New GE Approach to Evaluate Technologies Contributing to Economic Growth and Reducing Global Warming[1]

Hsiang-Ling Han[2]
Economics Division
Babson College
Babson Park, MA 02457
han@babson.edu

JEL Classifications: Q2, Q4

Abstract

New developments in renewable energy technology, particularly solar building-integrated photovoltaic (BIPV) electricity-generating technology, have the potential for accelerating the rate of environmentally sustainable economic development. In sunny developing countries, like Brazil, the shortages of electricity in urban areas and many gaps in rural electrification make the application of BIPV supportive of economic growth. BIPV can greatly reducing urban commercial and residential buildings' operating costs, saving much of the capital costs of what would otherwise without BIPV, and providing the most economical and environmentally benign form of rural electrification. The paper investigates, from the market point of view, whether the non-polluting BIPV is economically competitive in the market places that would induce both private and public investments. Analyses in the paper are entirely to demonstrate and confirm quantitatively that environmentally benign renewable energy technologies, particularly BIPV in Brazil and other sunny countries, are mature technologies bearing no more technological risk than their predecessors, and that they are economically competitive in many markets sharing the same characteristics.

---

[1] This paper is prepared for the Third Annual Conference on Global Economic Analysis, June 27 - 30, 2000, in Melbourne, Australia. Please do not quote without permission.

[2] The author would like to thank Dr. Clark Abt for his continuous support and helpful comments. Financial support from the Board of Research at Babson College is gratefully acknowledged. All remaining errors are the author's.

1 Introduction

New developments in renewable energy technology, particularly solar building-integrated photovoltaic (BIPV) electricity-generating technology, have the potential for accelerating the rate of environmentally sustainable economic development. In sunny developing countries, like Brazil, the shortages of electricity in urban areas and many gaps in rural electrification make the application of BIPV supportive of economic growth. BIPV can greatly reducing urban commercial and residential buildings' operating costs, saving much of the capital costs of what would otherwise without BIPV, and providing the most economical and environmentally benign form of rural electrification. Beyond the protection of environment by emission permits trading, the alternative solution would lead to the advancement of both economic development and environment, without one advancing at the expense of the other.

The analyses in the paper are to demonstrate and confirm quantitatively that environmentally benign renewable energy technologies, particularly BIPV in Brazil and other sunny countries, are mature technologies bearing no more technological risk than their predecessors, and that they are economically competitive in many markets sharing the same characteristics. Many researchers have made the environmental argument alone, assuming that environmental benefits even at net economic costs would be sufficient to motivate public action and private investment. However, it has not often been the case. Another alternative approach adopted in this paper is to demonstrate the economic rationale for non-polluting renewable energy technologies substitution for non-renewable polluting ones.

Two analytical methodologies, from both micro as well as macro economic perspectives, are used in the study. Economic impacts of a decade's implementation of BIPV are computed and predicted for the next decade with the use of both micro and macroeconomic models. The net impacts on GDP depend on the degree of BIPV implementation. Degree of implementation is the principal component of uncertainty in the range of forecasts, and is the dominant policy variable in Brazil and most other sunny countries. Long-term benefits from reduced environmental pollution and reduced generation of climate-changing greenhouse gases as a result of BIPV technology, and its other environmental, health, and social net benefits are not computed in the present models, but are expected to strengthen the findings. The findings demonstrate that substituting renewable, non-polluting solar energy resources of BIPV sheathing and roofing for conventional building sheathing and roofing and fossil fuel-generated energy sources does not cost jobs and economic growth, on the contrary even in the short run of a few years contributes significantly to economic growth and job creation.

This paper presents a new modeling approach, which combines traditional econometric methodology and newly developed neural network techniques to measure impacts of implementing renewable energy technologies, from both macro and micro points of view, and to investigate whether the renewable energy technologies are economically competitive in market places.

2 Reasoning Behind the Model

Through the history of industrialization, it is known that the key factor contributing to the real production for any country is energy. Energy is the fundamental driving force of all economic growth. Energy is what feeds us as measured in calories. Energy is what warms us as BTU's or thermos. Energy is what lights our homes and workplaces as lumens. Energy is what powers our manufacturing machinery and communications in kilowatt hours. Energy is what transports us as horsepower. All these forms of energy are mutually convertible, and all of these forms of energy are in the stage of shortage around the world, especially in the developing and newly industrialized countries.

It is also known that the poorest parts of the world population and geography lack electricity and other locally available and affordable sources of energy needed for agriculture, communication, education, health care, housing, manufacturing, and transportation. In most of the three quarters of the world's population living in poverty in developing areas and lacking electricity, the local cost of electricity generated by fossil fuel-powered thermal power plants and nuclear power plants is already higher than that of electricity locally generated by the non-polluting renewables of solar-photoelectric, solar-thermal, wind turbine, hydro-electric, and biowaste-fed fuel cell power plants that can be built in small modules and can distribute electricity more efficiently in lower population density areas. The comparative cost of conventional fossil-fuel energy, which must exploit economies of scale with large centralized power plants ideally co-located with their fuel sources, is even greater over time, as the externalities of environmental costs, transportation costs, and increasing scarcity costs are incorporated. Over the same time periods that total (including environmental) costs of fossil-fuel energy rise, the total costs of the non-greenhouse gases-emitting renewables - solar, wind, hydro, and waste-fed fuel cells - will continue to decrease as a result of increasing economies of scale and specialization in their production and application.

Clearly the world needs solar energy (together with the other solar-related renewables of wind, hydro, and biowaste-fed fuel cells) for the environmentally sustainable economic development of its poorest populations and areas. Then why is most (over 95%) of the world's private investment, public investment, and even parastatal investment (World Bank, Asian Development Bank) in energy infrastructure going into fossil-fuel power plant construction? Moreover, all of these investments are not short-term investments, but generally investments over a full decade that do not generate positive economic returns until their second decade. There are many reasons given, but one rarely given is the lack of a comprehensive and verifiable vision of the economic and social benefits of the environmentally superior alternative of non-emitting solar and other renewables. Applying the proposed model and the empirical analyses, we hope we will be able to fill in the void in this area.

The principal innovation of the proposed model is to demonstrate and confirm quantitatively that environmentally benign renewable energy technologies are mature technologies bearing no more technological risk than their predecessors, and that they are economically competitive in many markets. The model is unique in combining a standard macroeconomic equilibrium model with geo-coded energy, transport, housing, and environmental sectoral models; it is capable of incorporating disaggregated micro models of alternative regional and urban energy systems with diverse renewable and non-renewable energy sources and various efficient energy uses. The model focuses on discovering the economic incentives of adopting renewable energy technologies. Long-term benefits from reduced environmental pollution and reduced generation of climate-changing greenhouse gases as a result of renewable energy technologies are not computed in the present model, but are expected to strengthen the findings.

3 The Macro-Mezzo-Micro Model

This section presents the Macro-Mezzo-Micro Model. The model will first be compared to the National Energy Modeling System (NEMS) of Energy Information Administration, Department of Energy, the computable general equilibrium (CGE) model of Zhang (1998), and the META-Net economic modeling system developed by the Lawrence Livermore National Laboratory (LLNL).

NEMS is a comprehensive model designed to represent the important interactions of supply and demand in US energy markets. It is a modular system which consists of four supply modules (oil and gas, natural gas transmission and distribution, coal and renewable fuels); two conversion modules (electricity and petroleum refineries); four end-use demand modules (residential, commercial, transportation, and industrial); one module to simulate energy/economy interactions (macroeconomic activity); one module to simulate world oil markets (international energy activity); and one module that provides the mechanism to achieve a general market equilibrium among all the other modules (integrating module).

Zhang constructed a CGE model for energy and environmental policy analysis of the Chinese economy. It incorporates the transitional characters of China and emphasizes the use of market mechanisms and price incentives. The CGE modeling approach complement the parallel interactive NEMS. In addition, Zhang modeled the energy sector and its linkages to the rest of the economy, particularly focused on energy and environmental issues as quantifying the economy-wide effects of policies aimed at limiting carbon dioxide (CO_2) emissions.

Our modeling approach is also a hierarchically interactive modeling approach. At the national (macro) level, we first introduce a KLEM (capital, labor, energy, and material) production function for an oil-importing country. Our modeling approach of the energy sector is similar to Zhang (1998), but it is distinctly different in emphasizing the following key issues: (1) renewable energy sources and their corresponding consumption efficiency and production efficiency; (2) the geographical locations of the energy resources and its implications on the transportation costs of energy supply; (3) the economies of scale for renewable energy production; (4) a national employment and energy strategy based purely on economic incentives. Because of the emphasis on economic benefits, we do not incorporate the environment related tax issues and welfare measures into the model, as Zhang (1998) did.

The demand functions for capital, labor, energy, and material were derived from the national production function. These demands for production factors then form the base of micro interactive analysis. Figure 1 presents the overall nesting structure of the model.

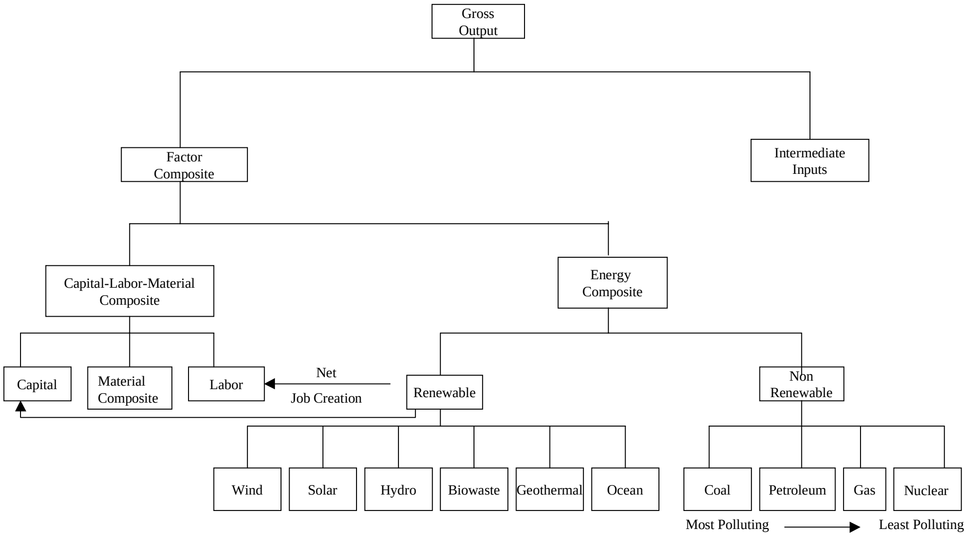

Figure 1: Nesting Structure of the KLEM Production Function

The methodology behind the entire modeling approach can be described as follows. First, we use artificial neural networks at the micro level to setup and calibrate the behaviors of each energy production sector in an economy. The initial conditions for neural network are from the optimal demands calculated from the KLEM model. Second, these simulated energy production functions form a basis for the mezzo level CGE analysis. We use CGE model to describe the interactions between these energy sectors and other production sectors in an economy and estimate the parameters that control the interactions. Finally, the interactive CGE model is combined with the macro KLEM production function to estimate impacts of initial action of the individual production sector on the overall macroeconomic performance. The detailed CGE model setup will be discussed in the subsection following the introduction of micro neural network modeling.

3.1 Neural Network Specification and Implication for the Energy Sectors

Neural networks can take many different functional forms (see Kuan and White, 1992). The form used for modeling the production sectors is as follows:

$$Y^t = B_0 + \sum_{n=1}^{N} \left[B_n \times \frac{1}{1 + e^{-(a_{n,0} + \sum_{k=1}^{K} a_{n,k} X_K^t)}} \right] + u^t. \tag{1}$$

Where Y is output, a_n, B_n are parameters, and X_k are explanatory variables. To understand this nonlinear function, consider the following example. If the number of explanatory variables (K) is three, and the number of notes (N) is two, then the network function takes the following form:

$$\begin{aligned} Y^t = {} & B_0 + B_1 \times \frac{1}{1 + e^{-(a_0 + a_1 X_1^t + a_2 X_2^t)}} \\ & + B_2 \times \frac{1}{1 + e^{-(b_0 + b_1 X_1^t + b_2 X_2^t)}} + u^t. \end{aligned} \tag{2}$$

Although this function is nonlinear in the explanatory variables and most of the parameters, it has linear components. This is clear if we rewrite the network function as follows:

$$Y^t = B_0 + B_1 \times H_1^t + B_2 \times H_2^t + u^t. \tag{3}$$

Expressed in the language of the neutral network literature, each H in equation (3) represents a note in the hidden layer. And, for the particular specification we use here, the output function, which is shown in equation (3), is linear in these values.

At the start of the first iteration, demands are generated by the optimization of the KLEM production function. These are passed down the network. At market nodes the total market demand is allocated to the suppliers based on their relative prices. The market model recognizes that there is variability of prices within a market by efficiency level and by location. That variability contributes to market penetration of a technology even if it is more expensive than its competitors on the average (of locations, times, and technological states of the art). The conversion nodes represent fixed-coefficient production processes. Based on the input-output coefficients, one can compute the quantity of each input that is required to produce the output. The quantities demanded for each input eventually reach the resource nodes. At this point, the model begins to compute prices and send them back up through the network. Resource nodes contain resource curves that provide the marginal price for a particular resource required to produce the quantity demanded as a function of the total resource that has been exploited up to that period, the location of the resource, and the transportation cost for the resource to end-users. The conversion nodes receive the prices for each input. Based on the prices of inputs, their input-output coefficients, capital costs, operating costs, the unit availability, the conversion nodes compute the price required in order that the owner of the process will receive a target rate of return on capital investments. The market nodes compute a quantity weighted average price for the market and pass that on up. When the prices are received by the end-use nodes, a new quantity demanded is computed using a demand curve. The quantities are passed down to start a new iteration. Figure 2 shows iterations of the process. After calibrating the energy production functions from the supply block in Figure 2, we then enter the CGE analysis.

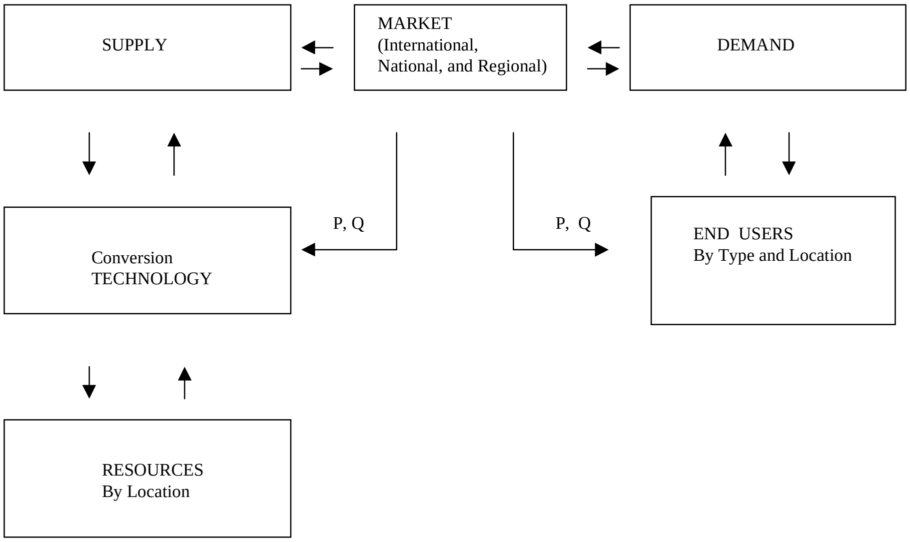

Figure 2: Relations of Demand and Supply for Energy Markets

3.2 The Computable General Equilibrium (CGE) Model

The CGE model links the energy sectors with other sectors in an economy and includes the following blocks: production and factors, price, income, expenditures, investment and capital accumulation, foreign trade, and market clearing conditions and macroeconomic balances.

3.2.1 Production and factors

The production block includes 21 sectors. There are eleven sectors that are associated with the production of goods and services, *i.e.*, agriculture, aerospace, automobile, chemical, communication, computer, health care, manufacturing, pharmaceutical, transportation, services. There are ten sectors that relate to the supply and distribution of energy (both non-renewable and renewable), *i.e.*, coal, petroleum, gas, nuclear, wind, solar, hydro, biowaste, geothermal, and ocean. For simplicity, all sectors in the production of goods and services are assumed to operate at constant returns to scale. However, the energy sectors are allowed to have economies of scale. In each sector, gross output is produced using (at least) one of the ten energy inputs, capital, labor, material, and intermediate goods and services, with the substitution taking place across energy inputs, capital, labor, and material.

Production function The nested KLEM production function can be expressed as follows:

$$VA_i(t) = \overline{A}_i e^{\lambda_i(t)\cdot(t-t_0)} K_i\,(t)^{\alpha_K}\, L_i(t)^{\alpha_L} M_i(t)^{\alpha_M} \tag{4}$$

where $VA_i(t)$ = composite capital-labor input of sector i in period t; $\overline{A}_i$ = shift parameter associated with composite capital-labor input of sector i; $K_i\,(t)$ = fixed capital stock of sector i in period t; $L_i(t)$ = employment by sector i in period t; $M_i(t)$ = material by sector i in period t; α_{Ki} = share of capital input in the value added aggregate of sector i; α_{Li} = share of labor input in the value added aggregate of sector i; α_{Mi} = share of material input in the value added aggregate of sector i; $\alpha_{Ki} + \alpha_{Li} + \alpha_{Mi} = 1$; t_0 = base year, $\lambda_i(t)$ = productivity growth rate in sector i in period t; e = exponential function.

$$E_i(t) = \overline{B}_i \cdot \prod_{j=12}^{21} [e^{aei_i(t)\cdot(t-t_0)} VE_{ji}(t)]^{b_{ji}} \tag{5}$$

where $E_i(t)$ = composite energy input of sector i in period t; $\overline{B}_i$ = shift parameter associated with composite energy input of sector i; VE_{ji} = intermediate input of energy j by sector i in period t; b_{ji} = share of energy input of type j in the energy aggregate of sector i; $aei_i(t)$ = autonomous efficiency improvement in energy use of sector i in period $(t - t_0)$.

$$EVA_i(t) = \Omega_i \left(\omega_i VA_i(t)^{\rho_i} + (1 - \omega_i) E_i\,(t)^{\rho_i}\right)^{1/\rho_i} \tag{6}$$

where $EVA_i(t)$ = aggregate of inputs from the composite capital-labor-material and the composite energy in sector i in period t; Ω_i = efficiency parameter associated with composite input of capital, labor and energy aggregate in sector i; ω_i = distribution parameter associated with value added aggregate in sector i; $\rho_i = (\sigma_i - 1)/\sigma_i$, where σ_i is the elasticity of substitution between the value added aggregate and the energy aggregate in sector i.

$$Q_i(t) = \sum_{j=1}^{11} a_{ji} Q_i(t) + EVA_i(t) \tag{7}$$

where $Q_i(t)$ = gross output of sector i in period t; a_{ji} = input-output coefficients that represent intermediate requirements from sector j per unit of output of sector i.

Unit costs The unit costs of the composite capital-labor-material input $VA_i(t)$ and the composite input $EVA_i(t)$ are the duals of production functions above. The unit cost of composite energy input $E_i(t)$ is the dual of the production function plus the geo-coded transportation costs.

$$CVA_i(t) = \frac{1}{\overline{A}_i e^{\lambda_i(t)\cdot(t-t_0)}} \left(\frac{UK_i(t)}{\alpha_{Ki}}\right)^{\alpha_{Ki}} \left(\frac{W_i(t)}{\alpha_{Li}}\right)^{\alpha_{Li}} \left(\frac{UM_i(t)}{\alpha_{Mi}}\right)^{\alpha_{Mi}} \tag{8}$$

where $CVA_i(t)$ = unit cost of composite capital-labor-material input of sector i in period t; $UK_i(t)$ = user cost of capital in sector i in period t; $W_i(t)$ = wage rate in sector i in period t; $UM_i(t)$ = user cost of material in sector i in period t.

$$CE_i(t) = \frac{1}{\overline{B}_i} \prod_{j=12}^{21} \left(\frac{PE_j(t)}{e^{aei_i(t)\cdot(t-t_0)} b_{ji}}\right)^{b_{ji}} + \sum_{j=12}^{21} \sum_{l=1}^{n} T_{lj} \tag{9}$$

where $CE_i(t)$ = unit cost of composite energy input of sector i in period t; $PE_j(t)$ = user price of energy j in period t at the production site; T_{jl} = transportation cost of energy j from location l to end-users.

$$CEVA_i(t) = \Omega_i^{-1} (\omega_i^{\sigma_i} CVA_i(t)^{(1-\sigma_i)} + (1 - \omega_i)^{\sigma_i} CE_i(t)^{(1-\sigma_i)})^{1/(1-\sigma_i)} \tag{10}$$

where $CEVA_i(t)$ = unit cost of the composite input $EVA_i(t)$ of sector i in period t.

Demands for primary factor and intermediate goods Given the technology described above, producers are assumed to be motivated by economic incentives and to minimize their production costs. Solving the first order conditions and using the unit cost definitions, we can derive the optimal demands for the inputs of labor, capital, and energy type j as follows:

$$L_i(t) = \alpha_{Li} PVA_i(t) Q_i(t) / W_i(t) \tag{11}$$

$$K_i(t) = \alpha_{Ki} PVA_i(t) Q_i(t) / UK_i(t) \tag{12}$$

$$M_i(t) = \alpha_{Mi} PVA_i(t) Q_i(t) / UM_i(t) \tag{13}$$

$$E_i(t) = \left(\frac{1-\omega_i}{\omega_i}\right)^{\sigma_i} \left(\frac{CVA_i(t)}{CE_i(t)}\right)^{\sigma_i} VA_i(t) \tag{14}$$

$$VE_{ji}(t) = \frac{b_{ji}}{\alpha_i} \cdot \frac{1-\omega_i}{\omega_i} \cdot \left(\frac{E_i(t)}{VA_i(t)}\right)^{\rho_i} \cdot \frac{UK_i(t) K_i(t)}{PF_j(t)} \tag{15}$$

where $PVA_i(t)$ = value added or net price of sector i in period t.

3.2.2 Prices

Prices of imports and exports The domestic prices of imports are in the local small open economy's currency and include *ad valorem* taxes, while the world market prices are in US dollars and are exogenous under the small open economy assumption. The exchange rate is the price of a dollar in terms of the local currency.

$$PM_i(t) = (1 + tm_i) \cdot WM_i(t) \cdot ER(t) \tag{16}$$

where $PM_i(t)$ = domestic (the small open economy) price of imports of good i in period t; tm_i = import tariff rate of good i; WM_i = world (dollar) price of imports of good i in period t; $ER(t)$ = exchange rate between US\$ and domestic currency in period t.

$$PX_i(t) = (1 + te_i) \cdot WX_i(t) \cdot ER(t) \tag{17}$$

where $PX_i(t)$ = domestic price of exports by sector of origin i in period t; $WX_i(t)$ = world (dollar) price of exports by sector of origin i in period t; te_i = export subsidy rate of good i.

Price of composite commodity Price of composite commodity is determined by the corresponding unit cost function that is dual to the KLEM production function:

$$P_i(t) = \Psi_i^{-1} (\mu_i^{\psi_i} PM_i(t)^{(1-\psi_i)} + (1-\mu_i)^{\psi_i} PD_i(t)^{(1-\psi_i)})^{1/(1-\psi_i)} \tag{18}$$

where $P_i(t)$ = composite price of commodity i in period t; $PD_i(t)$ = price of domestic good i in period t; Ψ_i = shift parameter associated with composite commodity i in import demand function;

μ_i = share parameter associated with imported good i in import demand function; ψ_i = price elasticity of substitution between imported and domestically-produced commodity i.

Domestic sale price The price of domestically produced commodity i is the average of domestic price of exports and domestic good price:

$$PS_i\,(t) = (PX_i\,(t)\,X_i(t) + PD_i(t)D_i(t))/Q_i(t) \tag{19}$$

where $PS_i\,(t)$ = sale price of domestically-produced commodity i in period t; $X_i(t)$ = total exports of commodity i in period t; $D_i(t)$ = total domestic demand for domestic commodity i in period t.

Sectoral net price The sectoral net price is defined as the output price minus indirect business taxes and the cost of intermediate inputs:

$$PVA_i\,(t) = PS_i(t) \cdot (1 - itax_i) - \sum_j a_{ji}P_j(t) \tag{20}$$

where $itax_i$ = indirect business tax rate of sector i.

Price of capital services

$$PK_i(t) = \sum_j sf_{ji} \cdot P_j(t) \tag{21}$$

where $PK_i(t)$ = price of fixed capital goods in sector i in period t; sf_{ji} = fixed capital composition coefficients that represent the share of sector j in total fixed capital investment of sector i.

User price of capital

$$UK_i(t) = (\delta_i + R) \cdot PK_i(t) \tag{22}$$

where δ_i = depreciation rate of fixed assets in sector i; R = real rate of interest.

User price of energy at the production site

$$PE_j = (1 + \tau f_i\,(t)) \cdot P_j(t) \tag{23}$$

where $\tau f_i\,(t)$ = *ad valorem* tax rate on energy j.

Price of consumer goods Price of consumer goods is a weighted average of price of composite commodity and price of energy.

$$PC_j(t) = \sum_{i=1}^{11} w_i \cdot P_i(t) + \sum_{i=12}^{21} w_i \cdot PE_i(t) \tag{24}$$

where w_i = the weight of intermediate good i required to produce one unit of consumer good j; and $\sum w_i$ equals to one.

GDP deflator

$$\frac{Y(t)}{RY(t)} = P_{index}(t) \tag{25}$$

3.2.3 Income

National income The nominal national income is calculated using the following function:

$$Y(t) = \sum_i [PVA_i(t) \cdot Q_i(t)] + INDT(t) + TARIFF(t) - NETSUB(t) \tag{26}$$

where $INDT(t)$ = total indirect tax revenue in period t; $TARIFF(t)$ = tariff revenue in period t; $NETSUB(t)$ = total export subsidies in period t. The real national income is calculated by dividing the nominal income with the GDP deflator.

Factor income

$$WB_i(t) = W_i(t) \cdot L_i(t) \tag{27}$$

$$YM_i(t) = UM_i(t) \cdot M_i(t) \tag{28}$$

$$YK_i(t) = PVA_i(t) \cdot Q_i(t) - WB_i(t) - YM_i(t) \tag{29}$$

where $WB_i(t)$ = labor income in sector i in period t; $YM_i(t)$ = material income in sector i in period t; $YK_i(t)$ = capital income in sector i in period t.

Household income

$$Y_h(t) = w_h(t) \sum_i WB_i(t) + ts_h(t) \cdot GTF(t) \tag{30}$$

$$YD_h = (1 - htax_h) \cdot Y_h(t) \tag{31}$$

where $Y_h(t)$ = total income of household h in period t; $GTF(t)$ = government transfer payments; $w_h(t)$ = share of household h in total labor income in period t; $ts_h(t)$ = share of household h in total government transfers in period t; YD_h = disposable income of household h in period t; $htax_h$ = household h income tax rate.

Government revenue

$$YG(t) = TARIFF(t) + INDT(t) + HHTAX(t) + ER(t) \cdot FBOR(t) \tag{32}$$

where $YG(t)$ = total nominal government revenues in period t; $HHTAX(t)$ = total household tax revenues in period t; $FBOR(t)$ = net foreign borrowing in US dollars in period t.

3.2.4 Expenditure

Household consumption

$$C_{hi}(t)/pop_h(t) = \gamma_{hi} + \beta_{hi}/PC_i(t)\left(\frac{YD_h(t)}{pop_h(t)} - \sum_j PC_j(t) \cdot \gamma_{hj}\right) \tag{33}$$

where $C_{hi}(t)$ = total consumption of consumer good i by household h in period t; $pop_h(t)$ = total population of type h in period t; γ_{hi} = per capital subsistence quantity of consumer good i for household h; β_{hi} = marginal budget share associated with consumer good i for household h.

Government purchases

$$G_i(t) = e_i(t) \cdot GN(t) \tag{34}$$

where $GN(t)$ = aggregate real government purchases in period t; $e_i(t)$ = expenditure share of commodity i in total government consumption in period t; with $\sum e_i(t)$ equals to one.

3.2.5 Investment and capital accumulation

Allocation of investment across sectors

$$CK_i(t) = ac_i(t) \cdot Q_i(t) \tag{35}$$

$$DK(t) = INV(t) - \sum P_i(t) \cdot CK_i(t) \tag{36}$$

where $CK_i(t)$ = inventory investment in period t to produce one unit of good i; $ac_i(t)$ = requirement of circulating capital per unit of output i in period t; $DK(t)$ = total investment in fixed assets in period t; $INV(t)$ = total nominal investment in period t. The sectoral investment is determined by

$$DK_i(t) = ak_i(t) \cdot DK(t)/PK_i(t) \tag{37}$$

where $DK_i(t)$ = investment in fixed assets of sector i in period t; $ak_i(t)$ = a share of sector i in total fixed capital investment in period t, with $\sum ak_i(t)$ equals to one.

Demand for fixed investment goods

$$FI_i(t) = \sum_j sf_{ji} DK_j(t) \tag{38}$$

Total value of depreciation

$$DEPR(t) = \sum \delta_i PK_i(t) \cdot K_i(t) \tag{39}$$

3.2.6 Foreign Trade

Import Demand Assume that domestic consumers use a composite commodity i (including energy), which can be imported and domestically-produced, and these two products are not perfectly substitutes. Consumers will minimize total expenditure on composite commodity i (both imports and domestically produced):

$$\min_{M_i(t),D_i(t)}[PM_i(t)M_i(t) + PD_i(t)D_i(t)] \tag{40}$$

subject to the KLEM production function defined above. The first-order conditions for expenditure minimization is as follows:

$$\frac{M_i(t)}{D_i(t)} = \left(\frac{\mu_i}{1-\mu_i}\right)^{\psi_i}\left(\frac{PD_i(t)}{PM_i(t)}\right)^{\psi_i} \tag{41}$$

where $PD_i(t)$ = price of domestic good i in period t; $PD_i(t)$ = price of imports good i in period t; μ_i = share parameter associated with imported good i in import demand function; ψ_i = price elasticity of substitution between imported and domestically-produced commodity i.

Export demand We assume that the world demands for the small open economy's products take the following constant elasticity form:

$$X_i(t) = X_0 e^{grt_i(t)(t-t_0)} \cdot \left(\frac{WO_i(t)}{WX_i(t)}\right)^{\xi_i} \tag{42}$$

where X_0 = base year exports of commodity i; $WO_i(t)$ = average world (dollar) price of export of commodity i in period t; grt_i = *ex ante* export growth rate of commodity i in period $(t-t_0)$; ξ_i = price elasticity of export demand for commodity i.

Export supply We also assume that the total domestic products $Q_i(t)$ is a constant elasticity transformation of (divided into) domestically-consumed goods and exports.

$$Q_i(t) = \Phi_i(\upsilon_i X_i(t)^{\varphi_i} + (1-\upsilon_i)D_i(t)^{\varphi_i})^{1/\varphi_i} \tag{43}$$

where Φ_i = shift parameter associated with gross output of sector i in export supply function; υ_i = share parameter associated with exported good i in export supply function; $\varphi_i = (1+\eta_i)/\eta_i$, where η_i is the price elasticity of transformation between foreign and domestic sales of commodity i. Given the domestic good price $PD_i(t)$ and the domestic price of exports $PX_i(t)$, the domestic producers are assumed to maximize total profit from sales of good i (including the renewable energy technology):

$$\max_{X_i(t),D_i(t)}[PX_i(t)X_i(t) + PD_i(t)D_i(t)] \tag{44}$$

subject to the constant elasticity of substitution production function. The first-order conditions for profit maximization is:

$$\frac{X_i(t)}{D_i(t)} = \left(\frac{1-\upsilon_i}{\upsilon_i}\right)^{\eta_i} \left(\frac{PX_i(t)}{PD_i(t)}\right)^{\eta_i} \tag{45}$$

Foreign trade balance (in US$)

$$FTB(t) = \sum_i WX_i(t) \cdot X_i(t) - \sum_i WM_i(t) \cdot M_i(t) \tag{46}$$

3.2.7 Market clearing conditions

Product market clearing Sectoral supply of composite commodities must equal all domestic demands.

$$S_i(t) = V_i(t) + \sum_h CI_{hi}(t) + G_i(t) + FI_i(t) + SK_i(t) \tag{47}$$

where $V_i(t)$ = demand for intermediate goods by sector i in period t; $CI_{hi}(t)$ = demand for intermediate goods i by household h in period t.

Labor market clearing

$$\sum_i L_i(t) = L^s(t) \tag{48}$$

where $L^s(t)$ is total labor force available in period t.

Material market clearing

$$\sum_i M_i(t) = M^s(t) \tag{49}$$

where $M^s(t)$ is total material available in period t.

Capital market clearing

$$\sum_i K_i(t) = K^s(t) \tag{50}$$

where $K^s(t)$ is total capital stock available in period t.

4 Preliminary Findings

As stated in the introduction section, the costs of fossil fuel energy, which are already higher than those of locally generated renewable energy electric power, are continually increasing in the populous poor areas of the world. It is not only because the fossil fuel energy must be transported and distributed to the people in those areas but also because of the associated environmental costs and risks of fossil fuel energy generation. The empirical study of this paper is focused on the impact of a decade's implementation of renewable energy technologies, particularly the building-integrated photovoltaic (BIPV) electricity-generating technology, in Brazil.

The net impacts on GDP depend on the degree of BIPV implementation. Degree of implementation is the principal component of uncertainty in the range of forecasts, and is the dominant policy variable in Brazil and most other sunny countries. It is found that substituting renewable, non-polluting solar energy resources of BIPV sheathing and roofing for conventional building sheathing and roofing and fossil fuel-generated energy sources does not cost jobs and economic growth. It can contribute significantly to economic growth and job creation even in the short run of a few years. The application of the model can be extended to other renewable energy technologies in other countries like the United States, South Africa, and China.

4.1 Micro Economic Analysis

Building curtain wall sheathing of good quality glass, aluminum, or stainless steel costs about \$15 per square foot. Solar electric power-generating PV curtain wall sheathing costs about \$25 per square foot now, but is expected to cost only \$15 per square foot in five to ten years - about the same as the conventional metal or glass sheathing and roofing it would replace. SMUD (Sacramento Municipal Utility District in California) reports \$12 per square foot costs for PV panels, producing electric energy at a cost of \$3.00 per watt (including \$1.50 for PV panels and \$1.50 for balance-of-system wiring costs) by year 2002. Solar architect Gregory Kiss of Kiss and Cathcart, New York, estimates that electric power generating capacity of BIPV will double from 6 watts per square foot to 12, while prices will drop from current \$25 per square foot to \$15 within ten years. It shows an improvement from a current \$4 per watt to \$1.25 per watt. By comparison, SMUD module costs will be \$1.50/watt in 2002.

Using the above BIPV cost and electric power output estimates and assuming \$0.10 per kWh grid power cost, for construction of a medium-size six-story (100' x 50' 6-story) sun-facing solar-powered office or apartment building with 10,000 square feet of BIPV sheathing and roof, located free of shadowing from 20 to 40 degrees North Latitude (Key West to Boston) or 20 to 35 degrees South Latitude (Rio and Sao Paulo to Montevideo or Santiago), the current payback time for investment in optimal solar BIPV sheathing and roofing is about six years (3 to 4 years in Rio where power costs 18 cents per kilowatt hour), with a competitive internal rate of return requiring little or no risk discounting. In ten years, given current trends in PV cost reduction and efficiency improvement, payback will be about two years (or one year in Rio). After payback, grid-connected solar buildings will have zero or near-zero annual electricity costs, greatly reducing operating and life cycle costs.

4.2 Macro Economic Analysis

Our preliminary findings for the macroeconomic competitiveness of BIPV in Brazil are as follows. Assuming the new building construction rates of up to 10% per year, Brazil would have to roughly double its central grid power generation capacity in the next decade, if no BIPV implemented. That is, from roughly 270,000 GWh/yr. in 1996 (Geller et al, 1997) or roughly 300,000 GWh/yr. in Year 2000, to about 600,000 GWh/yr. in 2009. With BIPV, to take care of additional loads not reducible by BIPV, such as shadowed building sites or added electric equipment in the many (over half the total by 2009) older non-PV retrofitted buildings, only about a 20% increase in capacity would be required. The difference in 2009 generating capacity requirements, without BIPV (business as usual) and with maximum implementation of BIPV is the difference between 420,000 and 600,000, or 180,000 GWh/yr. This is the maximum potential cost avoided by full BIPV implementation. The possible impacts on real GDP growth are between 1% to 5% depending on the building construction rates as well as the average saving per square foot for BIPV. The microeconomic competitiveness for BIPV, i.e., the incentives for private investors to initiate any BIPV project, is still under investigation.

5 Conclusions

This paper combines and applies both classical and new econometric modeling approaches to model the economic impacts of substituting non-polluting renewable energy resources and technologies for the currently prevalent fossil fuel energy resources and their associated combustion technologies. The model can be applied in general to sunny developing areas of oil-importing lower-income countries, specifically China, the Philippines, South Africa, and Brazil.

The energy and environmental conditions in these four countries have important similarities and differences among themselves and with other relatively poor, sunny, and oil-importing countries struggling for economic growth and better quality of life, such as India and Egypt. The similarities that attracted our attention were their current costly dependence on oil imports for transportation and other energy end uses. Their major cities suffering increasingly from unhealthy and costly air pollution, and their fossil-fuel-powered economies contributing significantly to greenhouse gases and the danger of global warming and climate change. Yet their domestic solar and other renewable energy resources were not only superior economically and environmentally, but, if exploited by currently available renewable energy-generating technologies, would support faster rates of per capita economic growth than less environmentally sustainable approaches.

Another most important characteristic shared by these nations was and remains their shortage of capital investment for renewable energy-efficient supply and end use, making them much more dependent on international donors and investors than the industrialized nations that have developed the most efficient renewable energy-efficient technologies. In short, they all present significant and attractive environmentally sustainable investment opportunities that are under-developed, for reasons of misperceived technological risk and lack of economic incentives. The model attempts to provide foundations showing there are pure economic incentives to invest in these countries with the most recent available renewable technologies.

It is found in the preliminary study that Brazil will benefit more economically by replacing much of the new urban buildings' energy supply with distributed Building-Integrated Photovoltaics (BIPV) to greatly increase urban electric power supplies for lighting and HVAC (heating, ventilation and air conditioning). The BIPV technology is not only with much lower cost and higher contribution to GDP and employment growth than building less labor-intensive, more capital- and import-intensive fossil fuel power plants, but also greatly reduces contribution to air pollution and global warming.

In summary, the model developed in this paper provides a comprehensive quantitative basis for the evaluation of investment projects in energy production and consumption (end-use) for particular locations at particular times. It integrates, in commensurable economic terms, the economic, environmental, and technological choices and issues. The model also allows for the examination of the inter-relationship among energy efficiency, labor productivity, and capital productivity that is not addressed in the NEMS model. The model allows a more in-depth geo-coded analysis for the renewable energy resources which was not addressed by Zhang (1998). When completed, it will provide public and private investors and decision-makers a wider and better choice, based upon economic incentives, for energy resources.

References

[1] Lamont, Alan. 1997, Analysis of Market Penetration Scenarios of Clean Coal Technologies in China using the LLNL China Energy Model, unpublished paper, Lawrence Livermore National Laboratory, Livermore, California.

[2] The National Energy Modeling System: An Overview, Energy Information Administration, U.S. Department of Energy, March 1996.

[3] Zhang, Z., 1998, The Economics of Energy Policy in China, Edward Elgar Publishing Ltd.