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FORECAST MODELS OF ELECTRIC ENERGY CONSUMPTION BY VILLAGE RECIPIENTS OVER A LONG-TERM HORIZON BASED ON FUZZY LOGIC

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Summary. In this work, four fuzzy models of yearly electric energy consumption were constructed and differed from one another in the method of inference and/or the shape of the fuzzy set membership function. The suitability of models for forecasting was evaluated on the basis of analysis of acceptability and accuracy of forecasts determined based on the constructed models. The most accurate predictions were those determined on the basis of Mamdani model.

Key words: electric energy, long-term forecasting, fuzzy models.

INTRODUCTION

Long-term forecasts of annual electric energy consumption by village recipients are of practical significance in technical as well as economic terms. They are the initial stage for planning strategic development of electric energy infrastructure in a given area. Changes in agricultural production and the living standards of villages require modernization and development of electric energy devices in villages. These alterations are becoming harder to predict under the conditions of the market economy, which often decreases the capability of executing a forecast of good quality for demand of electric energy over a long-term horizon.

A significant problem is also the acquisition and simulation of a sufficient amount of data. This problem arises when forecasts are carried out based on end-use or econometric models. This is why models based only on analysis of time series are used more often, but with the utilization of new tools and methods, such as the artificial intelligence method. Models built based on the artificial intelligence method can be very useful in cases where the principle describing cause and effect relationships in a given system is not known. Methods based on fuzzy logic belong to the group of artificial intelligence methods.

The aim of this work was to elaborate on fuzzy models of annual consumption of electric energy by village recipients and to evaluate the suitability of these models for long-term forecasting.

MATERIAL AND METHODS

The realization of the aim of the work was carried out based on the statistics of electric energy sales by a selected distribution company from southeastern Poland.

The following fuzzy models of systems with one input and one output were considered in this work [Mamdani 1974, 1977; Małopolski, Trojanowska 2009a, 2009b; Mielczarski i in. 1998; Pedrycz 1984, 1993; Piegat 1999; Takagi, Sugeno 1985; Trojanowska, Małopolski 2004, 2007, 2009]: Mamdani models (M models) with Gaussian membership functions in the input space of the model, Takagi-Sugeno models (TSg models) with Gaussian membership functions in the input space of the model, Takagi-Sugeno models (TSt models) with trapezoidal membership functions in the input space of the model, relational models (Rel models) with trapezoidal and triangular membership functions in the input space of the model.

In these models, selection of the fuzzy set membership function as well as the methods of defuzzification was carried out, using the method discussed in the works of Trojanowska and Malopolski [2004, 2007, 2009a, 2009b].

RESULTS

The experiments carried out so far of long-term forecasting have indicated that the set of input data from the history of the forecasted process should include at least 15 years [Dobrzańska 1998, 2002]. Shorter periods of observation do not make it possible to bring out the developmental dynamics of the process.

Figure 1 shows the course of yearly electric energy consumption by recipients from the rural regions of southeastern Poland over the next 26 years. During this period of time, the consumption of electric energy was initially characterized by a significant rising trend, as a result of which the demand for energy increased nearly two-fold over 6 years. After that period, the consumption of electric energy began to decrease. The increasing trend soon recurred, but it was so slight that only now have sales of electric energy to village recipients by the studied distribution company reached the level from over twenty years before.

In the work, among 26 sets of data regarding yearly consumption of electric energy, 22 were used for construction of forecasting models and verifications of acceptability of forecasts calculated on the basis of these models. The last four sets of data served to evaluate the accuracy of forecasts.

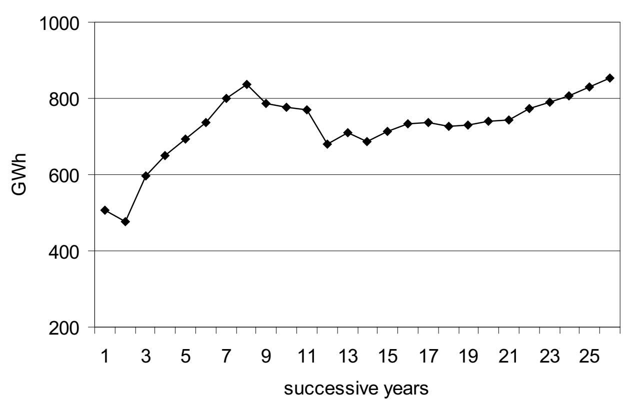


Fig. 1. The course of annual consumption of electric energy by village recipients in southeastern Poland

Due to the nonstationary course of yearly consumption of electric energy, fuzzy models describing the functional dependency y = f(x) were determined, where y is the increment of electric energy consumption during a given year, and x is the increment of consumption of electric energy in the previous year. The method of coupled gradients was used for the optimization of the fixed structure model [Osowski 1996], and the constructive principle was used for the selection of the best model [Piegat 1999].

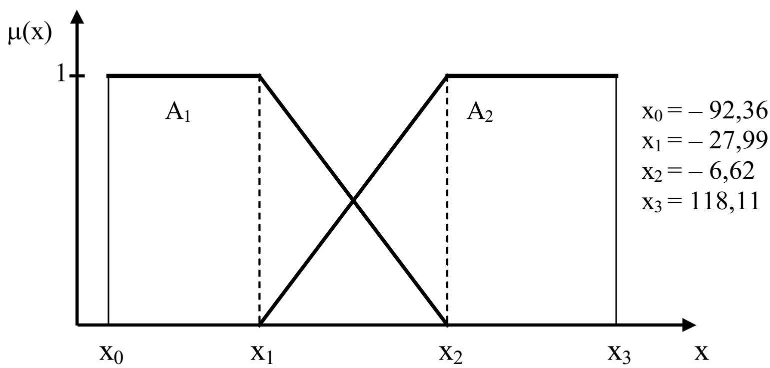
The rule bases in the open form of the Mamdani model are as follows:

R1: IF (x near – 38.31) THEN (y near 25.55), (1)
R2: IF (x near – 4.74) THEN (y near – 92.36),
R3: IF (x near – 1,37) THEN (y near – 92,36),
R4: IF (x near 38,60) THEN (y near – 45,31),
R5: IF (x near 42,48) THEN (y near 54,76),

and for the Takagi-Sugeno model with Gaussian membership functions in the input space of the model:

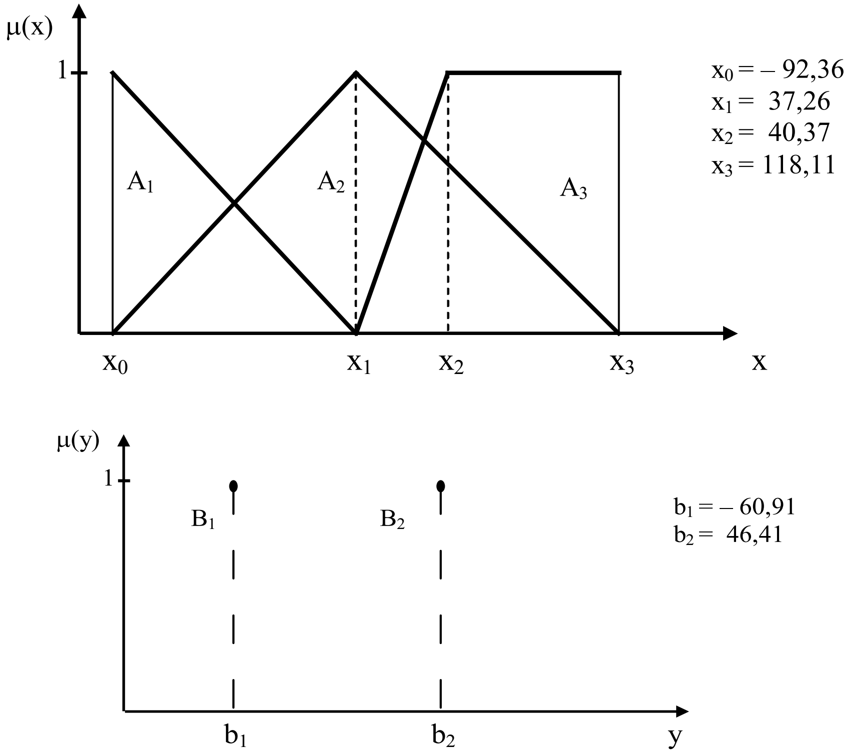
R1: IF (x near – 14.09) THEN (y = 39.68 + 0.12x), (2)
R2: IF (x near – 2,61) THEN (y = – 154,73 + 1,35x),
R3: IF (x near 4,86) THEN (y = 24,13 – 1,49x).

The courses of membership functions and rule bases of the TSt type Takagi-Sugeno model are shown in Figure 2, and those of the relational model in Figure 3.



R1: IF (x is A_1) THEN (y = 91,17 + 0,85x (3)
R2: IF (x is A_2) THEN (y = –15,89 + 0,75x)

Fig. 2. Courses of membership functions and rule base for the Takagi-Sugeno model (TSt)



R1: IF(x jest A_1) THEN (y is 0,31B_1) OR (y is 0,99B_2 (4)
R2: IF (x is A_2) THEN (y is 0.10B_1) OR (y is 0.01B_2)
R3: IF(x is A_3) THEN (y is 0,01B_1) OR (y is 1,00B_2)

Fig. 3. Courses of membership functions and rule base for the relational model

MODELING CONSUMPTION OF ELECTRIC ENERGY EVALUATION OF FORECAST QUALITY

Forecast acceptability

Within the scope of evaluation of acceptability of forecasts of electric energy consumption, the results of the executed forecasting procedures were compared with real process executions. Specifically, time courses of the determined real consumption of electric energy and expired forecasts of this consumption based on the constructed models were observed through analysis of their matching (Fig. 4), and the mean absolute percentage error (MAPE) values were determined as the most often used measurement of acceptability of electric energy demand forecasts.

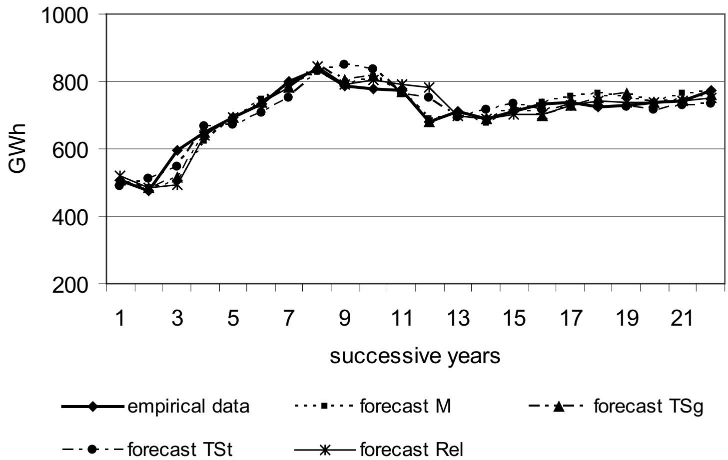


Fig. 4. Expired forecasts of annual electric energy consumption

Errors were determined from the dependency [Dittman 2002]:

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\frac{|y_t - \hat{y}_t|}{y_t}\cdot 100 \quad (5)$$

where: y_t - real electric energy consumption during year t,

$\hat{y}_t$ - electric energy consumption forecast for the year t,

n - number of observations used for elaboration of the model (n=22 years).

The values of these errors are listed in Table 1. The errors of all forecasts are slight, which confirms the satisfactory matching of all the models to the real sales of electric energy, allowing for the acknowledgement of all the elaborated forecasts as being acceptable.

Table 1. Comparison of the acceptability of forecasts of yearly consumption of electric energy

Model	M	TSg	TSt	Rel
MAPE [%]	2,23	2,10	3,87	2,86

Forecast accuracy

The accuracy of forecasts is determined after the expiration of the period for which the forecast was determined, and the degree of forecast accuracy is measured using ex post errors [Cieślak 1999].

In the work, the Theil coefficient (I^2) and the Janus coefficient (J^2) were used for evaluation of forecast accuracy along with the MAPE error, which was determined for the empirical range of forecast verification.

The Theil coefficient was calculated from the dependency [Zeliaś i in. 2004]:

$$I^2 = \frac{\sum_{t=n+1}^{T} (y_t - y_t^*)^2}{\sum_{t=n+1}^{T} y_t^2}, \tag{6}$$

where: y_t^*- forecast of electric energy consumption for the period t>22 years, T=26 years.

$\sqrt{I^2}$ provides information of what the total relative prediction error is during the period of empirical forecast verification, without regard as to what caused this error.

In turn, the Janus coefficient serves to test the validity of the model and is described by the formula [Zeliaś i in. 2004]:

$$J^2 = \frac{\frac{1}{T-n}\sum_{t=n+1}^{T} (y_t - y_t^*)^2}{\frac{1}{n}\sum_{t=1}^{n} (y_t - \hat{y}_t)^2}. \tag{7}$$

A comparison of forecast accuracy is included in Table 2.

Table 2. Comparison of the accuracy of forecasts of yearly consumption of electric energy

Year	Real value	Model M	Model TSg	Model TSt	Model Rel
23	791,321 GWh	797,422 GWh	754,211 GWh	777,025 GWh	756,588 GWh
24	807,689 GWh	816,872 GWh	786,432 GWh	790,042 GWh	788,261 GWh
25	831,212 GWh	833,24 GWh	807,398 GWh	804,094 GWh	807,474 GWh
26	853,328 GWh	856,763 GWh	820,247 GWh	832,993 GWh	823,349 GWh
MAPE	-	0,64 %	3,52 %	2,41 %	3,29 %
I	-	0,71 %	3,60 %	2,48 %	3,36 %
J^2	-	0,01	0,25	0,12	0,22

The executed calculations showed that all the estimated models are still valid (J≤1) and in each case, the main reason for the occurrence of forecast errors was prediction load (at 78 to 96 percent).

Analysis of prediction accuracy was decidedly the most advantageous for forecasts determined based on the Mamdani model. In this case, 78% of the slight ex post total forecast error was caused by prediction load, approx. 9% by insufficient forecasting elasticity, and 13% by insufficient prediction of turning points.

Despite the small forecasting ex post error determined based on the Mamdani model, it can be considered as what should be done for forecasts made using this method to be even more accurate, all the more that full correctness was observed. It was proven that all four forecasts were overestimated (Fig. 5). Forecasts can then be simply corrected, e.g. through decreasing each forecast by the mean value of the observed prediction load, that is by about 5.2 GWh.

Correction of the forecast (Fig. 3) caused a decrease of all standards of forecast quality (MAPE=0.30%, I=0.33%, J^2=0.002).

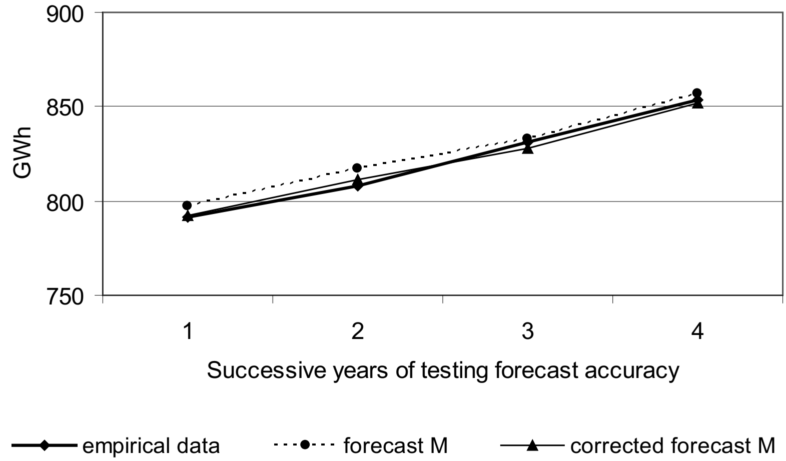


Fig. 5. Courses of yearly real electric energy consumption and forecasts before and after correction during the period of empirical forecast verification

CONCLUSIONS

The obtained test results confirmed the suitability of the fuzzy forecast models with Mamdani, Takagi-Sugeno and relational inference types presented in the work for prediction of annual demand for electric energy of village recipients. All the determined forecasts based on the elaborated models can be acknowledged as good due to the fact that ex post forecasting errors did not exceed 5%. The overwhelming majority of these errors were caused by prediction load, which can easily be overcome.

Out of all the forecasts, the ones that were decidedly the most accurate were proven to be those determined based on Mamdani models.

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MODELE PROGNOSTYCZNE ZUŻYCIA ENERGII ELEKTRYCZNEJ PRZEZ ODBIORCÓW WIEJSKICH W DŁUGIM HORYZONCIE CZASOWYM OPARTE NA LOGICE ROZMYTEJ

Streszczenie. W pracy zbudowano cztery modele rozmyte rocznego zużycia energii elektrycznej różniące się między sobą typem wnioskowania lub/i kształtem funkcji przynależności zbiorów rozmytych. Przydatność modeli do predykcji oceniono na podstawie analizy dopuszczalności i trafności prognoz wyznaczonych w oparciu o zbudowane modele.

Najbardziej trafne okazały się prognozy wyznaczone w oparciu o modele Mamdaniego.

Słowa kluczowe: energia elektryczna, prognozowanie długoterminowe, modele rozmyte.