# Towards a New Energy and Environmental Policy for Egypt: Development of Clean Sources in an Emerging Economy

Selim, Tarek

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Tarek H. Selim
Associate Professor of Economics, American University in Cairo
tselim@aucegypt.edu


**Outline:**

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Tarek H. Selim[1]
Associate Professor of Economics, American University in Cairo
tselim@aucegypt.edu

## 1. PROBLEM AND JUSTIFICATION

Within the new world order, it is generally seen that sustainable development is a tradeoff between resource efficiency and social equity such that total resource essentials in society can become sustainable in the long run in a manner that meets the needs of current generations without compromising the ability of future generations to meet their own needs. Egypt as an emerging economy falls under this paradigm, which requires countries to adapt their natural resource management and energy policy directives towards new sustainability solutions.

An emerging economy such as Egypt, striving for its identity under a new world order, entails a shift in its energy policy away from traditional energy sources which are non-sustainable in the long run. This will require the inclusion of new policy dimensions related to energy conservation and efficiency, climate change, development of clean energy sources, and long run sustainability within a global perspective. Consequently, a new energy policy mandate is a critical requirement for Egypt's future.

This mandate, however, will provide a solution to long run energy sustainability for the country so long as the following constraints are addressed: (1) it constitutes a necessary condition in the country's path towards sustainable development, (2) it is implemented simultaneously as a target and constraint, and (3) social welfare and political sacrifice are complemented by incentive-based systems in contrast to authoritarian or universality solutions.

## 2. THE EGYPTIAN ENERGY SECTOR: A BRIEF BACKGROUND

The structure of the Egyptian energy sector is seen comprised of oil reserves, natural gas reserves, and potential for clean energy sources, including nuclear energy. Currently, the two main energy resources of Egypt are oil and natural gas. Egypt is an oil producing country where most of the production is extracted from the Suez Canal. Egypt's oil reserves were 3.7 billion barrels in 2006 and have grown to 4.1 billion barrels in 2008. In recent years natural gas has become an increasingly crucial source of energy. The Abu Madi, Badreddin and Abu Qir fields in the Nile delta account for nearly 50% of Egyptian natural gas reserves. Proven natural gas reserves have risen from 67 trillion cubic feet (tcf) in 2006 to 76 tcf in 2008. Forecast models however, have Egypt's oil and natural gas depletion rates varying. For the past decade the amount of oil production has decreased due to over extraction in previous years. Egypt is expected to import around 300,000 barrels per day by 2015 and double that amount by 2025. Egypt's oil sector has X-inefficiency and high relative costs of extraction (approximately $9 per barrel) relative to Persian Gulf producers ($3-$5 per barrel), in US$ 2008 prices.

Natural gas, on the other hand, has a better forecast but with problematic long run sustainability issues. While most economic data agree that natural gas exploration exceeds the rate at which it needs to be to match consumption, Egypt has enough natural gas to last until 2025, or until 2030 the latest. It is unclear what the impact is going to be if a complete shift to natural gas consumption is implemented as a substitute for oil. Such an impact is to be compounded by the announced lift of oil subsidies gradually along the medium term. Additionally, natural gas proven reserves require efficient extraction rates contingent on economies of scale not yet realized in Egypt. Political decision making sometimes outweigh economic benefits particularly within the Arab and Middle East regional context. The global benchmark of 20% profit margin in natural gas economic returns is not yet realized.

In general, depletion of traditional energy resources (oil and natural gas) is largely due to high demand placed on them by high population growth and increasing development efforts. The government subsidizes the oil industry in order to provide gasoline at an affordable price. As far as resource depletion is concerned, it is claimed that such a policy encourages depletion as the demand for oil is kept artificially high through the subsidy. In other words, it is claimed that the government subsidizes *over consumption* of the oil reserves. As a consequence of this policy, Egypt moved from being a net exporter in 1998 to a net importer in 2008. However, it is also seen that lifting the oil subsidy will not solve the country's anticipated energy gap by 2020. This is because of the highly inelastic nature of oil consumption (an estimated oil price elasticity of -0.02). Consequently, traditional energy sources of oil and natural gas will be insufficient in ensuring long run energy sustainability for the country. Alternative energy sources, such as nuclear, solar, wind, and biogas are deemed essential for achieving such a sustainability target. Moreover, given Egypt's position in the new world order as an emerging economy, the development of clean energy sources is no longer a luxury but a requirement for the country's alignment to global governance such as those related to climate change and greenhouse emissions.

## 3. OBJECTIVE OF THE STUDY

The objective of this study is to design a new energy policy mandate for Egypt as an emerging economy within the new world order along national policy directives and global governance measures. In particular, an analysis of the Egyptian energy sector will be conducted from an energy sustainability perspective, including analysis of traditional hydrocarbon (oil and gas) energy sources, energy conservation and efficiency targets, feasibility and requirements for the development of alternative clean energy sources (such as nuclear energy, solar energy, and other alternatives), and the crafting of an overall comprehensive energy policy mandate for the country's future. Reflections and policy directives on sustainable development for Egypt, emerging economies, and global governance will be addressed.

## 4. ENVIRONMENT AND SUSTAINABILITY: A NEW PERSPECTIVE FOR EMERGING ECONOMIES

Pure environmentalism and pure resource exploitation can be integrated together to form an encompassing sustainability solution. This is the main message of this work based on an innovative "structure-concentration-incentives" methodology applied to Egypt. Sustainable development is generally seen as a tradeoff between resource efficiency and social equity such that total resource essentials in society can become sustainable in the long run in a manner that meets the needs of current generations without compromising the ability of future generations to meet their own needs.

However, the approach of analysis goes beyond traditional sustainability dimensions. Environmental sustainability cannot be implemented without the direct inclusion of structure (form), concentration (effect), and incentives (drivers) as critical policy choices because: (1) they constitute a necessary condition in any country's path towards sustainable development, (2) they must be implemented simultaneously as a target and constraint, and (3) they require social and political sacrifice complemented by endogenous-based systems in contrast to authoritarian solutions. Egypt is taken as a case study application to such an approach. A policy road map is then outlined and the country's path of environmental sustainability is analyzed from economic, social, political, ecological, technological, and institutional dimensions. The structure-concentration-incentives methodology provide a basis that achieves environmental sustainability based on endogenous source-driven forces of change in contrast to the traditional effects-dominant oriented approach. The methodology undertaken can be used as a framework of analysis in treating the subject of environmental sustainability for any developing country. Yet, Egypt provides a rich case for treating the subject on the grounds of its historical, socio-economic, and political construct.

## 5. CORE ENVIRONMENTAL PROBLEMS FACING EGYPT: THE GENERAL CHALLENGE

Ahmed, Laila, and John live in a village with only one source of food: a pond with 100 fish in it. For them to survive, each one must only eat one fish a day. If they follow such a rule, they will give the fish time to reproduce and regenerate. One day, Ahmed, after eating the fish decides that he is still hungry. So he takes one extra fish and eats it. "What is the harm in taking one extra fish?" he justifies, "Chances are Laila and

John are doing the same." After a few days they all discover that the fish is depleted. There is no more food. It comes as no surprise that the fish are all gone. Just like Ahmed cheated one day, Laila cheated the next, and John cheated another. They all assumed that either no one will cheat or that everyone will cheat, so why not be the one to do it? They all decided to benefit their short run hunger at the expense of long term sustainability. Coupled with the fact that there is no immediate cost to incur for cheating, they all acted upon the impulse of self interest without taking into consideration collective welfare.

The above scenario is fictional, but it paints a clear picture of what the real environmental problem facing Egypt and other developing countries is: depleting resources for short term benefit without taking into consideration long term impact[2].

Since Egypt became more industrialized, the number of heavy industry factories producing such products as petrochemicals and cement has increased. With that increase however, comes a high pollution rate that, left alone, will render such industrial development unsustainable for future generations. Egypt is treading the line between progress and economic prosperity on one hand and sustaining the resources which allow for such economic development on the other. Such a trade off is one of the most critical challenges facing the country in the coming future[3].

Perhaps the most striking example of the above mentioned scenario at play is how the natural resources of Egypt have been depleted. The two main energy resources of Egypt are oil and natural gas. Egypt is an oil producing country where most of the production is extracted from the Suez Canal. Egypt's oil reserves were 3.7 billion barrels in 2006 and have grown to 4.1 billion barrels in 2008[4]. In recent years natural gas has become an increasingly crucial source of energy. The Abu Madi, Badreddin and Abu Qir fields in the Nile delta account for nearly 50% of Egyptian natural gas reserves. Proven natural gas reserves have risen from 67 trillion cubic feet (tcf) in 2006 to 76 tcf in 2008[5]. This should create a rosy world of energy supply for the country's future.

Forecast models however, have Egypt's oil and natural gas depletion rates varying. For the past decade the amount of oil taken out has decreased due to over extraction in previous years. Egypt is expected to import around 300,000 barrels per day by 2015 and double that amount by 2025.[6] Natural gas on the other hand has a better forecast. While most modeling agrees that exploration is not at the rate at which it needs to be to match consumption, Egypt has enough natural gas to last until 2030. It is unclear though what the impact is going to be if a complete shift to natural gas happens as a substitute for oil.

Depletion of these energy resources is due largely to high demand placed on them by high population growth and increasing development projects. The government subsidizes the oil industry in order to provide gasoline at an affordable price. As far as resource depletion is concerned, such a policy encourages depletion as the demand for oil is kept artificially high through the subsidy. In other words, the government subsidizes *over consumption* of the oil reserves. As a consequence of this policy, Egypt moved from being a net exporter in 1998 to a net importer in 2008. If the country continues to move in this direction of uncontrolled consumption, we worry that such critical energy resources will dry out in the near future[7].

Even more pressing than the issue of the mismanagement of energy resources is the treatment of *water resources* in the country[8]. The Nile represents not only a source of water for Egyptians and their crops, but a symbol of national identity. It is the river that symbolizes Egyptian wealth of tradition and history and the water that comes out of it has a spiritual meaning for every Egyptian. Yet, the private business owners, the small farmers, and the government seem to pay little to no attention to the cleanliness and the sustainability of this river. Egypt is currently facing a *critical water problem.* Assuming a population of 80 million, the current water levels are at 1,000 cubic meters per person. A country is in danger of water shortage when the level is below 1,700 cubic meters per person.[9] Even more concerning than decreasing quantities of water is the continually diminishing quality of available water. Factories have found that the Nile and the associated lakes are low-cost disposal sites to throw their chemical wastes into. For example, in the governorate of Alexandria, in Lake Mariout, about one million cubic meters of waste is being thrown by factories on a daily basis.[10] Additionally, *untreated sewage water* is regularly dumped into the Nile signaling a lack of quality control with ineffective regulation. The combination of such waste forms a great harbor for anaerobic bacteria – bacteria that needs no oxygen—to grow and produce harmful chemicals into the water such as hydrogen sulfide. Such chemicals are then consumed by humans and animals either through drinking directly or through watering crops that are then consumed.

The problem of diminishing water quality is further contributed to by individual farmers in the large agriculture sector of the country. Studies have shown that within the governorate of Sohag farmers dump the water left over from irrigating their crops -containing pesticides- without treating it properly and that they use lakes as dumping sites for their waste.[11] Furthermore, they do not use effective irrigation techniques to preserve the water source. Rather, just as Ahmed, Laila and John did, they use as much water as they want to benefit their own crops because of inefficient water pricing and their disregard to *social costs* of externalities. To further complicate the problem, the government utilizes Chlorine as a water purifier. While the World Health Organization (WHO) set 5 milligrams of Chlorine per cubic meter as acceptable, the levels of Chlorine are still higher in Egyptian water than those in other countries. Many nations have shifted to Ozone as a purifier but the poor infrastructure of water pipes in Egypt acts as a major impediment for such a shift.[12]

It is not only the lack of drinking water that poses a threat, but rather the lack of water as a *source* for growing crops and a source of energy production. The continued diminishing water quantity and quality threatens to put the economic development projects at a halt –it does not appear to be long term sustainable at current levels. Laws are in the books, but the *enforcement* mechanism is lacking. The People's Assembly issued law 48 of 1982, but in 2008 the enforcement of that law still remains incomplete. Whether it is governmental corruption or business carelessness, all of the parties are contributing to the erosion of water resources in the country. Factories continue to dump, farmers continue to waste water, but singers and poets somehow still keep writing about the greatness of the Nile. In other words, the collective value of the Nile is highly recognized but individual actions do not reflect that value.

In addition to water pollution and mismanagement of energy resources, the nation is facing a serious *air pollution* problem[13]. Economic development actually requires some level of air pollution, however sustainable development requires keeping the pollution in check. The main problem of air pollution in Egypt is the presence of large dust and smoke particles in the air. The particles that pose the most danger according to various sources are ones that are less than 10 micrometer in diameter. Measurements show that the level of dust particles exceeds that allowable by law. Some of that presence is due to natural factors. Due to the presence of large areas of desert in Egypt, the strong wind can easily move the dust particles into highly populated areas of the country. This is known as the *dispersion factor:* Egypt has a really poor dispersion factor, meaning that the dust particles can travel very fast within the country.[14] Furthermore, factors that are man made add to that effect such as farmers that do not irrigate properly causing the land to crack. Desertification of the land and the less emphasis there is on sustainable agriculture the more the land fractures causing increasing levels of dust particles in the air. Such particles can cause respiratory system infections and if left unchecked would make living in many areas of the country nearly unbearable.

The development of new factories and new industries has exasperated the air quality. Carbon dioxide and nitrogen emissions are increasing in urban cities at a high rate due to the entrance of new industries such as petrochemicals and cement. Burning fuel in production or in car usage increases the amount of smoke in the air. According to the Yale Center of Environmental Law and Policy 2006 Report, Egypt currently ranks 130 out of 133 countries ranked by air quality from least to most polluted. The problem is even more apparent in urban cities such as Cairo. Cairo's air pollution, according to the World Health Organization, is 10-100 times more polluted than acceptable international standards. suspended particulate matter concentrations, hydrocarbons and lead are some of the materials found in dangerous quantities within Cairo air. The presence of such matter means that there is a 2 in 1000 chance of getting cancer for those exposed daily to Cairo air.[15]

Just as with water protection measures, laws exist in the books to protect air. Law no. 4 has been issued to protect air from factory emissions.[16] However, without real enforcement all citizens are placed in danger. Factory owners can get around the regulations aided by the fact that the majority of the public pay little attention to the pollution problems plaguing the country. Sustainable development requires looking at the long term impacts and controlling them to form the best climate for economic progress. Running after short term gains creates an environment of the tragedy of the commons[17]: everyone attempts to eat a bigger piece of the pie thinking that it is an infinitely elastic one. However, if air reaches an intolerable level, then these cement plants or petrochemicals factories will be forced to shut down. Treating their employees from the harsh health effects of polluted air such as lung cancer or tuberculosis will burden society with high economic costs. With an unsustainable labor force comes an unsustainable industry that will on the long run render society unproductive.

The environmental degradation problem facing Egypt can be pinned down to three inter-related causes[18]. The first one is the *weakness of governmental enforcement.* Legislation necessary to protect the environment are legal imprints that are not uniformly enforced. In fact, if everyone followed them Egypt would have a much lower level of polluted air, water and better management of natural resources. However, the presence of easy ways out such as *Ikramia* (hidden transaction costs) and the corruption threatening the society at large are problems that result in inaction. The second cause is the lack of an entrepreneurial spirit and a long term vision within Egyptian businesses. If business owners start to calculate profits and growth while *internalizing environmental costs*, the merchant's non-innovative mentality will completely shift. Currently the over arching mentality is bringing in as much profit as one can in the fiscal year. Unknowingly, businesses are acting to destroy resources that are non-renewable with no regard to future generations.

The more appalling cause and striking issue is the problem of the *culture of degradation* that has taken a hold on many Egyptians. While the government can enforce laws against established businesses that throw their waste into the various water resources, it is very difficult for them to do the same for individuals who throw their solid waste into any water resource[19]. The dominant culture in Egypt stresses immediate over consumption with disregard to the long term lasting environmental impact of such behavior. Basic observation of the streets or lakes in any village illustrates that some people find such public places as a convenient dumping location for their waste. Even when the state attempts to clean out those lakes, individuals go back to their own old habits, a characteristic of *social resistance to change.* The main reason is that the individual throwing his or her waste does not see the immediate impact on the water or air they pollute. Just like our friend Ahmed could not understand why his taking of an extra fish would be a problem, until he realized the fish were completely gone, these individuals fail to recognize that if everyone threw their garbage into different water resources then they will ultimately become unusable.

The culture of degradation is not specific only to water resources but extends to other environmental spheres[20]. An appreciation of our collective natural resources has to be cultivated *internally* for us to be able to sustain them. This culture of degradation needs to shift for government and business to follow and change their attitudes towards our environment. Society needs to transform itself through a newfound sense of individual responsibility towards effective *collective* implementation of environmental regulation. Only through such a transformation will we reach our common hope of sustainable development for our nation.

## 6. THE SUSTAINABILITY SOLUTION: STRUCTURE-CONCENTRATION-INCENTIVES APPROACH

### Introduction

This work presents a *multidisciplinary* analysis to Egypt's sustainability path regarding efficient utilization of natural resources with environmental compliance for the benefit of current and future generations. Its main purpose is to deliver *sustainability solutions* to many of Egypt's energy and environmental problems. The approach utilized is based on balanced sustainability dimensions whereby pure environmentalism and pure resource exploitation are integrated together to form an encompassing solution. The approach undertaken is multidisciplinary on *economic, social, political, ecological, technological,* and *institutional* dimensions.

The economic dimension calls for an *efficiency-equity tradeoff* such that efficient resource extraction rates must not exceed equity valuations for future generations. Such a tradeoff is fundamentally important for Egypt's sustainability path. A call for big push industrial development entails excessive resource extraction rates for higher immediate consumption or export-oriented growth which can cause environmental degradation to be paid for by future generations as an opportunity cost. Consequently there is a need to align the country's growth rate with an economic sustainability constraint such that over-depletion of resources are minimized along with their respective negative externalities. This is a major challenge for a developing country such as Egypt.

Social preferences are of no less importance. The individual Egyptian citizen who values his private property is capable of valuing the existence of public resources for the welfare of coming generations. He is also capable of valuing the risk of environmental non-compliance as it relates to behavioral changes in society. In general, social networks in *people-centered societies* such as Egypt enhance such behavior. These effects have direct repercussions on the degree of social welfare in the community such as poverty and unemployment. Moreover, such social issues contain implicit utilitarian values which can be collectively formed as social preferences. Consequently, social preferences for environmental sustainability require "resource existence value" in the social utility of the population. There is also the need towards a collective behavioral pattern of pro-active environmental compliance without falling into the trap of immediate reactive solutions. These social challenges are essential towards the country's long run sustainability target.

Beyond the socio-economic dimension comes political organization. If the above challenges are deemed necessary, then the sufficiency condition lies in politics. A country's path towards sustainable development must be accompanied by sufficient political will in organizing the masses towards the target of environmental compliance. The main challenge facing any country in this domain is achieving such a target with free political choice away from authoritarian command and control regulations. In addition, transparency and *government accountability* are major challenges which must be addressed. These issues are the core of political choice and form the basis of a successful public policy towards environmental sustainability. In retrospect, Egypt has to overcome these challenges one way or the other in order to achieve its sustainability targets. If this is attained, then the country is on its way towards full political transformation.

Ecological constraints on a country's path towards sustainable development can be the most debatable. This is caused by the *environmentalism-industrialization debate* as a double edged sword. On the one hand, a country looking for industrialization would regard strict ecological constraints as limits to its growth. On the other hand, pure environmentalism with its ecological savings limits a country's industrial development. Hence, taking one stand against the other always entails a hefty opportunity cost. Yet, ecological sustainability constraints can be implemented by *degree* rather than sudden compliance. For example, a country has the choice of ecological sustainability based on *non-existent* constraint (no ecological valuation), *weak* constraint (ecological lifetime valuation), *semi-strong* constraint (ecological re-cycling valuation), and *strong* constraint (continuous physical ecological balance). Consequently, sustainability constraints on the ecology of the country's resources are a matter of degree, but the intensity of such a degree can be evolving with the nature of a country's level of development. Egypt, for example, is seen to be evolving from a non-existent towards the start of a weak sustainability constraint.

Technology is vital for a nation's development. It is even more vital for a country fetching for its sustainability path. This is true because the choice of technology is always a *critical pre-condition* to a nation's fulfillment of its sustainability targets. Technology itself can take various forms in its know-how of organizing resources into value-added output. For example, process technology, product technology, and technological diffusion are multiple forms of technological advancements which can be applied directly to the environment field. Specifically, cement filters are a type of process technology, recyclable packaging a type of product technology, and green marketing a type of technological diffusion. The choice of environmental technology requires *a spirit of entrepreneurship* beyond traditional merchant behavior. Such a challenge for a country like Egypt is not only based on business innovation but also involves a change of mentality towards market (give and take) in contrast to authoritarian (command and control) incentives.

All of the above challenges cannot be successfully implemented without sound institutions taking the lead in environmental performance. Beyond legislation, *"on the ground" enforcement* of environmental regulations require well established institutions with a high level of diverse human capital coupled with the existence of political or media pressure. Institutional structure of environmental public policy is a highly valuable tool for target sustainability solutions to be implemented effectively. The structure of environmental institutions include public, as well as private, entities calling for environmental compliance. In addition, the form of implementation should take "the carrot and the stick" approach initially, then gradually evolve towards *endogenous* environmental compliance. Such a challenge requires *institutional coordination* and stakeholder assessment at and beyond the project level. Specifically, the additionality constraint of environmental impact assessment at the project planning level is drastically insufficient to meet such a challenge. On the other hand, insufficient planning and reactive after-the-fact implementation are also drastically inefficient and would lead to a chaotic mismanagement of environmental resources. A country like Egypt must address this issue seriously and consider environmental compliance as a network mechanism within a well crafted coordinated institutional structure. Achieving this purpose at least cost and minimal bureaucracy is probably the most difficult challenge of all.

**Structure, Concentration, and Incentives**

The above challenges and their multiple associated dimensions call for a *concrete proposal* regarding Egypt's path towards sustainable development. This proposal can be developed by analyzing three angles of the sustainability debate applied to a developing country such as Egypt:

(1) Structure,
(2) Concentration, and
(3) Market Incentives.

**(1) Structure:**

The *structure*, or form, of a country's environmental sustainability includes elements of: (a) compliance (prohibition vs. permit schemes), (b) coordination (cultural and institutional decision making), and (c) competitiveness (structural shift in resource advantage).

*Compliance*

Authoritarian command and control policies have often resulted in greater information asymmetry in environmental data together with non-interactive social preferences and thus have not been highly effective in guaranteeing a given sustainability target. Permit schemes have cured this disadvantage but often at the expense of the risk of mal-distribution compliance. An efficient scheme of structural compliance must therefore embed both prohibition and permit schemes in a monitoring system that includes both simultaneously. This provides *flexibility* in achieving a given sustainability target. For example, marketable permits may be used but with a prohibition cap on maximum permits. Lump-sum fees may be used as an entry deterrent coupled with progressive emissions taxes from the source. Resource extraction permits can be exercised but accompanied with prohibition of non-green technologies. In all cases, a hybrid structural combination of permit and prohibition dimensions is vital for the effective fulfillment of environmental sustainability. This is seen as a necessary condition for environmental compliance on the ground.

*Coordination*

Environmental compliance cannot be implemented effectively without efficient coordination mechanisms on the individual and institutional levels. Individual preferences play a critical role in such coordination mechanisms. Specifically, existence value and willingness to pay in the *internal preferences* of a typical citizen carry profound motivational forces for environmental compliance. If individual citizens value their own public resources, and such valuation is coordinated amongst the masses, then a sustainability target is more easily attained. Such coordination may require intensive education and media pressure. Yet, social networks can quickly propagate such coordination measures especially if aligned with private incentives. On the other hand, environmental valuation in individual preferences is not enough to guarantee effective implementation. This has to be *jointly* planned with institutional coordination. As have been mentioned before, the carrot and the stick approach can be implemented initially, with gradual evolvement towards endogenous environmental compliance. Hence, social preferences and institutional decision making must be aligned together to form a basis for effective coordination.

*Competitiveness*

A country's environmental competitiveness cannot be guaranteed with mere existence of abundant natural resources nor the mere existence of static environmental compliance. Natural endowments in physical resources typically generate a comparative advantage in trade. However, such advantage may not be sustainable so long as natural resource extraction rates are not ecologically balanced. In other words, excessive resource depletion for an immediate growth target cannot provide a suitable basis for long run competitiveness. A "competitive advantage" in a nation's environmental resources requires continuous sustainability targets to be implemented in a dynamic fashion. It is generally seen that this is a difficult, but not impossible, objective to attain. However, it demands the above mentioned coordination and compliance issues prior to its implementation. Environmental competitiveness must therefore be accompanied with a structural shift in resource utilization. The aim is to achieve a competitive advantage in environmental compliance such that *minimum external cost and maximum resource sustainability* are mutually attained.

**(2) Concentration:**

Environmental concentration, or *intensity of impact*, carries a benefit-cost assessment of sustainability based on two major elements which contain within themselves a classical debate: (a) entitlement vs. functioning, and (b) pro-industrialization vs. pro-environmentalism.

*Entitlement vs. Functioning*

The entitlement vs. functioning debate is a *quantity-quality* dilemma, or better still, a distribution-effect dilemma. Amartya Sen, the Nobel Prize economist, has questioned the impact of quantity (distribution) of resources when its impact on human well being (welfare effect) is small and/or sometimes negative (detrimental). One good example of this dilemma, for the case of Egypt, is water resources. It is seen that Egypt is under the water poverty index due to intense water pollution (functioning) whereas public policy essentially targets an increased population access to a water source (entitlement). A similar reasoning can be seen in other social services, such as health and education, where most of the population is entitled to free public enrolment (entitlement), but the quality of service is notoriously low (functioning). Hence, the entitlement-functioning dilemma is rooted in Egyptian society at its very core. This happens to impact environmental performance in a similar manner. Specifically, there exists appropriate environmental legislation on an entitlement basis, but such legislation is not met by effective monitoring or compliance on the ground, hence ultimately leading to inefficient functioning. On similar grounds, the entitlement-functioning debate runs across natural resource utilization such as ecotourism and solar energy. God's entitlements to Egypt in its natural resource base include rare ecology coupled with a historical oriental flavor, a combination very special for ecotourism, but such entitlement has had little functioning development. Also, free entitlement of solar energy is not seen to produce an effective functioning market. Consequently, the entitlement-functioning dilemma is an important element in determining the intensity of impact from the use of environmental resources. Pollution concentration, intensity of resource utilization, and environmental quality are critical examples in this domain.

*Pro-industrialization vs. Pro-environmentalism*

The intensity of impact in environmental sustainability is heavily tied to the industrialization-environmentalism debate on several grounds. First, based on *valuation*, pro-industrialization has almost no limits to resource extraction, and regards strict environmental regulations as a detriment to investment expansion and growth potential. Ironically, it may regard pollution concentration as a positive sign to a country's level of development. On the other hand, pro-environmentalism has upper bound limits to resource extraction, regards strict environmental regulations as necessary for long run sustainability, and values pollution concentration as a welfare loss to society. Second, based on *dynamics*, pro-industrialization pushes for industrial development prior to strict environmental compliance, with the assumption that industrialization increases pollution concentration only in the short run, whereby advanced clean technologies in production and higher willingness to pay in society will ultimately take effect in the long run, such that pollution concentration will eventually drop after the country develops. In contrast, pro-environmentalism pushes for environmental regulations at all times, such that short run resource utilization implicitly accounts for future (i.e. long run) generations, and whereby pollution concentration with its corresponding welfare losses are effectively "contained" at all times, specifically in the short run *for* the long run. Third, based on *technology*, pro-industrialization ensures the free choice of technology such that technical upgrading and technological diffusion are attained with no limits to such a choice in the process of development. The argument is that the free choice of technology will ultimately generate its own clean technologies via the market mechanism in due course of time. Future technology will become green by endogenous preferences. On the other hand, pro-environmentalism calls for green technology at present and arranges for R&D efforts to generate such technology if non-existent. The argument for environmentalism is that green technology needs an initial stimulus and that its social costs are immediately absorbed by reduction in pollution concentration to sustainable levels. In addition, the advent of such implementation requires regulations exogenous to the free market mechanism.

*Benefit-Cost Assessment*

The above two debates generate a benefit-cost assessment to the sustainability dimension and its associated pollution concentration level. This is especially evident in relation to the dynamics of a country's development. In general, it is seen that the benefits of pollution concentration are similar to the benefits of big push industrialization: *unconstrained growth, free choice of technology, faster investment expansion to economies of scale and comparative advantage, and long run environmental compliance when social willingness to pay and endogenous preferences are met*. On the other hand, the costs of pollution concentration include outlays related to *health, social equity, welfare losses, existence value at the expense of future generations, environmental quality degradation, opportunity cost of emissions reduction, and reduced potential for long run competitive advantage*. These benefits and costs form the foundation at which the sustainability debate remains. They should not be valued as an accounting equation, nor should they be optimized in a complex quantitative model, nor should they be taken fully by value judgment. As a rule, benefit-cost assessment to sustainability has no unique solution.

**(3) Market Incentives:**

A well defined structure with efficient environmental concentration are necessary elements for long run sustainability. However, these elements cannot be sustainable without adequate *incentives* for environmental compliance. Those incentives must be *market-based* in order to ensure endogenous compliance based on self-valuation, social networks, or simple rent-seeking behavior. Market incentives can take different modes: (a) environmental entrepreneurship, (b) economic liberalization, and (c) public mobilization.

*Environmental Entrepreneurship*

This is probably the most important element of all. Environmental entrepreneurs are risk taking agents looking for economic profits using an innovative or unforeseen method. They must have profound perseverance since they are most likely moving against the tide (i.e. against the status quo). Also, environmental entrepreneurs are the *agents of change* towards a given sustainability target. They can be managers, traders, technology experts, or even garbage collectors. What they commonly seek is a business drive for innovation. Market incentives for environmental entrepreneurs include new methods, new technologies, or even new markets. They also include cost reductions in environmental compliance. The origin of such entrepreneurs is either based on economic valuation (profit seeking incentive), self-egoism (individual and self-esteem incentives), or discrete (risk taking) incentives. The result of their activities ultimately yield better technologies, more rents for society, and least cost environmental compliance. Their diffusion of local innovation may not only be the driving force towards environmental sustainability but can also be an ignition force in the process of development.

*Economic Liberalization*

Market liberalization through endogenous free choice in demand and supply elements dictate the scope of sustainable development. However, such free choice has to be balanced by effective regulation which itself should be market-based and not only based on prohibition schemes. As a reflection of this, more market liberalization in a developing country such as Egypt is highly desirable as a precondition for environmental sustainability. Examples of market-based regulations include marketable pollution permit schemes, bargaining in ecological conservation, further liberalization of trade to stimulate environmentally friendly products, new market incentives for renewable technology, and transparency in environmental information. Applications to this in Egypt include energy subsidies, water resources, involvement in Kyoto Protocol’s clean development mechanism, wildlife conservation, and formation of a solar energy market.

*Public Mobilization*

Why is public mobilization a significant element in environmental market incentives? A critical reason is public valuation of environmental resources. Public opinion plays a key role in mobilizing resources towards a specific target. It can also hinder the development of an environmental target if there is insufficient public demand for its purpose. Political decision making is largely influenced by public opinion, and consequently, public mobilization creates its own demand, and supply of, market players to achieve a common target. The role of education and the media in developing countries such as Egypt have a large effect in shaping public opinion. And this should be proven true also in environmental compliance. It should be noted that public mobilization in Egypt towards a short run target is easier than a long run target but the latter has a heavier impact on sustainable development. Another dimension is indirect willingness to pay and implicit existence value of a given resource. Social valuation directly affects individual preferences, and hence the above valuations would be greatly affected by a positive change in internal preferences if public mobilization towards environmental sustainability is deemed successful. Hence, the long run target of endogenous market-based environmental compliance requires effective public mobilization to achieve its purpose.

## 7. ECONOMIC ANALYSIS OF EGYPT'S ENERGY SECTOR: OIL, NATURAL GAS, AND ALTERNATIVE SOURCES

### Introduction[21]

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, on the other hand, 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.

On the other hand, 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 14th 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 then faced with the challenge of having to answering 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.

### The World Energy Market: General Characteristics

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 may 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 storage 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.

**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.[22] 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 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). 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.[23] In 2001/2002, Egypt ranked third in worldwide natural gas consumption, with a daily consumption of 2.6 billion cubic feet (bcf).[24] 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.[25]

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 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.

**Table 1. World Energy Market for Oil and Natural Gas: Comparative Characteristics**

| | *World Oil Market* | *Natural Gas Market* |
|---|---|---|
| *Elasticity* | 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 thermal efficient than gas. 1 cubic meter of oil has the same energy content as 1,000 cubic meters of natural gas | Gas is less thermal 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 way. | 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).

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.[26]

*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 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. By analyzing the trend of oil production, consumption and exports in Egypt from 1980 until 2004, and 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.

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. 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.

*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; EIA 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 derived. 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.[27] Conditional on those assumptions, the author estimates that Egypt will become a net importer of oil as early as 2007/2008.

*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 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.

*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.

**Egypt's Energy Sector: Sustainability Analysis**

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 elasticity, 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.[28]

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.[29] 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.

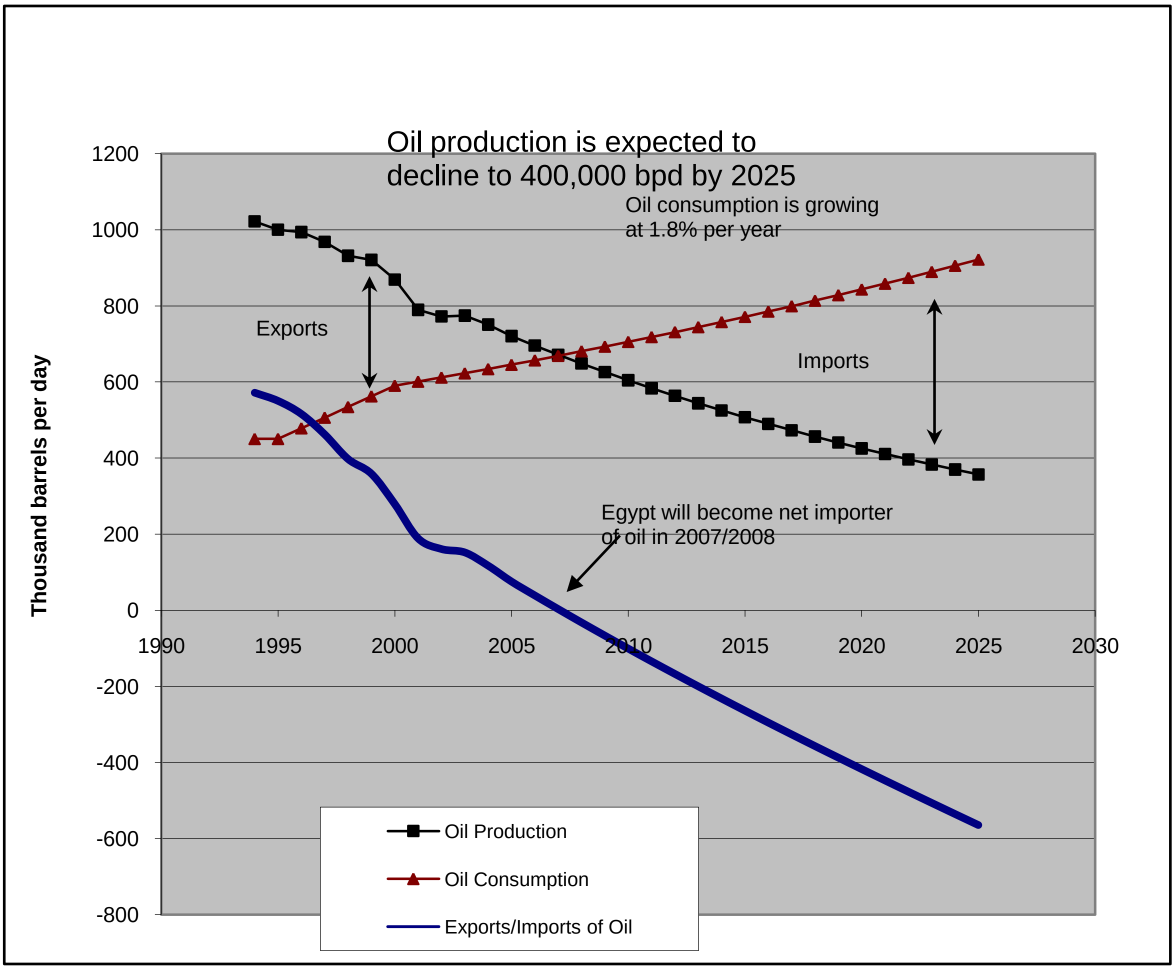
**Table 2. Comparison and Elasticity Estimates for Oil and Natural Gas in Egypt**

| | *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, growth rate of 6 percent for GDP, and data analysis based on proven (not probable) reserves Cross elasticity measure is estimated based on prices, whereas income elasticity measure is based on 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 1).

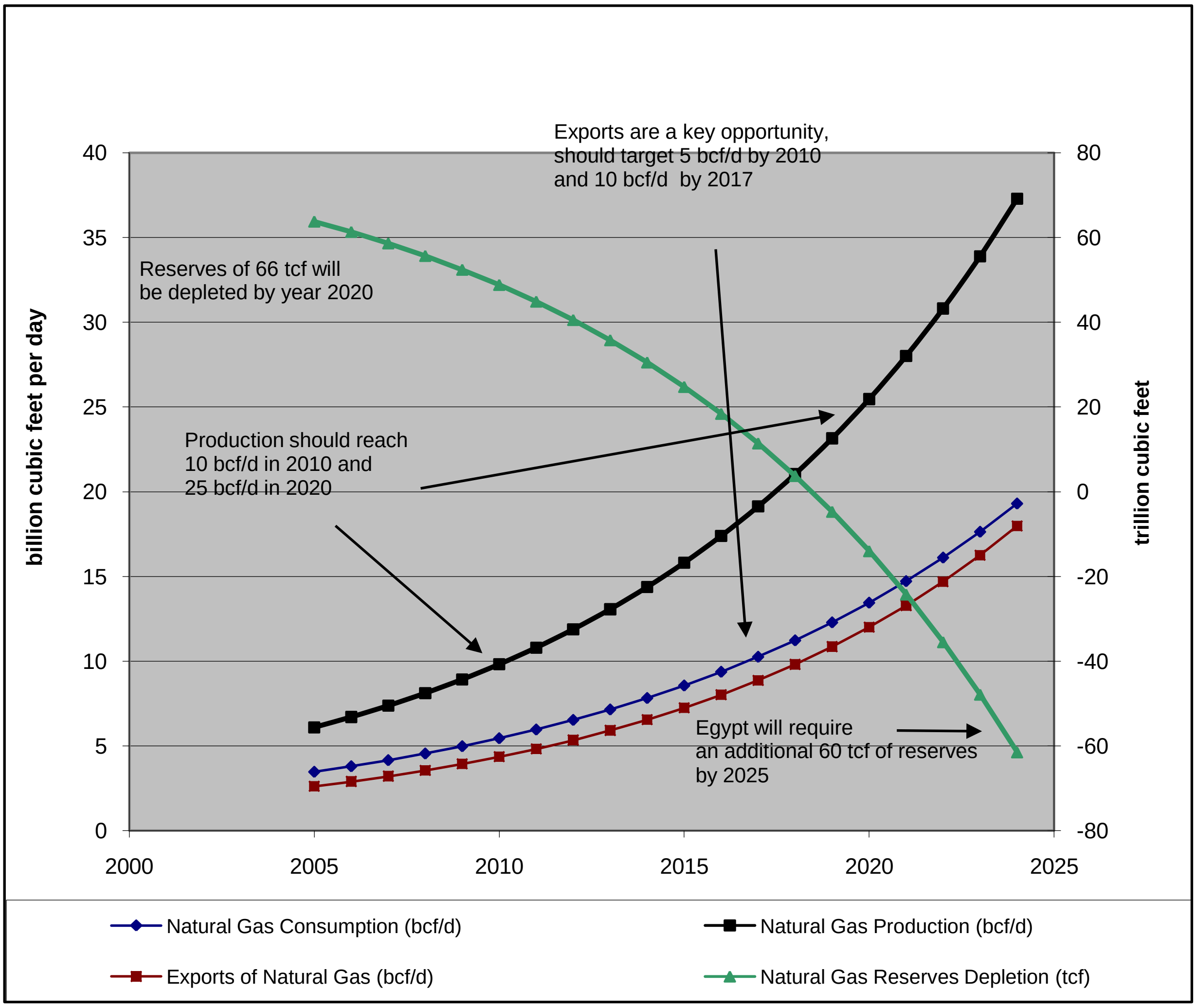
**Figure 1: Egypt's Oil Future**




*Source*: Author's calculations based on model results. Please note that this analysis has been conducted initially in 2006, and therefore the forecast of Egypt becoming a net oil importer in 2008 is itself a forecast. This forecast has in fact become reality.

The future of natural gas in Egypt looks brighter (Figure 2). 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 2).

**Figure 2. Egypt's Natural Gas Future**




*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.

**Strategic Recommendations for Egypt's Energy Sector**

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 Fact book, CIA, 2006 Please list in references). 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).[30] Electricity generation is the highest consumer of gas (62.4 percent), followed by manufacturing industries (26.2 percent), 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. Strategic 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 are expected. Persistence of consumption characterized as a necessary good. | Longer term gas subsidy changes are expected. Consumption will remain characterized as a normal good. |

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).[31] Furthermore, since the oil and gas 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). 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.

Table 4 outlines future recommendations for Egypt's energy sector. These recommendations are based on estimated model results for energy resource sustainability. Major assumptions include constant elasticity of substitution between oil and gas, competitive advantage through unit cost reduction (Stein's competitive advantage), economies of scale 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.

**Table 4. Strategies for Egypt's Energy Sector**

**1. RE-ORIENT ENERGY SOURCES**

- 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.
- Household expenditure impacts (LE 110 per household per month is estimated as economic burden of lifting energy subsidies).
- Enforce minimum wage rate 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)**

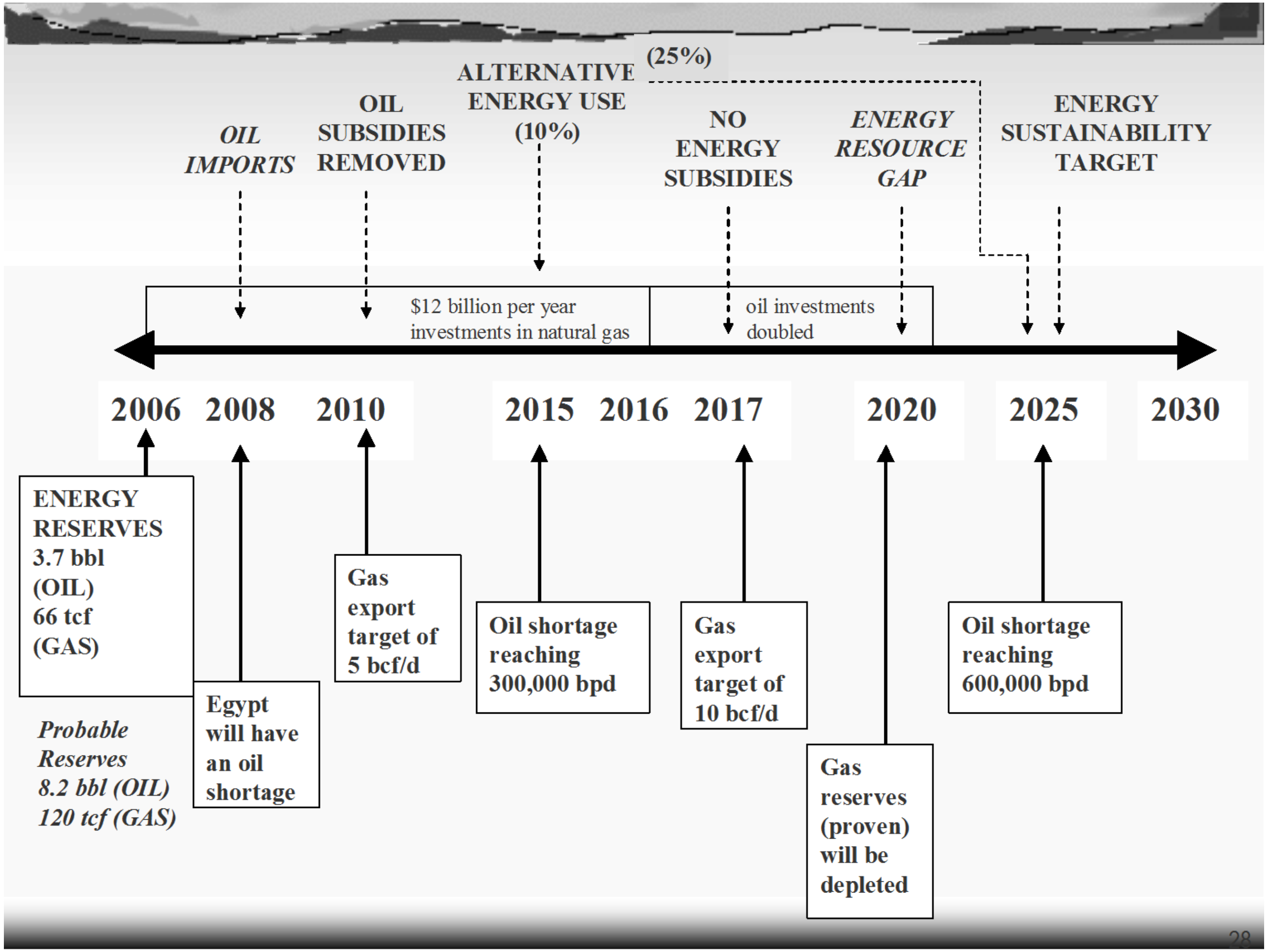
- Target $120 billion investments in natural gas production at $12 billion per year over ten years (2007-2017)
- Target growth in investments for oil production at 5.25 percent per year, such that oil investments are doubled by the end of the next 15 years
- Utilize alternative energy sources (solar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

**4. ALTERNATIVE ENERGY SOURCES INCLUDING RENEWABLES AND NUCLEAR**

- 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/renewable 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.

Figure 3: Strategic Timeline Implementation for Energy Sustainability in Egypt



**Remark on Energy Sustainability for Egypt**

The central theme in the previous analysis is applying Hartwick's methodology 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[32]. 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.

## 8. EGYPT'S PATH TOWARDS NUCLEAR ENERGY: AN ECONOMIC FEASIBILITY PERSPECTIVE

### Introduction[33]

This section assesses the economic feasibility of nuclear power generation in Egypt. It is motivated by the assumption that Egypt's traditional energy resources of oil and natural gas are not sustainable in the future compared to forces of population growth, a growing base of industrial production, expected rate of GDP growth, and subsequently, aggregate electricity demand. Recent studies have foreseen a countrywide energy shortage as early as 2020.[34,35] This necessitates a study of: (1) the economic *feasibility* of the use of nuclear technology to meet the future energy needs of the Egyptian economy, (2) the *critical factors* behind the choice of *appropriate technology* to face future energy demand, minimize technological risk, and make available cost-effective nuclear solutions, and (3) the required intensity of *nuclear reactor technology* for Egypt's energy security.

Nuclear power is defined as the controlled use of nuclear chain reactions to provide energy for the generation of electricity.[36] According to an International Atomic Energy Agency (IAEA) study (IAEA 2007), nuclear power generation provides 7 percent of the world's total energy supply (thermal equivalence) and 15.7 percent of the world's electricity supply. This by itself is a testimony to the high efficiency of nuclear technology compared to conventional means. The United States produces 20 percent of the world nuclear supply (the largest quantity in absolute terms) whereas France produces the highest share of nuclear supply (80 percent) relative to total domestic electrical energy demand.[37]

Egypt is currently at an early planning stage to utilize nuclear energy technology for electricity generation. This is guided by a sustainability criterion regarding Egypt's energy demand and supply balance. According to a study by the World Nuclear Association (WNA), in 2005 Egypt produced 92 billion kWh/yr from 18 GWe of nuclear plant, giving per capita electricity consumption of 1350 kWh/yr. Egypt now holds approximately 23 GWe of electricity supply in 2008.[38] Electricity distribution by source is roughly 88 percent from gas and 12 percent from hydropower (mostly from the Aswan High Dam). Currently, a limited amount of oil is used in electricity generation after the Egyptian government announced that all thermal power plants must run on gas instead of oil.[39] Overall, the expected per-capita electricity demand growth is estimated to be 4-5 percent per annum until 2025.[40] This corresponds to a supply capacity or stock increases of 8 to 9 percent annually.[41]

Egypt has its own history when it comes to nuclear power. In 1964, a 150 MWe nuclear plant[42] with 20,000 $m^3$/day desalination was proposed, and in 1974 a 600 MWe plant was planned. Egypt's Nuclear Power Plants Authority (NPPA) was established in 1976, and in 1981 the *Dabaa* site on the Mediterranean coast was selected for a nuclear power plant. This plan fell through following the Chernobyl accident in 1986. Consequently, an agreement on peaceful uses of atomic energy was reached with the International Atomic Energy Agency (IAEA) based on nuclear cooperation and non-weapon proliferation.[43] By 2006, a nuclear cooperation agreement was reached with China,[44] and in early 2008 serious talks were conducted with Russia concerning technical cooperation in the area of nuclear power usage. In addition, the United States, United Kingdom and France have expressed interest in cooperating with Egypt regarding its potential use of nuclear energy.

Egypt already has a 1961-vintage 2 MW Russian research reactor and a 22 MW Argentinean research reactor at *Inshas* in the Nile delta, which started in 1998. Both are experimental pilot programs and rely on outdated technologies. So far, Egypt does not have a single operating nuclear generator for commercial energy purposes. There is also a technical feasibility study for a nuclear cogeneration plant at *Dabaa* conducted in October 2006. The Egyptian minister of energy and electricity announced that a minimum capacity of 1,000 MWe commercial reactor may be built there by 2017. The multi-billion dollar project will be implemented with the assistance of foreign technology, and it has been announced that such a mega project is of national importance due to energy security, civil liability and international obligations with respect to nonproliferation.[45]

## Methodology

This section conducts an economic feasibility assessment of the use of nuclear power in Egypt. The study follows the economics and technology guidelines relevant to Egypt based on the following reference documents:

(1) World Nuclear Association (WNA), *The New Economics of Nuclear Energy*, December 2005;
(2) Massachusetts Institute of Technology (MIT), Nuclear Energy Experts Committee, Program on Science, Technology and Public Policy, *The Future of Nuclear Power*, 2003;
(3) International Association for Energy Economics (IAEE), *Nuclear Power Generation*, September 2007.

The first reference document provides comprehensive technological selection criteria of the appropriate nuclear technology using a cost-effective risk-minimizing nuclear solution. The second reference uses an economic feasibility framework in cost-benefit analysis for the potential use of nuclear energy, whereas the third reference is a highly specialized economics of technology document for the efficient use of nuclear energy in developing countries. These references have been used extensively by the US Department of Energy and the IAEA especially for emerging nuclear energy countries. The MIT study has been cited as one of the most important technological assessment document for countries pursuing the nuclear option (IAEA 2007).

The flow of the analysis in this section is as follows:

(1) Demand estimation and factor decomposition based on regression analysis. Per capita electricity consumption is forecasted based on time series data (1980-2007) by the use of elasticity (sensitivity) elements. The forecast is run to the year 2050.
(2) The flow and stock of electricity supply is estimated on the assumption of demand and supply equilibrium. This is based on decomposed factor elements including price, income, output and productivity for the electricity sector in Egypt.
(3) The stock of electricity supply based on conventional thermal sources is estimated and an energy gap outlook is used to economically estimate the potential use of nuclear energy as governed by critical feasibility parameters.
(4) Timeline of implementation for nuclear power plants is estimated based on discounting, opportunity costs and break-even analysis.

The above methodology is based on pure economic feasibility grounds and hence should be taken as the *minimum required level* of nuclear energy technology for the country's future.

## Egypt's Electricity Sector: Analysis and Forecast[46]

Egypt's installed generating capacity stood at 17.06 gegawatts (GW) as of 2004, and has reached 18.01 GW in 2005, 23 GWe in 2008, with plans to add 4.5 GW of generating capacity by 2010. Overall, natural gas fuels more than 85 percent of Egypt's electricity production with the remainder coming from the Aswan High Dam.

Table 5 below shows an analysis of the electricity sector in Egypt based on a supply-demand balance. Historical values were used from 1980 to 2007 in order to calculate elasticity estimates and decomposition of various economic factors.[47]

Electricity demand (per capita consumption) shows a 4.16 percent incremental growth rate (100 percent per capita demand impact) distributed as follows:[48]

(1) population growth (*H*) contributes 0.80 percent (19.2 percent impact rate);
(2) GDP real production index (*P*) contributes 1.49 percent (35.8 percent impact rate);
(3) income (*I*) contributes 1.57 percent (37.7 percent impact rate);
(4) productivity increases (*R*) contribute 0.3 percent (7.2 percent impact rate).

Generally, it may seem that the impact of population growth is not substantial. A possible reason is that most electricity demand by households is shared rather than per capita based. For example, an air conditioner is shared by all those living in a household rather than consumed individually. Hence, the contribution of 0.80 percent per person would have multiple impacts if the number of people per household is factored in.

The impact of production on electricity demand is a little over one-third, which can be a direct consequence of the energy intensity of production. However, a rise in personal income also has over one-third contribution. Finally, productivity increases contribute a small 0.3 percent with a 7.2 percent impact rate showing the lack of innovation in electricity usage across most sectors of the economy.

In addition, elasticity measures for electricity consumption with respect to price, income (real GDP per capita) and GDP output yield elasticity values of 0.37 (inelastic), 1.23 (elastic), and 0.93 (neutral), respectively. Therefore, total electricity demand is deemed a necessity in terms of consumer expenditure with respect to prices, yet a luxury in terms of consumer expenditure with respect to income level. The economy's output is uniformly proportional to total electricity demand.

Egypt's total electricity supply (generation) has shown a 5.6 percent annual increase during the period 1980-2005. Total supply as a stock variable (total installed capacity) was 5 GWe in 1980, 10 GWe in 1990, 17 GWe in 2000, 18 GWe in 2005 and reached 23 GWe in 2008. The average increase in total installed capacity was less than 1 GWe per year for the past three decades.

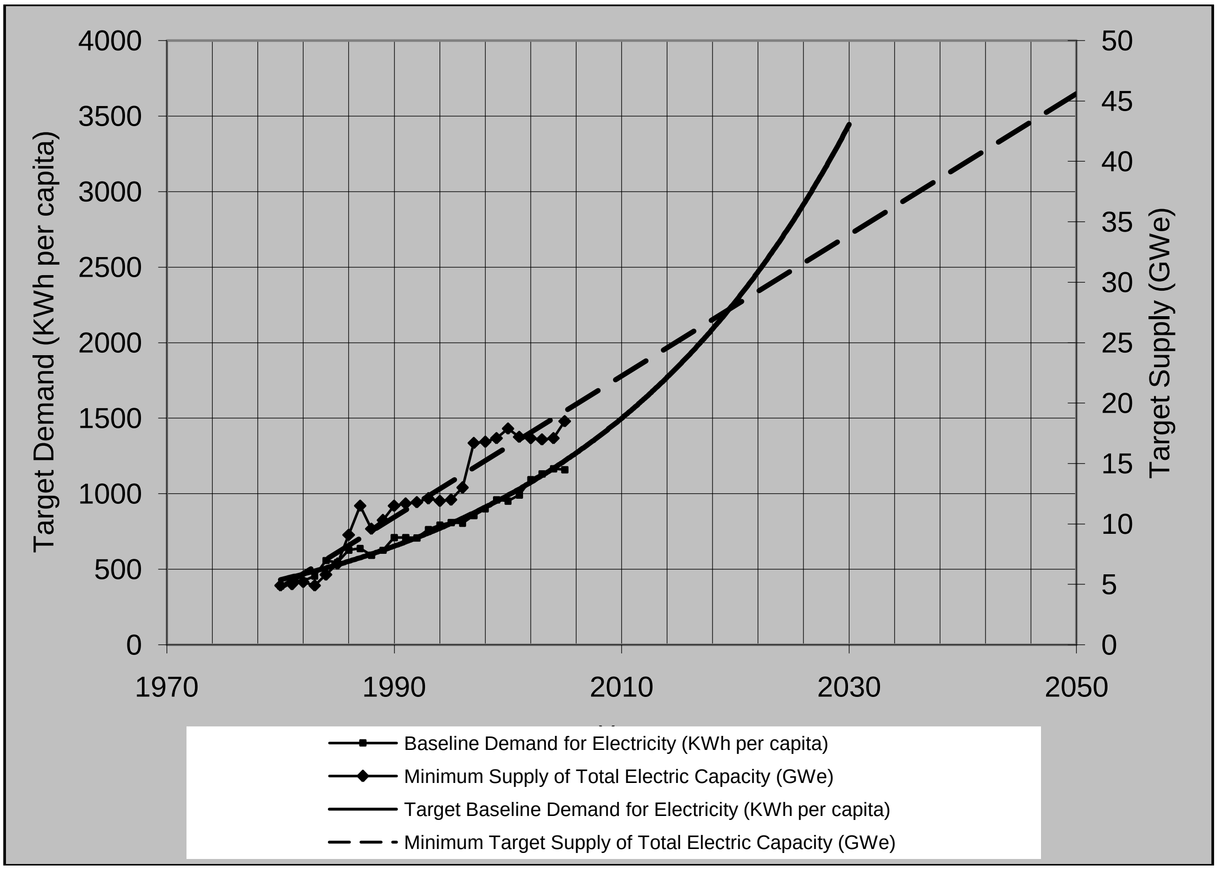
Given the sensitivity results of the decomposition in Table 5, the baseline target demand and corresponding *minimum* supply levels for Egypt's electricity sector are shown in Figure 4. It is forecasted that baseline per capita demand for electricity will reach 1500 KWh by 2010, 2000 KWh by 2018, and 3500 KWh by 2030, whereas the economic forecast for *minimum* electricity supply as total installed capacity is 26 GWe by 2018, 35 GWe by 2030, 40 GWe by 2040 and 45 GWe by 2050.[49] This forecast is the *minimum* economically desirable supply based on baseline expected demand growth outlined in Table 5 below.

**Table 5. Analysis of the Electricity Sector in Egypt (1980-2007)**

| | **Sensitivity of Electricity Sector in Egypt to Different Economic Variables** | **Comment** |
|---|---|---|
| Per capita electricity consumption | 1350 kWh per capita per year (2007)<br>Long-run minimum target of 4000 kWh per capita (2050) | 3,500 kWh per capita required by 2030 |
| Total electricity consumption | 4.16 percent incremental growth rate (100% per capita demand impact) | 1980-2007 |
| *Contribution of population growth* | 0.80 (19.2% impact rate) | Decomposition by regression |
| *Contribution of GDP production index* | 1.49 (35.8% impact rate) | Decomposition by regression |
| *Contribution of per capita GDP growth rate* | 1.57 (37.7% impact rate) | Decomposition by regression |
| *Contribution due to growth in productivity* | 0.3 (7.2% residual impact) | Residual (productivity) |
| Electrical installation capacity (supply) | 18 GWe (2005) installed (non-nuclear)<br>23 GWe (2008) installed (non-nuclear)<br>4 GWe (2030) minimum required by nuclear energy<br>6 GWe (2050) minimum required by nuclear energy<br>1,000 MWe per plant minimum nuclear supply capacity<br>4 nuclear plants required by 2030 and 6 nuclear plants required by 2050 | 20% target value of additional installed capacity, with a bare minimum constraint of 10% for total installed capacity |
| Price elasticity (sensitivity of electricity demand to price increase) | 0.37<br>(with a decomposition of 85% thermal electric generation and 15% to hydroelectric generation) | Inelastic (relatively insensitive) |
| Income elasticity (sensitivity of electricity demand to income increase) | 1.23<br>(historical average, 1980-2007) | Elastic (highly sensitive) |
| GDP elasticity (sensitivity of electricity demand to GDP) | 0.93<br>(historical average, 1980-2007) | Neutral |

*Note*: Author's calculations. The significance of the decomposition of total electricity consumption by regression is tested with a critical t-statistic (at 95 percent confidence level) of 2.07. Results imply significance based on t values of 3.34, 4.89 and 2.72 for population, GDP production and per capital GDP growth rates, respectively. The contribution of productivity is derived using the criteria of "Solow residual" (Mankiw 1992).

**Figure 4: Baseline Demand and Minimum Supply Balance for Egypt's Electricity Sector**



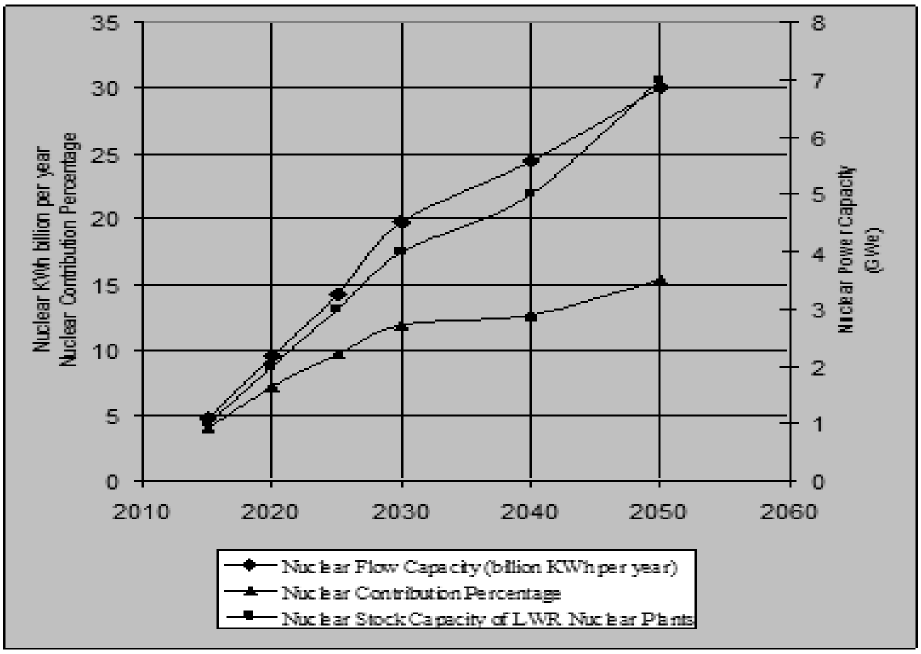

*Source*: Author's calculations.[50]

**Egypt's Nuclear Energy Potential**

Egypt will need its first nuclear power plant by 2015 or 2017 at the latest, with additional nuclear plants by the years 2020, 2025, 2030, 2040 and 2050—a total of six nuclear plants. Nuclear plants should be capable of generating 4 GWe of electricity generation by 2030 and 7 GWe by 2050, ultimately reaching 15 percent of total electricity supply. Each nuclear plant should have a minimum capacity of 1000 MWe per plant using *LWR (Light Water Reactor) nuclear reactor type technology.*[51] The initial capital cost of the first nuclear power plant is estimated at $2.5 billion in 2008 US dollar prices. The corresponding target nuclear supply is 4.8 billion KWh in 2015, 9.5 billion KWh in 2020, 14.3 billion KWh in 2025, 19.8 billion KWh in 2030, 24.4 billion KWh in 2040 and 30.0 billion KWh in 2050.

The estimated choice of nuclear energy is summarized in Table 6 below. The selection of nuclear technology is assumed to follow the guidelines mentioned above, which also conform to the most consistent results on this topic as applied to Egypt (MIT 2003; WNA 2005; IAEA 2007). Figure 5 shows Egypt's required nuclear capacity (2010-2050). Three inter-related nuclear supply requirements are illustrated: (1) *Nuclear flow capacity* (billion KWh per year), (2) *Nuclear contribution percentage* (defined as the ratio of nuclear supply by total electrical demand forecast), and (3) *Nuclear stock capacity of LWR nuclear plants* (GWe of nuclear power).

**Figure 5: Egypt's Nuclear Capacity Requirements (2010-2050)**




*Source*: Author's calculations.

Egypt's nuclear capacity requirements dictate a rising (i.e., *progressive*) share of nuclear energy contribution to total electricity supply with a target contribution share of 4 percent in 2015, 12 percent in 2030 and 15 percent in 2050. The long-term target is to achieve 30 billion KWh per year of electricity generation by nuclear energy with a nuclear plant stock installation capacity of 7 GWe, distributed across six nuclear power plants of LWR nuclear cycle capability.

The progressive intensity and timeline of nuclear energy for Egypt conforms to the experience of other developing countries such as Mexico, Argentina, Brazil, Bulgaria, Pakistan and Romania[52] (WNA 2005; IAEA 2007; IAEE 2007).

It is noteworthy here that there exists other more advanced fuel cycles than the open-cycle LWR reactor. Yet, open LWR nuclear fuel cycles are seen as the most desirable on an economic basis and as such the most demanded by other developing countries, the most cost-effective, the least costly initially (MIT 2003; WNA 2005; IAEA 2007), and fall within the feasible economic range (derived in Section 5 below). Future developments in the energy field may lower the initial cost of thermal and fast reactors with reprocessing in a "closed" fuel cycle that includes Plutonium Recycle Mixed Oxide, or PUREX/MOX, and in such case, such technologies would become feasible in the case of Egypt (refer to Section 5 below). Additionally, evolutionary LWRs may become economically feasible in the future. Nuclear reactors with closed fuel cycles like PUREX could generate double the energy intensity output of an LWR open fuel cycle and does not require decommissioning at its terminal life, but is four times as expensive in capital cost and requires a high maintenance team with specialized training. Thus, it involves higher operating costs and "exponentially higher risk" of negligence or mismanagement (MIT 2003). Other alternatives include LWR advanced designs, high temperature gas reactor (HTGR), and liquid-metal-fast-reactor (LMFR), which could generate higher energy output intensity, but are considered experimental in nature due to their exceedingly high technology skills, and because there exist very few real life commercial nuclear plants on the ground in the case of developing countries. These advanced technologies can generate more electricity output per plant, but such technologies are not economically feasible for a developing country like Egypt, generally because of risk and labor issues in addition to high capital cost in excess of the feasible limit.[53] Nevertheless, it should be noted that the LWR nuclear cycle has a long-term disadvantage compared to advanced nuclear technologies in its decommissioning cost requirement[54] at its terminal life of 40 years. More advanced nuclear cycles do not include this requirement.

**Table 6. Nuclear Energy Forecast for Egypt (2010-2050)**

| Year | Forecasted Electricity Consumption (kWh per capita) | Estimated Nuclear Energy Usage | Minimum Potential for Nuclear Production (kWh billion) | Numbe r of Nuclear Plants | Estimated Future Capital Cost of Nuclear Power (Undiscounted) | Discounted Cumulative Capital Cost of Nuclear Power (2008 US$) | Estimated Operating Cost of Nuclear Power (2008 US$ millions) | Estimated Uranium Fuel Cost Requirement (2008 US$ millions) |
|---|---|---|---|---|---|---|---|---|
| 2010 | 1500 | 0 GWe (0%) | - | None | - | - | - | - |
| 2011 | 1562 | 0 GWe (0%) | - | None | - | - | - | - |
| 2012 | 1627 | 0 GWe (0%) | - | None | - | - | - | - |
| 2013 | 1695 | 0 GWe (0%) | - | None | - | - | - | - |
| 2014 | 1766 | 0 GWe (0%) | - | None | - | - | - | - |
| 2015 | 1839 | 1 GWe (4.0%) | 4.8 | 1 | $2 billion | $1.16 billion | $125.5 | $18.8 |
| 2016 | 1916 | 1 GWe (3.9%) | 4.8 | 1 | - | - | $117.3 | $18.1 |
| 2017 | 1995 | 1 GWe (3.8%) | 4.8 | 1 | - | - | $109.7 | $17.4 |
| 2018 | 2078 | 1 GWe (3.7%) | 4.8 | 1 | - | - | $102.5 | $16.7 |
| 2019 | 2165 | 1 GWe (3.6%) | 4.8 | 1 | - | - | $95.8 | $16.0 |
| 2020 | 2255 | 2 GWe (7.2%) | 9.5 | 2 | $2.7 billion | $2.05 billion | $177.2 | $30.5 |
| 2021 | 2349 | 2 GWe (7.0%) | 9.5 | 2 | - | - | $165.6 | $29.4 |
| 2022 | 2446 | 2 GWe (6.9%) | 9.5 | 2 | - | - | $154.7 | $28.2 |
| 2023 | 2548 | 2 GWe (6.8%) | 9.5 | 2 | - | - | $144.6 | $27.2 |
| 2024 | 2654 | 2 GWe (6.6%) | 9.5 | 2 | - | - | $135.2 | $26.1 |
| 2025 | 2764 | 3 GWe (9.7%) | 14.3 | 3 | $3.8 billion | $3.25 billion | $190.1 | $36.7 |
| 2026 | 2879 | 3 GWe (9.6%) | 14.3 | 3 | - | - | $177.7 | $35.2 |
| 2027 | 2999 | 3 GWe (9.4%) | 14.3 | 3 | - | - | $166.1 | $33.9 |
| 2028 | 3124 | 3 GWe (9.2%) | 14.3 | 3 | - | - | $155.2 | $32.6 |
| 2029 | 3254 | 3 GWe (9.1%) | 14.3 | 3 | - | - | $145.1 | $31.3 |
| 2030 | 3389 | 4 GWe (11.9%) | 19.8 | 4 | $5.3 billion | $4.45 billion | $187.7 | $41.7 |
| 2040 | 5094 | 5 GWe (12.7%) | 24.4 | 5 | $10.5 billion | $5.65 billion | $117.6 | $34.7 |
| 2050 | 7657 | 7 GWe (15.4%) | 30.0 | 6 | $25.7 billion | $7.16 billion | $73.5 | $28.8 |

*Note*: Author's calculations based on forecast results given in Table 5 and Figure 4. Assumptions include 7 percent opportunity cost of capital, 90 percent operating capacity, 40 year lifetime per nuclear plant, LWR nuclear technology reactor types for all nuclear plants, a 3 percent yearly price increase for uranium, 1000 MWe per nuclear plant generation, 0.515 cents per KWe uranium requirement with 3-5 percent uranium enrichment requirement based on 0.711 percent U-235 content. Estimated nuclear operating expenses are assumed to start at 4.2c/kWe compared to 5.6c/KWe for conventional thermal power plants. (MIT 2003; WNA 2005; IAEA 2007).

**Break-Even Feasibility Analysis for Egypt's Nuclear Energy**

The above analysis assumes that nuclear energy is economically more feasible at all energy capacity levels compared to thermal power plants. This may not be necessarily true for all energy output levels or cost of capital variations. This demands an economic feasibility assessment for the potential use of LWR nuclear technology in Egypt as compared to thermal plants.

Consequently, the above *nuclear supply requirements* entail an economic feasibility (break-even analysis) as a benchmark of comparison between nuclear LWR power plants and their equivalent conventional thermal plants. The break-even analysis for nuclear power generation compared to conventional thermal power can be estimated using the following parameters:

$K_N$ = Capital cost of nuclear power plant ($2000 per KWe);
$K_T$ = Capital cost of thermal power plant ($500 per KWe);
$X$ = Target electricity power flow per year (KWh per year);
$C_N$ = Operating unit cost of nuclear generation (4.2 cents per KWh);
$C_T$ = Operating unit cost of thermal generation (5.6 cents per KWh);
$\eta_x$ = Relative efficiency (thermal plant efficiency is 72 percent of nuclear plant efficiency);
$r$ = Discount rate (opportunity cost of capital) with a bare minimum rate of 5 percent;
$t$ = Lifetime of power plant (40 years for both);
$DC_t$ = Decommissioning cost at terminal life for nuclear power only ($350 per KWe).

Hence, the break-even formula for nuclear energy is given by:[55]

$$\left(K_N - K_T\right) + X\left[\frac{C_N - C_T}{100}\right]\left(\frac{1}{\eta_x}\right)\left[\frac{(1+r)^t - 1}{r(1+r)^t}\right] + \frac{DC_t}{(1+r)^t} = 0 \qquad (1)$$

The two energy supply options (nuclear *vs.* thermal) can be compared by the net discounted value of nuclear costs as related to their equivalent thermal costs by Equation 1 above. If the net benefits from the two options are assumed to be similar over time per unit of energy supply, then the relative cost dimension (including opportunity costs and efficiency factors) would provide the extent of nuclear feasibility compared to thermal power. The rationale is that even though nuclear power is initially more costly, and terminally more costly, yet its higher efficiency coupled with lower operating costs per unit of energy supply can overcome these higher costs.[56]

Based on the present value feasibility criterion, the only unknown in Equation 1 is the yearly target supply of electricity generation (*X*). Hence, there exists a minimum break-even level of energy supply by which nuclear power is economically feasible. Given this rationale, the break-even energy supply for nuclear feasibility $X_{BE}$ is determined as:

$X_{BE}$ = 4.4 billion (2)
(KWh per 1000 MWe nuclear plant capacity).

Hence, the *minimum feasible energy supply output by nuclear technology* is 4.4 billion KWh annually per LWR 1000 MWe plant.

Table 6 shows that Egypt's nuclear potential has an average of 4.86 billion KWh per plant with a lower to upper bound range of 4.75-4.95 billion KWh of nuclear energy supply per plant. Therefore, nuclear energy is economically feasible for Egypt's future energy plans since future energy demand exceeds the minimum feasible energy supply output by nuclear technology.[57]

The feasibility of nuclear energy generation in Egypt has several limits to its implementation. Table 7 shows the critical values by which nuclear energy is generally feasible. In particular, Egypt's nuclear feasibility has both upper bound (maximum) and lower bound (minimum) critical values for various parameters. Critical parameters for nuclear feasibility include the following *maximum critical values for nuclear feasibility*:

(1) capital cost of $2.682 billion (2008 US$);
(2) discount rate of 13.2 percent;
(3) unit nuclear operating cost of 6.03 cents per KWh;
(4) price of uranium of 0.74 cents per KWe.[58]

**Table 7. Nuclear Sensitivity Analysis for the Case of Egypt**

| Critical Feasibility Parameter | Parameter Description | Critical Value | Conditions |
|---|---|---|---|
| Maximum feasible capital cost | Nuclear capital cost per 1000 MWe | $2.682 billion (2008 US $)[59] | Generate output of 4.86 billion KWh per year with discount rate constrained at more than 3% |
| Maximum discount rate for nuclear feasibility | Discount rate (opportunity cost of capital) | 13.2% | 1000 MWe nuclear plant |
| Maximum unit cost of operating nuclear power | Unit cost of nuclear power | 6.03 cents per KWh | 90% nuclear plant capacity |
| Maximum price of uranium for nuclear feasibility | Price of uranium (including enrichment) | 0.74 cents per KWe | U-235 content of 0.711% with enrichment of 3 to 5% |
| Minimum nuclear operating efficiency | Absolute nuclear operating efficiency | 28% | Normal efficiency is 33% |
| Minimum electricity output for nuclear feasibility | Nuclear output | 4.4 billion KWh per year | Expected range of 4.75-4.95 billion KWh per year for Egypt (2010-2050) |
| Minimum nuclear plant lifetime | Nuclear lifetime | 33 years per nuclear plant | Normal lifetime is 40 years |
| Minimum nuclear stock capacity per plant | Nuclear LWR technology stock capacity | 905 MWe | Normal LWR capacity is 1000 MWe |

*Source*: Author's calculations.

In addition to maximum critical values for nuclear feasibility, there also exist the following *minimum critical values for nuclear feasibility* as described in Table 7:

(1) output of 4.4 billion KWh per year;
(2) nuclear plant lifetime of 33 years;
(3) nuclear operating efficiency of 28 percent;
(4) 905 MWe nuclear capacity per plant.

Accordingly, although nuclear energy supply is generally feasible for Egypt's future, such feasibility contains both upper and lower bound critical values for various economic parameters. Hence, *Egypt's nuclear feasibility is not universal*, but conditional on multiple critical values for multiple economic parameters. Such a constraint on nuclear feasibility should be taken seriously in the implementation phase of nuclear operation in Egypt.

**Discussion of Results**

Egypt's nuclear energy potential is economically feasible. Nuclear energy is desirable for future demand-supply energy sustainability and is critical for the country's future power supply in the electricity sector. Per capita demand consumption is estimated to grow exponentially by 4.17 percent per year and its equivalent power supply in stock capacity is estimated at 8.08 percent annually.[60] The electricity demand factors are: (1) population, (2) output, (3) income, and (4) productivity, representing 19 percent, 36 percent, 38 percent and 7 percent impacts, respectively. This implies that output (production levels) and income (expenditure levels) are the dominant economic factors in electricity demand and future electricity supply.

Based on feasible nuclear supply requirements as provided in Tables 1 and 2, Egypt's nuclear capacity requirements dictate a rising (i.e., progressive) share of nuclear energy contribution. As dictated by economic feasibility, target nuclear contribution shares of total electricity supply are 4 percent by 2015, 12 percent by 2030 and 15 percent by 2050. The *progressive share* of nuclear technology to total power supply could be seen as an economic asset whereby learning effects can be factored in and labor training on nuclear safety and operational technologies can be accounted for. The first nuclear power plant is economically desirable by 2015 or 2017 at the latest. Six nuclear plants are economically feasible as forecasted to the year 2050. The long-term target should be to generate 15 percent of total countrywide electricity supply by nuclear technology. Such a long-term target is to start initially with a 4 percent contribution share in 2015-2017 and should reach 15 percent by 2050 along the following time schedule of feasibility:

(1) 4 percent nuclear contribution share by 2015-2017 (first nuclear plant);
(2) 7 percent nuclear contribution share by 2020 (second nuclear plant);
(3) 10 percent nuclear contribution share by 2025 (third nuclear plant);
(4) 12 percent nuclear contribution share by 2030 (fourth nuclear plant);
(5) 13 percent nuclear contribution share by 2040 (fifth nuclear plant);
(6) 15 percent (long-term target) nuclear contribution share by 2050 (sixth nuclear plant).

The above timeline of nuclear plant installation is not without bounded constraints. It has been derived, based on the break-even feasibility analysis in Section 5, that *each nuclear power plant* has critical feasibility parameters related to planning, implementation and lifetime operation. These critical feasibility parameters are as follows:[61]

(1) Maximum feasible initial capital cost for a single nuclear power plant is $2.682 billion (2008 US$) per 1000 MWe of nuclear electricity supply;
(2) Maximum unit cost of nuclear operations is 6.03 cents per KWh (nuclear operating cost);[62]
(3) Maximum price of uranium for nuclear feasibility is 0.74 cents per KWe (in 2008 US$ prices);[63]
(4) Minimum nuclear power plant lifetime is 33 years;[64]
(5) Minimum absolute nuclear operating efficiency is 28 percent;[65]
(6) Minimum nuclear plant capacity is 90 percent (nuclear operational capacity);
(7) Minimum scale for nuclear feasibility is 4.4 billion KWh per year for LWR 1000 MWe nuclear capacity plant;[66]
(8) Maximum opportunity cost of capital (interest rate) for nuclear feasibility is 13.2 percent annually;
(9) Minimum power output is 905 MWe per nuclear plant;[67]
(10) Minimum nuclear contribution share to countrywide electricity supply is 4 percent (with a long-term target of 15 percent).

The above feasibility conditions are highly critical in planning, operation and implementation of Egypt's nuclear power plants program and should complement the timeline schedule of nuclear plant installation previously outlined.

**Remark on the Feasibility of Nuclear Power as an Alternative Source for Egypt**

Demand and supply analysis and forecast for Egypt's electricity sector take a conservative approach. It is found that nuclear technology is economically feasible and is forecasted to generate a *progressive share* of electricity in Egypt. Based on LWR (light water reactor) nuclear technology, six nuclear plants are required by 2050, with a time schedule of shared power generation with respect to total countrywide electricity supply equivalent to 4 percent in 2017, 10 percent in 2025, 12 percent in 2030 and 15 percent by 2050. The study shows that minimum feasible energy supply output by nuclear technology is 4.4 billion KWh annually per nuclear LWR 1000 MWe capacity. In addition, several *critical factors dictate nuclear feasibility* for Egypt. These include:[68] initial capital cost per nuclear plant (maximum feasible capital cost of $2.682 billion in 2008 US$ per 1000 MWe nuclear capacity); discount rate (maximum rate of 13.2 percent); unit nuclear operating cost (maximum operating cost of 6.03 cents per KWh); price of enriched uranium (maximum price to purchase at 0.74 cents per KWe including cost of enrichment);[69] nuclear plant lifetime (minimum plant lifetime of 33 years); nuclear operating efficiency (minimum nuclear efficiency of 28 percent); and nuclear capacity per plant (minimum capacity of 905 MWe per nuclear plant). In short, Egypt's potential for nuclear energy is both feasible and necessary from an economic point of view. However, such feasibility is not universal, but conditional on multiple critical factors that act as bounded constraints on nuclear feasibility concerning planning, implementation and lifetime operation. All the above conclusions are from an economic feasibility point of view. Beyond economics, further study is needed.

## 9. A NOTE ON BEHAVIORAL ECONOMICS IN THE USE OF SOLAR ENERGY IN EGYPT[70]

### Introduction

The behavioral economics literature applies psychology to economics and hopes to more accurately capture such cognitive processes as "mental accounting" (Thaler, 1985) and "overconfidence, optimism, anchoring, extrapolation, and making judgments of frequency or likelihood based on salience (the availability heuristic) or similarity (the representativeness heuristic)", all of which can operate to create suboptimal outcomes (Mullainathan and Thaler, 2000, p. 4). Kahneman and Tversky (1979) apply the descriptive contributions of "prospect theory" to an understanding of "loss aversion", the idea that people are more sensitive to decreases in their well being than to increases – an idea that has powerful implications for public acceptance of policies in the face of uncertainty.

This section aims to address the issue of renewable energy policy in Egypt, a country that is not particularly endowed with fossil fuel reserves (at least relative to its Gulf neighbors), a country with strategic interests in exporting the little it has (particularly in the form of natural gas) for hard currency rather than selling its energy at a subsidized loss domestically. It is a country that says publicly that it would stand to benefit greatly from substitution by local renewable resources. But though the government recognizes the huge comparative advantages it could achieve through active utilization of its renewable energy resources, this country has consistently missed its targets. This is despite private and government initiatives to introduce and promote solar heating systems since 1979 when Jihan Sadat, wife of the assassinated president of Egypt, championed the use of solar hot water by building a successful demonstration project in Munafiyya that is remembered to this day by craftspeople in historic Cairo.

Hansen et al. (2004) report that energy analysts of all perspectives suggest the "likelihood of a significant increase in the cost or a shortfall in the availability of conventional fossil fuel resources by 2030 and perhaps sooner." Yet while Arab policy makers are beginning to talk about using domestic solar energy as a conservation measure to extend the life of and improve the quality of fossil fuels ("solar upgrading") and say they are seeking ways to improve the efficiency of energy usage, Egypt's total surface area of glazed solar collectors is less than that of tiny Belgium, and no subsidies are offered to help businesses or consumers improve the situation. Egyptian Oil Minister Sameh Fahmy told a group of environmentalists (April 3, 2006) that Egypt was going to expand its operations in seeking new gas and oil reserves and countered criticisms that it wasn't moving fast enough to embrace solar energy saying that "the oil ministry is not involved in renewable energy, we have separate entities for that, and we don't want to interfere with their activities", suggesting a lack of coordination between sectors that might be working at cross purposes. For the sake of argument, however, this study will start with the assumption that the Egyptian policy makers are doing everything they can and that the problems lie elsewhere.

### Hypotheses

This study assumes a null hypothesis, *H0*, that the Egyptian government is not putting effective resources behind their stated renewable energy policy. This hypothesis can then be examined against three alternate hypotheses that have been suggested by government officials and private businesses for the failure of widespread adoption of domestic solar hot technologies in Cairo:

(1) The first alternate hypothesis, *H1*, "*the economic argument*", is that solar hot water systems, in material and labor costs, is simply too expensive to be adopted by the average Cairo citizen despite proven long term advantages, and will not make sense until prices for non-renewable energy go up dramatically or prices of renewable energy systems go down.

(2) The second hypothesis, *H2*, "*the spatial infrastructure argument*", is that Cairo lacks the physical infrastructure and thus the resultant agglomeration economies (spatial advantages, lowered transaction costs, non-tradable interdependencies) that would permit an entrepreneurial manufacturing and innovation class to build local capacity and make it feasible for Cairo to tap into its solar resources.

(3) The third hypothesis, *H3*, "*the social argument*" is that there isn't enough awareness in the marketplace of the benefits of solar hot water to create an incentive for the investment in mass production that is necessary to achieve favorable economies of scale, and that there is social aversion to non-universal consumer practices.

**Solar Water Heating**

Solar water heating has a long history in Egypt, home of the Sun-God *Ra*. The pharaohs are known to have captured the sun's heat in black pools of water during the day and then drained the hot water into pipes in the floor of the palaces at night[71], anticipating today's 'green' and 'cost-saving' enthusiasms for "solar hydraulic radiant floor heating" by thousands of years[72]. Islamic scientists in the early 10th century, chief among them philosopher and mathematician, *Abu Ishaq Yusuf AI Kindi*, obsessed with tales of Archimedes saving Syracuse (Sicily) from a Roman siege using solar "death ray" mirrors in 213 B.C[73]., made the study of solar-heat-concentrating optics a major part of their studies in geometry.[74]

John Ericsson, inventor of the iron-clad civil war ship USS Monitor, urged early European industry leaders in 1887 to move to Egypt to capture the sun's heat "where sufficient power can be obtained to enable him to run more spindles than a hundred Manchesters." During the British occupation in the early 20th century, anxieties over the rising prices and shortages of imported coal from Liverpool inspired the creation of The Egyptian Sun Power Company, a joint venture by German-American engineer Frank Schuman and the Egyptians. In 1910 they established the first practical industrial scale solar steam engine run irrigation scheme using a field of parabolic reflectors and water pipes in the Cairo suburb of Maadi[75]. Schuman declared, *"Sun power is now a fact and no longer in the 'beautiful possibility' stage... It will have a history like aerial navigation. Up to twelve years ago it was a mere possibility and no one took it seriously."* Schuman's project, however, ran out of steam during the first world war when the discovery and control of cheap middle eastern oil discouraged continued use of solar hot water[76].

A renewed interest in solar thermal technologies after the Iranian oil embargo of 1979 did eventually lead to at least 10 firms in Egypt locally producing domestic solar hot water systems. In 1994 a European Solar Industry Foundation (ESIF) study[77] claimed:

> "The annual market is around 20,000 square metres and a total of 180,000 square metres of solar collectors have been installed and are in operation particularly in new cities. The government has adopted measures to support market promotion through mandatory use of solar DHW systems in new buildings. In 1986, the New and Renewable Energy Authority (NREA) was established as the main national body for the promotion of Renewable Energy. The same year, local standards for solar water heaters were issued as well as a coded practice for DWH."

The study, concluding that Egyptian oil reserves would peak by 2005, gave the stated Egyptian targets as follows:

> The following results are expected when the target of installing 2,000,000 square metres solar collectors is achieved in the year 2005 or hopefully earlier:

| | |
|---|---|
| Energy production by solar collectors: | *1.100.000* MWh/year |
| $CO_2$ emissions avoided: | *340.000* tonnes/year |
| Creation of new jobs | *17,500* |

The creation of new jobs is based on the estimation that 5 people are needed to produce, sell, install and repair 100 square metres of solar collectors (including storage, supports, etc.) and on the assumption that the yearly production by 2005 will be 350,000 square metres.

Despite ministerial decrees, and despite the creation in 1993 of The Egyptian Renewable Energy Development Organisation (EREDO) for R&D in renewable energy, and despite vigorous policy recommendations that the State rescind its 40% import tax on CIF prices and its 10% VAT (added to both imported and locally manufactured solar components), the State has not changed its incentive structure in the past 20 years and gross profits remain around the discouraging 17.4% instead of the 35% needed to encourage investment and growth in the solar heating sector. Cairo, "the city of the sun", until 2008 is still woefully lacking in any visible or meaningful development of solar thermal technology.

In a paper for Green Markets International, "Solar Water Heating (SWH) as a Climate Protection Strategy: The Role for Carbon Finance", Samuel Milton and Steven Kaufman (2005)[78] note that despite the potential environmental and economic benefits of widespread SWH use, a multitude of barriers still hinder the technology's broader adoption. These generally include high up-front system costs compared to conventional alternatives, a lack of available financing for SWH businesses and consumers, insufficient quality control, and a lack of awareness about the favorable lifecycle economics of SWH technology vis à vis conventional water heaters.

Milton and Kaufman (2005) are particularly optimistic about the Kyoto Protocol's Clean Development Mechanism (CDM) providing the opportunity for carbon trading to support environmental protection and economic development in third world countries like Egypt. But even though the World Bank is now implementing such strategies to stimulate the supply side of SWH (particularly with the Wadi Holdings agro-industrial corporation who manufacture their own solar hot water systems for their farms and factories and laborers), yet on the demand side, use and awareness of SWH is still notably lacking. In spite of face-saving claims by the NREA that "Egypt has performed successful programs for the development of solar thermal technologies and its applications"[79] and Greenpeace Mediterranean spokesman Sven Teske's placating announcement at a recent press conference in Cairo concerning the concentrated solar thermal electric plant in Koraimat that "Egypt is leading the world in exploiting (solar thermal) technology and demonstrating the solar potential of sunbelt regions"[80]; yet there is little real action on the ground, particularly compared to neighboring countries such as Cyprus, Greece, Palestine and Turkey.[81] Egyptian resort hotels in the eco-tourism industry and some state-controlled housing schemes seem to be the only sectors responding aggressively to the "ministerial decree for mandatory use of solar thermal systems for new houses and hotels [that has been] in force since 1986."[82] In fact, most apartment houses in Egypt, especially new housing projects in the desert development region, though possessing flat roofs suitable for SWH, are plumbed, wired and piped for the easy installation of gas and electric on demand heating units. No provision is made for easy use of solar hot water units.

**Remark on the Behavioral Economics Problem of Using Solar Energy in Egypt**

This section has analyzed solar energy policy in Egypt and has tried to identify the different causes for lack of its effective implementation. Although solar energy is clean, renewable, free and perpetually continuous as an energy source, requires simple technology, and can be used with locally available materials, yet its widespread use in Egypt is heavily lacking especially in comparison to other countries within its own region. Multiple dimensions constitute the core causes for this effect. Tables 1 and 2 below summarize a factor-based approach to the three hypotheses outlined in this section as the core causes for this policy failure. The three "hypotheses" are compared to the null hypothesis *H0* which states that the Egyptian government is not putting effective resources behind their stated renewable energy policy. Based on historical facts, the null hypothesis is rejected. Alternative explanations proposed in this section are *H1* "the economic argument", *H2* "the spatial infrastructure argument", and *H3* "the social argument". Based on rationality factors in Table 8, and on relative factor weights given in Table 9, the three hypotheses have the following comparative scores: 1.3, 0.9, and 1.6, respectively. The largest cause is, therefore, the "social argument", followed by "the economic argument". The infrastructure argument is inferior to the other two. In essence, social behavior constraints followed by economic causes constitute the focal dimensions to the lack of widespread solar energy use in Egypt. Solar energy policy failure in Egypt is thus a question of behavioral economics.

**Table 8. Rationality Dimensions**

| *Factor* | *H1* | *H2* | *H3* | *W* |
|---|---|---|---|---|
| Relative absolute cost | +++ | - | ++ | 7/78 |
| Prices | ++ | ++ | ++ | 8/78 |
| Social consensus | +/- | +/- | +++ | 8/78 |
| Knowledge culture | + | +/- | ++ | 2/78 |
| Government policy | +++ | ++ | +/- | 10/78 |
| Infrastructure | +/- | +++ | +/- | 3/78 |
| Short term usage | - | - - | +/- | 3/78 |
| Long term usage | - - - | + | ++ | 8/78 |
| Spatial networks | ++ | +++ | +/- | 5/78 |
| Innovation | +++ | ++ | ++ | 5/78 |
| Economies of scale | ++ | +/- | +++ | 11/78 |
| Awareness | + | +/- | ++ | 3/78 |
| Investment incentives | ++ | + | + | 5/78 |
| | *1.3* | *0.9* | *1.6* | |

*Note: Hypothesis H1, H2, and H3 are compared to the null hypothesis H0. The relative weight of each factor (W) is computed based on the Factor-Causality Analysis found in Table 9 below.*

**Table 9. Factor-Causality Analysis**

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | Sum | W |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Relative absolute cost | X | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 7 | 7/78 |
| 2 | Prices | 0 | X | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 8 | 8/78 |
| 3 | Social consensus | 1 | 0 | X | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 8 | 8/78 |
| 4 | Knowledge culture | 0 | 0 | 0 | X | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 2 | 2/78 |
| 5 | Government policy | 1 | 1 | 1 | 1 | X | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 10 | 10/78 |
| 6 | Infrastructure | 0 | 0 | 0 | 1 | 0 | X | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 3/78 |
| 7 | Short term usage | 1 | 0 | 0 | 1 | 0 | 0 | X | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 3/78 |
| 8 | Long term usage | 1 | 1 | 1 | 0 | 1 | 1 | 1 | X | 1 | 1 | 0 | 0 | 0 | 8 | 8/78 |
| 9 | Spatial networks | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | X | 1 | 0 | 1 | 1 | 5 | 5/78 |
| 10 | Innovation | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | X | 0 | 1 | 1 | 5 | 5/78 |
| 11 | Economies of scale | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | X | 1 | 0 | 11 | 11/78 |
| 12 | Awareness | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | X | 0 | 3 | 3/78 |
| 13 | Investment incentives | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | X | 5 | 5/78 |

*Note: Based on factor-to-factor comparisons, a value of 1 signifies higher priority ranking whereas 0 signifies a lower priority ranking.*

## 10. SUMMARY AND POLICY RECOMMENDATIONS

***(Towards A New Energy And Environmental Policy Using The Structure- Concentration-Incentives Approach)***

The purpose of this section is to provide a summary of critical energy and environmental policy recommendations for Egypt based on the structure-concentration-incentives approach outlined at the beginning of the work followed by a multidisciplinary summary of recommended strategies. It is evident from previous analysis that a new energy policy cannot be separated from a general resource-based environmental policy for Egypt. However, it should be noted that the following constitute suggested targets for achieving energy sustainability for Egypt by 2025:

- **Energy resource gap and energy sustainability can be achieved by 2025.**
- **25% of total energy supply should be clean alternative sources by 2025.**
- **Of these 25%, a minimum of 10% must be based on nuclear energy, 5% recommended by solar energy, and the remaining 10% by other clean non-fossil alternative sources (such as wind, hydro, biofuel etc.).**
- **The long run target for energy sustainability regarding nuclear energy is the year 2050, by which a minimum of 15% energy supply should be nuclear.**
- **Energy growth requirement is 3% annually to 2025.**
- **X-inefficiency for oil is a critical problem which can be technologically solved by meeting a least cost target of $3 per barrel (indexed by 2006 world prices).**
- **Gas economies of scale should be achieved towards a 20% margin coupled with production expansion to 35 billion cubic feet per day by 2025.**
- **Gradual reduction of energy subsidies with complete removal by 2017.**
- **As a consequence of energy subsidy removal, inflation targeting policy must be addressed to minimize 5-7% additional inflationary pressure on the economy.**
- **Solar energy usage is constrained by the problem of behavioral economics and is not an infrastructure argument. Hence, a successful solar energy policy must address social preferences more than spatial infrastructure.**
- **Nuclear energy has conditional feasibility requirements for its implementation:** initial capital cost per nuclear plant at a maximum feasible capital cost of $2.682 billion in 2008 US$ per 1000 MWe nuclear capacity; discount rate at a maximum rate of 13.2 percent annually; unit nuclear operating cost at a maximum operating cost of 6.03 cents per KWh; price of enriched uranium at a maximum price to purchase at 0.74 cents per KWe including cost of enrichment; nuclear plant lifetime at a minimum plant lifetime of 33 years; nuclear operating efficiency at a minimum nuclear efficiency of 28 percent; and nuclear capacity per plant at a minimum capacity of 905 MWe per nuclear plant. Recommended nuclear reactor is evolutionary LWR (Light Water Reactor) as a lower bound.
- **The above requirements are for achieving energy sustainability by 2025, with an expansion to 2050, based on weak sustainability approach to energy resources.**
- **Beyond 2050, energy policy should target semi-strong resource sustainability.**

General environmental policy for Egypt based on the structure-concentration-incentives approach is outlined below.

### Structure

*Compliance*

(1) Movement away from authoritarian command and control policies
(2) Movement towards more flexible environmental permit schemes
(3) Compliance to be engraved in social preferences
(4) Compliance to be based on endogenous grounds
(5) Detailed transparent legislation for non-compliance
(6) Prohibition schemes to be implemented in most critical situations only
(7) Government and public sector compliance to its own rules

*Coordination*

(1) Environmental awareness as a required education curriculum
(2) More media intensity for environmental attentiveness
(3) Align social networks with private incentives
(4) Short-term institutional coordination: carrot and stick approach
(5) Long-term institutional coordination: free choice

*Competitiveness*

(1) Movement from static to dynamic environmental restrictions
(2) Sustaining comparative advantage in natural resource base
(3) Movement towards competitive advantage by continuous sustainability targets
(4) Export promotion of environmentally friendly products
(5) Sacrifice of subsidies towards long run environmental competitiveness

**Concentration**

*Entitlement*

(1) Movement away from universal entitlements
(2) Movement towards target group entitlements
(3) Enhance quality of entitlement even at the partial expense of quantity
(4) Add existence value to the resource extraction mechanism
(5) Legislative cap entitlements on pollution permits

*Functionings*

(1) Public policy should target functionings more than entitlements
(2) Provide target subsidies
(3) Provide preventive measures from the source
(4) Reduce tariffs on environmentally friendly technology
(5) Effective monitoring based on the market mechanism
(6) Enhance Egypt's global functioning by utilizing CDM (Kyoto Protocol's Clean Development Mechanism)

*Industrialization*

(1) Pro-industrialization expansion contingent on flexible environmental compliance
(2) Pro-industrialization in accordance to the dynamics of weak sustainability constraint
(3) Short-term industrial development: constrained path
(4) Long-term industrial development: free path
(5) Enhance technological diffusion of industrial-based environmental processes
(6) Enhance social diffusion of industrial-based environmental products

*Environmentalism*

(1) Upper bound limits on natural resource extraction within the weak sustainability constraint
(2) Lower bound limits on environmental conservation
(3) Pollution concentration regulated, and hence "contained", with progressive timeline of implementation
(4) R&D outlays as a stimulus for green technologies
(5) Short-term resource utilization must include resource savings for future generations and weak environmental compliance
(6) Long-term resource planning should include strong environmental compliance

*Important Benefit-Cost Elements of Assessment*

(1) Tradeoffs are mandatory
(2) No unique solution to sustainability
(3) Trap in "limits to growth" argument
(4) Free choice with environmental incentives
(5) Endogenous economic willingness to pay
(6) Social network diffusion of environmental valuation

(7) Political public policy on institutional coordination
(8) Current benefits of comparative advantage
(9) Future benefits of competitive advantage
(10) Existence value for future generations
(11) Cost of environmental quality degradation
(12) Opportunity cost of emissions reduction

**Incentives**

*Entrepreneurship*

(1) Promote rent-seeking behavior in the environment field
(2) Promote market incentives for environmental entrepreneurs
(3) Promote technology transfer in the short term
(4) Promote local innovation in the short and long term
(5) Associate entrepreneurship with cost reductions in environmental compliance

*Market Liberalization*

(1) Market liberalization as a precondition for environmental sustainability
(2) Support market-based environmental regulation schemes
(3) Support the market bargaining process in environmental conservation
(4) Support new market incentives for renewable technology
(5) Enhance trade liberalization in green services
(6) Enhance transparency in environmental information on local and international levels

*Public Mobilization*

(1) Develop a public opinion valuation for environmental resources
(2) Develop environmental services in mass communication
(3) Develop environmental awareness in younger generations
(4) Extend public mobilization to political decision making

Based on the above recommendations for Egypt, a *multidisciplinary summary of recommended strategies* is given in Table 10 below. It provides implementation measures of general recommendations based on energy and environmental policy dimensions facing the country: *economic, social, political, ecological, technological, and institutional*. It is considered a summary of critical strategies and implementation measures needed for solving the core environmental problems facing our nation.

**Table 10. Multidisciplinary Summary of Recommended Strategies**

| **Dimension** | **STRATEGIES AND IMPLEMENTATION MEASURES** |
|---|---|
| *Economic* | ▪ Strike the right balance in the efficiency-equity tradeoff of environmental resources by endorsement of the Coase method of environmental conservation<br>▪ Move away from authoritarian command and control policies especially inefficient prohibition schemes<br>▪ Promote market-based environmental regulation schemes including environmental permits<br>▪ Incorporate the notion of existence value in environmental policy<br>▪ Minimize grave negative externalities with respect to water, air and solid waste pollution from the source<br>▪ Maintain comparative advantage of natural resources in the short term<br>▪ Manage resource depletion by gradual removal of energy subsidies and incorporation of market prices but with the incorporation of minimum wages<br>▪ Target competitive advantage of natural resource utilization in the long term |
| *Social* | ▪ Create sound environmental awareness to the masses by promoting media intensity towards a clean environment<br>▪ Use celebrities and media campaigns to challenge the status quo and motivate change<br>▪ Develop a new behavioral change towards pro-environmental preferences in new generations through the inclusion of environmental conservation in the education curriculum<br>▪ Promote social network diffusion of environmental awareness by people friendly non-authoritarian methods<br>▪ Achieve better alignment of social networks with private incentives to build a base of environmental entrepreneurs |
| *Political* | ▪ Arab cultural heritage of *Hima* should be applied to environmental protectorates<br>▪ Government and the public sector must not be exempt from regulatory rules of environmental conservation<br>▪ There should be no political exceptions to the rule of law<br>▪ Public policy should target functionings more than entitlements<br>▪ Extend public mobilization to political decision making such that the *Tragedy of the Commons* problem can be minimized by free political choice and endogenous public forces<br>▪ Promote political cooperation in environmental conservation and eliminate inflexible authoritarian regulations |

**Table 10. Multidisciplinary Summary of Recommended Strategies (Continued)**

| Dimension | STRATEGIES AND IMPLEMENTATION MEASURES |
|---|---|
| *Ecological* | ▪ Plan a progressive ecological sustainability path<br>▪ Impose project-based (weak) ecological sustainability constraint in the short term<br>▪ Achieve continuous (strong) ecological sustainability constraint in the long term<br>▪ Enhance Egypt's global ecological position by utilizing CDM (Kyoto Protocol's Clean Development Mechanism) in line with the progressive ecological plan<br>▪ Impose upper bound limits to ecological depletion to achieve ecological balance within Egypt's industrialization-environmentalism dynamics<br>▪ Achieve lower bound limits to ecological conservation by using regulated market schemes such as permits and the Coase method<br>▪ Develop preventive ecological conservation schemes from the source |
| *Technological* | ▪ Promote local R&D for green technologies<br>▪ Promote the usage of environmentally-friendly technology by reducing tariffs or using tax holidays<br>▪ Promote technology transfer via green partnerships with foreign firms and donors<br>▪ Enhance technological diffusion of industrial-based environmental processes<br>▪ Enhance social diffusion of industrial-based environmental products<br>▪ Encourage local innovation, entrepreneurship, and rent seeking in clean technology projects |
| *Institutional* | ▪ Minimize institutional bureaucracy and design more transparent institutional organizations<br>▪ Achieve effective monitoring based on non-authoritarian market based regulation methods<br>▪ Implement prohibition regulations in most critical emergency situations only<br>▪ Implement transparent non-compliance standards with no institutional or stakeholder exceptions<br>▪ Promote institutional research of environmental problems on the ground<br>▪ Develop and enhance institutional coordination based on environmental compliance targets and regulations |

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## ENDNOTES

[1] Tarek H. Selim is Associate Professor of Economics at the American University in Cairo and Faculty Affiliate to Harvard Institute for Strategy and Competitiveness. He has published extensively in leading international journals and conferences. His research output includes more than sixty research articles and book reviews, and he won his school's research excellence award in 2006. Professor Selim has PhD in economics from George Washington University, MBA from Johns Hopkins, and holds professional certificate programs from MIT, Harvard, Georgetown, Oxford, and Imperial College. His most recent book publication has been *Egypt, Energy and the Environment: Critical Sustainability Perspectives*, Adonis & Abbey (UK) Publishers, London, 2009.
[2] For more concrete examination, please refer to Selim, T., Egypt, Energy and the Environment: Critical Sustainability Perspectives, Adonis and Abbey (UK) Publishers, London, 2009. Chapters 2, 16, and 17.
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[4] See Chapter 6 of Selim, T., Egypt, Energy and the Environment: Critical Sustainability Perspectives, Adonis and Abbey (UK) Publishers, London, 2009.
[5] Refer to previous note.
[6] Refer to previous note.
[7] See Chapters 6 and 7 of Selim, T., Egypt, Energy and the Environment: Critical Sustainability Perspectives, Adonis and Abbey (UK) Publishers, London, 2009. Also see Chapter 8 on alternative energy use (solar energy).
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[17] See Chapter 16 of Selim (2009) for an application of the tragedy of the commons to Wadi Degla Protectorate.
[18] See Chapters 4, 10, and 14 of Selim (2009) for more specific topical analysis on wildlife conservation, industrial ecology, and comparative biodiversity.
[19] See Chapter 9 of Selim (2009) for a more thorough analysis of solid waste management with recommendations for Egypt.
[20] See Chapters 5 and 15 of Selim (2009) for specific analysis on marble quarries depletion and ecotourism sustainability, respectively.
[21] Adapted from research developed for the Egyptian Center for Economic Studies (ECES): "On Efficient Utilization of Egypt's Energy Resources: Oil and Gas", ECES Working Paper No. 117, 2007.
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[27] 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.

[28] Price elasticities are based on real prices (indexed by consumer prices over time) from 1991.
[29] Energy/GDP impact of 0.5 is decomposed into the respective elasticities of oil and natural gas

$$0.3\eta^{oil} + 0.9\eta^{gas} = \eta^{energy} = 0.5$$

[30] Am Cham (2003).
[31] AmCham (2003).
[32] This actually took place. The forecast is based on historical data prior to 2007.
[33] Adapted from research developed for the Egyptian Center for Economic Studies (ECES): "On Economic Feasibility of Nuclear Power Generation for Egypt", ECES Working Paper No. 143, 2009.

[34] IAEA (2007).

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[42] kWh: Kilo-Watt Hour of Electricity (in 1,000 Watt-Hours of Electric Work)

GWe: Gega-Watt of Electricity (in billions of Watts of Electric current)

MWe: Mega-Watt of Electricity (in millions of Watts of Electric current)

[43] IAEA (2007).

[44] WNA (2007).

[45] NPPA (Nuclear Power Plants Authority), personal correspondence.

[46] The forecast in this section is based on projections related to the country's population growth rate, GDP growth rate, industrial production growth, income growth rate and productivity increases. The main approach is based on historical data (1980-2007) and "business as usual" scenario, which provides a conservative scenario leading to minimum levels of electricity generation for Egypt's future.

[47] The historical data of 1980-2007 is based on actual supply-demand balance, whereas subsequent forecasts are based on the conservative scenario outlined in the previous footnote.

[48] Factor decomposition uses the following equation for growth in *TC* (per capita electricity consumption) decomposed by the following contributing factors: population (*H*), GDP production (*P*), income (*I*), and productivity (*R*): $\left[\frac{\Delta TC}{TC}\right] = \alpha\left(\frac{\Delta H}{H}\right) + \beta\left(\frac{\Delta P}{P}\right) + \gamma\left(\frac{\Delta I}{I}\right) + \eta\left(\frac{\Delta R}{R}\right)$.

[49] These forecasts are based on the conservative assumptions outlined earlier and hence provide a "bare minimum" estimate. This economic analysis is a precondition for developing critical "break-even" feasibility criteria in the next two sections. It has also been mentioned to the author through personal correspondence with the NPPA that the minister of electricity spoke about possible supply in excess of 52 GWe by 2027. The minister's future prospects fall within the feasible economic criteria derived in this paper.

[50] Please note the assumptions mentioned based on the conservative scenario.

[51] Based on required nuclear energy supply in Table 5. This is in conformance to the recommended nuclear technology for Egypt found in MIT (2003) and IAEE (2007). Evolutionary LWRs may become feasible in the future including Generation III/III$^+$ nuclear power plants, such as ABWR, AP1000, EPR, HWRs, GCRs and FBRs. The latter is based on feedback from Egypt's Nuclear Power Plants Authority (NPPA), written correspondence.

[52] Progressive installation of nuclear plants for developing countries and their dates vary. Examples of waiting periods between different installations include Mexico (1989, 1994), Brazil (1987, 1991), Bulgaria (1987, 1991) and Romania (1996, 2007). Similar progressive timelines have been applied in Pakistan, India and Argentina (WNA 2005; IAEA 2007; IAEE 2007). The exception to this is South Africa (1983, 1984), which has installed graphite nuclear technology built by the UK under the apartheid regime. An alternative *sliding* approach to nuclear plant installation has been implemented by advanced economies such as Sweden, Canada, France, UK, Japan, Russia, Germany and the US.

[53] Using Break-Even Analysis for the maximum feasible capital cost.

[54] LWR nuclear plants have an added terminal life "decommissioning cost requirement" where both low-level waste disposal fees and the amount of labor required to perform specific tasks comprise the two largest portions of estimated decommissioning costs. Consequently, a 1000 MWe LWR nuclear plant would require an additional $350 million at its terminal life of 40 years.

[55] This is based on the present value feasibility criterion with annuity of cost-benefit differentials between nuclear and thermal power plants, and also includes the added LWR nuclear decommissioning cost requirement at the terminal life. Comparative efficiency is also factored in using $\eta_X$. Capital costs are $K_N$ (nuclear) and $K_T$ (thermal). Environmental costs are omitted but do not affect the general conclusions since nuclear technology is more environmentally friendly but also carries the risk of nuclear leakage.

[56] The above break-even analysis does not include environmental costs. Nuclear technology is generally deemed more environmentally friendly and carbon-free although it involves the continuous risk of nuclear leakage.

[57] Technically, the NPPA has provided the author with the corresponding "capacity factor" for $X_{BE}$ as 51.6 percent, given that a capacity factor of 75 percent is typical for a base-load generation unit. Hence, in addition to economic feasibility, the derived critical value is technically feasible. Actual implementation would yield a capacity factor in excess of the critical value.

[58] Includes cost of enrichment.

[59] EPC cost: overnight capital cost (engineering, procurement and construction).

[60] Per capita electricity annual consumption growth of 4.17 percent is indexed by historical population growth (2.4 percent) and GDP elasticity (1.23) for an energy supply growth (stock growth rate) of 8.08 percent annually.

[61] All economic figures are in 2008 US dollars unless otherwise specified.

[62] International estimates are at 4.2 cents per KWh for nuclear operational expenses (IAEE 2007; EIA 2007; Kristiansen 2007).

[63] Includes cost of enrichment. The price of uranium is based on the international uranium market. The average price of enriched uranium for the past two years has been in the range of 0.515 cents per KWe but with 3 percent price volatility (Kristiansen 2007). The cost of enrichment itself is a portion of this price and has been estimated to be between 37 to 40 percent of the price (Kristiansen 2007; MIT 2003). During the past two years, the cost of enrichment stood at 0.19 cents per KWe (Kristiansen 2007).

[64] Normal nuclear power plant lifetime with LWR nuclear technology is 40 years (WNA 2005; EIA 2007; IAEE 2007).

[65] Normal nuclear operating efficiency for LWR nuclear cycles is 33 percent (WNA 2005; EIA 2007; IAEE 2007).

[66] The expected range for Egypt is 4.75-4.95 billion KWh per year (see Table 7).

[67] The common (average) nuclear output for LWR nuclear power plants is 1000 MWe per plant. This may change in the future especially when evolutionary LWRs become more widely operational.

[68] All economic figures are in 2008 US$ prices unless otherwise indicated.

[69] Estimated cost of enrichment is 0.19 cents per KWe nuclear output.

[70] Co-authored by T. H. Culhane, *Department of Urban Planning University of California in Los Angeles (UCLA)*

[71] <http://www.ecomall.com/solar.htm>

[72] <http://www.backwoodshome.com/articles/hackleman64.html>

[73] <http://web.mit.edu.nyud.net:8090/2.009/www/lectures/10_ArchimedesResult.html>

[74] <http://www.trmkt.com/902manu.html>

[75] <http://html.rincondelvago.com/tipologia-de-energias-alternativas.html> <http://habitat.aq.upm.es/boletin/n9/amvaz.html>

[76] Habitar el Desierto, Segunda Parte <www.tdx.cesca.es/tesis_upc/>

[77] <www.solar.demokritos.gr/market/egypt.doc>

[78] Water heating typically represents a high percentage of energy consumption in homes and businesses, in some cases 30% or more. When SWH systems supplement or replace conventional water heaters they displace some or all of the fuel that would have been used in those systems. While carbon intensity of baseline fuels for water heating varies, it is generally high in many locations. Consequently, emissions of greenhouse gases and other pollutants are reduced, helping to mitigate climate change while often improving local air quality, and sometimes indoor air quality as well. Solar water heating contributes to economic development in a number of ways. For example, without the need for highly capital-intensive manufacturing equipment, SWH systems are

made in many developing nations, small and large alike. As such, substantial new job opportunities in manufacturing, retail sales, and business administration, as well as system design, installation, and maintenance can result from greater adoption of SWH technology. Additional local economic benefits include substantial savings of conventional fuel costs, with payback periods of three years or less in some locations. Despite the potential environmental and economic benefits of widespread SWH use, a multitude of barriers still hinder the technology's broader adoption. These generally include high up-front system costs compared to conventional alternatives, a lack of available financing for SWH businesses and consumers, insufficient quality control, and a lack of awareness about the favorable lifecycle economics of SWH technology vis à vis conventional water heaters. Emerging markets for international trade in GHG reduction credits offer important opportunities to overcome barriers and help advance SWH technology. Since global efforts to fight climate change began in earnest, GHG trading has been considered a practical way to control emissions while enabling compliance flexibility and cost efficiency to participants. Today, numerous voluntary and regulatory GHG trading programs are in operation. Furthermore, with the Kyoto Protocol's CDM standards entry into force, the market is now expanding more rapidly than ever. For developing nations, the Kyoto Protocol's Clean Development Mechanism (CDM) provides the opportunity for carbon trading to support environmental protection and economic development. The CDM enables trade in GHG reductions between developing and industrialized nations for activities that contribute to sustainable development.

[79] <http://www.nrea.gov.eg/solar_energy.htm>

[80] <http://www.greenpeace.org/international/press/releases/greenpeace-report-proves-solar>

[81] By 1995 Egypt had 18,000 meters squared installed with an annual market of 20,000 meters squared. By the year 2000, some 900,000 meters squared of glazed solar collectors were in use in Europe, almost half of them in Germany. Adding Austria and Greece accounted for just over 75% of the installations. Strongest growth in Europe is expected to come from Germany and Italy followed by France, Netherlands, Portugal, Spain and the UK.

For comparison:

| | |
|---|---|
| China | 4 million |
| India | 2 million |
| Japan | 1 million |
| Europe | 890,000 |
| South Korea | 500,000 |
| Turkey | 430,000 |
| Israel | 400,000 |
| USA | 25,000 |

Source: <http://www.solarbuzz.com/consumer/solarthermal.htm>

[82] 1994 ESIF study: <www.solar.demokritos.gr/market/egypt.doc>