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Renewable energy for sustainable electrical energy system in India

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ABSTRACT

Present trends of electrical energy supply and demand are not sustainable because of the huge gap between demand and supply in foreseeable future in India. The path towards sustainability is exploitation of energy conservation and aggressive use of renewable energy systems. Potential of renewable energy technologies that can be effectively harnessed would depend on future technology developments and breakthrough in cost reduction. This requires adequate policy guidelines and interventions in the Indian power sector. Detailed MARKAL simulations, for power sector in India, show that full exploitation of energy conservation potential and an aggressive implementation of renewable energy technologies lead to sustainable development. Coal and other fossil fuel (gas and oil) allocations stagnated after the year 2015 and remain constant up to 2040. After the year 2040, the requirement for coal and gas goes down and carbon emissions decrease steeply. By the year 2045, 25% electrical energy can be supplied by renewable energy and the CO_2 emissions can be reduced by 72% as compared to the base case scenario.

1. Introduction

India's electrical power scenario is characterized by a considerable gap between demand and supply (i.e. 24.7% in the year 2005), which may grow up to 70% in the business as usual scenario in the year 2045 (Mallah and Bansal, 2009a). This gap between demand and supply can be reduced up to 50% by full exploitation of energy savings potential in various sectors of economy. The remaining gap can be filled by a contribution of coal, hydro, gas, nuclear, wind, small hydro and other renewable energy sources (Mallah and Bansal, 2009b).

For rational allocation of various energy sources, it is essential to use models for optimum and least cost solutions, which help to formulate a rational energy policy.

Forecasting future energy demand and optimum allocation of energy resources are necessary requirements for a rational energy policy. A number of studies have been conducted so far to forecast energy demand in future. Energy demand projections based on the GDP have been reported by Dincer and Dost (1997). Galli (1998) estimated the relationship between energy intensity and income levels by forecasting long-term energy demand in emerging Asian countries. Erdogan and Dahl (1997) investigated the impact of income, price and population on the aggregate, industrial, manufacture and mining sectors of energy in Turkey. Hunt et al. (2003) presented UK energy demand for various sectors underlying trends and seasonality. Crompton and Wu (2005) presented energy consumption in China: past trends and future directions. Mirasgedis et al. (2006) presented a model for mid-term electricity demand forecasting incorporating weather influences. Shiu and Lam (2004) have studied electricity consumption and economic growth in China. Wolde-Rufael (2006) has estimated electricity consumption and economic growth: a time series experience for 17 African countries. Yoo (2005) studied electricity consumption and economic growth: evidence from Korea. Nasr et al. (2000) studied econometric modeling for electricity consumption in post-war Lebanon.

Using the MARKAL model, Mallah and Bansal (2009c) showed that full exploitation of energy saving potential leads to a situation where allocations for coal and gas stagnate after the year 2015. The green house gas (GHG) emissions also reduce correspondingly. India has more than 189 GW renewable energy potential (PC, 2006); in contrast, the installed capacity, except for large hydro, for renewable energy is only 9000 MW, i.e. only 7% of the total installed capacity. Contribution of large hydro is 30 GW (MNRE, 2006).

Considering the future electricity demand projected by Mallah and Bansal (2009a) through the time series and econometric model, MARKAL allocations have been worked for renewable energy implementation in a rational as well as aggressive way. The present installed electric capacity, of course, is assumed to be available throughout the year of forecasting.

Electricity generation from renewables is assumed to have increasing importance in the context of large negative environmental externalities caused by electricity generation, due to the

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predominance of fossil fuels in the energy mix. Managing environmental and social impacts has been drawing considerable attention in policy-making project development, and operations. The increasing environmental concern is about the contribution of coal-fired power generation to air emissions, mainly due to the poor quality of Indian coal with an average ash content of 40% or more. Studies have shown that power sector contributes about 40% of the total carbon emissions. In this context, it is imperative to develop and promote alternative energy sources that can lead to sustainability of the energy system. Although at present the contribution of renewable electricity is small, the capabilities promise the flexibility of responding to emerging economic, socio-environmental and sustainable development needs. There are opportunities for renewable energy technologies under the new climate change regime as they meet the two basic conditions to be eligible for assistance under UNFCC mechanisms: they contribute to the global sustainability through GHG mitigation; and they conform to national priorities by leading to the development of local capacities and infrastructure. This increases the importance of electricity generation from renewables. Considerable experience and capabilities exist in the country on renewable electricity technologies. An overall energy system framework is used for assessing the future role of renewable energy in the power sector under baseline and different mitigation scenarios over a time frame of 40 yr, between 2005 and 2045.

The following three scenarios including base case scenario have been developed to implement the renewable energy in the Indian power sector:

- Base case scenarios (BCS);
- Renewable technology scenario and
- Aggressive renewable technology scenario.

Base Line Scenario (BCS) presumes continuation of current energy and economic dynamics and provides a reference for comparing the impacts of policies or alternate futures. It assumes what is often called a 'business-as-usual' dynamics. This scenario presumes no policy intervention for GHG emissions control other than normal non-market and long-term policy interventions related to energy and technology.

The Renewable Technology Scenario considers the government policies towards renewable energy implementation in next two-three planning periods and projections made by the ministries. Around 15,000 MW additional grid power installed capacity to be met through renewable power by 2012 and capacity addition of around 30,000 MW are envisaged up to the year 2022. Therefore, renewable power capacity by the end of the year 2022 is likely to reach 54,000 MW, which would correspond to a share of 5% in the then electricity-mix (MNRE, 2006).

The Aggressive Renewable Technology Scenario considers the full exploitation of renewable energy potential existing in the country up to the year 2045. The Aggressive Renewable Technology Scenario has been considered because in the last two decades renewable energies have been exploited at a faster rate and seem to continue in the future with a more faster rate due to international pressure to reduce green house gas in the atmosphere. Energy conservation potentials have also been considered with these scenarios as developed in Mallah and Bansal (2009b).

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. 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 (e.g., mining, petroleum extraction, etc.), conversion and processing (e.g., power plants, refineries, etc.), and end-use demand for energy services (e.g., boilers, automobiles, residential space conditioning, etc.). The demand for energy services may be disaggregated by sector (i.e., residential, manufacturing, transportation, and commercial) and by specific functions within a sector (e.g., residential air conditioning, heating, lighting, hot water, etc.). 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 (e.g., conversion efficiencies) and energy service demands. As a result of this integrated approach, supply-side technologies are matched to energy service demands.

3. MARKAL model development

3.1. Base case scenario (BCS) development

The use of scenarios guides the actual analysis of technological futures and assists in understanding how complex systems may evolve. Scenarios are internally consistent depictions of how the future may unfold, given assumptions about economic, social, political and technological developments as well as consumer preferences (Manne and Wene, 1992). Scenarios explore plausible futures by using a model or models to generate an outcome (or set of alternative outcomes) consistent with a set of motivating assumptions, sometimes called a "storyline". It is important to stress that these consequences should not be interpreted as predictions, for example, about levels of new technology market penetration or emission trajectories. Rather, the technology parameters and economic data used as inputs are best seen as starting-point assumptions that reflect a range of reasonable estimates.

Scenario analysis aims to examine how changes in model parameters (inputs) affect outputs across sets of related storylines, rather than focus on the results from a particular scenario. No attempt is made to consider every possible future. These comparative analyses alternately look forward to examine how competing sets of input assumptions drive technology adoption and emissions, and backward to identify the energy technology pathways available to meet some future environmental or technological goal. Scenarios, therefore, facilitate assessment of the consequences of varying assumptions, the range of possible futures, and trade-offs and branch points that govern choices among these futures (Fishbone and Abilock, 1981).