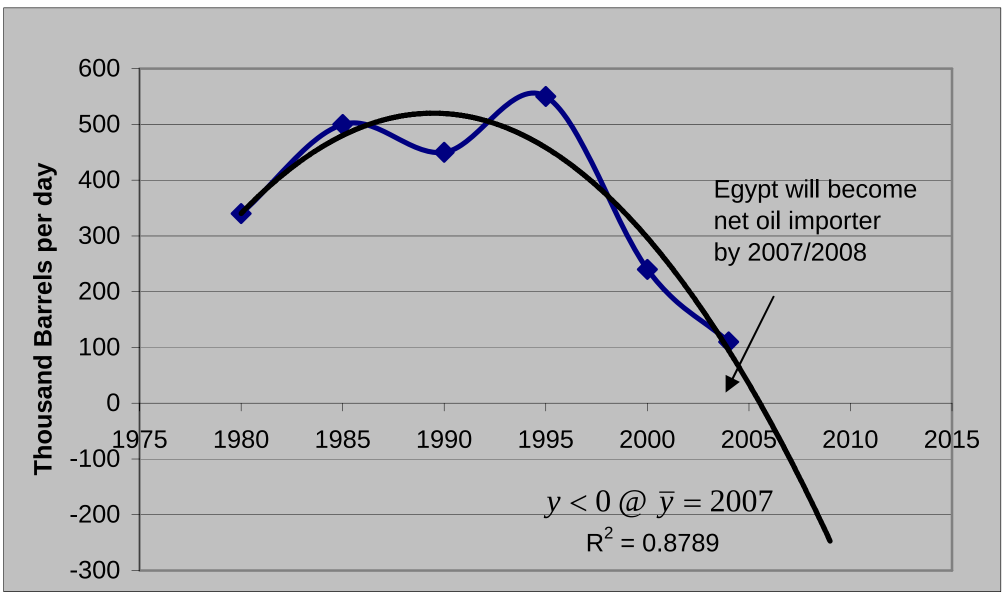
The Gulf of Suez remains by far the biggest producing region in Egypt, accounting for about 70 percent of total oil production, although its share is falling. The second biggest oil-producing region is the Western Desert, which accounts for 17 percent. Egypt also draws oil from the Sinai Peninsula (7 percent) and the Eastern Desert (6 percent) (APRC 2003, p.94; OFE 2001).

Oil Exports

Egypt has little crude oil left for export, since its domestic refining industry requires nearly 700,000 bpd of feedstock. The Egyptian General Petroleum Corporation (EGPC) is still able to export a small volume of crude, but its exports of refined products are now greater in volume as well as in value. Egypt was a net oil exporter of around 100,000 bpd in 2004 (AmCham 2003, p.19; Energy Information Administration 2006). Net exports sharply decreased since 1995 from

560,000 bpd. Recent estimates put Egypt's oil production, consumption, and exports at 700,000 bpd, 590,000 bpd and 110,000 bpd, respectively. The trend of Egypt's oil exports is seen in figure 4. The author uses a combination of moving averages and non-linear forecast to estimate the expected future trend of oil exports using historical data ($R^2 = 87.89\%$). The main assumption utilized is constant income elasticity of demand based on historical averages (1980-2005), constant population growth rate and a targeted increase in average income (GDP per capita) of 6 percent annually. This scenario is seen as the most reasonable with the information currently available.[9] Conditional on those assumptions, the author estimates that Egypt will become a net importer of oil as early as 2007/2008.

Figure 4. Historical Trend of Egypt's Oil Exports since 1980



Source: IDSC data with trend estimated by author.

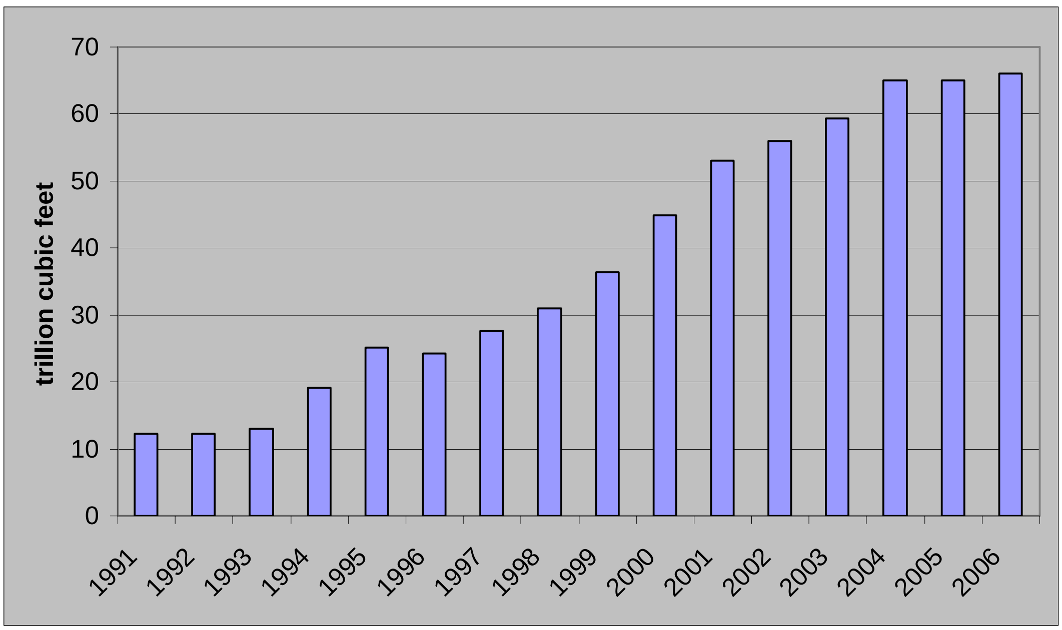
Natural Gas Reserves

Natural gas is destined to become more and more important to the future of Egypt because of major recent discoveries making it an abundant resource. There are vast reserves of natural gas

[9] Income elasticity of demand is calculated to be the prime determinant of effective quantity demanded for oil at a historical GDP/demand elasticity of 0.3, such that future oil exports is the residual of production, after accounting for needed domestic consumption per capita. This is reinforced by a completely inelastic price elasticity of oil demand at 0.02. Hence, the core assumption here is that quantity demanded is a main function of population and future income levels but not predominantly based on future prices.

with a strong potential for more discoveries. Beginning in the early 1990s, foreign oil companies began more attractive exploration for natural gas in Egypt, and very quickly found a series of significant natural gas deposits especially in the Western Desert, the Nile Delta, and under the Mediterranean Sea. Proven reserves stand at 66 trillion cubic feet (tcf) in 2006, a little more than the 65 tcf in 2004, up from 55 tcf in 2002, and significantly up from 40 tcf in 2000, with probable reserves estimated at 120-140 tcf as a lower bound range. Major discoveries between 1997 and 2001 in the Nile Delta and the Western Desert doubled Egypt's proven reserves. Figure 5 shows the increase in Egypt's natural gas proven reserves over time.

Figure 5. Historical Proven Natural Gas Reserves in Egypt



Source: APRC (2003); IDSC (2006): and AmCham (2003).

Natural Gas Production and Consumption

Egypt's natural gas sector has been expanding rapidly, and production nearly doubled in the last six years. Production in 2005 stood at more than 3 billion cubic feet per day (bcf/d) from 1.6 bcf/d in 1999, and is expected to reach 7 bcf/d in 2006. Output from the Abu Madi and Badreddin fields account for more than half of the country's production. In the past, consumption has been almost identical to production—at 98.5 percent of production capacity in the last 15 years. Thermal power plants account for about 65 percent of Egypt's total gas consumption. Large industrial consumers have also been switching to gas, including petrochemical plants, a large new fertilizer plant in Suez, and several major new steel projects in Alexandria, Suez, and south of Aswan. Some 20,000 taxis in Cairo have been modified to run on Compressed Natural Gas (CNG) as part of a pilot program. British Gas heads a group that includes Orascom (an Egyptian construction firm), and Edison International SpA that intends to invest $220 million in a distribution network to serve Upper Egypt down to Assiut, an area with no existing gas service. The network may be expanded as far south as Aswan.

4. EGYPT'S ENERGY SECTOR: SUSTAINABILITY ANALYSIS AND FORECAST

Hartwick's energy sustainability model (Hartwick 1977; Hanley, Shogren and White 1997; and Cairns and Yang 2000) provides an optimal allocation solution to energy resources based on sustainable development constraints. Hartwick's model (usually referred to in the literature as 'Hartwick's Rule') is a dynamic model relating efficient extraction rates to total energy reserves and the forecasted rate of sustainable consumption. Hartwick's Rule, as an application to the model, implies that efficient utilization of energy resources will deliver optimum resources extraction rates, such that current welfare is maximized without compromising the ability of future generations to maximize their own welfare. Consumer welfare, in Hartwick's model, depends entirely on consumption. Production rates are derived from the path of sustainable consumption.

Based on Hartwick's methodology, different economic sensitivity analyses have been conducted on oil and natural gas in this research. Those are based on the assumptions of historical population growth rates, future growth in domestic demand (demand-driven market analysis), and estimated elasticity over time. Dynamic optimization analysis is conducted to reach the rate of resource depletion based on annual resource extraction rates (annual efficient production levels).

For price elasticities, it was found that demand price elasticity for oil is 0.02, while it was found to be 0.26 for natural gas. Hence, oil is almost completely price inelastic, whereas natural gas is generally price inelastic. Thus, for the case of oil, prices are not a key factor in the pattern of domestic consumption over time. Since both oil and natural gas are price inelastic, both are considered necessary goods in consumption. Oil is considered almost completely price inelastic (it is very difficult to be substituted) due to its importance as a necessary input in most of Egyptian industries. Hence, there exists a "resistance to change" on the part of consumers for a significant price increase in oil. In essence, lifting oil subsidies will not generate a sizeable reduction in consumption. Even for natural gas, if price increases by a significant 20 percent, domestic consumption will decline by only 5 percent.[10]

With respect to income elasticity, it was found that income elasticity for oil is 0.43 whereas that of natural gas is 1.4. Consequently, relative to income levels and associated budget expenditures of households, oil is a necessary good whereas natural gas is a normal good. A rise in income is associated with more demand increase for natural gas than that of oil. Based on elasticity estimates, it is calculated that social losses (additional economic burdens) per Egyptian household from totally lifting oil subsidies will be LE 110 per month/household (by 2005 standards). This is a substantial portion of a typical citizen's annual average income. Hence, the removal of oil subsidies should be undertaken in phases. In addition, the expected inflationary pressure from lifting oil subsidies is derived. It is estimated that total elimination of oil subsidies will cause an additional 5 to 7 percentage points of inflationary pressure on the Egyptian economy. This is based on multiplier effects of higher commodity prices for most essential goods due to higher input costs and higher transportation costs across the supply chain. Consequently, the political economy and real sector adjustments to this inflationary pressure must be accounted for within a strategy of gradual removal of oil subsidies.

The relationship between oil and natural gas to value of GDP was also estimated. It is found that sensitivity of oil/GDP is 0.3 whereas that of natural gas is 0.9. The weighted average of energy elasticity to GDP is 0.5. Consequently, the decomposition of energy to GDP yields an oil impact share of 67 percent and a natural gas impact share of 33 percent.[11] This has important repercussions on target GDP growth rates. In essence, a target GDP growth rate of 6 percent will necessitate energy demand growth at 1.8 percent annually for oil.

[10] Price elasticities are based on real prices (indexed by consumer prices over time) from 1991.
[11] Energy/GDP impact of 0.5 is decomposed into the respective elasticities of oil and natural
$0.3\eta^{oil} + 0.9\eta^{gas} = \eta^{energy} = 0.5$.

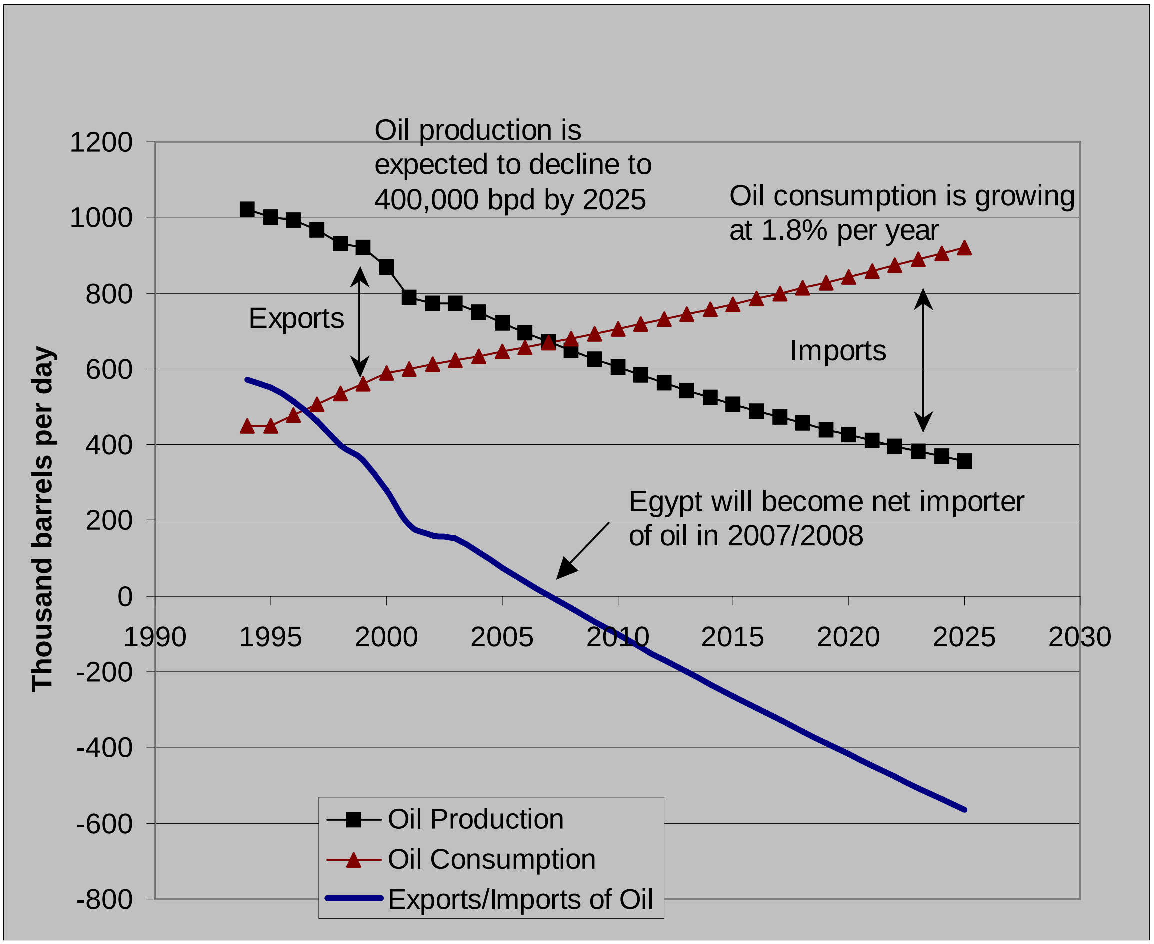
Table 2. Comparison and Elasticity Estimates for Oil and Natural Gas in Egypt

	Oil	*Natural Gas*
Reserves	A historical decline in reserves. Total proven reserves at 3.7 billion barrels.	New reserves with strong potential for more discoveries. Total proven reserves at 66 trillion cubic feet.
Production	A decrease in production due to subsidization, technical X-inefficiency reasons and decline in reserves. Historical 3.45 percent annual decline (12-yr horizon).	Production has doubled due to increase in reserves and increase in demand as a substitute for oil as it is environmentally friendly. Historical 12.2 percent annual growth (6-yr horizon).
Consumption	An increase in consumption due to economic growth.	An increase in domestic demand mainly due to thermal power plant conversion.
Price Elasticity	Demand price elasticity is 0.02 (completely inelastic).	Demand price elasticity is 0.26 (inelastic).
Cross Elasticity	Cross elasticity between oil and gas > zero, they are substitutes.	
Income Elasticity	Income elasticity is 0.43, which shows that it is a necessary good.	Income elasticity is 1.4 (normal good).
Areas of Production	70 percent from the Gulf of Suez, 16 percent from the Western Desert, 7 percent from the Sinai Peninsula and 6 percent from the Eastern Desert.	The Nile Delta, the Western Desert and under the Mediterranean Sea.
Main Players	EGPC (state-run), Gupco, Petrobel, Badr el-Din Petroleum Company, El Zaafarana Oil Company and Shell.	EGPC (state-run), IEOC, Eni-Agip, BP-Amoco, British Gas, Shell, Edison, International SpA and Repsol-YPF.
Transportation	Suez Canal and Sumed Pipelines.	Pipelines.
Exports	A decline in exports due to increase in local consumption accompanied by a decrease in production.	Beginning of exports in 2004/2005 looking for new opportunities after the increase in reserves.
Elasticity of Substitution	It was found that the elasticity of substitution between oil and gas in production is 3.4; while the elasticity of substitution in consumption is 4.06.	
Energy/GDP elast.	Oil/GDP elasticity is 0.3.	Natural Gas/GDP elasticity is 0.9.

Source: Author's calculations based on historical and forecast results. Assumptions include constant elasticity of substitution between oil and natural gas over time in consumption and production, constant target growth rate of 6 percent for GDP, and data analysis based on proven (not probable) reserves taken as the country's total energy resource endowments. Cross elasticity measure is estimated based on prices, whereas income elasticity measure is estimated based on the economy's per-capita GDP.

A forecasted oil production decline of 3.4 percent annually implies that Egypt's oil imports will average an increase of 5.2 percent annually. Consequently, it is projected that Egypt will become a net importer of oil by 2007/2008, with net oil shortages reaching 100,000 bpd in 2008, 300,000 bpd in 2015, and as high as 600,000 bpd in 2025 (see figure 6).

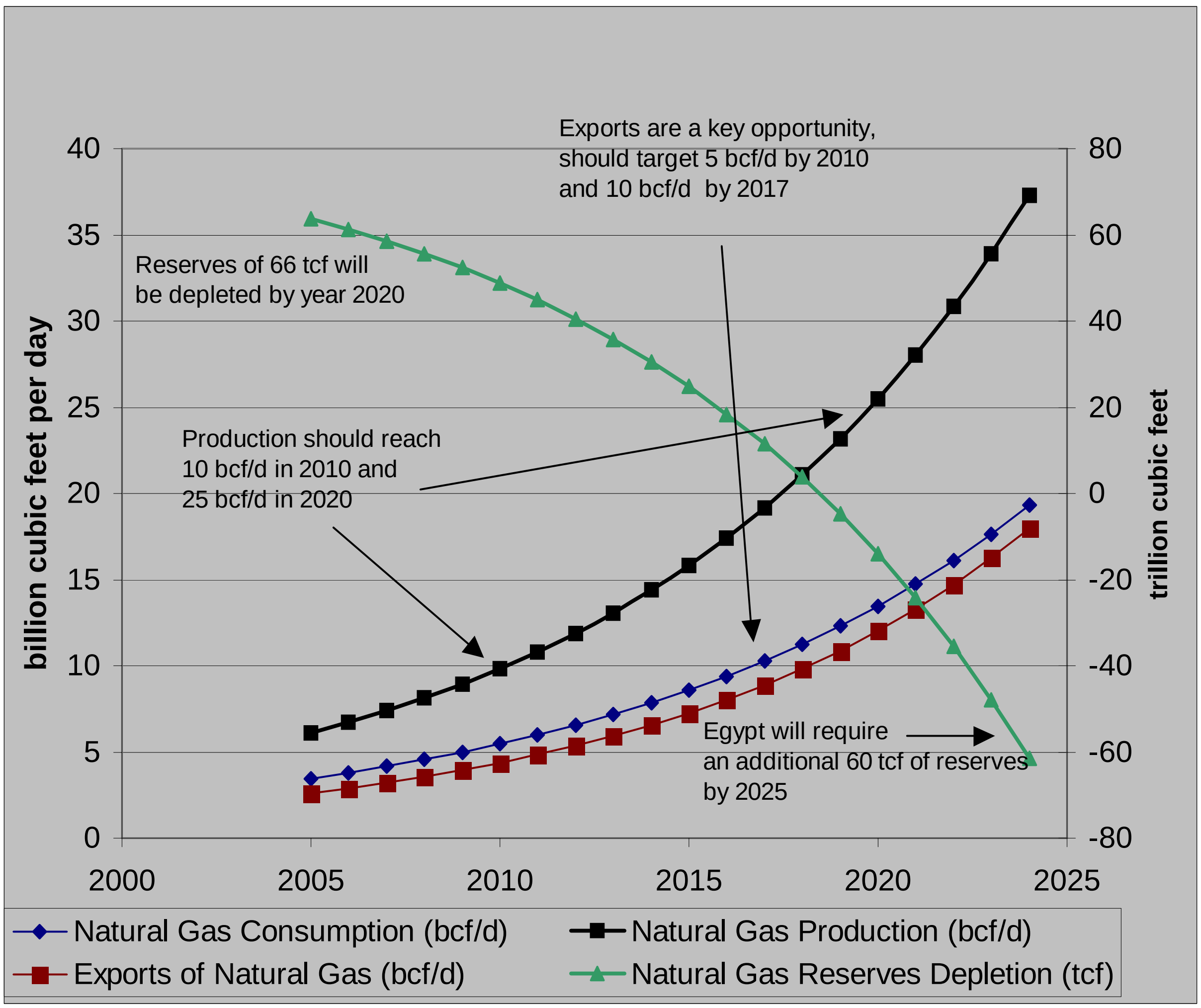
Figure 6. Egypt's Oil Future: Sustainability Analysis and Forecast



Source: Author's calculations based on model results.

The future of natural gas in Egypt looks brighter (figure 7). Even though consumption of natural gas is expected to rise steeply with time until 2025, production can overcome such demand and can produce a sizeable volume of exports. Consumption is expected to rise by nearly 9.45 percent annually due to the combined effects of population growth, output growth (GDP growth), and the transition from oil to gas in thermal power generation. Production is expected to reach 7 billion cubic feet per day (bcf/d) in 2006, and economic policy should target a production rate of 10 bcf/day by 2010 and 25 bcf/d by 2020. In retrospect, exports are a key opportunity for natural gas in Egypt. Egypt should be able to deliver an export volume of 5 bcf/d by 2010 and 10bcf/d by 2017 (see figure 7).

Figure 7. Egypt's Future of Natural Gas: Sustainability Analysis and Forecast



Source: Author's calculations based on model results.

Based on sustainability calculations, the author estimates that Egypt's proven reserves of 66 trillion cubic feet will be depleted by 2020, and that the economy will require an additional 60 tcf of additional reserves of natural gas by 2025. These additional reserves are within the probable gas reserve endowments of the country (120-180 tcf of probable reserves are the current estimate). This, of course, will require complementary investment costs associated with exploration and resource distribution. However, profit margins of 20 percent are expected to persist with time, conditional on economies of scale in production.

5. EGYPT'S ENERGY SECTOR: FUTURE OUTLOOK AND RECOMMENDATIONS

In general, the petroleum industry in Egypt should be considered one of the major economic development catalysts in the economy mainly due to investment generation and not particularly because of employment generation. Hence, physical capital requirements are key to the future growth of the industry, especially as those are related to economies of scale and associated reduction in unit production costs (thus creating what has been commonly known as "Stein's competitive advantage"). In retrospect, energy resource endowments are necessary, but not sufficient, conditions to impact long term development. In addition to resource endowments (comparative advantage), a sustainable element of competitive advantage must be present. This can be achieved by process innovations yielding cost-reduction advantages in the energy industry in comparison to other countries. That is not yet achieved in Egypt.

Local investments in the petroleum industry recently amounted to around LE7.8 million ($1.7 million) while foreign investment was around $2.1 million. However since the oil and gas industry is a capital intensive industry, manpower in crude oil was only 33,300 workers in 2004, and in oil products was slightly less at around 30,300 (World Energy Council 2002). It should be noted, however, that since energy is a highly capital intensive industry, it does not hold the key to Egypt's unemployment problem, which ranges between 10 percent (official figures) and 15 percent (unofficial estimates) (World Factbook, CIA, 2006). Future energy sector expansion will rely heavily on the amount of investments rather than the level of employment absorption.

The oil and gas sector fulfils around 95 percent of Egypt’s energy requirements, distributed between oil (53 percent) and natural gas (42 percent).[12] Electricity generation is the highest consumer of gas (62.4 percent), followed by manufacturing industries (26.2 percent),

[12] AmCham (2003).

petrochemicals (9.4 percent) and residential and commercial users (2 percent). Egypt's energy resources are therefore predominantly demand driven by thermal power generation, and supply driven by the amount of proven reserves. Due to the discoveries of substantial natural gas reserves, Egypt currently has a potential comparative advantage. This should be further developed into a competitive advantage so that export potential is maximized to the fullest extent possible. In particular, Stein's competitive advantage (reduction of unit costs with time through process innovations) can deliver promising future results if Egypt targets a $3 per barrel for the cost of oil extraction. This requires technology transfer with local process innovation, which is not one of the main characteristics of the Egyptian human development path (World Bank 2005).

Table 3 below summarizes the outlook for Egypt's energy sector until 2025.

Table 3. An Outlook for Oil and Natural Gas in Egypt Until 2025

	Oil	***Natural Gas***
Consumption Growth	1.8 percent average annual growth rate until 2025.	9.45 percent average annual growth rate until 2025.
Production Targets	Oil production is expected to decline to 400,000 bpd by 2025, with annual production decline of 3.45 percent.	Production should reach 10 bcf/d in 2010 and 25 bcf/d in 2020.
Exports	An oil shortage is expected by 2007/2008.	Exports are a key opportunity. Gas exports should target 5 bcf/d by 2010 and 10bcf/d by 2017.
Imports	Required imports of oil at 100,000 bpd in 2008, 300,000 bpd in 2015, and 600,000 bpd in 2025.	No required imports of natural gas are expected until 2025.
Pricing	Phased relaxation of oil subsidies is expected. Persistence of consumption characterized as a necessary good.	Longer term gas subsidy changes are expected. Consumption will remain characterized as a normal good.

Source: Author's calculations based on model results.

One of the main critiques of the oil and gas industry in Egypt is its high level of subsidies. Prices are extremely distorted and do not reflect international prices. Furthermore, subsidies carry with them a huge amount of public debt as well as external debt. The government announced in its 2004 budget that it has spent around LE14 billion to cover petroleum subsidies ($1 is equivalent to LE5.7 at the time of writing this research).[13] Furthermore, since the oil and gas

[13] AmCham (2003).

sector is subsidized both to consumers as well as to intermediate industries, the oil and gas sector actually partially subsidizes all productive activities in the Egyptian economy (Seda 2005). And while Egypt faces falling oil production from its mature oil fields, and hence declining revenues in spite of increasing international oil prices, domestic consumption will force it to become a net oil importer by 2007/2008 as analyzed in this paper. Unless Egypt reforms its existing pricing mechanism in the oil sector, it would further augment a chronic problem. Moreover, the lifting of oil subsidies should be implemented in phases in order to contain inflation and hedge against increasing poverty. The recent partial lifting of oil subsidies is along those lines. However, as have been estimated in this research, since oil is almost completely price inelastic, a sizeable reduction in oil consumption should not be expected even when subsidies are totally lifted.

Overall, the energy sector in Egypt needs major restructuring. As an outcome of this paper's model results, Table 4 below outlines future recommendations for Egypt's energy sector. These recommendations are based on estimated model results for energy resource sustainability.

Table 4. Strategies for Egypt's Energy Sector

1. OPTIMAL EXTRACTION OF ENERGY SOURCES (OIL AND GAS)

- Re-orient future energy policy towards gas as a new strategic resource in addition to oil.
- Energy growth requirement of 3 percent a year (based on GDP growth rate of 6 percent a year) until 2025.
- Achieve competitive advantage in gas through process innovations based on unit-cost-reducing strategy, while maintaining a target profit margin of 20 percent.
- Gas economies of scale by production expansion from 7 bcf/d in 2005 to 35 bcf/d in 2025.
- Reduce X-inefficiency in oil production through the upgrade of technology by meeting a least cost target of $3 per barrel.

2. REDUCTION/REMOVAL OF ENERGY SUBSIDY

- Gradual reduction in energy subsidies with a total energy subsidy removal scheme by 2017.
- Oil subsidies should be removed by 2010.
- Reduce household expenditure impacts (additional LE 110 per household per month).
- Enforce minimum wage level as required by Article 23 of the Egyptian Constitution; and determined by UNDP Millennium Development Goals at LE 342 per month.
- Implement 'inflation targeting' to combat an additional 5-7 percent inflationary pressure due to subsidy removal.

3. ENERGY SUSTAINABILITY (INVESTMENT REQUIREMENTS)

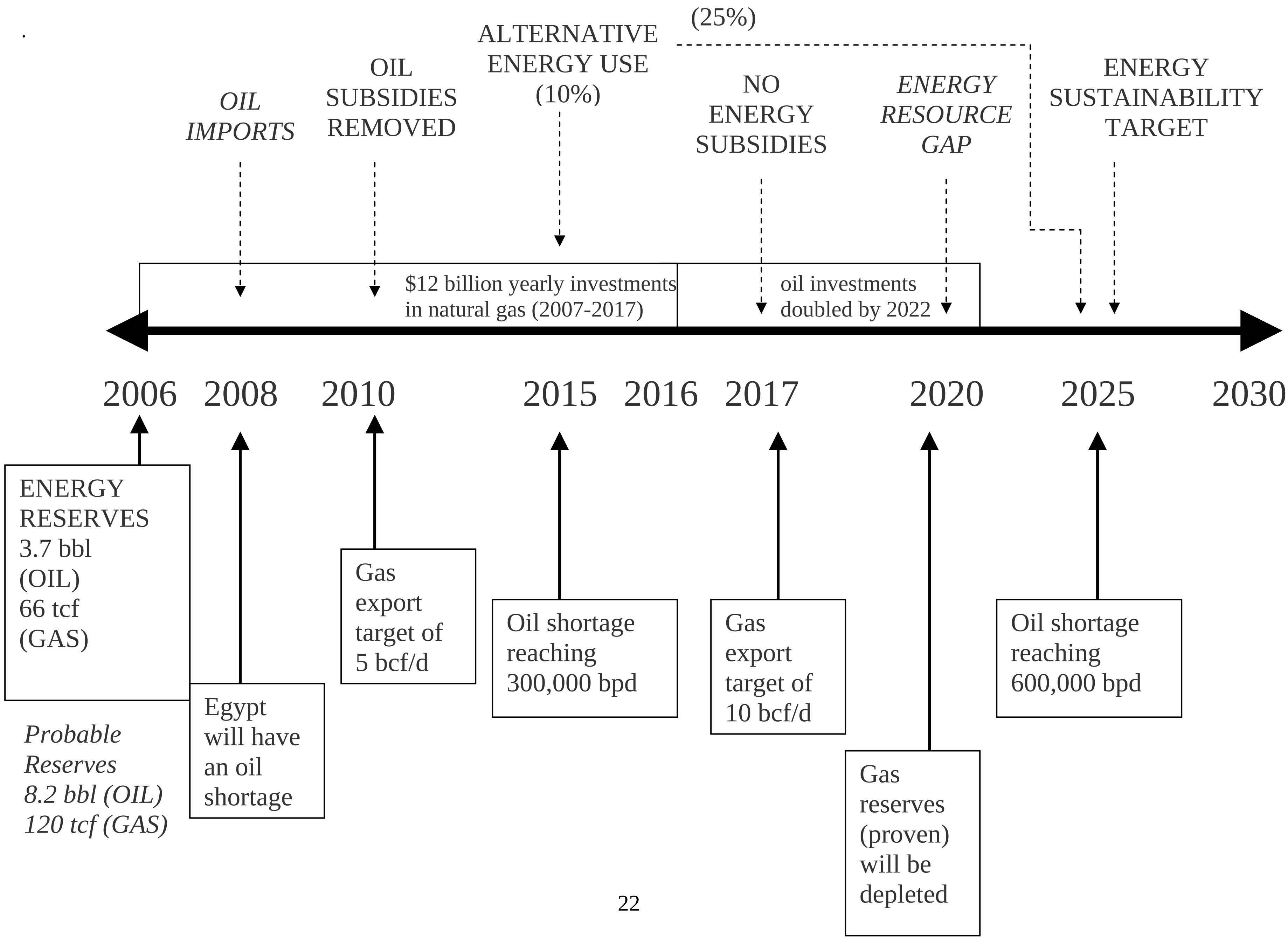
- Target $120 billion investments in natural gas production at $12 billion per year over the next ten years (2007-2017)
- Target growth in investments for oil production at 5.25 percent per year, such that total oil investments are doubled by the end of the next 15 years.
- Utilize alternative energy sources (solar and nuclear) to cover the energy resource gap starting in 2008 for oil and 2020 for natural gas

4. ALTERNATIVE ENERGY SOURCES

- Alternative energy use must increase to 5 percent by 2010, 10 percent by 2015, and 25 percent by 2025 (currently <1 percent)
- Substitute domestic oil consumption by minimum reduction targets of 7,000 bpd in 2010 and 10,000 bpd in 2025 (lower bound) through solar/alternative energy use.
- Oil import reduction targets of 80,000 bpd in 2015 and 225,000 bpd in 2025 by nuclear energy use as an economic alternative to oil imports.
- Improve environment by a potential gain of $130 per ton of reduced carbon emissions (Kyoto Protocol Standards)

Source: Author's recommendations based on model results. Major assumptions include a 6 percent target GDP growth rate, constant elasticity of substitution between oil and gas, competitive advantage through unit cost reduction (Stein's competitive advantage), X-inefficiency and economies of scale are based on least unit cost of Arabian Gulf producers, household income data based on IDSC data, and nuclear energy feasibility based on announced government policy and opportunity cost analysis to oil imports.

Figure 8. Timeline Implementation for Energy Sustainability (Summary of Results)



6. Conclusion

The central theme in this research is analysis and forecast of Egypt's oil and natural gas resources, regarding consumption, production, and exports/imports, with proposed strategies for sustainable development. The efficient utilization of energy resources in Egypt requires a major policy shift from oil historically regarded as the country's strategic energy resource, to a future in which natural gas should complement oil as the nation's strategic energy resource for decades to come.

The energy sector in Egypt will remain a high priority sector and a strategic resource for the country's future. Egypt will remain to be a price taker in world energy markets. Historically, oil has been more price inelastic than natural gas, whereas natural gas has higher income elasticity. Given proven reserves, oil production is declining due to X-inefficiency, and is expected to decline further, reaching as low as 400,000 barrels per day in 2025. Egypt is expected to be a net importer of oil in the very near future and as early as 2007/2008. Oil consumption, on the other hand, is forecasted to increase at 1.8 percent per year through 2025, and the removal of oil subsidies, when undertaken, is not expected to guarantee a substantial reduction in oil consumption. On the other hand, natural gas should see a production growth of 10 percent per year, with the proven 66 trillion cubic feet of gas reserves fully depleted by 2020. This depletion, however, includes sizeable export proceeds. Comparative advantage alone (i.e., resource endowments) cannot generate sustainable development in the future. Investors can continue to generate comfortable profit margins (70 percent for oil) conditional on economies of scale and the achievement of Stein's competitive advantage (lower comparative unit costs) targeting $3/barrel. Large investment costs are required for natural gas production, accompanied by a 20 percent profit margin. It is estimated that a $12 billion per year investment package over the next ten years (2007-2017) is required for natural gas sustainability, in order to achieve an overall energy growth rate of 3 percent per year, with the economy growing at a 6 percent GDP growth rate.

Subsequently, recommended strategies for Egypt's energy sector have been proposed, summarized as follows: (1) optimal extraction of energy sources, (2) reduction/removal of energy subsidies, (3) energy sustainability (investment requirements), and (4) alternative energy use including solar and nuclear energy. A timeline implementation for such strategies is outlined.

APPENDIX

Optimal Resource Extraction Model:

The following model (Hartwick's model) was utilized as part of the analysis undertaken in this paper (based on the works of Hartwick 1977; Hanley, Shogren and White 1997 and Cairns and Yang 2000):

Let $x(t)$ be the stock (reserves) of resource at time t, $u(t)$ the quantity (production rate) extracted at time t,

$P(t)$ the price path of the resource,

and r is the discount rate.

It is logical to have the following equation of motion for $x(t)$:

$$\frac{dx(t)}{dt} = \dot{x} = -u(t)$$

In other words, the stock (reserves) declines at every time *t* by the amount of extraction (production).

Assuming extraction costs given by $C(u(t), x(t))$ with $C'(u) > 0$, $C_x \leq 0$, and $C''(u) < 0$, such that extraction costs are an increasing function of production flow rate, but such an increase is diminishing with quantity, and including a "stock effect" $C_x \leq 0$ (unit extraction costs are lower for reserves having the potential of economies for scale), the dynamic extraction path will be given by maximizing net benefits over time:

$$Max\{u(t), T\} \in \int_{t=0}^{T} e^{-rt} \left[P(t)u(t) - C(u(t), x(t))\right] dt$$

$\dot{x}(t) = -u(t) \quad \forall t$

$u(t) \geq 0 \quad \forall t$

$x(0) = x_0 = \overline{R}$

$x(T) \geq 0$

$u(t) = D(P(t))$.

Using the current value Hamiltonian (optimal control problem) yields:

$H_c = P(t)u(t) - C(D(P(t)), x(t)) - m(t)u(t)$

where $m(t)$ is the current value multiplier,

with $m(t) = e^{rt}\lambda(t)$,

where $\lambda(t)$ is the standard Lagrangian multiplier.

This optimal control problem is then solved by:

$\frac{\partial H_c}{\partial u(t)} = P(\bullet) + P'(\bullet)u(t) - m(t) = 0$ (1) Sustainability Constraint

$\dot{m} - rm(t) = -\frac{\partial H_c}{\partial x(t)} = 0$ (2) Equation of Motion

$\dot{x}(t) = \frac{\partial H_c}{\partial m(t)} = -u(t)$ (3) Resource Depletion

$\lambda(T) = 0$ (4) Transversality (terminal cycle) Condition

This gives rise to the following solution(s):

(a) When there is no stock effect, $C_x = 0$:

$$\dot{u} = D'(\bullet)\dot{P} = \frac{\dot{m}}{1/D'(P(t)) - C_{uu}}$$

(b) When there is a stock effect, $C_x < 0$:

$$\dot{u} = \frac{\dot{P} - \dot{m} - C_{ux}\dot{x}}{C_{uu}}$$

(c) When there are external costs, $e(t) > 0$:

$$\dot{u} = \frac{rP - rC_u}{1/D'(P(t)) - C_{uu}} - \frac{e(t)\left[r - \dot{e}/e(t)\right]}{1/D'(P(t)) - C_{uu}}$$

In solving for the optimal extraction rate, this paper assumed no stock effects, and did not account for valuation of externalities (external costs in production were not accounted for). The author recommends extension of his results to incorporate stock effects and externality valuations, but this is beyond the scope of this research.

Elasticity of Substitution between Oil and Natural Gas in Egypt

One of the most common measures of the economy's energy substitution possibilities is the elasticity of substitution (σ). The elasticity of substitution defines the relative change in quantity proportions (in this case, between oil and natural gas) in response to a relative change in their prices. This is done for production (relative change in input proportions in response to relative change in prices) and consumption (relative change in commodity usage in response to relative change in prices). In general, it is possible that the elasticity of substitution will vary; however, it is convenient to assume that elasticity of substitution is constant with time as it is assumed in this paper (LeBel 1982, p.293; Clarkson and Deyes 2002). The elasticity of substitution between oil and gas in Egypt is calculated for both the production and consumption using the following model:

$$\ln\left(\frac{Q_{OIL}}{Q_{NG}}\right) = \alpha + \sigma \ln\left(\frac{P_{NG}}{P_{OIL}}\right) + \varepsilon$$

where, Q_{OIL}= quantity of oil production or consumption (barrels of oil equivalent).

Q_{NG}= quantity of natural gas production or consumption (barrels of oil equivalent).

P_{OIL}= price of oil (US$ per barrel).

P_{NG}= price of natural gas (US$ per barrel).

σ = elasticity of substitution between oil and gas.

The value of σ is always positive, as the oil-gas ratio moves in the same direction as gas-oil price ratio. If σ is high ($\sigma \rightarrow \infty$), this means that oil and gas can be thought of as perfect substitutes for each other. On the other hand, if σ is very low (σ=0), this case shows that both oil and gas should be used in a fixed ratio regardless of the change in their price ratio. Running the above regression for Egypt for the period 1991-2003 for both production and consumption sides, it was found that the elasticity of substitution between oil and gas in production is 3.4; while the elasticity of substitution between oil and gas in consumption is 4.06.

The period from 1991 to 2003 witnessed economic growth due to implementing the Economic Reform and Structural Adjustment Program (ERSAP) in Egypt from 1991. However, such economic growth has recently slowed down. To forecast the growth of energy demand as a whole or growth of oil and natural gas consumption separately, Energy/GDP elasticity of 0.5 was calculated covering the period 1991-2003. This shows that when Egypt's GDP grows at 1 percent, energy demand would grow at 0.5 percent. Therefore, by applying an anticipated 6 percent rate of economic growth in Egypt, it is expected that energy should grow by 3 percent per year. The Oil/GDP elasticity (sensitivity between oil production and GDP growth rate) was also calculated and found to be 0.3, while the natural gas/GDP elasticity was found to be 0.9. Hence, for 1 percent GDP growth, oil should grow at 0.3 percent and natural gas at 0.9 percent.

Hartwick's Rule and the Sustainability Constraint

Both oil and gas are exhaustible resources that are irreversible. That is, if they are consumed, such consumption cannot be reversed, and if they are not consumed, then there has been an opportunity lost of not consuming or exporting their value. In an influential paper published in 1977, John Hartwick proposed a rule for ensuring sustainability (i.e. non-declining consumption through time), in the case where an economy made use of a non-renewable resource (such as oil or natural gas) in its economic process. Hartwick shows that, so long as the stock of capital does not decline over time, non-declining consumption is also possible. Hartwick stated clearly what has come to be known as Hartwick's rule for this type of economy: "*if the accumulation of capital always exactly compensates in value for the resource depletion, then the level of consumption remains constant*" (Cairns and Yang 2000, p.1; Hanley, Shogren, and White 1997, p.426).

Hartwick argued that a sufficient condition to enjoy a constant consumption path is to invest in reproducible capital all the returns from the exhaustible resource use. This incorporates the discount rate (opportunity cost of time), and growth rate of consumption, indexed by uncertainty (relative risk). Using Hartwick's rule to get the social extraction rate to reach a sustainable consumption path for Egypt, we have to use the following formula:

$$r = \rho + \eta g$$

where, r is the social (optimal) extraction rate.

ρ is the social discount rate.

η is the coefficient of relative risk aversion.

g is the growth of consumption of the exhaustible resource (oil or gas).

By applying the above formula to Egypt, and substituting for ρ=15 percent (historical social discount rate in Egypt), η=1 (assuming risk neutrality) and g_o= 1.8 percent (growth rate of consumption of oil in Egypt) and g_{ng}= 9 percent (growth rate of consumption of natural gas in Egypt); the economic extraction rates for oil and natural gas were derived, with the added constraint of GDP growth target rate of 6 percent annually. The paper assumes proven oil and gas reserves to begin with as the initial time period (the start of the Transversality cycle), to derive the historical extraction paths, then, calculates for each resource an efficient forecasted extraction path.

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