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Beyond sensitivity analysis: A methodology to handle fuel and electricity prices when designing energy scenarios

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ABSTRACT

World market fuel prices vary and have historically been very difficult to predict. Especially the price of oil has shown remarkable and unexpected increases and decreases throughout the past 5 decades. The same kind of uncertainty can be seen in many of the new cross-border markets for the trade of electricity, which have been introduced in recent decades. These uncertainties pose a challenge to the design and assessment of future energy strategies and investments, especially in the economic assessment of renewable energy versus business-as-usual scenarios based on fossil fuels. From a methodological point of view, the typical way of handling this challenge has been to predict future prices as accurately as possible and then conduct a sensitivity analysis. This paper includes a historical analysis of such predictions, leading to the conclusion that they are almost always wrong. Not only are they wrong in their prediction of price levels, but also in the sense that they always seem to predict a smooth growth or decrease. This paper introduces a new method and reports the results of applying it on the case of energy scenarios for Denmark. The method implies the expectation of fluctuating fuel and external electricity prices.

1. Introduction

In recent years, many countries and regions around the world have formulated policies with the aim of decarbonizing current energy supplies. Such policies are often driven by a desire to deal with the threat of climate change. However, other reasons such as energy security, job creation and industrial development often also play an important role [1–3]. These aims call for the design and assessment of long-term future energy strategies meant to help determine how to implement such objectives in the best way, including identifying least-cost strategies and calculating the cost of such strategies compared to business-as-usual policies based on fossil fuels.

An essential part of these efforts is to decide what expectations one should have with respect to future world market fuel prices, because such expectations, by nature, have huge impacts on the results. Furthermore, the introduction of international electricity markets means that the exchange of electricity also plays an important role. As such, the same challenge arises when determining expectations for future electricity exchange prices as for fuel prices.

The choice of expectations for future fuel and electricity prices has an important influence on the results in at least two aspects:

- Firstly, on the design of the desired solution, especially if optimisation models or similar methodologies are used to identify the optimal investment strategy. For obvious reasons, high or low fuel and/or electricity prices will influence the identification of the optimal or best solution.
- Secondly, on the assessment of the cost of choosing one strategy against another, especially when a renewable energy strategy is compared to a fossil fuel strategy, or if a renewable energy strategy with little flexibility in terms of integrating fluctuating productions from wind, etc. is compared with a smart energy systems [4–6] strategy that includes a high degree of flexibility.

Since the design and assessment of future sustainable energy strategies involves quite time consuming and complex calculations, it often calls for the use of advanced energy system analysis tools and models. Many such models have been developed, described and applied in the academic literature. Review papers listing and comparing these models find that they are both numerous and difficult to compare [7]. Some models focus on specific aspects such as e.g. forecasting [8], buildings [9] or a shift towards distributed generation [10]. Some have a national approach [1], while others have a regional focus [11]. In [12], different types of models such as energy planning models, energy supply-demand

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models, forecasting models, renewable energy models, emission reduction models and optimization models have been reviewed and presented.

The typical purpose of using such models is to assist in the design, planning and implementation of future energy systems by comparing different scenarios and/or identifying best strategies, often referred to as optimal solutions. Many creators of widely used energy system models identify their models as optimization models such as e.g. the HOMER [13,14] or the BALMOREL [15,16] models. Other models use the term simulation, such as e.g. the EnergyPLAN model [17] or models within district heating [18,19], building design [20] or policy design in the electricity sector [21]. Some models combine the two terms, either by discussing optimization algorithms as part of simulation models [22], or by comparing and/or combining the two types of models [23,24]. Yet another method can be seen in approaches such as exergoeconomics [25,26] and emergy [27,28], in which the idea is to combine thermodynamic optimization with economics. Some also add extensions to existing optimisation models in order to include the effect of limited foresight [29] or adds stochastic elements to include uncertainties [30].

When attempting to identify least-cost scenarios or solutions – no matter whether one uses an optimization or a simulation model – the fuel and electricity exchange cost assumptions become essential, especially if only one future price development is utilised. However, as will be discussed in this paper, there is a fundamental difference between using a specific set of future price level prognoses and assuming that the price level will go up and down from year to year. It is important to realise that fuel and electricity prices are to some extent interlinked, and hence, here the term "price level" refers to an overall price level across different types of fuel and electricity.

For example, if one assumes that future electricity prices will increase or remain at a constantly high level then the optimal solution will typically be to invest in wind turbines and power plants. By contrast, assuming decreasing or constantly low electricity prices will lead to optimal investments in heat pumps and electrolysers. But, if one assumes that future prices will go both up and down then the best solution will likely be a flexible combination of the two. From an energy system analysis model and tool perspective, the key point is that investment optimization models are typically not as well suited to do the latter as models that use a simulation approach, a point which is also argued in this paper. Consequently, the method discussed in this paper also has model and tool implications. For a more detailed discussion on how the choice of models influence the making and use of scenarios please see more in the following paper [31].

The aim of this paper is to raise awareness on the problems related to the typical approach of prices prediction, and demonstrate how to go beyond sensitivity analysis in the handling of fuel and electricity prices when designing energy scenarios.

2. Examples of historic fuel price predictions

Historically, fuel prices have gone up and down and have been affected by economic, geopolitical or natural events [32]. Fig. 1 is a well-known diagram that shows the historic development in the yearly average crude oil price in 2016-USD/barrel.

As seen in Fig. 1, the crude oil price has fluctuated significantly since 1970, with a price peak in 1979–1980 due to the two oil crises in the 70s, and two additional peaks in 2008 and again after 2009. The price drop in 2009 is related to the 2008 financial crisis. The recent price drop seen at the end of the graph has taken prices down to a level of 40–50 USD/barrel.

Outside the USD area, another important aspect of price development is the currency exchange rate. In Fig. 2 the historical development of the monthly price of crude oil in Denmark since 1991 is presented as an example.

As seen in Fig. 2, the price of oil in Denmark has seen a development similar to that presented in Fig. 1, though here the cost is also influenced by the USD to DKK/EUR exchange rate. The price fluctuations seen in both figures underline the challenge involved in predicting the crude oil price, with international events potentially having huge effects. Moreover, the crude oil price influences the price of other fuels such as coal.

These fluctuating fuel prices form the basis for future price predictions at both the country and international levels. As such, predicting the oil price has also received attention within research [35–39]. The International Energy Agency's (IEA) price predictions often play an important role at the international level, since similar predictions made by national authorities such as the Danish [40] often refer to IEA's reports. In practice, the same predictions are used by a variety of organizations, since authorities, NGOs, industries and lobbyists all typically prefer to rely on and refer to official projections and predictions.

As currency exchange rates, handling costs, etc. affects the energy market prices it is relevant to focus on a specific geographical case. In this paper, the case of Denmark is used, as predictions based on IEA predications are made and published by the Danish Energy Agency (DEA) on a regular basis [40]. Typically, these predictions refer to the IEA and are used by many different parties in Denmark [41,42]. These predictions are used in the application of Danish law when permissions for new energy investments are granted as well as by many different parties during energy policy discussions.

Fig. 3 shows the actual historic crude oil price development together with DEA's price forecast for crude oil in an eleven-year period from 2005 to 2016 alongside three of IEA's price forecasts from 2010 and one from 2015.

As shown in Fig. 3, price predictions by DEA show significant changes. There is a nearly four-fold gap between the lowest and highest oil price expectations in 2030, ranging from 5 to 19 EUR/GJ. During the period from 2005 to 2008, which saw relatively low but increasing oil prices, DEA expected that the crude oil price would decrease in the coming years and thereafter increase slowly. The forecasts after 2008, when actual prices had begun to decrease, predict that the crude oil price would continually increase. Liao et al. [44] found that IEA's expectations to GDP has been the leading source of energy demand forecast errors.

However, what may be the most characteristic about all the predictions is that they involve smooth curves with smooth increases or decreases over many years. But, historically, as shown in Fig. 3, Figs. 1 and 2, the crude oil price has fluctuated through the years, and has not seen a continuous increase or decrease during any prolonged period.

3. Examples of historic electricity price predictions

As previously mentioned, electricity price predictions have recently become equally important as fuel prices in the design and assessment of suitable energy scenarios and investments. In Denmark, such predictions relate to the Nord Pool Spot market. As part of their fuel price predictions, DEA also makes predictions for electricity prices. Fig. 4 shows a number of DEA price forecasts compared to the actual historic yearly average system prices on Nord Pool Spot.

As seen in Fig. 4, expectations of future system prices on Nord Pool Spot vary significantly between the different DEA price forecasts. For example, the predictions for price in 2030 vary by a factor of almost 2, i.e. between 42 and 78 EUR/MWh. However, DEA has always expected that the Nord Pool System price (in fixed prices) will increase in the long-term. As the actual historical prices show, the system price on Nord Pool Spot varies significantly from year to year and in the last couple of years it has seen a significant decrease, reaching prices considerably below any of the predictions. Unger et al. [45] found that decisions made in individual countries historically have shown to potentially have a large consequence on the electricity prices on Nord Pool Spot.

The electricity price predictions are not as smooth as the fuel price