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A mathematical modeling for incorporating energy price hikes into total natural gas consumption forecasting

V. Majazi Dalfard [a], M. Nazari Asli [b], S.M. Asadzadeh [c,*], S.M. Sajjadi [d], A. Nazari-Shirkouhi [e]

[a] Young Researchers Club, Kerman Branch, Islamic Azad University, Kerman, Iran
[b] Department of Management, Imam Khomeini International University, Qazvin, Iran
[c] Department of Industrial Engineering, College of Engineering, University of Tehran, Iran
[d] Faculty of Entrepreneurship, University of Tehran, Tehran, Iran
[e] Faculty of Industrial and Mechanical Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran

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ABSTRACT

In some countries that energy prices are low, price elasticity of demand may not be significant. In this case, large increase or hike in energy prices may impact energy consumption in a way which cannot be drawn from historical data. This paper proposes an integrated adaptive fuzzy inference system (FIS) to forecast long-term natural gas (NG) consumption when prices experience large increase. To incorporate the impact of price hike into modeling, a novel procedure for construction and adaptation of Takagi–Sugeno fuzzy inference system (TS-FIS) is suggested. Linear regressions are used to construct a first order TS-FIS. Furthermore, adaptive network-based FIS (ANFIS) is used to forecast NG consumption in power plants. To cope with random uncertainty in small historical data sets, Monte Carlo simulation is utilized to generate training data for ANFIS. To show the applicability and usefulness of the proposed model, it is applied for forecasting of annual NG consumption in Iran where removing energy subsidies has resulted in a hike in NG prices.

1. Introduction

Natural gas (NG) touches our lives in countless ways every day. NG fuels our cars, heats our homes and cooks our food, and also helps generate electricity so NG is an important component of many nations' energy equation. Ample supplies, robust emerging markets and uncertainty about nuclear power all point to a prominent role for gas in global energy mix [1].

Energy price always has been an influential factor in estimation of energy consumption so that energy market research has devoted special attention to this interesting subject [2,3]. Aside from energy price shocks, the energy shocks of the 1970s for example, the rise and fall in energy prices are not such dramatic that could make structural changes in energy supply and demand functions. However, in some countries in all sectors of the economy, energy prices are highly subsidized as the cost of energy is considered very low in the basket of global services costs. Removing such subsidies will cause a hike in energy prices that may alter the current relationship between inputs and outputs in energy equilibrium. Furthermore, the historical estimated demand functions are strongly suspected to yield unreliable forecasts (see [4]). Focusing on this problem, this paper aims to develop a fuzzy inference system for natural gas forecasting with hike in prices.

The growth in energy consumption is intrinsically linked to the growth in the society and economy. Various approaches and models have been applied to describe and forecast the evolution of energy consumption. Among those, two well-known distinct approaches are statistical approach including time-series models [5,6] and econometric models [7–9], and artificial intelligence (AI) approach [10–12].

* Corresponding author. Tel.: +98 21 44400134.
E-mail address: smasadzadeh@ut.ac.ir (S.M. Asadzadeh).

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AI techniques are increasingly diversifying today and have gained special attention in energy forecasting. AI techniques have shown interesting results in modeling non-linear functions [13–15]. Furthermore, neuro-fuzzy systems use fuzzy rules which allow modeling fuzziness and ambiguity in the modeling environment and are capable of dealing with uncertainty and complexity in the given data set [12,15].

By using adaptive network-based fuzzy inference system (ANFIS), Zhang and Mao [16] investigated the interrelationship between energy consumption and economic growth in China. Cheng and Wei [17] used ANFIS for electricity load forecasting and their experimental results indicated that the ANFIS modeling is superior to ANN modeling. Azadeh et al. [18] forecasted short term natural gas consumption by ANFIS and showed that ANFIS has outperformed ANN and other conventional methods for natural gas consumption estimation. Authors in [12] presented an ANFIS-Stochastic Frontier Analysis approach for long-term natural gas consumption forecasting and behavior analysis in stochastic environments. In [19], a new hybrid ANFIS computer simulation was used for improvement of electricity consumption forecasting.

Long term forecasting of energy consumption usually uses socio-economic and demographic variables as the inputs of the estimation model. Reddy and Balachandra [20] looked at various factors that influence the energy demand in India and develop the energy and environmental outlook in the year 2010. This was done by developing an integrated mathematical model incorporating various factors such as gross domestic product (GDP) and population growth. The model presented in [21] estimates natural-gas demand, based on average trend of the economy development. Parikh et al. [22] estimated demand projections of petroleum products and natural gas in India. They considered GDP and population as inputs of their NG estimation model. Kankal et al. [23] proposed a model for improvement of estimating energy consumption in Turkey based on four socio-economic and demographic variables (GDP, population, import and export amounts).

Looking back at the previously AI-based models reviewed above, an important missing parameter is the energy price. This shortcoming actually restricts the application of these models for the cases with hike in energy prices. Another gap in this literature is the lack for incorporating electrical energy consumption for estimation of the gas consumption in power generation sector. According to Energy Information Administration [24], more than 40% of electricity in the world is generated using natural gas as the fuel; therefore incorporating electricity consumption in the estimation of NG consumption would help improvement of its forecasting.

To address these two aforementioned issues, this paper proposes a combined model of fuzzy inference system and linear regressions to forecast NG consumption. Regression models are used to construct the first order TS-FIS. A novel procedure for construction and adaptation of Takagi–Sugeno type fuzzy inference systems (TS-FIS) is suggested. In the adaptation phase, expert knowledge is used to define new fuzzy rules. A unique feature of the proposed model is that it is adaptive and flexible to the situations with hike in energy prices. Another interesting feature of the proposed model is that it uses electricity consumption data to improve the estimation of total NG consumption. The proposed combined adaptive FIS model of this study is also compared with some of the current studies in the light of some qualitative features (Table 1). Results in Table 1 show that the proposed combined adaptive FIS model of this study is in an advantageous position as it embeds expert knowledge for forecasting, accounts for price hike, and incorporates electricity consumption for NG modeling.

The remainder of the paper is organized as follows. Section 2 presents the proposed combined adaptive FIS model. In Section 3, the methodology of the proposed model is presented. In Section 4, to show the applicability of the proposed model in NG forecasting, a case study is discussed which considers the removal of natural gas subsidies in Iran, 2011. The paper ends with key findings in case study and proper conclusions.

2. The proposed combined adaptive FIS model

In this section, a step-by-step description of the elements of the proposed model is presented. In this model (Fig. 1), NG consumption in end-use sectors (end-use NG) and NG consumption in power plants (NGPP) are the target elements so that they are forecasted in an integrated manner.

Table 1
The features of the combined adaptive FIS versus other methods.

Model	Reference study	Features						
		Data complexity and non-linearity	Data uncertainty and non-crisp data set	Intelligent modeling and forecasting	Dealing randomness in data	Embedding expert knowledge for forecasting	Accounting for price hike	Incorporating electricity consumption for NG modeling
ANFIS	[12,17,18]	✓	✓	✓	✓			
ANN	[14,23,25,26]	✓		✓	✓			
Econometric	[21,22]	✓	✓	✓				
Combined adaptive FIS	This study	✓	✓	✓	✓	✓	✓	✓