One approach to using fuzzy logic for the establishing of natural gas tariffs

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Abstract: - This paper introduces an attempt to establish natural gas tariffs based on experts' fuzzy estimations on the example of Georgia. We consider the existent situation in tariffication processes. We discuss the necessity to use new approaches for implementation of these processes. We introduce a new approach for determination of natural gas tariffs based on fuzzy logic and its algorithm. At the end we show the example of practical application of the proposed method

Key-Words: - Natural gas tariff, Parameter, Fuzzy set, Fuzzy aggregation, Algorithm.

1 Introduction

First of all we would like to emphasize that this research does not aim at creation of new formulas in order to determine tariffs (bicycle invention). Here, we are talking about quantitatively new approach to determine importance of the parameters entered into the methodologies. The use of fuzzy logic in determining the various parameters of the electricity sector is not new (see e.g. [2,6]), but the authors have not met the use of fuzzy sets in the gas sector.

In Georgia natural gas tariffs are established by Georgian National Energy Regulatory Commission (GNERC). For tariff determination all licensees involved in natural gas sector (supply, transportation, distribution and consumption) have to present to GNERC their tariff applications.

Licensees always provide to regulatory body subjective parameter values (for instance, salary fund, fuel cost, repairs fund, etc.) in their applications. This is naturally caused by the licensees' wish to get high tariff in order to maintain more profit. That is why, many parameters in these applications are subjective and indefinite, while tariff size should satisfy the interest of not only the producer, but the customer as well, i.e. it should balance their interests. Besides, important pre-project tariffing case should be considered as well (i.e. natural gas unit is not yet put into the operation). In such case, the information is almost fully predictive. Let us review the most general application, introduce the following marks and analyze the nature of parameters:

x_1 – gas volume in network, this parameter carries certain degree of uncertainty;
x_2 – number of employees, this parameter carries certain degree of uncertainty;
x_3 – remaining cost of main operational fund, this parameter carries certain degree of uncertainty;
x_4 – natural gas purchase price (customs value), this parameter carries certain degree of uncertainty;
x_5 – distributed natural gas, this parameter carries certain degree of uncertainty;
x_6 – natural gas production costs, this parameter carries uncertainty;
x_7 – salary fund, we may say for sure, that practically all the licensees present overestimated salaries in their applications, therefore, this parameter contains subjective elements;
x_8 – depreciation of main operational fund, this parameter can be considered true;
x_9 – costs on repairing of main facilities (funds), this parameter carries high degree of uncertainty;
x_{10} - electricity costs, this parameter carries certain degree of uncertainty;
x_{11} – fuel and lubricants, this parameter contains subjective elements;
x_{12} – communication and internet costs, this parameter carries certain degree of uncertainty;
x_{13} – percentage of credit, this parameter can be considered true;
x_{14} – other expenses, this parameter contains elements of uncertainty;
x_{15} – total expenses without VAT, this parameter carries certain degree of uncertainty;
x_{16} – customs duties, this parameter can be considered true;

x_{17} – customs fees, this parameter can be considered true;
x_{18} – property charge, this parameter can be considered true;
x_{19} – land tax, this parameter can be considered true;
x_{20} – income taxes, this tax is fixed, therefore this parameter is true;
x_{21} – other expenses (travel, etc.), the parameter contains elements of uncertainty;
x_{22} – running costs, total, this parameter carries high degree of uncertainty;
x_{23} – profit earned on the difference in currency rates, this parameter can be considered true;
x_{24} – net profit (loss) of the company, this parameter contains elements of uncertainty;
x_{25} – total annual income including the cost of natural gas, this parameter contains elements of uncertainty;
x_{26} – regulation fee payable to GENERC, this parameter can be considered true;
x_{27} – natural gas supply tariff (margin), this parameter contains elements of uncertainty;
x_{28} – natural gas transportation tariff without VAT, this parameter carries certain degree of uncertainty;
x_{29} – natural gas transportation tariff including VAT, this parameter carries certain degree of uncertainty;
x_{30} – GEL to $US rate, this parameter is obviously uncertain;
x_{31} – cost of 1000 cubic meters of natural gas in US dollars, this parameter carries high degree of uncertainty;
x_{32} – GEL to USD conversion and bank service, this parameter carries high degree of uncertainty;
x_{33} – profitability of all expenses, this parameter carries high degree of uncertainty;
x_{34} – supply costs and taxes including profit, this parameter carries high degree of uncertainty ;
x_{35} – bulk supply tariff without VAT, this parameter carries high degree of uncertainty;
x_{36} – bulk supply tariff including transportation tariff without VAT, this parameter carries high degree of uncertainty;
x_{37} – bulk supply tariff including transportation tariff and VAT, this parameter carries high degree of uncertainty.

So, the set of the parameters with true values is:

$$\{x_8, x_{13}, x_{16},\ldots,x_{20}, x_{23}, x_{26}\}, \qquad (1)$$

and the set of the uncertain parameters is as follows:

$$\{x_1,\ldots, x_7, x_9,\ldots,x_{12}, x_{14}, x_{15}, x_{21}, x_{22}, x_{24}, x_{25}, x_{27},\ldots,x_{37}\}. \qquad (2)$$

As we see, 28 parameters out of 37 contain uncertainty and/or subjective elements at various degrees.

One of the most effective ways to take account of uncertainty is a using of group decision strategy, i.e. an involving in problems' decision certain group of professionals. Processes of group decision-making by their nature represent a transformation from individual opinions of experts into the resulting one.

Since subjectivity, vagueness and imprecision influence the assessments of experts [3], the use of fuzzy sets theory seems to be an efficient tool for finding a consensus [1,8,9].

We think usage of fuzzy set theory for the perfection of tariff determination and regulation is adequately reflecting uncertainty aspects of the parameters existing in current power market and enabling to raise tariffication process to new level.

The present paper claims the presentation of a new method for establishment of natural gas tariffs based on aggregation of experts' fuzzy estimates.

2 Essential Notions and Theoretical Background

$\Psi(X)=\{\mu \mid \mu : X \to [0;1] \subset \Re\}$ - lattice of all fuzzy sets in *X*.
$\varnothing$ - minimal element of $\Psi(X)$: $\mu_{\varnothing}(x)=0, \forall x \in X$.
U - maximal element of $\Psi(X)$: $\mu_U(x)=b, \forall x \in X$.
We say that the function *v:* $\Psi(X) \to \Re^+$ is *isotone valuation* on Ψ (*X*) if :

$$v(A \cup B)+v(A \cap B)=v(A)+v(B)$$
and
$$A \subseteq B \Rightarrow v(A) \le v(B),\ A,B \in \Psi(X).$$

We say that the isotone valuation *v* is *continuous* if for each $a \in [v(\varnothing); v(U)]$ there exists $A \in \Psi(X)$ such that $v(A)=a$. The isotone estimation *v* determines the following *metric* on $\Psi(X)$:

$$\rho(A,B)=v(A \cup B)-v(A \cap B). \qquad (3)$$

$\Psi(X)$ with isotone valuation *v* and metric (3) is called *the metric lattice of fuzzy sets* [5].

Definition 1[4]**.** In the metric lattice the fuzzy set *A** is the representative of the finite collection of *fuzzy* sets $\{A_j\}, j=\overline{1,m},$ *m*=2,3,…, if

$$\sum_{j=1}^{m}\rho(A^*,A_j)\le\sum_{j=1}^{m}\rho(B,A_j),\ \ \forall B\in\Psi(X).$$

Definition 2[5]**.** The finite collection of fuzzy sets $\{A_j^{'}\}$ is a regulation of the finite collection of fuzzy sets $\{A_j\}$ if for each $x\in X$ the finite sets $\{\mu_{A_j}(x)\}$ and $\{\mu_{A_j^{'}}(x)\}$ are equal and $\mu_{A_1^{'}}(x)\le\mu_{A^{'}}(x)\le\ldots\le\mu_{A_m^{'}}(x),\ \ j=\overline{1,m},\ m=2,3,\ldots.$

On the basis of axiomatic approach, the concept of coordination index of finite collection of fuzzy sets is introduced in the metric lattice.

Theorem 1[4]**.** *In the metric lattice of fuzzy sets the functional $S\{A_j\}$ is a coordination index of the finite collection of fuzzy sets* $\{A_j\}$, $j=\overline{1,m}, m$=2,3,… *if*

$$S\{A_j\}=q(\rho(\varnothing,U)-[(2m+1)/4]^{-1}\times\sum_{j=1}^{m}\rho(A^*,A_j)),$$

$q>0$.

Moreover, if the isotone estimation v is continuous, this representation is unique.

Here and further on symbol [ ] denotes an integer part of a number and the representative A^* of the given finite collection is determined as follows:

$$A^{'}_{[m/2]}\subseteq A^*\subseteq A^{'}_{[(m+1)/2]+1}, \tag{4}$$

It is obvious that

$$S_{\max}=q\rho(\varnothing,U),\ q>0. \tag{5}$$

Definition 3[5]**.** In the metric lattice of fuzzy sets the finite collection of fuzzy sets $\{A_j\}$ is similar to the finite collection of fuzzy sets $\{B_j\}$ if for each $x\in X$

$\rho(A_i^{'},A_{i-1}^{'})=k\rho(B_i^{'},B_{i-1}^{'}),\ \ i=\overline{2,m},\ \ j=\overline{1,m},\ m=2,3,...,$ where $k>0$ is the coefficient of similarity, $\{A_j^{'}\},\{B_j^{'}\}$ are the regulations of $\{A_j\}$ and $\{B_j\}$ respectively.

We denote the similarity of two finite collections of *fuzzy* sets in the metric lattice of fuzzy sets as $\{A_j\}\overset{k}{\cong}\{B_j\}\Leftrightarrow\{B_j\}\overset{1/k}{\cong}\{A_j\}$ or simply $\{A_j\}\cong\{B_j\}$.

Theorem 2[5]**.** *If* $\{A_j\}\overset{k}{\cong}\{B_j\}$ *then for the coordination indices of these two finite collections of fuzzy sets the equality* $S\{A_j\}=kS\{B_j\}+(1-k)S_{\max},\ j=\overline{1,m}\ \ m=2,3,...$ *holds*.

Theorem 3[5]**.** *In the metric lattice of fuzzy sets with continuous isotone estimation for any two finite collection of fuzzy sets* $\{A_j\}$ *and* $\{B_j\}$ *such that* $S\{A_j\}, S\{B_j\} < S_{\max}$ *there exists the finite collection of fuzzy sets* $\{C_j\}$ *such that* $\{C_j\}\cong\{B_j\}$ *and* $S\{C_j\}=S\{A_j\}$, $j=\overline{1,m}$, m=2,3,…

Let $\Psi(X)=\{\mu|\mu: X\to[0;1]\}$, $X=\{x_1, x_2,\ldots,x_N\}$, N = 1,2,… . We determine the isotone estimation of fuzzy set A in the following way:

$$v(A)=\sum_{i=1}^{N}\mu_A(x_i),\qquad x_i\in X,\quad A\in\Psi(X).$$

By (3) the estimation v determines the following metric:

$$\rho(A,B)=\sum_{i=1}^{N}|\,\mu_A(x_i)-\mu_B(x_i)\,|\ x_i\in X, A,B\in\Psi(X).$$

In such a case we obtain a discrete modification of the coordination index determined by Theorem 1:

$$S\{A_j\}=q(N-[(2m+1)/4]^{-1}\sum_{j=1}^{m}\sum_{i=1}^{N}|\,\mu_{A^*}(x_i)-\mu_{A_j}(x_i)\,|),$$

$$q>0. \tag{6}$$

It is clear that

$$S_{\max}\{A_j\}=qN,\ q\ge 0\,. \tag{7}$$

In this paper for determining the parameters of fuzzy nature, we will use the method for fuzzy aggregation [5]. For appropriate surveys of such methods see e.g. [7]).

The essence of the offered method is the following. We calculate the coordination index of experts' evaluations in each element of the given universe. The element, where the coordination index reaches its greatest value, represents the point of the maximal coordination. The maximal coordination of experts is the fundamental concept of this method. People are not automata and cannot work with the same concentration. It is supposed that if in an element experts achieved the maximal coordination, potentially they could achieve the same result in any other elements of the given universe. For example, a long jumper is evaluated by his best attempt in the finite series of jumps. We take the best attempt of group of experts as the basis and map the remaining attempts on this basis under the original theoretical background. Namely, we introduce the concept of similarity of finite collections of fuzzy sets based on the metric approach. Then we construct such a finite collection of one-element fuzzy sets in each point of the universe that is similar to the analogous collection in the point of maximal coordination and, at the same time, has the greatest coordination index. Out of all mentioned above we discount the opinion of each expert in all elements in equal significant manner. Then, by using the specific kind of fuzzy aggregation operator we obtain the result of group decision-making.

To realize the proposed approach the following special aggregation operator is suggested:

$$\mu_{A^*} = \begin{cases} (\mu_{A'_{[m/2]}} + \mu_{A'_{[(m+3)/2]}})/2 \quad if\ \sigma_1 = \sigma_2 \\ \mu_{A'_{[m/2]}} + \dfrac{\sigma_1}{\sigma_1+\sigma_2}(\mu_{A'_{[(m+3)/2]}} - \mu_{A'_{[m/2]}}), \\ otherwise \end{cases} \tag{8}$$

where $x_i \in X$, $A, B \in \Psi(X)$, $m = 2,3,...,$

$$\rho(A,B) = \sum_{i=1}^{N} |\mu_A(x_i) - \mu_B(x_i)|,$$

$$\begin{cases} \sigma_1 = \sum_{j=1}^{[(m+1)/2]} \rho(A'_j, A'_{[m/2]}), \\ \sigma_2 = \sum_{j=[m/2]+1}^{m} \rho(A'_j, A'_{[(m+3)/2]}). \end{cases} \tag{9}$$

3 Tariffication Model and its Algorithm

We underline that tariffication model mentioned here is not new, but majority of its parameters are determined in drastically new way.

Assume that the above model adequately reflects uncertainty aspects of currently existing natural gas market parameters and allows raising tariff determination and regulation process to a new level.

The most general formula for calculation of any tariff (natural gas supply, transportation, distribution and consumption) is as follows:

$$T = Q/E,$$

where T – value of tariff (GEL/**cubic meter**), Q – desired annual income (GEL), E – natural gas volume (**cubic meter**). Here GEL is the currency of Georgia, 1US$ ≈ 2.65GEL. Further,

$$Q = \sum 1 + \sum 2,$$

where $\sum 1$ is a sum of crisp parameters, while $\sum 2$ presents a sum of fuzzy parameters. Hence, we can rewrite the tariffication model as follows:

$$T = \left(\sum 1 + \sum 2\right)/E.$$

Now we should to calculate fuzzy parameters collected in $\sum 2$. Assume there are N fuzzy parameters, so we have the universe $X = \{x_1, x_2, \ldots, x_N\}$, $N = 1,2,\ldots$. Let m experts evaluate the degree of belonging of fuzzy object to the given universe. As a result, we obtain the finite collection of fuzzy sets $\{A_j\}$; $j = \overline{1,m}$; m=2,3… and should have a group decision-making. Formally we have $\Psi(X) = \{\mu \mid \mu : X \to [0;b] \subset \Re\}$. Let isotone valuation v be

$$v(A) = \sum_{i=1}^{N} \mu_A(x_i), \quad A \in \Psi(X).$$

By (3) from this it follows that metric is

$$\rho(A,B) = \sum_{i=1}^{N} |\mu_A(x_i) - \mu_B(x_i)|.$$

The essence of the offered method was presented in Section II and now we present the generalized algorithm of its realization.

Step 0: *Initialization: the finite collection of one-element fuzzy sets* $\{A_j\}$, *its regulation* $\{A'_j\}$, $j = \overline{1,m}$, $m = 2,3,\ldots$. *Denote the result of the fuzzy aggregation in element* x_i, $i = \overline{1,N}$ *by* $\mu(x_i)$.

Step 1: *Calculate the representatives of finite collection of one-element fuzzy sets* $\{A_j\}$ *in each element of universe X by* (7).

Step 2: *Compute the values of coordination indices of the finite collection of one-element fuzzy sets* $\{A'_j\}$ *in each element* x_i, $i = \overline{1,N}$ *by* (3). *Denote these values by* $S(x_1), S(x_2), \ldots, S(x_N)$ *respectively. Compute the value of* $S_{\max}$ *by* (6).

Step 3: *Choose out of the set* $\{S(x_i)\}$ *such element* S^* *which is greater than or equal to any other elements except* $S_{\max}$.

Step 4: *Do step* 5 *for* $i = \overline{1, N}$.

Step 5: *Compute* $\Delta = S^* - S(x_i)$:

- *If* $\Delta < 0$, *then* $\mu(x_i) = \mu_{A_j}(x_i)$.
- *If* $\Delta = 0$, *then compute the value of* $\mu(x_i)$ *by* (8);
- *If* $\Delta > 0$, *then calculate* k_i *from the following equation* $S^* = kS(x_i) + (1-k)m$; *further calculate*

$$c = \frac{\sum_{l=1}^{m} (\mu_{A_l^{'}}(x) - k \sum_{i=1}^{N} \mu_A(x_i))}{m}$$

and finally

$$\mu_{A_j} = \begin{cases} c + k \dfrac{\mu_{A^{'}_{[m/2]}} + \mu_{A^{'}_{[(m+3)/2]}}}{2} & if \quad \sigma_1 = \sigma_2, \\ c + k(\mu_{A^{'}_{[m/2]}} + \dfrac{\sigma_1 \rho(A^{'}_{[m/2]}, A^{'}_{[(m+3)/2]})}{\sigma_1 + \sigma_2}) & otherwise \end{cases},$$

where σ_1, σ_2 *are determined by* (9).

Step 6: *Representation is* $\{\mu(x_1),\ \mu(x_2), ...,\ \mu(x_N)\}$.

Step 7: *Defuzzification of parameters:* $x_1^{'}, x_2^{'}, ..., x_N^{'}$.

Step 8: *Tariff is*

$$T = \left(\sum 1 + \sum_{i=1}^{N} x_i^{'} \right) \Big/ E .$$

Relevant software was designed based on the above presented algorithm.

4 Illustrations

Here we set an example of the practical using of the proposed approach. The tariff application of the largest Georgian natural gas distributive company (GNGDC) has been considered. This application has included 9 crisp and 28 fuzzy parameters. 6 experts have been invited to evaluate these 28 fuzzy parameters. Then the obtained estimates have been treated by above mentioned approach, its algorithm and software.

In the table below the tariffication results computed by the licensee (required), Georgian National Energy Regulatory Commission – GNERC (approved) and the proposed approach are shown:

Tariff finder	Tariff, GEL/cubic meter
GNGDC	0.3251
GNERC	0.2858
Our approach	0.2792

We think that the approach based on fuzzy sets theory provides more adequate results in calculating the natural gas tariffs.

5 Conclusion

Here we summarize the essence of the proposed paper. We present the new approach for determination of natural gas tariffs. It is shown that in natural gas sector licensees' tariff applications majority of parameters contain uncertainty and/or subjective elements at various degrees. Hence, the use of fuzzy sets theory seems to be an efficient tool for the perfection of tariff determination and regulation.

The offered approach is based on theoretical results obtained in [4,5]. A new method for calculations of natural gas tariffs is introduced and its algorithm is given. The example of practical application of the proposed method is demonstrated.

The introduced approach may be used for tariffication of many others various goods and services as well.

References:

[1] Dubois D., Prade H., *Possibility Theory, an Approach to Computerized Processing of Uncertainty*, Plenum Press, New York, 1988.

[2] Gustave Nguene Nguene, Matthias Finger, A. fuzzy-based approach for strategic choices in electric energy supply. The case of a Swiss power provider on the eve of electricity market opening, *Engineering Applications of Artificial Intelligence*, Vol.20, No.I, 2007, pp.37-48.

[3] H.-S. Lee, Optimal consensus of fuzzy opinions under group decision making environment, *Fuzzy Sets and Systems*, Vol.132, 2002, pp.303-315.

[4] Tsabadze T., The coordination index of finite collection of fuzzy sets, *Fuzzy Sets and Systems*, Vol.107, 1999, pp.177-185.

[5] Tsabadze T., A method for fuzzy aggregation based on grouped expert evaluations, *Fuzzy Sets and Systems*, Vol.157, 2006, pp. 1346-1361.

[6] **T. Tsabadze** Application of fuzzy sets for the determination of electricity tariffs, NORTH

ATLANTIC UNIVERSITY UNION, Puerto De La Cruz, Tenerife, Spain, 10 - 12 December, 2011, pp. 214-219.

[7] J. Vaníček, I. Vrana and S. Aly, Fuzzy aggregation and averaging for group decision making: A generalization and survey, *Knowledge-Based Systems*, Vol.22, 2009, pp.79-84.

[8] Zadeh L.A., Fuzzy sets, *Information and Control,* Vol.8, 1965, pp.338-353.

[9] Zadeh L.A., The concept of a linguistic variable and its application to approximate reasoning, *Information Sciences*, Vol.8, 1975, pp.199-249.