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MODELLING THE DEMAND OF RURAL USERS FOR NATURAL GAS

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Summary. The study presents prognostic models of the annual demand for natural gas of rural users, and assesses the feasibility of such models to predict the annual gas consumption. The study is limited to the models of classical time series and derived from the deterministic chaos theory. The accuracy assessment of individual models has been performed through the development of expired gas consumption prognoses, and by determining mean absolute percent errors of the forecasts ex post. It has been found that auto-regressive models, exponential smoothing models with decreasing trend and Prigogine's logistics models derived form the deterministic chaos theory, are suitable for forecasting the annual gas consumption. The latter ones deserve particular attention, as with sudden changes of the demand figures, the forecast errors in the turning points are considerably less significant that those of the classical models.

Key words: natural gas, forecast, time series models, determined chaos theory

INTRODUCTION

As a result of the research, the documented resources of natural gas on the Earth are continuously growing. Within the last 15 years, the resources have grown almost twice, and they are currently estimated to be 150 trillion m^3 [www.kolmet.com.pl]. The natural gas is the most readily available hydrocarbon fuel in the world market. It can be used with high efficiency, and allows adjustment and automation of the supply and consumption processes. The processes related to mining, transport and storage of the gas are more environment-friendly than in the case of other fuels. Combustion of the natural gas makes practically no harm to the environment, which distinguishes it among other fuels. When sufficient amount of air is supplied, combustion of the gas produces no ash and black, and it can be unfailingly distributed among the users.

After the domination periods of oil and coal, the share of the natural gas in the structure of primary fuels consumption is increasingly higher. The high position of gas has become apparent since the middle of the 20th century. At present, the natural gas satisfies 22% of the global energy demand, whereas the share of coal is 26%, oil 37%, the nuclear and water power 7 and 3% respectively.

Also in Poland an increase in natural gas use has been apparent. In 1980 the consumption was 5054 hm^3, and the figure increased twice over the next two decades. The consumption of natural gas in agriculture is currently around 1554 hm^3, which is approximately 17% of the total natural gas used in Poland.

According to the Energy Law [Dz.U. Nr 54, 1997], all levels of the state administration are bound to develop natural gas supply plans, and at the same time to draw up consumption forecasts. The subject literature mentions a lack of reliable energy demand forecasts, including the natural gas supply.

The study presents prognostic models of the annual demand of rural users for natural gas, and is aimed at an assessement of the feasibility of such models to predict the annual gas consumption. The study is limited to the time series models. As the practice shows, those models are most willingly used for economic forecasting, as they can be constructed based only on the knowledge of the previous forecasted figures.

RESULTS

The structure of changes in the natural gas consumption in rural areas is shown in Figure 1. Currently, 17% of the rural areas are provided with gas supply facilities, and the gas is supplied to 743 thousand users, who consumed 1553,7 hm^3 of gas in 2003. In the last two decades, the gas consumption in rural areas increased almost five times. In that time, however, the demand for natural gas per individual user decreased by over 40 %. This is because the gas is undoubtedly a noble, but expensive energy carrier.

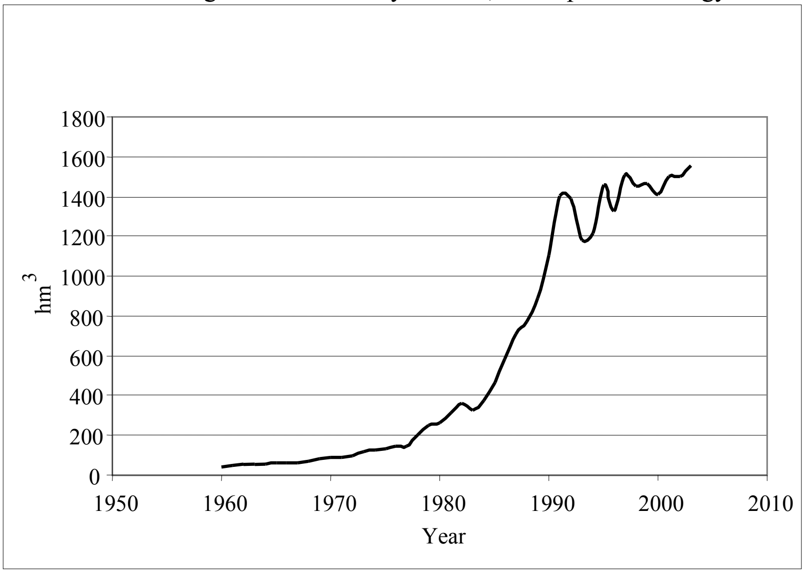

Fig. 1. Natural gas consumption by rural users in Poland between 1960 and 2003
Source: Statistics 1960–2004

The data from the past two decades have been used to construct the models of demand for natural gas, as that period is deemed sufficient for long-term forecasting [Dobrzańska 1998]. The accuracy assessment of the models has been carried out by developing the expired forecast of gas consumption ex post [Dittman 2003]. Only the models having the error below 10% have been compared in the study.

In the time series of natural gas consumption (Fig. 1), the systematic component can be distinguished in a form of an increasing trend, and after 1990, also some minor incidental variations are noticeable, which impede adequate matching of the model to the variable being explained.

While analysing the course presented in Figure 1, it has been found that, out of the classical time series models, some of the time series models with trend can be used to describe the gas consumption by rural users. This, in particular, applies to the analytic, auto-regressive and exponential smoothing models. Determining the trend function with the analytic method involves finding a function, which optimally matches the expressions of the time series of the explained variable. In the analytic models, the time variable serves as the explanatory variable, which is not a direct cause of the changes in the figures of the forecasted variable, but it synthesizes the effect of unknown factors which are not included in the model, allowing the quantitative explanation of those variables.

On the other hand, the idea of exponential smoothing consists in smoothing the time series of the forecasted variable, using the moving weighted average, whereas the weighs are determined according to the exponential principle. The analysis performed assessed the feasibility of the Holt's model, the exponential trend model and the decreasing trend model [Dittman 2003].

Table 1. Classic models of time series of annual demand for natural gas of rural users

Model	Empiric formula/initial values and model parameters	Forecast error %
Analytic models	$y^*_t = 944.57 \log(t) + 355.81$	8.16
	$y^*_t = 526.32 \cdot t^{0.382}$	8.37
	$y^*_t = 331.39 + 148.06\, t - 4.67\, t^2$	6.09
Holt's model	$S_o = 557.0$ $T_o = 56.95$ $\alpha = 0.7$ $\beta = 0.1$	8.25
Model of exponential smoothing with exponential trend	$S_o = 531.7$ $T_o = 1.213$ $\alpha = 0,9$ $\beta = 0,4$	9.15
Model of exponential smoothing with decreasing trend	$S_o = 553.9$ $T_o = 63.28$ $\alpha = 0.7$ $\beta = 0,1$ $\varphi = 0.$	7.91
Auto-regressive models	$y^*_{t+1} = 0.82\, y_t + 273.4$	7.24
	$y^*_{t+1} = - 676211 \dfrac{1}{y_t} + 1892$	8.40
	$y^*_{t+1} = 1834.91 \log(y_t) - 4351.42$	6.68
	$y^*_{t+1} = 7.314 \cdot y_t^{0,7273}$	7.08

where: y^*_{t+1}, y^*_t – natural gas demand forecast respective for a year t+1, t, hm^3, y_t – natural gas consumption per year t, hm^3, t – the subsequent years, where t = 1 stands for 1984, S_o – initial value of smoothing in the exponential smoothing model, T_o – initial value of trend increment in the time series, α, β, φ – model parameters.

While analysing the gas consumption, it can be observed that its figures are predetermined by those from the previous years. If this is the case, the auto-regressive models are practicable. In order to draw up annual forecasts of gas consumption, the linear, hyperbolic, logarithmic and power forms of functions [Cieślak 1999] are employed.

The estimation results of the parameters of classic models of the demand for natural gas in the rural areas of Poland, and the figures of the expired forecasts determined on the basis of those models, are presented in Table 1.

One of the alternative methods, currently in use, is the forecasting based on models derived from the deterministic chaos theory. According to the subject literature, in the stepped prediction models based on fractal dimension, Prigogine's and Schuster's models, and heuristic crossing models [Dobrzańska 2002] can be used.

The study has been limited to present the models based on the fractal dimension, and the Prigogine's models only, as others have proved not to be accurate enough for forecasting the demand for natural gas.

Fractals are such objects, any pieces of which are similar in shape to the original object. This property is called self-similarity. The self-similar processes running in time can be described analogically. Stepped prediction of self-similar random function of time, as the annual consumption of the natural gas can bee deemed, assumes correlation of those variables' figures in a year t and t+1, and its simplest model has a form:

$$X^*_{t+1} = X_t \frac{\sum_{i=2}^{t} X_i X_{i-1}}{\sum_{i=2}^{t} X_{i-1}^2} \tag{1}$$

Based on the logistics equation mentioned by Prigogine, the annual demand for the natural gas can be presented as follows:

$$X^*_{t+1} = X_t + rX_t(1 - \frac{X_t}{K}) \tag{2}$$

where:

r – the increase speed factor, K – development level.

The process depends on the value *r* and the relationship between *K* and *X* in the initial moment. In the study, the parameters *K* and *r* have been determined iteratically, based on the statistics of the annual consumption of the natural gas. The values in one-year intervals have been derived from the teaching sequence. The iterations were started by inserting the *K* figure corresponding to the highest annual gas consumption from the process history, and finished when the difference of the subsequent K figures reached $1 \cdot 10^{-6}$• K = 1372 and r = 0.37 have been obtained.

Mean values of expired forecast errors, determined on the basis of models derived from the deterministic chaos theory, are presented in Table 2.

Table 2. Errors in expired forecasts for the annual demand for natural gas of rural users, based on the deterministic chaos theory

Model	Forecast terror, %
Fractal	7.91
Prigogine's	6.06

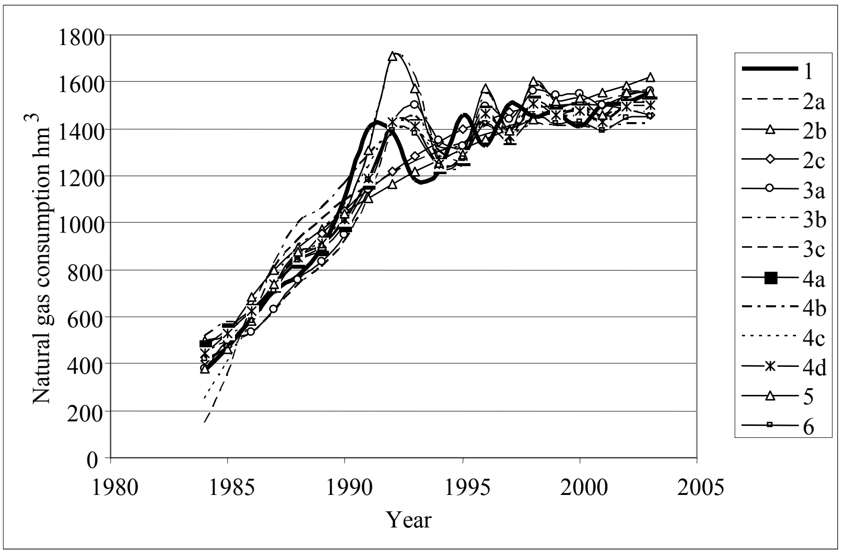

Fig. 2. Consumption of natural gas and expired forecasts for the annual gas consumption by rural users between 1984 and 2003: 1 – actual consumption; 2 – forecast – analytic model (2a – logarithmic function, 2b – power function, 2c – multinomial); 3 – forecast – exponential smoothing model (3a – with linear trend, 3b – with exponential trend, 3c – with decreasing trend); 4 – forecast – auto-regressive model (4a – linear function, 4b – hyperbolic function, 4c – logarithmic function, 4d – power function); 5 – forecast – fractal model; 6 – forecast Prigogine's model

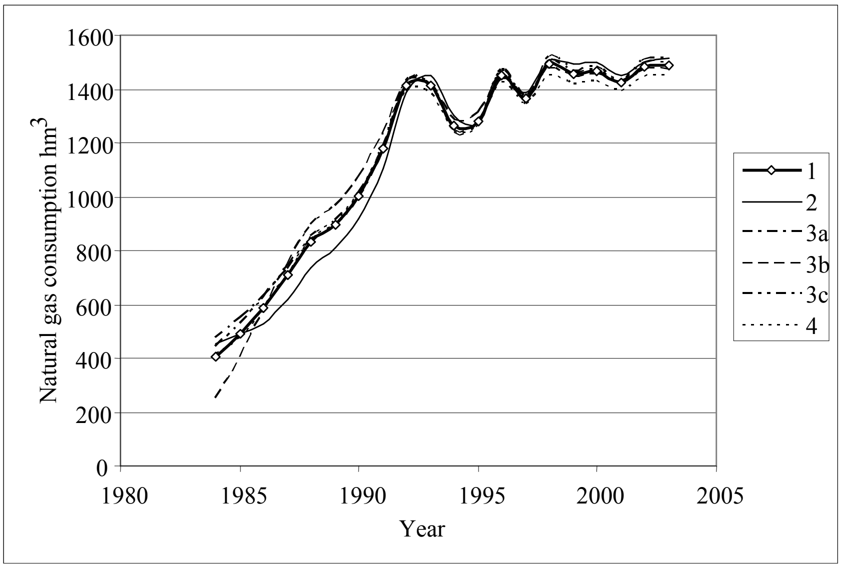

Fig. 3. Expired forecasts and combined forecast for the annual gas consumption by rural users between 1984 and 2003: 1 – combined forecast; 2 – forecast – exponential smoothing model with decreasing trend; 3 – forecast – auto-regressive model (3a – linear function, 3b – logarithmic function, 3c – power function); 4 – forecast Prigogine's model

Figure 2 presents a bundle of expired forecasts of the annual natural gas consumption, in order to compare them with the actual demand. As the comparison shows, not all the developed models are effective in reflecting the analysed course. Therefore, they have been removed from the set of forecasts, and the combined forecast has been determined for the annual consumption of the natural gas by rural users, as the average of individual courses (Fig. 3). The error in the so constructed expired forecast was 5.94%.

CONCLUSIONS

The developed models reflect the demand of rural users for natural gas with the accuracy 6-9%, which is satisfactory for the annual forecasting. Such errors, when compared with the matching of expired forecasts, determined on the basis of individual models, and with the actual gas consumption, indicate the feasibility of the auto-regressive models for exponential smoothing with the decreasing trend and of the logistics Prigogine's models, derived from the theory of deterministic chaos. Particular attention is drawn to the latter ones, as with sudden changes of the demand figures, the forecast errors in the turning points are considerably less significant that those of the classical models.

Accuracy of the forecasts can be increased by developing combined forecasts. The error of such forecast performed in the study was 5.94%, which proves that the combination of forecasts is more accurate than any of them separately.

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