Energy 35 (2010) 3031–3039

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Nuclear and clean coal technology options for sustainable development in India

Subhash Mallah*, N.K. Bansal

Shri Mata Vaishno Devi University, Katra -182320, Jammu & Kashmir, India

ARTICLE INFO

Article history:
Received 10 November 2009
Received in revised form
19 March 2010
Accepted 21 March 2010
Available online 27 April 2010

Keywords:
MARKAL
India
Clean coal
Advanced nuclear

ABSTRACT

Due to the growing energy needs along with increasing concerns towards control of greenhouse gas emissions, most developing countries are under pressure to find alternative methods for energy conversion and policies to make these technologies economically viable. Most of the energy is produced from fossil fuel in India which is not a sustainable source of energy. In this paper Indian power sector has been examined by using MARKAL model for introduction of clean coal and advanced nuclear technologies with implementation of energy conservation potential. The result shows that application of clean technologies gives energy security but not significant reduction in carbon dioxide emissions. When clean technologies apply with energy conservation a huge amount of CO_2 can be reduced and also economically viable. Three scenarios including base case scenario have been developed to estimate the resource allocations and CO_2 mitigation. The clean technologies with maximum savings potential shows 70% CO_2 reduction in the year 2045.

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% [1].

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 kWh in the year 2045 [1]. In the business as usual scenario, the supply will be only 1561 billion kWh, leaving a gap of 3520 billion kWh, 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 which is economically viable and reduce the emission at minimal cost. With the assumption of full exploitation of energy saving potential, it has been seen that the demand–supply gap of electrical energy can be reduced by 50% of the total requirement [2] and therefore, a huge amount of emission reduction at almost no cost.

The remaining gap of 50% requires environment friendly technologies for sustainable development. Therefore, 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, are: Clean coal and advanced nuclear technologies. Although there are some social constraints to nuclear power implementation, but in terms of energy security it is more viable solution.

New and advance power technologies using coal as the primary fuel are: IGCC (Integrated Gasification Combined Cycle) and PFBC (Pressurized Fluidized-bed Combustion). Nuclear recently has become very important option because of the Indo-US nuclear deal. The efficiency of power conversion for IGCC and PFBC are more than conventional coal power plant. IGCC and PFBC are also environment friendly.

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 [3] MARKAL scenarios have been developed for analysis of technology options for electric sector and also to estimate the impact on air quality. The future role of nuclear energy and the air quality implications of carbon capture and sequestration in U.S. electric market have also been discussed. A detailed database has been prepared by Shay et al. [4]. The UK MARKAL and MARKAL-Macro energy system models have been developed for scenarios and sensitivity analysis by UK Energy Research Centre [5]. A reduced version of the energy model MARKAL designed for applications at a regional and urban level, and in particular, Geneva, Switzerland [6]. In a dissertation, Barreto [7] has investigated the technological learning in energy optimization models and deployment of emerging technologies. Economics of

* Corresponding author. Tel.: +91 1991 285524; fax: +91 1991 285694.
E-mail address: subhas_mallah2k1@yahoo.com (S. Mallah).

0360-5442/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.energy.2010.03.041

greenhouse gas limitations in Indonesia has been studied by Ministry of Environment in collaboration with RNL (Riso National Laboratory), Denmark [8].

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 [9] fossil fuel and renewable energy technologies have been considered for future supply options and the requirement of electrical energy is projected by assuming constant and variable elasticity of demand. In a national energy map for India, i.e. Technology Vision 2030 [10], supply scenarios have been developed for new and renewable energy sources by projecting the demand using logistic and regression models. In a dissertation Mathur [11] has developed a modified dynamic energy and greenhouse gas reduction planning approach for Indian power sector. Shukla et al. [12] prepared a report entitled Development and Climate: an Assessment for India by using MARKAL modeling.

In this paper both clean coal and advanced nuclear technologies have been considered as future source of energy. The MARKAL bottom–up model has been used to estimate resource allocation and carbon dioxide emission in future. The effect of different energy savings potential with new technologies has also been estimated. Two alternative scenarios have been developed with respect to the base case. The first is the advanced technology scenario and the second is mixed scenario (with energy savings potential). In Advanced technology scenario only the penetrations of advanced nuclear and clean coal technologies (PFBC and IGCC) have been considered. The mixed scenario uses the energy saving potential in various sectors of Indian economy together with advanced technologies.

2. MARKAL model

MARKAL (MARKet ALlocation) is a widely applied bottom–up, dynamic technique, originally and mostly a LP (linear programming) model developed by the ETSAP (Energy Technology Systems Analysis Program) of the International Energy Agency [13]. 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 [13]. 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 sectors 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.

2.1. Nuclear technology representation in MARKAL

Nuclear power is the fourth-largest source of electricity 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 others are under construction and are expected to generate an additional 3160 MW [14]. There are 12 nuclear power plants planned to generate 13,860 MW so that a total of 21,140 MW power supplied by nuclear 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. The nuclear fuel cycles included in Indian MARKAL were determined by careful consideration of the nuclear technologies most likely to be deployed in the Indian power sector. The analysis considers the following technologies: heavy water reactors and advanced heavy water reactors. LWRs (Light water reactors) operating on a once-through fuel cycle (no reprocessing) currently have the lowest cost among commercially available reactors. But these reactors require enriched uranium which again rises the cost of electricity production because in Indian context it is very costly to install uranium enrichment plant. Heavy water reactor technology typically calls for larger plants with higher construction and capital costs, as compared to light water reactor plants. Moreover, the large amount of heavy water (deuterium) required to run these plants also necessitate significant infrastructure investments. A heavy water reactor's key advantage is its ability to use natural uranium, as compared to enriched uranium required by LWR. However, the demand–supply equilibrium is such that most analysts expect enough enriched uranium will be available at reasonable price for at least the next half-century (i.e. after the year 2050). As a result, heavy water reactors are included in the present MARKAL scenario study because the time periods we have taken are 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 not only fission uranium, but also convert fertile materials (primarily U^{238} and Th^{232}) into fissile products (primarily Pu^{239} and U^{233}). Breeder reactors produce more fissile material than they fission. Breeder reactors are not an economically attractive option in the wake of prevailing enriched uranium prices, at least in the short-term. Therefore, we did not include breeder reactors in the Indian MARKAL.

In India, PHWR (Pressurized Heavy Water reactors) 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 AHWR (Advanced Heavy Water Reactor) 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 MOX (Mixed Oxide) 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 be available only after the year 2020.

2.2. Clean coal technologies representation in MARKAL

Advanced clean coal technologies for power generation have been under development for thirty years. These technologies are designed to generate electricity with lower emissions and higher thermal efficiency than the conventional alternatives. More