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ENERGY SYSTEM PLANNING ANALYSIS USING THE INTEGRATED ENERGY AND MACROECONOMY MODEL

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SUMMARY

In the past, the energy planners through setting the desired level of economic growth simply used this figure as a base to which additional increases were made, dependent on changing population and supply conditions. Planning proceeded from the national, macroeconomic position, to the aggregate, sectoral and finally project levels. Such process was a virtual one-way linkage from economic growth rate to the energy sector; it is viewed in isolation from the reminder of the economy. Integration of energy system optimization model MARKAL and the macroeconomic growth model MACRO makes possible the analysis of two-way linkage between energy system and the economy. This paper presents review of relation between energy system and economy, including the basics of technology and economy oriented models and their integration in one model with applications.

KEY WORDS

model, energy system, economy, environment

CLASSIFICATION

JEL: C61, Q43, Q51

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INTRODUCTION

Models are usually developed to address specific questions and a therefore only suitable for the purpose and objectives they were design for. Besides many ways of classifying energy models, analytical admission distinguish engineering and economic approach. Because of strong relation between the energy system and economy, the interaction between this two modelling approaches is necessary.

RELATION BETWEEN ENERGY SYSTEM AND ECONOMY

Energy alone is not sufficient for creating the conditions for economic growth, but it is certainly necessary. Most studies of the relationship between energy use and economic development have focused on how the latter affects the former. Economic growth always leads to increased energy use, at least in the early stages of economic development. Empirical analysis demostrates the importance of energy in driving economic development [1].

The neoclassical production function attributes economic growth to increases in the size of the labour force and to the amount of capital available, as well as to increase in total factor productivity. By explicitly incorporating an energy variable in the production function, it is possible to estimate the contribution energy made to the growth of gross domestic product in several countries that grew veray rapidly in the 1980s and 1990s (the United States was included in the sample for comparison).

In every country studied, except China, the combination of capital, labour and energy contributed more to economic growth than did productivity increases. Energy contributed significantly to economic growth in all countries and was the leading driver of growth in Brazil, Turkey and Korea. Its contribution was smaller in India, China and the United States. This results suggest that energy plays a bigger role in countries at an intermediate stage of economic development, because industrial production often makes a large contribution to economic growth at this stage. The results also reflect government policies and the resource endowment of individual countries. Brazil and Mexico, where energy played the leading role in economic growth, have both industrialised rapidly. In Indonesia, the relatively low importance of energy probably reflects the country`s policy of importing sophisticated manufacturing technology via foreign direct investment.

The complementary relationship between energy use and economic growth is intuitively obvious. Less obvious is the extent to which constraints on the availability of energy and its affordability can affect economic development. Numerous studies have demostrated that energy, capital and labour can be substituted for one another to some degree. An increase in energy-input costs can be compensated by investing more in energy-efficient technology, shifting to less-intensive production or using more labour, where it is in surplus supply.

TECHNOLOGY AND ECONOMY ORIENTED MODELS

Technological models often neglect market-related decentralise behaviour of agents and cover only the energy-environment systems. Detailed technological models like MARKAL and EFOM usually characterised as bottom-up approaches, adopt a system-wide optimisation of energy system costs. They have been often criticized as lacking explicit representations of markets, related policy instruments and individual behaviour of agents.

Table 1. Contribution of factors of production and productivity to GDP growth in selected countries, 1980-2001.

	Average annual GDP growth (%)	Contribution of factors of production and productivity to GDP growth (% of GDP growth)			
		Energy	**Labour**	**Capital**	**Total factor productivity**
Brazil	2.4	77	20	11	-8
China	9.6	13	7	26	54
India	5.6	15	22	19	43
Indonesia	5.1	19	34	12	35
Korea	7.2	50	11	16	23
Mexico	2.2	30	60	6	4
Turkey	3.7	71	17	15	-3
USA	3.2	11	24	18	47

MARKAL is a dynamic linear programming model that optimizes a technology-rich network representation of an energy system. The model was developed at the Brookhaven National Laboratory (BNL) in a collaborative effort under the auspices of the International Energy Agency (IEA). In MARKAL model the entire system is represented as s Reference Energy System (RES), showing all possible flows of energy from resource extraction through energy transformation and end-use devices to demand for useful energy services. Each link in the RES is characterized by a set of technical coefficients (capacity, efficiency), environmental emission coefficients and economic coefficients (capital costs, date of commercialization). MARKAL finds the "best" RES for each period by selecting the set of options that minimizes the cost of the total system over the entire planning horizon [2].

Other example of technological models are market-oriented energy-environment system models as GEMS, GEMINI, ENPEP, NEMS and PRIMES (for EU). This models are often characterised as partial equilibrium models because they cover only the energy system and not the rest of economy [3].

PRIMES is a modelling system that simulates a market equilibrium solution for energy supply and demand in the EU member-states. PRIMES being a detailed energy system model, is able to provide evidence about the feasibility of quantified emission reduction objctives in medium to long term horizon. It can also evaluate a wide range of policy instruments, including command and control policy, including chnages (that affect the optimality of technology choices) within the industry structure, competition regimes and decentralisation of decision making. The dynamics of technology penetration can be simulated and influenced through a number of market and non market factors.

Macro-economy oriented models may well represent market-orientation, through the economic equilibrium paradigm, but often neglect the technological change aspects and the energy system details.

An example of such stand-alone model is GEM-E3 model for EU member states. GEM-E3 being a macroeconomic equilibrium model, is suitable for global characterisation of policies and the exploration of the interactions between the economy, the energy system and the environment. A general equilibrium model like GEM-E3 is, by design, appropriate to evaluate distributional effects over sectors and countries.

INTEGRATION OF THE MODELS

Both PRIMES and GEM-E3 models were conceived specifically for the study of climate change strategies but also for other purposes. They do not consider the very long term analyses. MARKAL-MACRO model is an example of model suitable for energy-economy-ecology long-term analyses.

The MARKAL-MACRO model is an integration of MARKAL and MACRO, a single-sector, macroeconomic growth model. Current MARKAL and MARKAL-MACRO users consists of most countries in OECD, and in many economies in transition and developing countries.

By combining MARKAL (a “bottom-up“ technological model) and MACRO (a “top-down“ neoclassic macroeconomic model) in a single-modeling framework (Figure 1), MARKAL-MACRO is able to capture the interplay between the energy system, the economy and the environment [4 – 6].

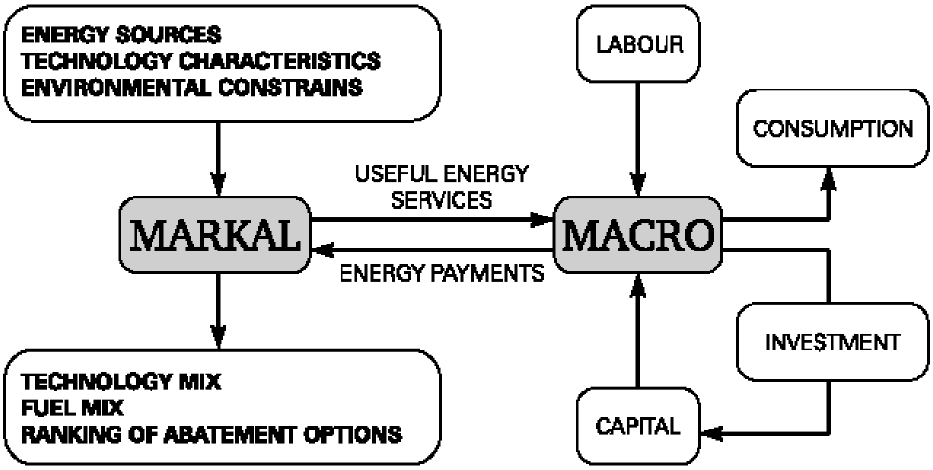

Figure 1. An overview of model MARKAL-MACRO.

As shown in Figure 1, there are two types of linkage between MARKAL and MACRO models. There are physical flows of energy between MARKAL and MACRO and energy cost payments from MACRO to MARKAL. The physical flow of energy is defined as useful energy demands which are exogenous to the stand-alone MARKAL version, but endogenous to the linked model. The costs of energy supply appear in the objective function of MARKAL, but enter into MACRO through the period-by-period constraints governing the allocation of the economy`s aggregate output between consumption, investment and energy cost payments.

The linkage between MARKAL and MACRO is based upon one key idea – the concept of an economy-wide production function. The principal advantage is that this enables to make a direct link between a physical process analysis and a standard long-term macroeconomic growth model.

The inputs to the production function consists of capital, labor and useful energy demands. Capital, labor and energy may each substituted for the other, but there are diminishing returns ot the substitution process [7]. To avoid the econometric estimation of many parameters, the production function is a nested constant elasticity of substitution (CES) form as presented with [8]:

$$Q = A\left[\delta K^{-\rho} + (1-\delta) L^{-\rho}\right]^{-1/\rho}, \tag{1}$$

where K and L stand for production factors kapital and labour, respectively. Variable A is efficiency factor, δ is parameter of distribution and ρ parameter of substitution.

At the top level, there is a capital-labor aggregate that may be substituted for an energy aggregate. At the bottom level, there is a unitary elasticity of substitution between capital and labor and the energy aggregate as shown in Figure 2.

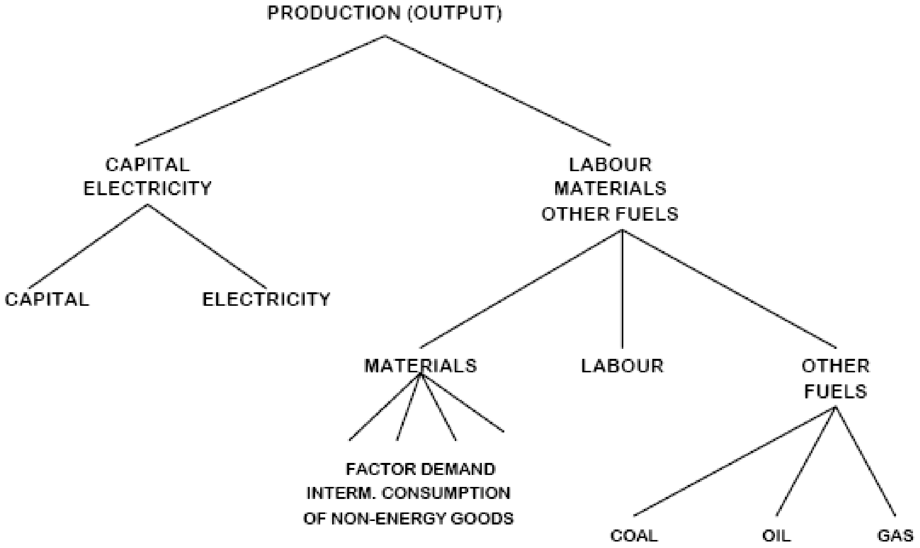

Figure 2. Structure of CES production function.

In the standrad version of MARKAL, it is dynamic linear model where markets are simulated by minimising an objective function incorporating the costs of energy technologies and resources. Model MACRO takes an aggregated view of long-term economic growth. The basic input factors of production are capital, labor and individual forms of energy. The economy`s outputs are used for investment, consumption and interindustry payments for the cost of energy. MACRO is solved by nonlinear optimization. It uses the criterion of maximum discounted utility of consumption to select among alternative time paths of energy costs, macroeconomic consumption and investment.

Different methods and modeling tools for energy system studies are often grounded in one of two disciplines: energy economics and system engineering. Energy-economic studies focus on links between energy demand and economic development. Their modeling tools are designed to account for economic feedback on energy demand from changes in energy prices, but include little detail on technological change. In contrast, engineering studies of energy demand focus on the efficiency of energy-using equipment. However, economic feedback is in general not included in the analysis tools. In studying the possibilities and costs of mitigating emissions of greenhouse gases, energy-economic and systems engineering studies have given different results.

RESULTS OF INTEGRATED MODEL APPLICATION

The example of MARKAL-MACRO application is national energy analysis for Sweden, for investigation of consequences of reducing energy-related carbon dioxide emissions for the Swedish energy system and economy. Different reduction level is studied on the basis of different international climate protocols. MARKAL-MACRO has been considered a valuable tool for this type of analysis, since the societal cost in term of reduction in GDP can be estimated na dthe marginal cost of reducing CO2 can be calculated [9].

MARKAL-MACRO has been used to evaluate different environmental tax and subsidy schemes. The results clearly show that the change in Swedish CO2 taxes and subsidy programs between 1990 and 1996 should lead to substantial reductions in CO2 emissions as presented in Figure 3. Tha tax change will lead to a strongly increased use of biomass, especially in the district heating sector. The tax scheme of 1996 includes energy tax, CO2 taxes for all energy use except for electricity production, sulphur tax and subsidies for biomass based cogeneration, wind power and solar heat. Obviously, the compounded change in energy taxation strongly curbs the emissions until the year 2020. However from 2020, at which time it is assumed that most of the nuclear power will be phased out, it is not enough to keep total emissions down.

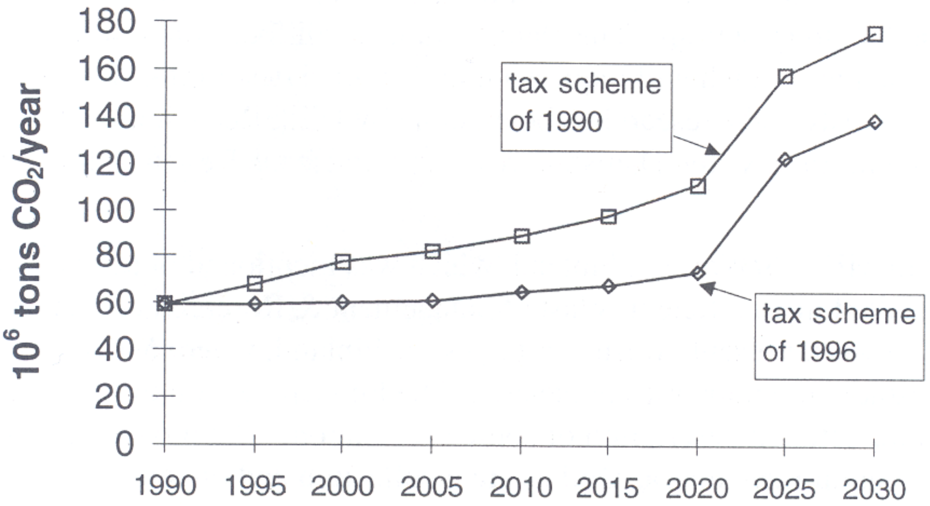

Figure 3. The total CO2 emissions from the Swedish energy system with the energy tax and subsidy scheme of 1990 versus the tax scheme of 1996.

MARKAL-MACRO has been used to study three different energy-environment issues of interest for Swedish energy policy. They illustrate the importance of the energy-economy interface and the value of using a linked energy-economy model. This issues are: the possibilities and cost of restricting carbon dioxide emissions; the possibilities and cost of phasing out the Swedish nuclear power and the value of carbon-free resources, such a biomass and end use energy efficiency improvements. The results have focused partly on the societal value of technologies or groups of technologies or resources and partly on the interplay between the technical energy system and the economy.

The value of an energy resource or a technology depends on the system of which it is a part and the external demands on this system. This statement is well illustrated by the MARKAL-MACRO results, which show that the value of biomass resources and end use energy efficiency improvements depends strongly on whether nuclear power is phased out and on the existence of CO2 restrictions. The value of a resource or technology is estimated by comparing the resulting development of GDP with and without the availability of the resource.

A certain CO2 reductions is achieved through a combination of technological changes and economic feedback effects. Firstly, technological changes within the energy system, such as fuel switching and efficiency improvements, lead to a reduction in CO2 emissions per unit of useful energy. These changes are modelled in the MARKAL model. The increasing energy prices lead to a reduction in the demand for useful energy, further reducing total CO2 emissions. This economic feedback results in a decrease in general economic activity (GDP) and partly in decreasing energy use per GDP. Both effects are taken into account through the link to the macroeconomic production function (MACRO). The allocation of CO2 reductions in the case of stabilizing emissions on the 1990 level is shown in Figure 4. The total reduction can be divided between different causes of reduction: reduced GDP growth, reduced energy use per GDP and technological changes within the energy system. A further division is then made between different sectors within the energy system.

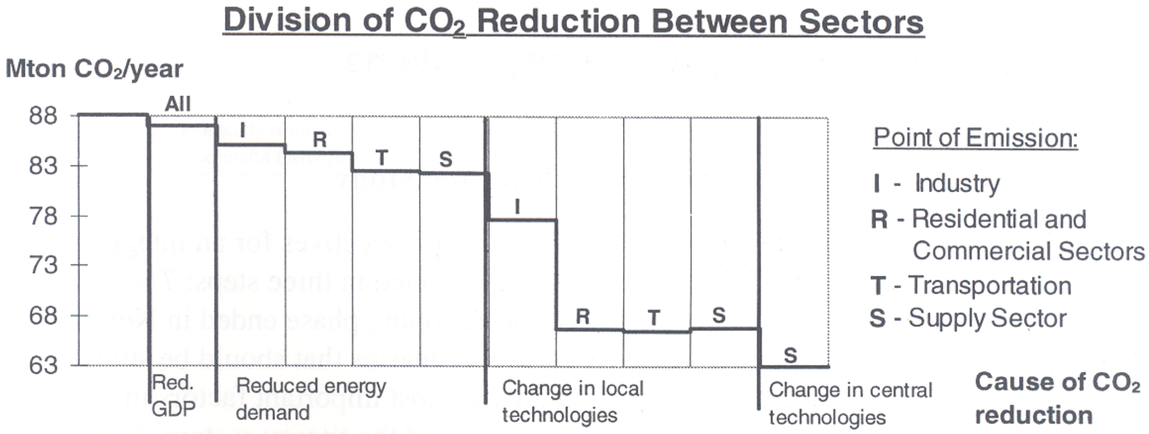

Figure 4. The CO2 reduction in the case of stabilization of emissions at the 1990 level compared to the business-as-usual case.

Another example of MARKAL-MACRO application is a project for the Clean Development Mechanism in Taiwan [10]. Under the Kyoto protocol a Clean Development Mechanism (CDM) was established which authorizes emission trading with a developing country as a means by which an industrialized country can meet its oblifgation to reduce greenhouse gases.

Before a CDM project can start, the participants – the host country and the investor in an industrialized country – must set and define baselines and criteria for quantification of emission reduction. Equally important is an agreement on how the accrued emission credits should be shared between the host and the investors.

This issues can be addressed within a single modeling framework; the MARKAL-MACRO model was used to evaluate the costs and benefits of what a CDM project might be, together with its impact on economic development.

The project to be evaluated was the transfer of technologies that are being promoted by the USEPA Energy Star Buildings program (in US this is market-based program in which commercial building owners and operators agree to make a series of energy-efficient improvements).

The case study started with the MARKAL-MACRO model of Taiwan and a database that already includes many conservation measures and efficient technologies currently available in the market. The database also included some advanced technologies that are likely to enter the market in the near future.

MARKAL-MACRO calculates the marginal cost of providing the new technology (compact fluorescent tubes, building tune-up, fan systems and heating and cooling system upgrades etc.) as the incremental change in national welfare when the technology is provided.

Total energy system cost are lower when the Energy Star Buildings measures are introduced. These costs include energy resource and fuel costs, investment in supply and demand technologies and operating and maintenance costs. Restricting future carbon dioxide emissions makes a pronounced reduction in these energy costs. This is the result of the substantial reduction in the use of fossil energy, especially coal.

The introduction of the Energy Star program has a positive impact on the growth in gross domestic product (GDP). Since this incremental growth stems from reduced fossil energy, it can fairly be considered an increase in the direction of sustainable development.

CONCLUSION

The energy-economy modelling together with the issues related to CO2 emission reduction implies more complexity because global energy, economy and environmental systems are affected, longer time horizon analyses with technology changes are necessary and market-related decentralised behaviour of agents need to represent. Most of the available empirical models cannot fulfill this requirements; technological models often neglect market-related decentralised behaviour of agents and cover only the energy-environment system. The capability of macro-economy oriented models are opposite to technical models. Because this situation limits the insight we can have on new issues, combination of such models became the best solution for complex analyses.

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ANALIZA PLANIRANJA ENERGETSKOG SUSTAVA INTEGRIRANIM ENERGETSKIM I MAKROEKONOMSKIM MODELIMA

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SAŽETAK

U prošlosti, planiranje vezano uz energiju odvijalo se postavljanjem željene razine ekonomskog rasta i njegove jednostavne uporabe kao temelja daljnjih porasta ovisnih o poulaciji i dovodima. Planiranje se kretalo od nacionalne, makroekonomske razine do agregata, sektora i naposljetku projektne razine. Takav je proces virtualna jednosmjerna poveznica ekonomske stope rasta i energetskog sektora, izoliran od ostale ekonomije. Integracija modela MARKAL za optimiranje sustava i modela makroekonomskog rasta MACRO omogućava analizu dvosmjerne veze između ekonomije i energetskog sustava. U ovom radu razmatra se stanje relacije između energetskog sustava i ekonomije, uključujući osnove tehnologije, modele usmjerene na ekonomiju, njihovu integraciju u jedan model i primjene.

KLJUČNE RIJEČI

model, energetski sustav, ekonomija, okoliš