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Forecasting electricity infeed for distribution system networks: An analysis of the Dutch case

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ABSTRACT

Estimating and managing electricity distribution losses are the core business competencies of DSOs (distribution system operators). Since electricity demand is a major driver of network losses, it is essential for DSOs to have an accurate estimate of the electricity infeed in their network. In this paper, motivated by the operations of a Dutch electricity distribution system operator, we examine how to estimate the electricity infeed in distribution networks one year in advance with hourly forecasting intervals, so that the DSOs may effectively hedge for their physical losses in the wholesale markets.

We identify the relevant factors for DSOs to forecast the electricity infeed in their networks, and to quantify their effects. We show that most of the calendar variables, such as national holidays, bridge days as well as days near holidays have a significant effect on electricity infeed. Our analysis reveals that the impact of calendar variables significantly depends on the hour of the day. On the other hand, economic and demographic factors do not seem to influence the electricity infeed for the planning horizon of DSOs. We also explore the influence of meteorological factors on the electricity infeed in the Netherlands. Finally, we develop and compare methods for electricity infeed forecasting, based on multiple regression and time series analysis. Our analysis reveals that the regression-based method outperforms the time series-based method on the average measures whereas the time series-based method is better in the worst case analysis. Hence, we point out that the forecasting methods used by DSOs may have significant implications on their financial hedging policies.

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1. Introduction and background

DSOs (distribution system operators) are accountable for electricity losses in their networks. These losses may be due to fraud, resistance in the cables, measurement errors, etc. In the Netherlands, depending on the properties of the network, about 4%–5% of the electricity fed into the network is lost in the distribution process.[2] To hedge for the distribution losses in their networks, DSOs purchase electricity in the spot and forward markets. However, fluctuating electricity prices coupled with highly uncertain distribution losses create significant financial risks for DSOs. To effectively hedge for these risks, DSOs need a reliable forecast of distribution losses in their networks (i.e., the volume risk), and then take a counterbalancing financial or physical position in the wholesale markets (see Ref. [1] for review of risk management activities in electricity markets).

DSOs face both administrative and technical distribution losses. Administrative distribution losses are driven by factors external to the power system, such as fraud and measurement errors. Technical distribution losses are caused by resistance in the cables and other physical properties of the grid. For our motivating DSO, administrative and technical distribution losses account for 35% and 65% of the total losses, respectively. The most important factor that influences the technical distribution losses is the total amount of electricity distributed through the grid. Other factors, such as the physical properties of the grid, are relatively stable over time [2–4]. It is therefore important for DSOs to have an accurate demand forecast so as to be able to estimate the distribution losses.

In this paper, we focus on estimating electricity infeed (demand) for a distribution grid which is the main driver of the operational distribution losses for the DSOs. We note that accurate demand forecasting is not only important for DSOs but also a central

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[2] The Dutch average was around 4.3% over the last 10 years. (http://www.indexmundi.com/facts/netherlands/electric-power-transmission-and-distribution-losses).

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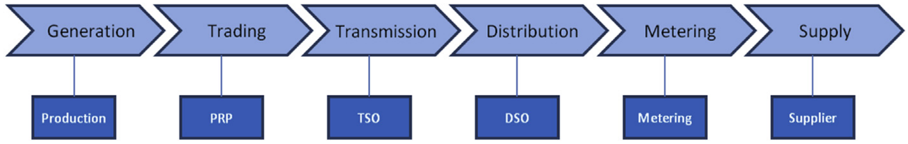

Fig. 1. Dutch electricity supply chain.

concern for other players in the electricity market including generators (for capital budgeting), transmission operators (to balance the flow of electricity in the network) and retailers (to manage their exposure to financial risks). Hence, our findings also provide the other players in the electricity supply chain with valuable insights and guidelines.

Although there is a large body of literature in electricity demand forecasting [5,6], the problem – to the best of our knowledge – has not been investigated from the DSOs' perspective. In particular, DSOs plan for electricity purchases one year in advance, and their positions are cleared hourly in the market. Hence they need a mid-term demand forecast with hourly forecasting intervals.

We present two methods for electricity infeed forecasting. The first method is a standard multiple regression, and the second one is a multiple regression model with a time series component based on the Box–Jenkins autoregressive integrated moving average approach. Two methods are compared to determine whether it is worthwhile to include a time series component in a regression-based forecasting model in practice. We collect infeed data (i.e., the sum of all electricity that is consumed in the electricity grid including the electricity that is consumed by the grid itself) from two large Dutch grids Noord and Brabant, from January 2007 until December 2010 and test our models. Furthermore, we generate separate models for each distribution grid, since several factors – such as the Dutch carnival – only influence the electricity infeed in a particular region.

Our analysis shows that most of the calendar variables including holidays, bridge days,[3] days near holidays and outdoor temperature have a significant effect on electricity infeed while the demographic and economic factors do not have a significant impact. Nonetheless, the effect of calendar variables significantly depends on the hour of the day and the day of the week. In particular, we show that while a national holiday on a weekday or Saturday has a significant negative impact on the infeed throughout the day, a holiday on a Sunday only has an effect on the electricity infeed during daytime. In addition, less electricity is used in the evening before a holiday and in the morning after a holiday. This is a surprising effect and is primarily driven by Dutch working habits. We also identify bridge days as a significant factor for infeed forecasting. A bridge day before a holiday only has an effect on the electricity infeed in the evening, while the electricity infeed during a bridge day after a holiday affects the whole day. We observe that school holidays have a small positive effect on the electricity infeed. During the holidays in the construction industry, less electricity is fed into the grid and the Dutch Carnival has a significant negative effect on the electricity infeed. As expected, the derivatives of the outdoor temperature, CDD (cooling degree days) and HDD (heating degree days), both have a positive effect on the electricity infeed. The effect of CDD is more pronounced than the effect of HDD in the Netherlands.

We find that the multiple regression method outperforms the time series method based on the MAPE (mean absolute percentage error). This finding shows that statistically sophisticated and complex methods do not necessarily provide more accurate forecasts than simpler ones. With a MAPE of slightly more than 3% in both regions it is shown that the multiple regression is suitable for hourly infeed forecasting with a horizon of one year. However, the time-series method provides lower maximum absolute errors compared to the regression method. Hence, the DSO should choose between these methods based on the cost of the available hedges in the financial market. If it is very costly to hedge for extreme cases, then the firm may be better off with the time-series model. Otherwise, regression models should be given preference.

The rest of the paper is organized as follows. In Section 1.1, we first outline the organization of the Dutch electricity market and provide a background for the research problem. Then, in Section 2 we discuss the relevant literature followed by the presentation of data used in this study in Section 3. In Section 4, we discuss our methodological framework for estimation and forecasting. Section 5 provides the numerical result, and Section 6 concludes with managerial insights.

1.1. An overview of the Dutch electricity market

The Dutch energy market is one of the most liberalized in the world. The liberalization is initiated with the introduction of the 1998 Electricity Act. The act provides individual customers and suppliers with more freedom to procure and sell electricity, while maintaining a framework that is focuses on reliability, sustainability and efficiency. This is established through a new government-owned entity, Tennet, which functions as the TSO (transmission system operator) of the high voltage grid. After a thorough debate, the Dutch government also decided to unbundle the low-voltage transmission grids and generators in 2008. This resulted in a new group of entities that own the low-voltage transmission grids called distribution system operators (DSOs) [7].

Since the deregulation of the Dutch electricity market in 1998, the roles of the participants in the market have changed dramatically. Before deregulation, the market was built upon a couple of major players that produced, distributed and supplied electricity for the whole Dutch market. These companies had a monopoly for a particular region (i.e., the consumers did not have the option to change their electricity supplier). Today, including the TSO and DSOs, six players are responsible for the primary process of delivering electricity to consumers in the Netherlands, as illustrated in Fig. 1.

The production company generates electricity from fossil fuel, uranium, wind etc. The planning of electricity production, transportation and consumption for every 15 min of the day is done by the PRP (Program Responsible Party). This planning process is elaborated to ensure the real-time balance of the grid, since electricity cannot be stored and has to be consumed at the time of production. A PRP is a legal entity which manages at least one physical connection to the grid and is the party that corresponds with Tennet. A PRP is responsible for forecasting its net demand, i.e., the difference between supply and demand coming through its physical connection, and the quantity that will be transported through certain transmission lines from its connection. These responsibilities are called program responsibility, and both forecasted quantities have to be ratified by Tennet on a daily basis [8]. With the introduction of the 1998 Electricity Act, firms can buy and sell

[3] Days in between a holiday and a weekend.

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