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Effects of stochastic energy prices on long-term energy-economic scenarios

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Abstract

In view of the currently observed energy prices, recent price scenarios, which have been very moderate until 2004, also tend to favor high future energy prices. Having a large impact on energy-economic scenarios, we incorporate uncertain energy prices into an energy systems model by including a stochastic risk function. Energy systems models are frequently used to aid scenario analysis in energy-related studies. The impact of uncertain energy prices on the supply structures and the interaction with measures in the demand sectors is the focus of the present paper.

For the illustration of the methodological approach, scenarios for four EU countries are presented. Including the stochastic risk function, elements of high energy price scenarios can be found in scenarios with a moderate future development of energy prices. In contrast to scenarios with stochastic investment costs for a limited number of technologies, the inclusion of stochastic energy prices directly affects all parts of the energy system. Robust elements of hedging strategies include increasing utilization of domestic energy carriers, the use of CHP and district heat and the application of additional energy-saving measures in the end-use sectors. Region-specific technology portfolios, i.e., different hedging options, can cause growing energy exchange between the regions in comparison with the deterministic case.

Keywords: Energy systems model; Scenarios; Stochastic optimization; Energy prices; Risk hedging

1. Introduction

Prices for fossil energy carriers, in particular oil and natural gas, have shown a steep rise since 2003. However, until 2004 very moderate assumptions 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. [1,2]). Nowadays such estimates are judged to be at least questionable and even predictions of up to 100 US$/bbl can be found [3,4]. In view of such changing expectations, a question arises: How can such different and apparently fast changing assumptions (cf. [5]) be even rudimentarily incorporated 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. [6–8]). 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. [9]). However, the effects 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, in particular within mitigation scenarios, 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

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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 to analyze the impact on the interaction between national energy systems via energy carrier exchange.

2. Model description

A multi-regional bottom-up optimization model is used for the analysis. The model is a partial equilibrium model, i.e. exogenously given demands for energy services must be fulfilled. The optimization criterions are the discounted system costs which are minimized, taking the imposed restrictions into account. Therefore, the model evaluates the effort for adapting the energy system (e.g. to fulfill a carbon constraint or to avoid risks) by the associated costs. Only costs for imports of energy carriers that have been extracted outside the model's system borders and technology costs are exogenous model assumptions. Prices are model endogenous quantities and correspond to marginal costs, i.e., perfect competition is assumed. Taxes and subsidies are not included in the model, because they are not tied to particular technologies and therefore not immanent to the system. 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 a stochastic optimization approach is also implemented (see Section 3).

The model maps the energy systems of the four EU countries Belgium (BE), France (FR), Germany (DE) and the Netherlands (NL) from the primary energy sector (e.g. mining, renewables, import/export) down to the consumer side (e.g. transportation, households), including intermediate conversion technologies (e.g. power plants, combined heat and power (CHP) plants, refinery) in the form of cross-linked processes. With respect to electricity trade the four countries plus Austria form a zone within central Europe with comparatively low congestion (see e.g. [10]). Other countries that have common borders with the four model countries such as Poland, the Czech Republic, Spain or Italy currently show severe congestions. In addition, natural gas imports from the Netherlands are still of significance for the neighboring countries Belgium (2004: 42% of total natural gas imports), France (20%) and Germany (22%) [11]. Also, the four model regions have followed different energy policies in the past and as a result have quite different supply structures at present. Therefore, these countries provide a good basis to exemplary show the impacts of introducing uncertain energy prices, in particular with respect to energy im- and exports.

The sectoral model structure for a single region is shown in Fig. 1 in a schematic way. The regions are linked by infrastructure technologies such as pipelines and high voltage grids which is indicated by the double-headed

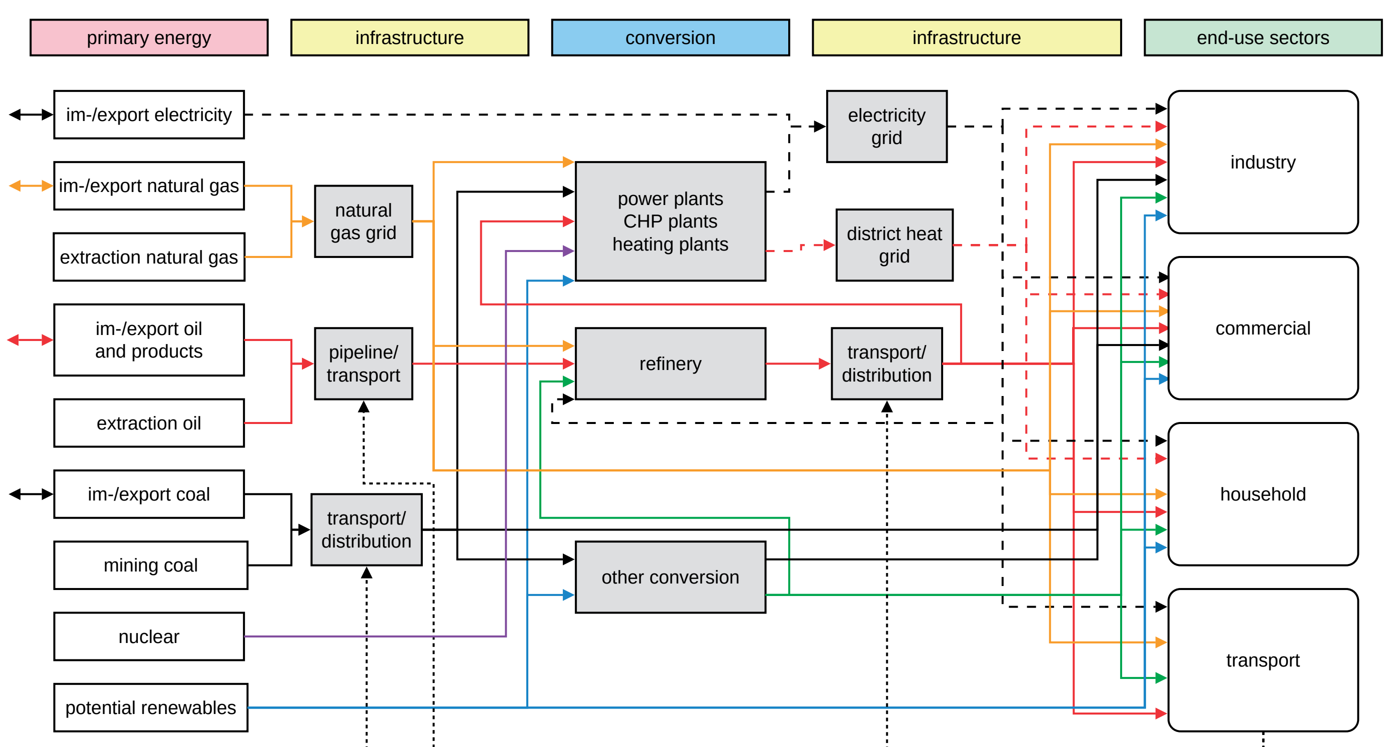

Fig. 1. Schematic model structure for a single region.