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Nuclear energy option for energy security and sustainable development in India

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ABSTRACT

India is facing great challenges in its economic development due to the impact on climate change. Energy is the important driver of economy. At present Indian energy sector is dominated by fossil fuel. Due to international pressure for green house gas reduction in atmosphere there is a need of clean energy supply for energy security and sustainable development. The nuclear energy is a sustainable solution in this context to overcome the environmental problem due to fossil fuel electricity generation. This paper examines the implications of penetration of nuclear energy in Indian power sector. Four scenarios, including base case scenario, have been developed using MARKAL energy modeling software for Indian power sector. The least-cost solution of energy mix has been measured. The result shows that more than 50% of the electricity market will be captured by nuclear energy in the year 2045. This ambitious goal can be expected to be achieved due to Indo-US nuclear deal. The advanced nuclear energy with conservation potential scenario shows that huge amounts of CO_2 can be reduced in the year 2045 with respect to the business as usual scenario.

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1. Introduction

Indian electrical installed capacity has a rapid growth from 1350 MW in the year 1947 to more than 140,000 MW presently. In spite of this rapid growth, there is a huge gap between demand and supply. The peak power shortage is up to 25.4% with an all India average of 11.7%, while the energy shortage is up to 20% with an all India average of 7.4%.

It has been shown that because of increasing economic activity and population, the electrical energy requirement in India will reach an estimated value of 5081 billion kW h in the year 2045 (Mallah and Bansal, 2009a). In the business as usual case, the supply will be only 1561 billion kW h, leaving a gap of 3520 billion kW h i.e. 70% of the total projected demand in the year 2045. Such a situation warrants a number of measures that are economically viable and environmentally sustainable. The best and one of the most effective ways of dealing these situations to reduce the demand through energy efficiency measures in all sectors of economy. The Bureau of Energy Efficiency has estimated an average energy conservation potential of 23% in these sectors (BEE, 2005). The remaining gap requires environment friendly technologies for sustainable development. It is seen therefore, that it is absolutely essential to provide additional capacities for power generation to meet the future demand. The possible options, keeping in mind the environmental aspect, is: nuclear technology. Nuclear recently has become very important option because of the Indo-US nuclear deal. It has been estimated by Department of atomic energy (DAE) that about 220 GW nuclear power will be installed up to the year 2045 (Kakodkar, 2004).

Several studies have been conducted to estimate resource allocations in the world as well as in India. In a report by United States Environmental Protection Agency (Johnson et al., 2006) MARKAL scenarios have been developed for analysis of technology options for electric sector and also to estimate the impact on air quality. The UK MARKAL and MARKAL-Macro energy system models have been developed for scenarios and sensitivity analysis by UK Energy Research Centre (Strachan and Kannan, 2007). In a dissertation, Barreto has investigated the technological learning in energy optimization models and deployment of emerging technologies (Barreto, 2001).

In India, several studies have been conducted by different research groups as well as ministries. In an integrated energy policy report by Planning Commission of India (PC, 2006) fossil fuel and renewable energy technologies have been considered for future supply options and the requirement of electric energy is projected by assuming constant and variable elasticity of demand. In a national energy map for India i.e. Technology Vision 2030 (TERI, 2006), supply scenarios have been developed for new and renewable energy sources by projecting the demand using logistic and regression models. In a dissertation Mathur (2001) has developed a modified dynamic energy and green house gas reduction planning approach for Indian power sector. Shukla et al. prepared a report entitled Development and Climate: an Assessment for India by using MARKAL modeling (Shukla et al., 2003).

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In this paper, advanced nuclear technologies have been considered as future source of energy production. The MARKAL bottom up model has been used to estimate resource allocation and carbon dioxide emission in future. The effects of different energy savings potential with new technologies have also been estimated. Four scenarios, including business as usual (BAU) scenario, have been developed. These are: BAU, advanced nuclear, advanced nuclear with 10% energy savings and advanced nuclear with energy conservation potential.

2. MARKAL model

MARKAL (acronym for MARKet ALlocation) is a widely applied bottom-up, dynamic technique, originally and mostly a linear programming (LP) model developed by the Energy Technology Systems Analysis Program (ETSAP) of the International Energy Agency (Loulou et al., 2004). MARKAL depicts both the energy supply and demand sides of the energy system. It provides policy makers and planners in the public and private sectors with extensive details on energy producing and consuming technologies, and it can provide an understanding of the interplay between the macro-economies and energy use. As a result, this modeling framework has contributed to national and local energy planning, and to the development of carbon mitigation strategies. The MARKAL family of models is unique, with applications in a wide variety of settings and global technical support from the international research community. Implementation in more than 40 countries and by more than 80 institutions, including developed, transitional, and developing economies indicates wide acceptability (Loulou et al., 2004). As with most energy system models, energy carriers in MARKAL interconnect the conversion and consumption of energy. This user-defined network includes all energy carriers involved in primary supplies, conversion and processing, and end-use demand for energy services. The demand for energy services may be disaggregated by sector and by specific functions within a sector. The optimization routine used in the model's solution selects from each of the sources, energy carriers, and transformation technologies to produce the least-cost solution subject to a variety of constraints. The user defines technology costs, technical characteristics and energy service demands. As a result of this integrated approach, supply-side technologies are matched to energy service demands.

3. MARKAL model development

Nuclear power is the fourth-largest source of electricity generation in India after thermal, hydro and renewable sources of electricity. As of the year 2008, India has 17 nuclear power plants in operation generating 4120 MW while 6 other are under construction and are expected to generate an additional 3160 MW (Jain, 2004). There are 10 nuclear power plants planned to generate 20,600 MW of power in coming decade.

In the Indian MARKAL model, all nuclear technologies draw on a single uranium supply curve. The uranium supply curve is based on estimates of global uranium reserves and the cost of extraction. Because the energy density (energy per unit weight) of uranium is high, transport costs were ignored. However, the demand-supply equilibrium is such that most analysts expect enough enriched uranium to be available at reasonable price for at least the next half-century. As a result, heavy water reactors are included in the present MARKAL scenario study because the time periods have taken from the year 2005 to 2045.

Enough supplies of uranium exist to build and operate then breeder reactors may emerge as a viable option to meet long-term energy supply goals. Breeder reactors are not an economically attractive option in the wake of prevailing enriched uranium prices, at least in the short-term. Therefore, it has not been included in the present Indian MARKAL.

In India, PHWR are likely to remain the dominant nuclear technology because there is significant experience with design, construction and operation of these plants. In the present scenario Advanced Heavy Water Reactor (AHWR) has been considered as advanced nuclear power technology. AHWR is a vertical pressure tube type, boiling light water cooled and heavy water moderated reactor using ^{233}U–Th Mixed Oxide (MOX) and Pu–Th MOX fuel. MOX reactors were included in the model, since it is at least plausible that plutonium recycling would be considered in the future, despite the high costs and risks of proliferation.

The Indian MARKAL includes the following nuclear technologies: PHWR, and AHWR. In the results that follow, the PHWR presented as "conventional nuclear" and the AHWR presented as "advanced nuclear". The techno-economic parameters of advanced nuclear technology are given in Table 1. Due to the long gestation period and some technical problems it has been considered that the technology will available only after 2020.

The Electric Generation Sector characterizes existing and new technologies available for electricity generation. Based on sector-specific electricity demand in various economic sectors, fuel prices, technology costs, and the environmental and operational constraints incorporated in the model. MARKAL determines the least cost way to meet system electricity demand and then calculates the resulting criteria pollutant and green house gas emissions.

The case for various energy efficiency potentials developed in a paper (Mallah and Bansal, 2009b) have been used as an energy demand input for MARKAL modeling. Clean coal and renewable technologies are already introduced and modeled in Mallah and Bansal (2010a,b) has been considered for techno-economic parameters. The various techno-economic parameters of Indian MARKAL are given in Table 1.

Table 1
Overview of key characteristics of candidate generation technologies in the Indian MARKAL model.

Technology	Start year	Lifetime (years)	Efficiency (%)	Availability fraction	Investment cost (US$/kW)	Fixed O&M cost (US$/kW)	Variable O&M cost (US$/kW h)
Coal thermal	2005	40	32	0.80	890	10.7	0.014
Gas thermal	2005	40	35	0.80	667	23.5	0.029
Oil thermal	2005	30	35	0.80	825	28.61	0.055
Large hydro	2005	50	80	0.70	1334	12.9	0.9
Nuclear	2005	40	35	0.75	1446	42	0.002
Advanced nuclear	2020	60	40	0.75	1250	55	0.0025
Wind power	2005	30	35	0.35	889	10	–
Small hydro	2005	35	80	0.64	1557	15.18	–
Other renewable	2005	30	54	0.65	885	41.5	0.48

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