Global Impact of Energy Use in Middle East Oil Economies: A Modeling Framework for Analyzing Technology-Energy-Environment-Economy Chain

By

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1. INTRODUCTION

No other region in recent history has been as prominent as the Middle East in the world's energy debate. Increased awareness about issues of sustainability of current development patterns, fierce competition in a global economy, concerns about global climate change, and the looming end of an era of cheap energy have intensified debate on fossil fuels and the volatile region of the Middle East. There is an extensive body of literature on the security of supplies and flow of energy from the Middle East, but much less attention has been paid to the region as a consumer of energy.

Oil and gas rich countries of the Middle East have among the highest per capita energy consumption and, peculiarly, energy intensity has been rising only in this region. Abundant and cheap oil and gas supplies in these countries have led to a concentration of energy intensive and inefficient industries and promoted a wasteful energy consumption pattern in transportation, commercial and residential sectors. With growing economic interdependence, an increasingly globalized energy market and environmental issues, the structure of the economies and energy consumption pattern in oil and gas rich countries of the Middle East has significant global implications. Recent studies emphasize the need for improvements in energy efficiency as an important short-term strategy for reducing carbon emissions while waiting for more capital-intensive responses to come on line in the longer term.

To explore choices of improving energy efficiency in energy-rich countries of the Middle East, this study lays out an integrated modeling framework for analyzing the technology-energy-environment-economy chain for the case of an energy exporting country. This framework consists of an input output process-flow model (IOPM) and a computable general equilibrium (CGE) model. The former investigates the micro-level production processes and sectoral interdependencies to show how alternative technologies affect the energy intensity of the economy (Lin, Polenske 1998 and Polenske, McMichael 2002). The latter belongs to the optimal depletion category of CGE models that analyzes energy economy interaction; it is an optimization model that solves the inter-temporal resource depletion problem subject to the workings of a multi-sector market economy, where relative prices play a crucial role (Ghadimi 1995, 2006). Such a formulation provides a systematic framework for analyzing the technology-energy-environment-economy chain in resource-rich developing countries. The main focus of this paper is to describe the theoretical structure of the class of CGE model proposed for this modeling framework.

The next section briefly discusses the important global energy-environment concerns, highlights the significance of the Middle East to the world energy, and points out research questions in energy exporting countries of the region. Section 3 introduces the proposed modeling framework consisting of a micro-level *input output process model* (IOPM) and a macro-level CGE model. Section 4 describes the optimal depletion CGE model which is the core component of the macro-model and the following section provides a detailed discussion of the theoretical structure of this class of models. The paper concludes with few remarks.

2. ENERGY-ENVIRONMENT CHALLENGES

In an increasingly interdependent world, the technology-energy-environment-economy interplay presents very distinct challenges. Major concerns at the global level are the issues of environmental degradation and threat to the future of mankind as a result of the growing population and rapid increase in energy consumption, particularly in developing countries. The Energy Information Administration (EIA) estimates that, by 2030, global energy consumption will grow by over 70 percent, and the International Energy Agency (IEA) predicts that developing countries, led by China and India, will account for more than 70 percent of the estimated 53 percent increase in global primary energy demand by 2030.[1] The United States, China, and India together will account for half of the projected growth in world oil demand, most of which is expected to flow from the Middle East.

There is an intensified debate about energy running out and the approaching end of the fossil-fuel era; at the same time there is a serious concern about climate change induced by increased atmospheric concentrations of greenhouse gases generated by consumption of fossil fuels. Fundamental questions about environmental consequences of energy production and consumption patterns and policies to ensure economic and environmental sustainability have recently led to wide and extensive research in these areas. Notable efforts include studies conducted by international programs such as the Intergovernmental Panel on Climate Change (IPPC)[2], academic institutions in the US including the Stanford Energy Modeling Forum (EMF)[3], the MIT Joint Program on the Science and Policy of Global Change[4], and European initiatives like the Alliance for Global Sustainability[5], an international partnership between science and technology

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[1] International Energy Agency (IEA), World Energy Outlook 2006.
[2] See http://www.ipcc.ch/. Much anticipated "Climate Change 2007" the IPCC 4th assessment report will soon be released.
[3] See http://www.stanford.edu/group/EMF/publications/index.htm.
[4] See http://web.mit.edu/globalchange/www/reports.html.
[5] See http://globalsustainability.org/content.cfm?uNav=302&uLang=1.

universities. The gist of a general observation by these studies is reflected in the excerpt from the Strategic Plan of the U.S. Climate Change Technology Program as:

> "…among the more significant factors expected to drive future GHG emissions growth are demographic changes (e.g. regional population growth), social and economic development (e.g., gross world product and standard of living), fossil fuel use (i.e., coal, oil, and natural gas), and land use changes. The most important factors limiting increases in future GHG emissions include improvements in energy efficiency; increases in nuclear, renewable, and non-CO2-emitting fossil energy supply; decreases in GHG emissions from industry, agriculture, and forestry; and rapid technological change that results in reducing GHG emissions[6]".

This observation clearly underlines the need for comprehensive frameworks to adequately understand and analyze complex energy-environment issues ranging from technological to socio-economic factors at the national, regional, and global levels.

Energy is the fundamental input for economic development, but energy consumption accounts for approximately 80% of global GHG emissions. The answers to challenges lie in both energy and environmental policies on a global scale. Global warming and the looming depletion of fossil fuel resources will increase the cost of energy in the long run. There is a general consensus that energy efficiency policies are the first viable response to reduce energy demand[7]. The main energy consumers had the highest share in energy intensity (energy consumption per unit of output) decline at the world level as it decreased by an average of 1.5% per year since 1980. In contrast, the Middle East, the major energy exporting region of the world, witnessed a steady increase in energy intensity for the same period - a phenomenon with grave long term implications for global energy security, affordability, and the environment.

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[6] U.S. Climate Change Technology Program, Strategic Plan, September 2006, page 28.
[7] Since 1990 energy efficiency improvements reduced energy demand in 2002 by 20%.

The significance of the Persian Gulf countries of the Middle East as a major supplier of world energy (about 60% of the world's crude oil reserves and 45% of total proven world gas reserves) is well established[8], but the significance of the region as a user of energy is not well studied or understood. The IEA predicts that due to rapid population growth and heavy subsidies[9] the demand for energy will more than double in MENA countries by 2030, with Iran and Saudi Arabia as the biggest contributors, accounting for 45% of total demand[10]. Energy intensive industries in the region may enjoy a comparative advantage, but abundant energy and often heavily subsidized prices has led to inefficient production and has promoted wasteful energy consumption in transportation, commercial and residential sectors. According to IEA reports the Middle East share of CO_2 emissions has increased from 1% in 1973 to 4.5% in 2004, while for the same period, the OECD share has declined from 65.9% to 48.6%.[11] Over the period of last 30 years, China, while experiencing remarkable growth, has reduced its energy intensity, whereas in Iran it has been rising (Polenske 2004). The pattern of energy use in energy-rich countries of the Middle East not only determines the sustainability of development there, it has far greater implications for the security of world energy supplies and for global climate change. Rapidly increasing domestic energy requirements in these economies will seriously curtail their capacity to export to a world with a

[8] In 2003, the Persian Gulf countries (Bahrain, Iran, Iraq, Kuwait, Qatar, Saudi Arabia, and the United Arab Emirates) produced about 27% of the world's oil, while holding 57% (715 billion barrels) of the world's crude oil reserves. OECD gross oil imports from Persian Gulf countries averaged about 11.6 million barrels per day (bbl/d) during 2003, accounting for 46% of the OECD's total net oil imports. Besides oil, the Persian Gulf region also has huge reserves (2,462 trillion cubic feet -- Tcf) of natural gas, accounting for 45% of total proven world gas reserves. http://www.eia.doe.gov/emeu/cabs/Region_me.html

[9] Subsidies on oil and energy in general in non-OECD countries are far higher than in OECD countries. Iran and Indonesia together subsidize oil more than the OECD subsidies energy in total. http://www.iea.org/textbase/papers/2006/oil_subsidies.pdf

[10] http://www.iea.org/textbase/papers/2006/birol.pdf

[11] http://www.iea.org/textbase/nppdf/free/2006/key2006.pdf

growing thirst for fossil fuel energy. The current consumption pattern and high energy intensity in the region will continue to increase the region's share in global GHG emissions.

There are two groups of interesting research questions in the case of energy exporting countries of the Middle East. The first deals with the structure of the economy and current energy consumption pattern affects sustainable development at national levels. The second deals with international effects of national energy-environment-economy policies. Among the first group of questions are:

- What factors account for high energy intensity in the economy?
- How does the structure of the economy and production technologies affect energy consumption patterns?
- How can energy-efficiency/energy-intensity/energy-productivity be improved?
- How has the sectoral energy consumption share evolved in recent decades and how are these changes related to the stage of economic development in the country?
- How does the domestic energy consumption pattern affect the long term sustainable development path?
- How does international energy price level affect the domestic economy?
- Is concentrating energy intensive industries an advantage for these countries? If so, how big is this advantage and how long will it last?
- In the face of profound political attention on nuclear energy production in this region, does investment in non-military nuclear energy production make sense economically?

The second group of questions includes the following:

- How does the energy consumption pattern, based on specific technologies and economic structure, affect world supply of fossil fuels and global climate change?
- How significant are these effects in the long run?
- What are the domestic, regional, and international economic impacts of resource depletion?

3. THE PROPOSED MODELING FRAMEWORK

There has been resurgence in developing sophisticated integrated models to investigate one or more aspects of the technology-energy-environment-economy spectrum. Policy makers need advice to determine which actions should be taken to reduce the environmental impacts of economic activities. Modeling has proven to be a cost-effective way to avoid costly policy mistakes. Some models (see for example Lackner and Sachs 2005) consider sustainability at the scale of man-kind and time scale of up to a century and have focused on the optimal mix of energy resource use and the costs and benefits of environmental mitigation. These global models are very long-term and their focus is on environment and related global issues such as Kyoto Protocol and carbon tax. Other models focus on energy-environment related issues in a socio-economic context (see for example Jorgensen, Dale W. and Peter Wilcoxen. 1991., McFarland, et al 2004., Metcalf 2006). Polenske (2005) has developed the technology-energy-environment-health (TEEH) chain, a concept focusing on the technological and other factors contributing to the rapid decline in energy-intensity in the industrial, household, and township and village sectors in China and the related pollution and health effects.

Many long-term models at the national level focus on the impact of changing energy supply conditions, depletion of nonrenewable resources, analyzing changes due to the penetration of new technologies, and the emergence of alternative energy sources. A more recent class of these energy-economy models is computable general equilibrium (CGE) models, based on general equilibrium theory and the neoclassical theory of economic growth (basic references are Hudson and Jorgenson 1975, and Manne 1977). Studies using the CGE approach to energy-economy interaction at the national level are numerous: Hudson and Jorgenson (1974) for the US, Lars Bergman (1986) for Sweden, and Longva and Olsen (1983) for Norway, and Dellink and van Ierland (2006) for the Netherlands. These models focus on the environment as well as energy and the economy but their main emphasis is on issues of national energy supply, security, and reliability in the developed countries and on issues of depletion and investment in developing countries.

Scientists and engineers are constantly studying multifaceted overlap of knowledge-energy spheres in trying to achieve higher energy efficiency from the scale of small machines to that of complex production and transportation systems at national and global levels. Improving energy efficiency requires dramatic changes in the way we work and live, changes in the ways we produce, access, and use goods and services over time and space. An important strand of literature extends input output and *structural decomposition analysis* (SDA), and *input output process models* (IOPM) to link the production technologies and detailed interdependencies of various sectors to overall economic performance. This framework is particularly appropriate in the environmental arena where, as environmental and natural resource issues become more prominent and serious, there is a greater need to look at the root causes of pollution and resource depletion

The proposed modeling framework builds on the research on IOPM and CGE models to present an integrated two-step model to cover the technology-energy-environment-economy (TEEE) chain in a resource-based energy exporting country. The integrated model will be applied to a case of an energy-rich country in the Middle East, to analyze the energy intensity and energy consumption pattern at a detailed micro-level, and the macro-level regional and global economic and environmental implications of such pattern. At the micro-level the adopted IOPM provides a detailed and disaggregated representation of the economy and traces the way in which various structural and technological factors have led to rise in energy intensity. The results are then used as base year data for the calibration of a *dynamic optimal depletion CGE model*, the core component of the macro-model, which portrays the interdependence of the energy sector and the rest of the economy. The next section introduces the dynamic optimal depletion CGE model in more detail.

4. AN OPTIMAL DEPLETION CGE MODEL

The models commonly referred to as "applied general equilibrium models" (AGEM) or "computable general equilibrium" (CGE) are large multisectoral, economy-wide nonlinear equilibrium models that are closely related to the Walrasian model of a competitive economy. "General equilibrium" typically refers to the Walrasian competitive equilibrium model where all economic agents are price takers who maximize profits or utility, and prices freely adjust to clear markets. This framework simply implies that supply equals demand. CGE models attempt to incorporate the fundamental linkages among production structure, pattern of demand and incomes of various institutions.

CGE models are essentially applied general equilibrium models. With advances in solution algorithms and computing power these models have proliferated in recent years. The availability of data and development of powerful yet low cost computers have made CGE models very attractive tools, particularly for addressing complex economy-wide issues. There is a growing trend toward the use CGE models for policy analysis both in developed and developing countries.

An important category of CGE models focuses on the relationship between the energy sector and the rest of the economy. These models offer a rich economy-wide picture but are not as detailed as the partial equilibrium within-sector energy models in their specification of the energy sector. The early references to this class of models include Hudson and Jorgenson (1975), Manne (1977), and Blitzer and Eckaus (1986). More recent examples include, Blitzer et al. (1990), Jorgenson and Wilcoxen (1990 and 1991), and the MIT Emissions Prediction and Policy Analysis (EPPA) model described in Babiker et al (2001). This latter category of models is extremely useful in the case of resource-based economies where the changes in the rest of the world prices and environmental policies, or changes in the extraction levels of resources, have profound impacts on the workings of the domestic economy.

Devarajan (1988) sketches out the formal structure of a class of models called *optimal depletion CGE models* and presents some results from the application of these models. Ghadimi (2006) presents a dynamic CGE model for analysis of exhaustible resources implemented for the case of an oil exporting developing country. The macro-level model proposed in this study belongs to the optimal depletion category of computable general equilibrium models. It is an optimization model that determines the optimal development path of the economy, hence, the inter-temporal depletion problem subject to workings of a multi-sector market economy. Such a formulation establishes general equilibrium linkages between the depletion profile of the resource and the rest of the economy by working through both factor and product markets.

The model consists of an intra-temporal price endogenous multisectoral model of a market economy, embedded in an inter-temporal optimal growth and development model. This general equilibrium approach allows capturing the economy-wide and sectoral distribution effects of resource depletion.

5. THEORETICAL STRUCTURE OF OPTIMAL DEPLETION CGE

This section presents an overall theoretical structure of the model through a discussion of the nature of the economic institutions or "actors" in the economy and the way in which they interact. The four major actors are: producers, households, government, and the rest of the world. Figure 1 depicts an economy-wide circular flow of income and provides an overall picture of links between actors in the economy. It should be noted that the model ignores the monetary side of the economy; the capital market or the financial sector acts only as a "savings pool", where all savings in the economy are collected and are channeled to real investment expenditure. The following sections provide a detailed discussion of the main institutions of the economy.

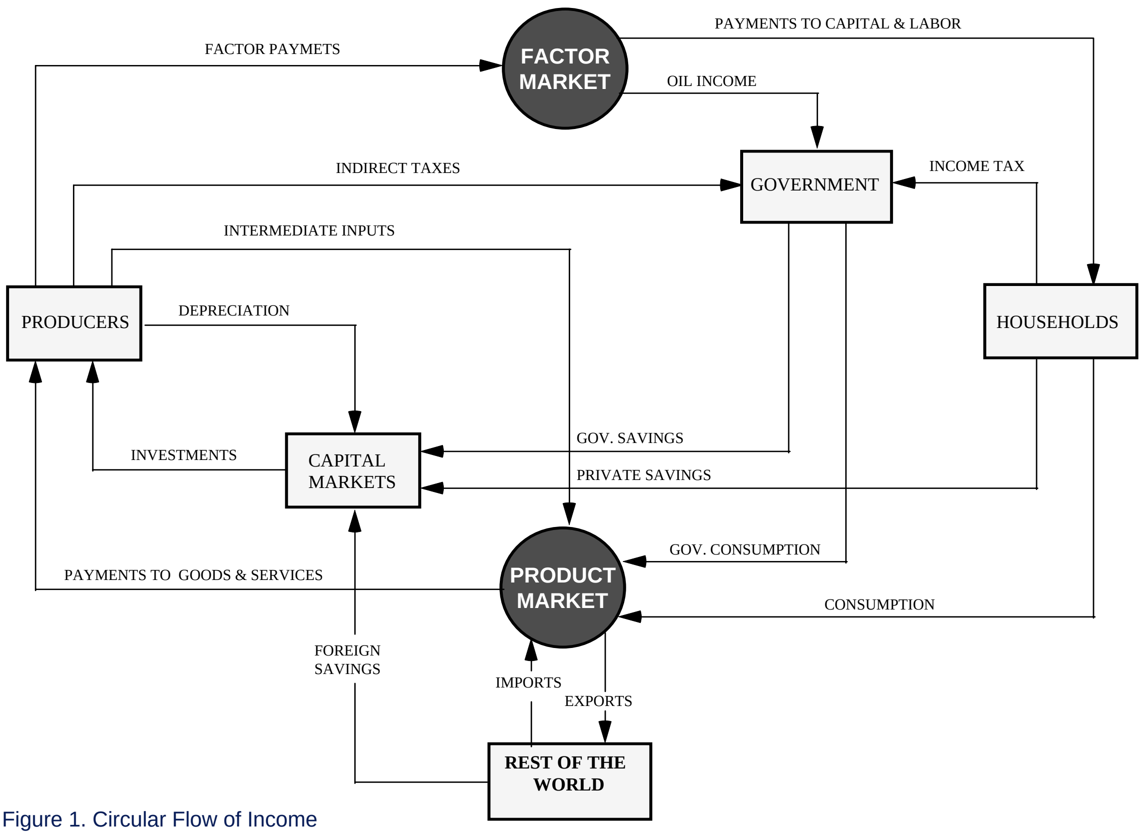

Figure 1. Circular Flow of Income

5-1 Producers

Producers are industries or sectors of production of the economy. The terms sector, producer, and firm will be used interchangeably throughout the study.[12] Each

[12] The functional forms used in this study exhibit constant returns to scale, therefore, there is no meaningful distinction between "firm" and "sector".

sector is assumed to behave as a single representative firm producing a single homogenous good. There are four sectors in the economy of which one extracts the non-renewable resource of oil. This sector is called the "oil sector" and the remaining sectors will sometimes be referred to as "non-oil sectors". The outputs of producers may be consumed domestically, used as material inputs in the production of other goods, or be exported.

There are three factors in the economy: man-made capital or "capital" for short, a natural capital or "resource", and labor. Households own capital in non-oil sectors and labor; government owns both physical and natural capital in the oil sector. All sectors employ capital, labor, and intermediate inputs in their production processes. It is assumed that intermediate inputs are demanded in fixed proportions to the level of gross output while the production technology for the primary factors is described by neoclassical constant returns to scale production function. The oil sector also is assumed to have a fixed coefficient demand for intermediate inputs and employs a combination of physical and natural capital along with labor to extract the exhaustible resource oil.

The behavior of all firms (sectors) is assumed to obey a profit maximization rule. Given wage rates and rentals on capital, they decide on the input factor rates that maximize their profits. Aggregation of sectoral factor demands determines the total demand for primary and intermediate inputs. Supplies of goods and services, given the availability of factors, are determined by the production technology of the firms.

As shown in Figure 1, producers make payments for their primary inputs to the owners of factors. They also pay other production sectors for using their products as intermediate inputs. Other outlays of the producers include depreciation expenditure, which goes to total savings pool, and indirect taxes, which are collected by the government. Producers receive payments by the households, government, and rest of the world when they purchase goods and services in the product market. Inflow of funds from savings pool augments the production capacity of the firms for future production.

5-2 Households

There is a single representative household in the economy which owns capital in non-oil sectors and labor. This household, as is illustrated in Figure 1, supplies factor services and receives payments made for them.

The household provides a fixed amount of labor, assumed to be an aggregation of various skill categories, and receives factor payments for that labor. Competitive profit-maximizing behavior assures that the nominal wage rate equals the value of the marginal product of labor. The household is also owner of the man-made capital and receives payments made to capital. There exist potential factor market distortions in the economy, so wage rates and capital returns may vary across sectors.

The household can either save or consume its income. The consumption of the household, however, follows a fixed pattern, that is the household spends a fixed portion of its income on the goods of each sector. In other words, the sectoral private consumption shares are constant. This specification is a simplified version of linear expenditure system and implies unit income and price elasticities of demand. These assumptions may be too restrictive for the long term, where the share of total consumption expended on certain goods might rise (or decline) in the course of development. However, we retain this simple demand structure to avoid unnecessary complexity introduced by a more elaborate specification.

5-3 The Government

The government earns its revenues through direct and indirect taxes, tariffs, and revenues from the oil sector. Tax and tariff rates are assumed to be exogenous and fixed over time -- we could vary these rates but we chose to focus on oil sector as the major constraint of development policy. The oil revenue is the total value added of the oil sector less the wage bill. The government's total expenditures are a fixed proportion of GDP and include purchases of goods and services from producing sectors on a fixed share basis. The net savings of the government is the residual of its revenues less its expenditures. The government participates in the capital market through lending and borrowing. It lends when it has a budget surplus and borrows when it has a budget deficit.

The government is assumed to be a benevolent selfless entity that is motivated solely by social welfare. It strives to balance its expenditures with its non-oil revenues and to channel its revenues from the exhaustible natural capital to augment man-made capital in the non-oil sectors of the economy.

The role of government in the dynamic behavior of the economy is extremely crucial. One important feature of the present model is its explicit treatment of the dynamic inter-period market equilibrium. Market forces establish a one-period equilibrium, or more precisely, a sequence of one-period equilibria. Social planners, on the other hand, determine the long run dynamic behavior of the economy by maximizing an inter-temporal social welfare function subject to constraints implied by competitive within-period equilibria and the total availability of the exhaustible resource.

At the intra-temporal level, the representative household offers a fixed amount of labor and capital on the market and government offers its exhaustible resource. Given prices of factor services and commodities, demands for and supplies of commodities and factor services are determined. These prices adjust to establish equilibrium between demands and supplies. However, at the inter-temporal level the behavior of the system is determined by attaining the optimal rates of resource extraction, household savings and sectoral allocation of investment. Given the market price of oil and a predetermined social rate of discount, the government, as the owner of the oil resource, determines the optimal rate of resource depletion and through its tax policies influences the household's savings decisions. Optimal investment allocation requires that the more productive and profitable sectors of the economy receive a larger share of total investment funds.

5-4 The Rest of the World (ROW)

The rest of the world is linked to the model through exports, imports, and foreign borrowing. There are a number of important international trade issues. There are two extreme and opposing assumptions underlying the treatment of foreign trade in the development planning literature: perfect substitution and perfect complementarity. The perfect substitution assumption maintains that products are not differentiated by their country of origin. As a result, a given product has the same price whether it is imported or produced domestically. Clearly, the perfect substitution assumption is far removed from what is observed in the real world, where domestic and foreign prices are seldom equal. Moreover, this assumption greatly overstates the role of trade policy in determining domestic prices. Another problem associated with the assumption of perfect substitution is that it results in over-specialization of countries in those sectors for which the domestic economy enjoys a comparative advantage, with no home production in other sectors.

Perfect complementarity, on the other hand, assumes that foreign goods and domestic goods cannot be substituted for each other at all, in other words, they have a zero degree of substitutability. This assumption understates the role of trade and exchange rate policy and introduces a great deal of unnecessary rigidity in the model.

The model analyzed in this study uses an intermediate specification of foreign trade that has become standard practice in nearly all developing country CGE models. This formulation, first formally used by Armington (1969) in his partial equilibrium analysis of import demand, allows some form of differentiation among products by their country of origin. This approach treats domestically produced goods and imported goods as imperfect substitutes. In other words consumers can choose between imports and domestic goods that are not identical. The price of domestic products can deviate from that of the imported products to the extent that the users do not find them substitutable. Analogously, imperfect transformability is assumed on the export side. This specification allows divergence between the domestic price of exports and their world prices.

6. CONCLUSION

Expanding populations, steady economic growth, energy-intensive industrial orientation, and heavy subsidies will continue to drive up energy demand in the Middle East. The technology-energy-environment-economy (TEEE) chain interaction in the region has profound national, regional, and global implications for the future energy scene and the environment. An integrated modeling framework covering the complex and interacting TEEE chain proposed in this study can help identify ways of making the transition from the present inefficient energy systems to a sustainable energy future in a region critical to global energy and environment.

A distinctive feature of computable general equilibrium models is that they can be used to measure changes in the domestic economy under alternative policies. These models produce detailed information on prices and quantities at the sectoral level. Therefore, this model can capture economy-wide impact of any change in the intersectoral relationships, production technology and, particularly, changes in the domestic energy production and use pattern. The model can be used to explore how changes in the extraction costs, discount rate, and in the structure of the model might affect the depletion profile of the exhaustible resource, hence, the level of the availability of energy for export after accounting for domestic use. It can also examine the effects of adopting various government savings policies, changes in the level of responsiveness of the financial markets, and changes in the absorptive capacity of the economy on the optimal depletion path. The model also explores the effects of changes in the international price of energy on domestic economy in general and oil exports in particular.

We envision the integrated model resulting from this project forming the foundation for a more general approach to strategic economic and environmental planning/decision support system for both policy makers at the national level and international policy making bodies. In a broad systems theory language, this study falls in the knowledge (information) energy conversion realm. The aim is to contribute to a deeper understanding of the underlying complex issues, identifying and deploying technological alternatives and policy options within specific socio-economic settings, in a country or a region, toward more sustainable development.

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