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Comparison of static and adaptive models for short-term residential natural gas forecasting in Croatia

Primož Potočnik [a,*], Božidar Soldo [b], Goran Šimunović [c], Tomislav Šarić [c], Andrej Jeromen [a], Edvard Govekar [a]

[a] University of Ljubljana, Faculty of Mechanical Engineering, SI-1000 Ljubljana, Slovenia
[b] HEP-Plin Ltd., Cara Hadrijana 7, HR-31000 Osijek, Croatia
[c] University of Osijek, Faculty of Mechanical Engineering Slavonski Brod, HR-35000 Slavonski Brod, Croatia

HIGHLIGHTS

- Comparisons of static and adaptive models for natural gas consumption forecasting.
- Comparisons of linear and nonlinear forecasting models (ARX, neural networks, SVM).
- Relevant inputs to forecasting models are determined by stepwise regression.
- Methods are applied to local distribution company and individual house data sets.
- The best results are obtained by using linear adaptive forecasting models.

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ABSTRACT

In this paper the performance of static and adaptive models for short-term natural gas load forecasting has been investigated. The study is based on two sets of data, i.e. natural gas consumption data for an individual model house, and natural gas consumption data for a local distribution company. Various forecasting models including linear models, neural network models, and support vector regression models, were constructed for the one day ahead forecasting of natural gas demand. The models were examined in their static versions, and in adaptive versions. A cross-validation approach was applied in order to estimate the generalization performance of the examined forecasting models. Compared to the static model performance, the results confirmed the significantly improved forecasting performance of adaptive models in the case of the local distribution company, whereas, as was expected, the forecasts made in the case of the individual house were not improved by the adaptive models, due to the stationary regime of the latter's heating. The results also revealed that nonlinear models do not outperform linear models in terms of generalization performance. In summary, if the relevant inputs are properly selected, adaptive linear models are recommended for applications in daily natural gas consumption forecasting.

1. Introduction

Planning and forecasting of natural gas consumption has become a vital component in providing the stability of distribution systems. Therefore, recently we can find a plenty of discussion about natural gas consumption forecasting which has been investigated at many different levels: at a world level [1,2], at national level [3–7], at both industrial [8,9] and residential sector [10–14], at the level of gas distribution systems [15,16], in both the commercial and residential sectors, and finally, at the level of individual customers [17,18]. Demand and production have been investigated by means of various forecasting tools, using various techniques, the forecasting horizons varying from a few hours ahead to a few decades ahead [19]. Many different tools have been applied in this area, such as autoregressive integrated moving average model [20], support vector regression [21], neural networks [22], and an adaptive network-based fuzzy inference system [23]. A recent broad overview of the various approaches which have so far been used in the field of natural gas consumption forecasting was summarized by Soldo [24].

Natural gas transmission system operators commonly utilize natural gas consumption forecasting models as supply–demand balancing tools. This area is usually regulated by the government,

* Corresponding author. Tel.: +386 1 4771 167; fax: +386 1 2518 567.
E-mail address: primoz.potocnik@fs.uni-lj.si (P. Potočnik).

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or by natural gas supply contracts. These regulations usually require the forecasting of future consumption within a defined tolerance range. Otherwise, a penalty system is applied, as for example in the case of Slovenia [25]. For this reason, local distribution companies need accurate forecasting models. This is also the case in Croatia, where natural gas regulations currently anticipate a future penalty system for short-term natural gas load forecasting. HEP-Plin Ltd., Croatia's local distribution company, will therefore need an online application for one day ahead forecasting of natural gas demand.

The existing literature on natural gas demand forecasting provides only a few comparative studies analysing the performance of different forecasting models. Comparisons between several mathematical models for natural gas consumption forecasting have been presented in Sabo et al. [16]. The presented results are obtained with three different models: Gompertz model function, FTW (Fermat–Torricelli–Weber approach) estimation and linear model function with usage of outside temperature and past consumption as input data. The results show that most acceptable forecast is provided by mathematical models in which natural gas consumption and temperature are related explicitly.

A comparison between the nonlinear mixed effect models with various autoregressive models with exogenous inputs was studied by Brabec et al. [17]. The authors presented natural gas consumption forecasting results for 62 individual customers. Results were obtained with NLME (nonlinear mixed effect models) and compared with traditional ARX (auto-regressive model with exogenous inputs) and ARIMAX (auto-regressive moving-average model with exogenous inputs) models. The authors observed that the NLME approach and individual time series (ARIMAX, ARX) approaches all have their merits, and evaluation using the Diebold–Mariano test to compare them showed no clear winner.

A comparison between seasonal autoregressive integrated moving average models with exogenous inputs (SARIMAX), neural network models (ANN) and ordinary least squares regression models (OLS) was examined by Taşpinar et al. [26]. The authors used four year consumption data of one region in Turkey and compared the results obtained with mentioned models. Their overall conclusion was that time series forecaster (SARIMAX) for prediction of daily natural gas consumption in residences performs better than ANN approaches. This study also indicated that local daily natural gas consumption can successively be forecasted in the short run covering meteorological parameters.

Furthermore, several papers have presented research results based on only one forecasting model, for example, an autoregressive integrated moving average model (ARIMA) [6], that has been applied to estimate the natural gas demand in Turkey. A statistical approach based on nonlinear regression principles has been proposed in [18]. The approach is based on customer segmentation into various types and is suitable for natural gas consumption estimation of individual residential and small commercial customers.

A neural network model with different training algorithms was studied by Kizilaslan and Karlik [22]. The models were developed for forecasting natural gas consumption for residential and commercial consumers in Istanbul in Turkey. The results showed that various artificial neural network models could be useful for the natural gas consumption forecasting, and the most efficient solution based on conjugate gradient descent neural network was confirmed.

Azadeh et al. [23] developed an adaptive network-based fuzzy inference system (ANFIS) for estimation of natural gas demand and reported good results on data representing Iranian natural gas consumption. The proposed approach is capable of handling non-linearity, complexity as well as uncertainty that may exist in actual data sets due to erratic responses and measurement errors. The input variables used included day of the week, demand of the same day in previous year, demand of a day before and demand of 2 days before, but the weather related parameters including the temperature have not been considered at all.

Consequently it is not possible, from the existing literature, to obtain clear answers to the following questions: which input variables and extracted features are the most relevant for the construction of forecasting models? What are the required embedding dimensions of the inputs? Which model is the most suitable for use as a forecasting tool in real-world short-term natural gas forecasting applications? Should the model be linear or nonlinear? Do adaptive models outperform non-adaptive models?

The aim of this paper is to provide new answers to these questions by constructing and comparing a broad range of natural gas consumption forecasting models with a one day ahead forecasting horizon. The comparative study includes linear modelling approaches (stepwise regression, auto-regressive model with exogenous inputs, adaptive auto-regressive model with exogenous inputs), as well as nonlinear modelling approaches (neural networks, adaptive neural networks, support vector regression), and brings new insights regarding the performance of static and adaptive versions of the forecasting models. The forecasting models are applied to two natural gas consumption systems on different scales: an individual house, and the residential sector of a local distribution company. A successful natural gas forecasting solution targeted for real-world applications depends on the synergy of many factors, including feature extraction, feature selection, data pre-processing, model selection with respect to model order, and the selection of linear/nonlinear and static/adaptive model structures, as well as learning approaches and applied training/validating procedures. The novelty of this approach is thus in demonstrating that a successful forecasting solution can be obtained by a balanced combination of feature extraction, feature selection, and the construction of a simple linear model with an adaptation mechanism. The performed research thus makes a contribution by providing a broad comparison between the various established forecasting models for short-term natural gas forecasting, and a novel combination of several known methods for building forecasting solutions. The conclusions of the paper provide answers regarding the appropriate selection of inputs, feature extraction, the choice of a suitable model structure (linear/nonlinear), the recommended training approach (static/adaptive), and the required model order, all of which are relevant for efficient short-term natural gas forecasting. The results of the research are directly applicable to the preparation of forecasting solutions for the natural gas market.

The paper is organized as follows: the aims of the research are described in the next section. The "Data sets" section describes the weather and natural gas consumption data collection and preparation process, presents the basic relations between the collected data, and describes extraction of additional features relevant for the forecasting task. The forecasting models applied in this study are introduced in the "Forecasting models" section, whereas in the section "Selection of relevant inputs" the stepwise regression based selection of relevant inputs is described. The "Forecasting framework" section presents the formulation of the forecasting task, the performance measures, and the cross-validation procedure, and describes the static vs. adaptive models testing procedure. Comparisons and evaluations of the forecasting results are presented in the "Results" section. The key findings of the research are summarized in the "Conclusions" section.

2. Research aims

HEP-Plin Ltd. is a local distribution company (LDC), which is obliged to forecast and nominate the amount of natural gas that will be consumed in the following day. The company needs an accurate forecasting tool in order to avoid the anticipated penalty