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STOCHASTIC ENERGY IMPORT PRICES IN A MULTI-REGIONAL ENERGY SYSTEMS MODEL

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Overview

During the last few years, the rapidly growing demand for fossil energy carriers, in particular oil and natural gas, has resulted in a steep rise in energy prices. However, until 2003 very moderate forecasts of future energy prices (20-30 US$$_{2000}$/bbl oil over the next two decades) had been used in most energy-related studies (e.g. (EIA 2004; IEA 2004)). Nowadays such estimates are judged to be at least questionable and even predictions of up to 100 US$/bbl can be found (EIA 2006; Goldman Sachs 2005). In view of such changing expectations, a question arises: How can such different (and apparently fast changing) assumptions be even rudimentarily incorporated into studies and in particular into energy systems models that are frequently used to aid scenario analysis in energy-related studies?

In energy models uncertainties are typically treated – if at all – by analyzing multiple deterministic scenarios. In stochastic energy systems models, usually only uncertainties related to future investment costs for technologies or restrictions (demands, emissions, etc.) are considered (see e.g. (Messner et al. 1996; Ybema et al. 1998)). On the other hand, energy price uncertainties are sometimes explicitly treated in supply-oriented models, e.g. to optimize the production portfolio of utilities (see e.g. (Loveaux and Smeers 1981)). However, the effect of energy price uncertainties on the competitiveness of energy-saving measures cannot be analyzed in supply-oriented models. The impact of uncertain energy carrier import prices on the supply structures and the interaction with measures in the demand sectors is therefore a focus of the present paper.

Apart from energy price uncertainties, the increasing intertwining of national economies in the context of globalization and, in particular, the liberalization of energy markets in the European Union, especially for electricity and natural gas, have a significant impact on the structures of national energy systems. An increasing interaction of the energy systems of the EU member countries is the result of this process. In addition, the reduction of greenhouse gas emissions is a global problem and as such can only be solved by joint action by the majority of countries. International agreements like the Kyoto Protocol are the foundations of global efforts to reduce GHG emissions. Hence, a multi-regional structure is a desirable feature of models used for such analyses.

Methods

A multi-regional bottom-up optimization model is used for the analysis . The model maps the energy systems of four EU countries (Belgium, France, Germany, The Netherlands) from the primary energy sector (e.g. mining, import/export) down to the consumer side (e.g. transportation, households), including intermediate conversion technologies (e.g. power plants, CHP plants, refineries) in the form of cross-linked processes. A large number of technologies are included with their corresponding specific energy consumptions, CO_2 emissions and costs. The model is a partial equilibrium model, i.e. exogenously given demands for energy services must be fulfilled. Apart from the commonly used deterministic so-called *perfect-foresight* optimization approach, a number of other optimization strategies are adopted in the model. A myopic *time-step* method as well as various stochastic optimization approaches are also implemented. Of the latter, an anticipative stochastic optimization technique is of particular interest for the present analysis.

As mentioned above, large uncertainties exist in the estimates of the future development of energy import prices, of which oil, natural gas and hard coal are the most important. To explicitly consider these uncertainties, a stochastic programming technique, first applied to the MESSAGE model (Messner et al. 1996), is used. The approach assumes risk aversion, parameterized by a risk factor $\rho > 0$, and in contrast to other stochastic optimization approaches (e.g. stochastic programming with recourse) it avoids large computational effort and provides satisfactory results. The limited computational overhead is of particular importance for application in bottom-up energy systems models, which typically include hundreds or thousands of technologies, easily resulting in systems of equations with a few hundred thousand equations and variables in the deterministic case.

Simulations of possible energy price paths are required as an input to the model. These are generated on the basis of a time-series analysis of historical real CIF (cost, insurance, freight) prices to Europe for crude oil, natural gas and hard coal (IEA 2005). Prices of other energy carriers such as oil products are coupled to the realizations of the prices for these three energy carriers by a fixed factor. A multivariate first-order autoregressive process (VAR(1)-process) is used to derive correlations between the energy prices from historic data. On the basis of this analysis, several thousand price scenarios for the period 2006-2030 are generated and subsequently serve as input to the energy systems model in an aggregated form.

Results

Linear programming models tend to favor single solutions and simplistic developments. This behavior is generally reduced by including a stochastic risk function into the model's objective function, leading to a diversification of investment decisions. In contrast to scenarios with stochastic investment cost for a (limited) number of technologies, the inclusion of stochastic energy import prices directly affects virtually all parts of the energy system.

Comparing the results of the deterministic and the stochastic model calculations, robust solution elements can be identified by means of solution (levels) and shadow price analysis (marginals). Taking into account the risk corresponding to energy import price uncertainties, the following results are commonly observed:

- domestic (fossil and renewable) energy carriers become more competitive
- wider application of combined heat and power (CHP) generation technologies and district heating
- increased use of energy-saving measures in the demand sectors
- increased exchange of electricity between the model regions due to different regional hedging options (e.g. use of nuclear power)

In the case of emission reduction scenarios, the generally observed fuel switch from coal to natural gas in the conversion sector is slightly reduced. Instead the application of natural gas in the demand sectors is increased, e.g. in the transport sector. These measures can be found within wide variations of the applied distribution of stochastic parameters and other key data and thus appear to be robust.

The degree of risk aversion can be varied by a single parameter ρ, thus making a continuous transition from the deterministic to the stochastic case possible. By increasing ρ hedging costs increase, thus producing a more robust solution (trade-off between deterministic costs and the solution's robustness). This mechanism allows a ranking of hedging options/strategies to be derived.

Conclusions

Some deficiencies of the deterministic linear programming technique frequently used in energy systems models can be over come by taking into account parametric uncertainties using a stochastic optimization approach with risk function. The relatively simple implementation of this stochastic optimization approach, as well as the manageable computational overhead in comparison with the deterministic model version, make the approach an attractive extension for energy systems models. In view of the currently observed volatility of energy prices, it is particularly useful for the treatment of uncertain energy prices and thus for the development of risk-hedging strategies.

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