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Parametric sensitivity analysis for techno-economic parameters in Indian power sector

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ABSTRACT

Sensitivity analysis is a technique that evaluates the model response to changes in input assumptions. Due to uncertain prices of primary fuels in the world market, Government regulations for sustainability and various other technical parameters there is a need to analyze the techno-economic parameters which play an important role in policy formulations. This paper examines the variations in technical as well as economic parameters that can mostly affect the energy policy of India. MARKAL energy simulation model has been used to analyze the uncertainty in all techno-economic parameters. Various ranges of input parameters are adopted from previous studies. The results show that at lower discount rate coal is the least preferred technology and correspondingly carbon emission reduction. With increased gas and nuclear fuel prices they disappear from the allocations of energy mix.

1. Introduction

The MARKAL Business As Usual (BAU) case presented in [1] provides a projection of the evolution of the Indian energy system from the year 2005 to 2045. The BAU case was generated using best estimates for the values of model inputs, such as the characteristics of current and future technologies, energy service demands, and regulations on criteria pollutant emissions. Since the true values for many of these inputs are unknown, the BAU case represents only one of many possible outcomes. Further, it does not itself convey information regarding the sensitivity of the energy system to input variations and assumptions.

Kannan [2] has performed an analysis for uncertainties in key low carbon power generation technologies in UK. Chen et al. [3] represents a two-stage inexact-stochastic programming model for planning carbon dioxide emission trading under uncertainty.

Various studies have been conducted in India using MARKAL energy model. In an integrated energy policy report by Planning Commission of India [4] fossil fuel and renewable energy technologies have been considered for future supply options. In a national energy map for India, i.e., Technology Vision 2030 [5], supply scenarios have been developed for new and renewable energy sources. In a dissertation, Mathur [6] has developed a modified dynamic energy and green house gas reduction planning approach for Indian power sector. Shukla et al. [7] prepared a report entitled Development and Climate: an Assessment for India by using MARKAL modeling. Sensitivity analysis has not been adequately discussed in any of these studies so far.

This paper describes the application of formal sensitivity analysis techniques to evaluate the model's response to changes in input assumptions. The results aid in characterizing and communicating the drivers that leads to such outcomes as: the penetration of particular technologies, the increase in fuel prices, efficiency improvement in new power generation technology, or an increase in availability factor. Sensitivity analysis also allows one to view the BAU case in the context of the range of possible future energy scenarios that may occur.

2. Sensitivity analysis background

In broader sense there are two types of sensitivities: global and parametric. Global sensitivity analysis techniques typically are applied in practice when the goal is to characterize the relationships among model inputs and outputs over a wide range of input conditions. In contrast, parametric sensitivity analysis, also known as local sensitivity analysis, is used to evaluate the response to a change in a single input, holding all other inputs constant [8].

Global sensitivity analysis involves perturbing multiple model inputs simultaneously and evaluating the effects of each input or combinations of inputs on model outputs. Inputs are often perturbed via Monte Carlo simulation. In Monte Carlo simulation, statistical or empirical distributions are assumed for inputs of interest. A value is sampled from each distribution, and the resulting set of

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values fed into the model. The values of relevant outputs are recorded. The combination of a set of inputs and the corresponding outputs constitutes one potential "realization." Typically fifty to several hundred realizations are generated in a Monte Carlo simulation. These realizations are then evaluated using visualization and statistical techniques to characterize the nature and strength in the relationships among inputs and outputs.

Parametric sensitivity analysis, in which one input is perturbed while others are held constant, is very useful in characterizing incremental responses to changes in inputs from a base or reference case. These responses can be characterized quantitatively, such as with a sensitivity metric or empirical derivative, or graphically. While parametric techniques do not characterize responses over combinations of inputs, they often play an important role both in preliminary analyses, as a cursory means to identify sensitivities of interest, and in more detailed analyses of input–output responses.

Global and parametric sensitivity techniques can be used independently or together. Such an analysis is required to provide detailed information about impacts of changes in specific inputs in the context of the BAU case.

To evaluate sensitivities within the Indian database and model, parametric sensitivity techniques have been used in this paper.

3. 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 [9]. 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.

4. Inputs for sensitivity analysis in MARKAL

Inputs included in the analysis are: discount rate, the future costs of natural gas and oil, the hurdle rate for new electric generation technologies, future nuclear investment cost, availability factor and efficiency improvement of clean coal technologies. Each of these inputs is expected to have an impact on the outputs, i.e., future resource allocations.

Table 1
Input parameters considered for sensitivity analysis in MARKAL.

Sensitive parameter	Unit	Range
Discount rate	Percentage	6.5–15
Efficiency		
IGCC	Percentage	38–58
PFBC	Percentage	34–50
Availability		
IGCC	Fraction	0.86–0.89
PFBC	Fraction	0.80–0.90
Hurdle rate	Percentage	5–25
Fuel prices		
Oil	US$/barrel	30–150
Gas	US$/thousand cubic feet	3–8
Nuclear investment cost	US$/kW	1160–3000

The next step in the analysis was to characterize ranges for the inputs. Each of the inputs, which were assumed to be independent of each other, was represented with a uniform distribution.

Discount rate is the most important parameter for sensitivity analysis because this affect whole of the energy system cost and allocations. A range from 6.5% to 15% has been taken in consideration for MARKAL simulations. The considered range for other inputs is summarized in Table 1.

The hurdle rate for new electricity generation technologies ranges from 0.05 to 0.25 [10]. Nuclear power investment cost has been taken from 1160 $/kW to 3000 $/kW [11–13]. The wide variation in investment cost is taken because of different reports in India as well as in the world. The clean coal technologies Integrated Gasification Combined Cycle (IGCC) and Pressurised Fluidised Bed Combustion (PFBC) still under test in India. For IGCC the efficiency range has been taken from 38% to 58% while PFBC efficiency varies from 34% to 43% [14]. The availability factor will improve for these technologies in future. On the basis of literature studies it has been taken from 0.86 to 0.89 [15].

5. Most sensitive parameters

Several parameters in the present approach are uncertain and sensitivity analyses are required to address their influence. The discount rate used in the computation of the total system cost has a strong influence in the technology choice of an energy optimization model because it affects the whole life cycle cost of the energy system. Oil and gas prices are also shows fluctuations and considered as uncertain in international market. The rise and fall in the prices of these fuels affects its utilization.

The investment cost of nuclear power is also a very sensitive parameter because of various treaties in the world. Some technologies have less installation cost but others have very high. According to their suitable condition countries of the world adopt the different technologies and as a result a large variations in the investment cost. Another important parameter which is equally important is the efficiency of new technologies. New technologies become more attractive options if they have higher efficiencies.

6. Parametric sensitivity analysis and MARKAL results

The BAU scenario developed with various techno-economic parameters in Mallah and Bansal [1] has been considered as