2008

Energy in a Resource-based Regional Economy: A Dynamic General Equilibrium Analysis

Hodjat Ghadimi
West Virginia University, Hodjat.Ghadimi@mail.wvu.edu

Energy in a Resource-based Regional Economy: A Dynamic General Equilibrium Analysis

By

Hodjat Ghadimi

RESEARCH PAPER 2008-2

Regional Research Institute
West Virginia University
3040 University Ave, PO Box 6825
Morgantown, WV 26506-6825 USA
Email: Hodjat.Ghadimi@mail.wvu.edu
Tel: (304)293-4101 Fax: (304)293-6699

Paper submitted to the
47th Annual Western Regional Science Association Meeting
Waikoloa, Hawaii, February 17-20, 2008

Abstract: States and even local governments are increasingly realizing the need for long-term sustainable energy-environment planning as an integral part of their economic development program. These sub-national units are progressively playing a more active role in advancing policies for the reliability, environmental sustainability, and exploring the economic development impact of their energy resources and supplies. This article outlines a modeling framework for an integrated analysis of the energy-environment-economy system in an energy resource-based region within a developed economy. The theoretical structure and mathematical skeletal of this dynamic optimal depletion computable general equilibrium model as the core of this modeling framework is presented in this paper. This model can be used to analyze complex economic development issues arising from energy-environment-economy interactions in regions enjoying an abundance of exhaustible fossil fuel resources.

1. Introduction

Within the US, more counties' socio-economic fortunes depend on energy than any other single resource. However, the intricacies of the role of energy in regional economies are not fully understood. States and even local governments are increasingly realizing the need for long-term sustainable energy-environment planning as an integral part of their economic development programs. California's 2000-2002 electricity crisis changed the long-standing perception that energy conservation and pursuit of more sustainable energy sources are matters best left to international, national, state, and regional policy makers. Sub-national units are increasingly playing a more active role in advancing policies for the reliability, environmental sustainability, and exploring the economic development impact of their energy resources and supplies. And yet, analytical tools available at this level for studying these phenomena are rudimentary at best.

To address this gap in knowledge and provide a mechanism for understanding better and managing energy resources for the benefit of social, economic, and environmental welfare, this article outlines a framework for a comprehensive and integrated analysis of the energy-environment-economy system. To this end, we will build upon research that binds energy and economics, energy and environment, and economics and welfare, within the context of a dynamic regional general equilibrium framework. We will develop a dynamic optimal depletion computable general equilibrium (CGE) model for an exhaustible resource-based region. The theoretical structure and mathematical skeletal of this dynamic optimal depletion CGE as the core of this modeling framework will be presented in this paper. This model can be used to analyze complex economic development issues arising from energy-environment-economy interactions in resource-based regions.

The next section presents a brief overview of energy-environment-economy models at global, national and regional scale and clarifies the overall objectives of this research. Section 3 explains the CGE modeling framework for energy and introduces a class of dynamic CGE models applied to exhaustible resources - appropriately called optimal depletion CGE. The theoretical and mathematical structure of the proposed model are presented in sections 4 and 5 and finally the paper concludes with few remarks on the prospects of regional applications of optimal depletion CGE models.

2. Background

There is an intensifying debate about declining energy supply and an 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 fossil fuel consumption. Fundamental questions about environmental consequences of energy production and consumption patterns and policies to ensure economic and environmental sustainability have led to a recent resurgence in long-term energy modeling (see for example Lackner and Sachs 2005). These models, which consider sustainability at the scale of man-kind and time scales of up to a century, have focused on the optimal mix of energy resource use and the costs and benefits of environmental mitigation. The global models are very long-term and their focus is on environment and related global policy issues such as the Kyoto Protocol and carbon tax.

Long-term modeling at the national level focuses on impacts of changing energy supply conditions and the depletion of nonrenewable resources, and analyzes changes due to the penetration of new technologies and the emergence of alternative energy sources. One prominent class of these energy-economy models is the computable general equilibrium (CGE) framework based on general equilibrium theory and the neoclassical theory of economic growth (basic references include Hudson and

Jorgenson 1975, and Manne 1977). CGE models are used to investigate how alternative public policies impact prices, quantities and welfare in real economies. The examples of applying CGE approaches to energy-economy interaction at national level include Hudson and Jorgenson (1974) for the US, Lars Bergman (1986) for Sweden, and Longva and Olsen (1983) for Norway, through more recent contributions such as Dellink and van Ierland (2006) for Netherlands. National models focus on environment as well as energy and the economy but their main emphasis is on issues of national energy supply, security, and reliability in developed countries and on issues of depletion and investment in developing countries.

Although the CGE approach has widely been applied to national economies, their application in regional modeling is relatively recent. The past decade, with advances in computing and availability of more comprehensive regional databases, has witnessed a surge of interest in regional CGE models. Still, there are only very few models addressing energy-environment-economy interaction at a regional level. Among the few, Despotakis and Fisher (1988) use a CGE model to study the impact of energy prices on the California economy, Conrad and Schroder (1993) assess the welfare effects of two alternative policies designed to curb carbon dioxide emissions, and Li and Rose (1995) study the economic impacts on Pennsylvania of increased carbon taxes. Research applying economy-wide general equilibrium models is very promising in elucidating important regional issues and also in clarifying inter-relationships between regional and national development and policy making.

Not only are there very few regional CGE models of energy-economy inter-relationships, but a surprisingly unexplored area is the analysis of regional resource depletion and its impact on the economy-environment at regional and national levels. The overall objective of this research is to develop a dynamic computable general equilibrium model to link a region's underlying natural resource base to its economic performance. The model will consist of an intra-temporal price endogenous multi-sectoral model of a market economy, embedded in an inter-temporal optimal growth and development model. This general equilibrium approach will capture the economy-wide and sectoral distribution effects of resource depletion.

3. The Proposed Modeling Framework

The models commonly referred to as "applied general equilibrium models" (AGEM) or "computable general equilibrium" (CGE) are large multi-sectoral, economy-wide nonlinear equilibrium models that are closely related to the Walrasian model of a competitive economy. "General equilibrium" typically refers to a Walrasian competitive equilibrium model where all economic agents are price takers who maximize profits or utility, and prices freely adjust to clear markets, implying that supply equals demand. CGE models attempt to incorporate the fundamental linkages among production structure, pattern of demand and incomes of various institutions. These are price-endogenous models because they are based on the assumption that prices are free to adjust until there is a consistency among the decisions made on the productive side of the economy and decisions made by households and other autonomous decision makers on demand side. General equilibrium and autonomous decision making are two concepts central to the CGE framework.

CGE models are essentially applied general equilibrium models. 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 of CGE models for policy analysis both in developed and developing countries. More recently CGE modeling has been used at the regional level to examine a broad range of problems including growth and development issues of urban systems, regional impacts of national changes, and development issues in a multi-region framework. A survey and critical appraisal of regional CGE models is presented in Partridge and Rickman (1998 and 2004).

<u>CGE framework for energy modeling.</u> Numerical economic models on energy fall into two general categories: models analyzing energy sector issues and models examining the interaction between the energy sector and the rest of the economy. The first category includes mostly partial equilibrium models with a very detailed and disaggregated representation of the energy sector. Although very useful for energy sector planning purposes this class of models essentially neglects the interdependence of the energy sector and the rest of the economy. These models are surveyed in Bergman (1988 and 1990), Deverajan (1988), and a general survey of CGE models for energy studies is offered in Bhattacharyya (1996).

The second category, appropriately called energy-economy interaction models, includes multisectoral and general equilibrium models focusing 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 first category in their specification of the energy sector. The early references of 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), Manne and Rutherford (1994), Bohringer (1996), and 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, environmental policies, or changes in the extraction levels of resources have profound impacts on the workings of the domestic economy.

<u>Dynamics in CGE Models.</u> CGE models can be static or dynamic. When dynamics are incorporated they may be based on the assumption of either static

expectations or perfect foresight agents. Static models are relatively easy to construct, given full availability of data, and with present computational capabilities are fairly manageable even when they are highly disaggregated. The general equilibrium solution to a static model is a price vector that results from the simultaneous intersection of the sectoral demand and supply functions. These single-period CGE models are very useful tools and have been used widely to address a variety of policy issues in a general equilibrium framework. However, many interesting economic questions are inherently dynamic and cannot be dealt with properly in a static framework. For instance, to analyze the implications of policies that affect savings and investment decisions and hence the accumulation of capital stock, one must use a dynamic or multi-period model. Similarly, the question of depletion of an exhaustible resource, which is the main focus of this study, is intrinsically a dynamic problem that can only be addressed properly in a dynamic setting.

The treatment of dynamics in CGE models covers a broad range. In general two distinct classes can be identified: 1- Forward-Moving Dynamics, and 2- Forward Looking Dynamics. Forward-moving dynamic CGE models, assuming static expectations, essentially solve for a sequence of static equilibria recursively and the notion of inter-temporal equilibrium is not pursued. Forward-looking dynamic CGEs, on the other hand, incorporate expectations of future outcomes formed by economic agents and solve for an inter-temporal equilibrium.

The forward-Moving approach to dynamics, first used by Adelman and Robinson (1978) and later articulated by Drevis, et al 1982, is the most common practice adopted by CGE model builders. This formulation of dynamics implicitly assumes that expectations of future events have no effect on today's decisions and that the behaviors of economic agents depend only on the past and present outcomes of economic activities.

Forward-looking dynamic CGE models are fully dynamic models in the sense that they capture the impact of future events and solve for inter temporal equilibrium. In other words, events in each period affect the equilibrium of all other periods so that in each instance decisions are made on the basis of past outcomes and expectations of all future events. The forward-looking class of dynamic CGE models is not yet widespread and the existing examples vary from two-periods to infinite time horizon models. Devarajan and Go (1998) describe the characteristics of a forward-looking intertemporal optimization CGE model and Jorgensen and Wilcoxen (1990) is a good example of forward-looking CGE models in the area of energy and the environment. This class of CGE models properly uses feedback to incorporate expected consequences of future events, and some argue that this formulation of dynamics is the only correct way to specify rational behavior.

An Optimal Depletion CGE Model. The main foci of this article are the optimal rate of depleting an exhaustible resource, the optimal level of investing in the environment, and the optimal allocation of total investment funds in the economy. The extensive literature concerned with optimal depletion of an exhaustible resource, with only a few exceptions, ignores the economy-wide and sectoral distribution effects of resource depletion. Typically, capital accumulation and consumption are discussed within the limited framework of the one-sector neoclassical growth models (Aarrestad 1978). These models do not consider the role of prices in influencing production and consumption decisions of firms and households, and undermine the significance of inter-sectoral interaction on the optimal depletion profile. In any realistic circumstance, the intensity of interaction among various sectors and markets across the economy has significant bearing on the depletion program, as does the level of domestic and international prices. Private and public consumption and savings decisions as well as the investment allocation mechanism in an economy directly affect its level of resource extraction. In these instances a general equilibrium approach that fully captures the economy-wide effects of resource depletion is the appropriate tool. Devarajan (1988) sketches out the formal structure of an optimal depletion model and presents some results from the application of these models. Ghadimi (1993 and 2006) presents a dynamic CGE model for analysis of exhaustible resources implemented for the case of an oil exporting developing country.

The model proposed here belongs to the optimal depletion category of computable general equilibrium models. It is a forward-looking 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 wellbeing of numerous regional economies within the US primarily depends on exhaustible oil, gas, and coal resources. The proposed model provides a systematic framework to analyze broad economy-wide implications of resource depletion and exploring complex energy-environment-economy interactions in resource-based regional economies.

4. Theoretical Structure of Optimal Depletion CGE models

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.

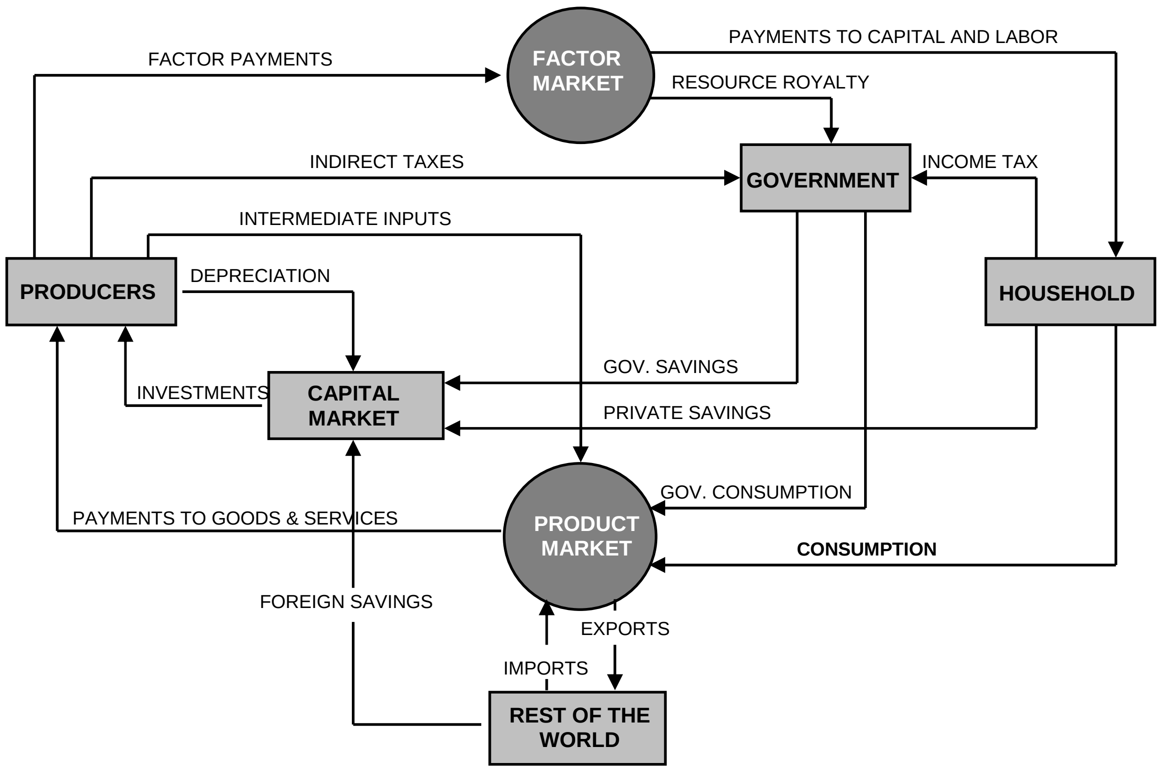

Figure 1. Circular flow of income

4-1 Producers

Producers are industries or sectors of production of the economy. The terms sector, producer, and firm will be used interchangeably throughout the study.[1] Each 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

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

non-renewable resource. This sector is called the "resource sector" and the remaining sectors will sometimes be referred to as "non-resource 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 and labor. 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 resource 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.

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.

4-2 Households

There is a single representative household in the economy which owns capital 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 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.

4-3 The Government

The government earns its revenues through direct and indirect taxes, tariffs, and resource royalty revenues from the resource sector. Tax and tariff rates are assumed to be exogenous and fixed over time and the resource royalty revenue is the total value added of the resource sector less the wage bill and normal return to physical employed in the sector. 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 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. 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 resource and a predetermined social rate of discount, the government determines the optimal rate of resource depletion and through its tax and resource extraction 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.

4-4 The Rest of the World (ROW)

The rest of the world is linked to the model through exports, imports, and foreign borrowing. The model analyzed in this study uses an intermediate specification of foreign trade that has become standard practice in 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.

5. Mathematical Structure of the Model

The skeletal mathematical structure of the proposed model consists of two main parts. One is the dynamics of the model which is briefly presented below and the other is the static sub-model that closely follows the standard static CGE models in the literature. The dynamic model includes the objective function and the two important intertemporal linkages in this model: depletion of the exhaustible resource, and optimal savings and investment allocation. In our model, we maximize the welfare of the representative household, which includes the present value of the utility of consumption over time and the present value of end-of-planning-horizon capital stock and the resource reserves:

$$\text{MAX } J = \int U(C_t) * e^{\Delta t} dt + \left[\overline{PK} * \sum_i K_{i,T} + \overline{PR} * RSRV(T) \right] * e^{-\Delta T}$$

Here, (C_t) represents Cobb-Douglas aggregation of consumption of $CD_{i,t}$ of goods from sector *i* in time period *t* with fixed consumption shares ch_i :

$$C_t = CD_{1t}^{ch_1} * CD_{2t}^{ch_2} \ldots\ldots CD_{nt}^{ch_n} \qquad \text{where} \qquad \sum_{i=1}^{n} ch_i = 1$$

Resource reserve updating

$$S_{t+1} = S_t - XD_{recource,t}$$

where S_t is stock of resource at t and $XD_{i,t}$ is domestic output. One important feature of the present model is its explicit treatment of the dynamic inter-period market equilibrium. The government within its purview of influence and considering consequent implications of its decisions sets a reasonable private marginal propensity to save *(MPS)* and the rate of investment in the resource sector, *(ISHR'resource')* so as to maximize the social welfare function as represented in the objective function. The non-resource sectors receive the remainder of investment funds based on their relative profitability in past and current periods. This specification of investment allocation assumes that non-resource sectors have myopic expectations (Dervis et al. 1982). Specifically, each non-resource sector's share of investment funds, $ISHR_{in}$, is equal to its share in aggregate capital income, SP_{in}, adjusted upward if the sector's profit rate is higher than the average profit rate and adjusted downward otherwise:

Investment shares in non-resource sectors

$$ISHR_{in,t+1} = SP_{in,t} + \Omega * SP_{in,t} * \left[\frac{RP_{in,t} - AVGRP}{AVGRP} \right]$$

Share in overall profits

$$SP_{in} = R_{in} * K_{in} \Big/ \sum_{jn} R_{jn} * K_{jn}$$

Determination of profit rates

$$RP_{in,t+1} = R_{in,t+1} + \left[PK_{in,t+1} - (1 + d_{in}) * PK_{in,t} \right] \Big/ PK_{in,t}$$

Economy wide profit rate

$$AVGRP = \left[\sum_{in} RP_{in} * K_{in} \right] \Big/ \sum_{in} K_{in}$$

The investment funds in each sector augment the sector's capital stock but at a decreasing rate as shown below:

Dynamic capital equation

$$K_{i,t+1} = K_{i,t} * (1 - d_i) + \theta_i * K_{i,t} \left[1 - \left[1 + \frac{DK_{i,t}}{2 * \theta_i * K_{i,t}} \right]^{-2} \right]$$

where θ is the investment cost adjustment coefficient and $DK_{i,t}$ is volume of investment by sector of destination. This specification embodies an absorptive capacity constraint, i.e. the marginal efficiency of sectoral investment declines if investment grows too rapidly. This is a simplified form of the absorptive capacity function used in Kendrick (1990). As the rate of investment, $\frac{DK}{K}$, rises, the return to additional *DK* declines. Technically, with such an absorptive capacity constraint, the rate of increase in capital stock, *K*, would be smaller than the rate of increase in investment as a percentage of capital stock, *DK/K*.

The static portion of the model is a multisectoral general equilibrium model of a Walrasian competitive economy. Apart from the peculiar effects of dynamics of the resource sector, the static model shares many of the features of the family of CGE models constructed for developing countries by Dervis, de Melo, and Robinson (1982) -- such as imperfect substitution in trade and imperfections in factor markets. The equations of the static sub-model are fully explained in Ghadimi 2006.

6. Conclusions

This research, as a part of an extensive research in various disciplines, strives to contribute to the critically important energy-environment-economy knowledge base at a regional scale. An integrated modeling framework covering the complex and interacting energy-environment-economy chain proposed in this study can help identify ways of making the transition from the present inefficient energy systems to a sustainable energy future. The long term goal of the proposed research is seen as a step toward providing the knowledge foundation upon which more sophisticated regional planning and policy making support systems can be based.

The proposed model provides a systematic framework to simulate various long term policies regarding the economic development of the region and environmental concerns. The model can be used, for example, to explore how changes in extraction costs, discount rates, and the economic and regulatory structure of the economy might affect the depletion profile of the exhaustible resource. It can also be used to examine various effects of adopting different savings and investment policies, and changes in the level of responsiveness of the financial markets on the optimal development path. The model also can be used to explore the effects of environmental constraints on resource extraction and exports. It can provide a direction and a measure of magnitude of optimal investment in related resource extraction technologies in the region while observing environmental constraints set by national energy and environment policies.

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 to be developed further and applied will be the first of its kind at the regional level, a level of analysis that is gaining importance as an increasing number of regions begin confronting the environmental consequences of various strategies for economic development, and the economic ramifications of policies aimed at environmental remediation. The model also differs from kindred models applied at the national level, in that it incorporates a private sector market for the control of energy resources rather than the more common national models in which a government sector directly controls resources.   We envision the model resulting from this project forming the foundation for a more general approach to understanding the complex relationships among the energy, environment, and economic systems. The formulation, refinement, and implementation of the model should not only provide new theoretical insights, but will also form the foundation of a regional level decision-making and planning support system.

References

Aarrestad, Jostein. 1978. "Optimal savings and exhaustible resource extraction in an open economy." *Journal of Economic Theory*:19, pp. 163-79.

Babiker, Mustafa H., John M. Reilly, Monika Mayer, Richard S. Eckaus, Ian Sue Wing and Robert C. Hyman. 2001. "The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Revisions, Sensitivities,and Comparisons of Results." *The MIT Joint Program on the Science and Policy of Global Change*.

Bergman, Lars. 1988. "Energy policy modeling: A survey of general equilibrium approaches." *Journal of Policy Modeling*, 10:3, pp. 377-99.

Bergman, Lars. 1990. "Energy and environmental constraints on growth: A CGE modeling approach." *Journal of Policy Modeling*, 12:4, pp. 671-91.

Bhattacharyya, Subhes. 1996. "Applied general equilibrium models for energy studies: A survey." *Energy Economics*, 18, pp. 145-64.

Böhringer, Christoph (1996). "Fossil Fuel Subsidies and Environmental Constraints: A General Equilibrium Analysis of German Coal Subsidies and Carbon Emission Restrictions." *Environmental and Resource Economics*, 8(3), 331-349.

Dellink, Rob, and Ekko van Ierland. 2006. "Pollution abatement in the Netherlands: A dynamic applied general equilibrium assessment." *Journal of Policy Modeling*, 28, pp. 207-21.

Dervis, K, J de Melo, and S Robinson. 1982. *General equilibrium models for development policy*. Cambridge: Cambridge University Press.

Despotakis, K. A., and A. C. Fisher. 1988. "Energy in a regional economy: A computable general equilibrium model for California." *Journal of Environmental Economics and Management*, 15, pp. 313-30.

Devarajan, S. 1988. "Natural resources and taxation in computable general equilibrium models of developing countries." *Journal of Policy Modeling*, 10 4, pp. 505-28.

Devarajan, Shantayanan., and Delfin S. Go. 1998. "The Simplest Dynamic General-Equilibrium Model of an Open Economy." *Journal of Policy Modeling*, 20:6, pp. 677-714.

Ghadimi, Hodjat. 1993. "Economic development in economies with an exhaustible resource: A dynamic computable general equilibrium analysis for the case of Iran. Ph.D. Dissertation. The Ohio State University.

Ghadimi, Hodjat. 2006. "A Dynamic CGE Analysis of Exhaustible Resources: The Case of an Oil Exporting Developing Country " *Rearch Paper #2006-7, Regional Research Institute, West Virginia University*.

Hudson, E, A, and D. W, Jorgenson. 1975. "U.S. energy policy and economic growth." *Bell Journal of Economics and Management Science*, 5:2, pp. 461-514.

Jorgensen, Dale W. and Peter Wilcoxen. 1990. "Intertemporal modeling of US environmental regulation." *Journal of Policy Modeling*, 12:4, pp. 1-30.

Jorgensen, Dale W. and Peter Wilcoxen. 1991. "Global change, energy prices, and U.S. economic growth." *Structural Change and Economic Dynamics*, 3:1.

Li, Ping-Cheng, and Adam Rose. 1995. "Global warming policy and the Pennsylvania economy: A computable general equilibrium analysis." *Economic Systems Research*, 7:2, pp. 151-72.

Longva, S., and O. Olsen. 1983. "Price sensitivity of energy demand in Norwegian industries." *Scandinavian Journal of Economics*, 85, pp. 17-36.

Manne, A. S. 1977. "ETA-Macro: A model of energy economy interactions." *Electric Power Research Institute, EA-592 Research Report 1014*.

Manne, A.S. and T.F. Rutherford, 1994, International trade in oil, gas and carbon emission rights: an
intertemporal general equilibrium model, The Energy Journal, 15, 57-76.

Partgidge, Mark D., and Dan S. Rickman. 1998. "Regional computable general equilibrium modeling: A survey and critical appraisal." *International Regional Science Review*, 21:3, pp. 205-48.

Partgidge, Mark D., and Dan S. Rickman. 2004. "CGE Modeling for Regional Economic Development Analysis". Draft Book Chapter for State-of-the-Art in Regional and Urban Modeling.