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ENERGY HEDGING USING GOAL PROGRAMMING

Abstract

Energy volume hedging is nowadays very important due to the current structure of the Polish energy market. Energy buyers plan their future demand, but its structure is very heterogeneous. In most cases, energy sellers can hedge energy by purchasing highly homogeneous futures contracts; thus some part of planned demand can't be effectively hedged. Unhedged open position should be minimized because of unknown cost at time *t*.

The aim of this paper is to propose a model of hedging electricity demand volume which minimizes open position. The problem has been solved using goal programming.

Keywords: energy hedging, goal programming, open position.

1. Introduction

The electricity market in Poland has been liberalized from the end of 1990s. This process gradually involves more areas of the electricity market. Usually, the TPA policy is the first impulse to changes. This policy strongly increases opportunities for competitions in every market with natural monopoly; without a doubt electricity infrastructure facilities are a classical example of natural monopoly in the theory of economics. Due to the TPA policy regarding the electricity market, every owner of an infrastructure facility has to grant access to the facility to every competitor who wants to use it. This means we can buy electricity from every firm offering it, not only from the one with infrastructure facilities close to our residence. The TPA policy changes the perception of electricity, which has now become a consumer good. The consumer can choose the best offer for him; hence, energy retailers have to compete.

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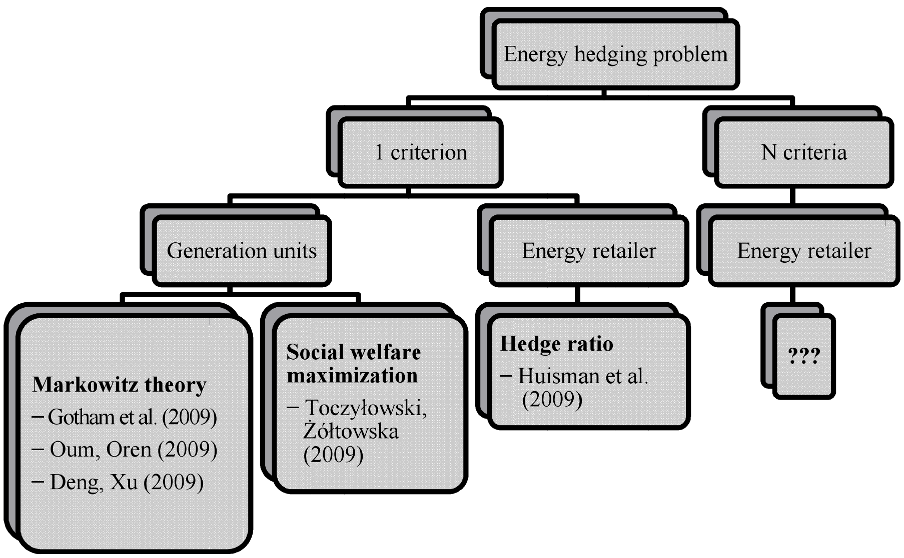
Many papers concerning electricity hedging problem exist in the literature. Most of them focus on optimization in generation units as a single criterion problem. For example, Gotham et al. (2009, p. 249-256) uses the Markowitz theory for optimizing energy production in generation units. However, Oum and Oren (2009, p. 43-56) as well as Deng and Xu (2009, p. 1523-1529) modify the standard mean-variance approach by using VaR as a risk measure. Toczyłowski and Żółtowska (2009) propose the maximization of social welfare coefficient for generation units. On the other hand Huisman et al. (2009, p. 169-174) deal with the hedging problem for energy retailers. There seem to be no papers dealing with the energy hedging problem for retailers as a multiple criteria problem. Schema 1 shows the results of recent literature studies.



Schema 1. Results of recent literature studies

The aim of this paper is to propose a model for fitting an offer which is satisfying for both the electricity consumer and retailer. Two criteria are considered: open position volume minimization (important for the retailer) and offer price minimization (important for the consumer).

The paper is divided into four parts. The first part contains basic definitions related to the problem of electricity hedging in energy market. The second part presents detailed information on the idea of electricity hedging and the formulation of the problem. After the problem formulation an illustrative example with results is given and, finally, conclusions with remarks on applying goal programming to the electricity hedging problem are presented.

2. Definitions

In general, an **energy consumer** is everyone using electricity: factories, enterprises, institutions such as schools, hospitals etc. and also households. In this paper, an energy consumer is a large production company with relatively high energy consumption level for whom electricity purchasing costs constitute a large share of its total expenses. Furthermore, the consumer has to be able to create an hourly schedule with **planned consumption** and to make it available to potential sellers. An example of a planned consumption schedule for the hours from 5:00 am to 4:00 pm for the first seven days of January 2013 is shown in Table 1.

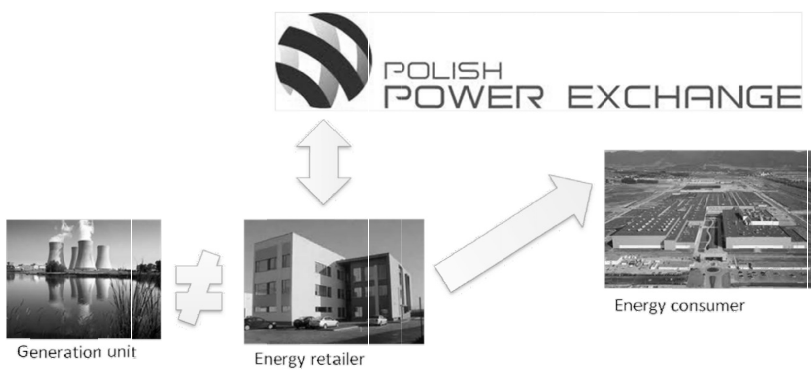
Table 1

Example of a planned consumption schedule

Planned consumption [MW]												
Day/hour		5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16
2013-01-01	**Mon**	5,2	5,8	5,8	5,4	5,4	5,3	5,2	5,8	5,3	5	5,7
2013-01-02	**Tue**	5,6	5,5	5,6	5,3	5,6	5,9	6	5,9	5,4	5,8	5,9
2013-01-03	**Wed**	5,1	5,5	7,7	7,7	7,7	7,9	7,6	7,3	7,6	7,9	7,6
2013-01-04	**Thu**	5,8	5,2	7,3	8	7,4	7,6	7,7	7,5	7	7,6	7,9
2013-01-05	**Fri**	5,2	5,5	7,4	7,6	7,5	7,1	7,7	7,3	7,1	7,3	7,6
2013-01-06	**Sat**	5,1	5,8	5,6	6	6	5,8	5,5	5,4	5	5,5	5,5
2013-01-07	**Sun**	5,1	5,2	7,7	7,6	7,6	7,7	7,5	7,3	7,7	8	7,6

Source: Own elaboration.

We also consider an **energy retailer**. The basic difference between an energy retailer and a **generation unit** is that an energy retailer does not produce electricity. When the retailer is about to sell energy to a customer, he has to buy it first on the market. In other words, he has to **hedge** the client's volume on the market. We also assume that the **market** is the Polish Power Exchange[1]. Schema 2 shows the relations between consumer, retailer, generation unit and market.



Schema 2. Relations between the electricity market participants

[1] Polish Energy Exchange website: http://www.polpx.pl/en [23.03.2013].

There are two basic energy segments in the Polish Energy Exchange (POLPX)[2]:

- Day-Ahead Market (DAM),
- Commodity Forward Instruments Market with Physical Delivery (CFIM).

The Day-Ahead market consists of 24-hour markets. We can buy or sell energy for the individual hours for one day ahead (day *t+1*). This means that today we can buy energy only for tomorrow. In the Commodity Forward Market, on the other hand, electricity forward contracts with physical delivery are used. The basic difference is that on day *t* we can buy or sell energy for a week, month, quarter and even a year ahead. The price for the total energy delivered is fixed, so there is no price risk. The most liquid products are forward contracts for baseload and peakload. According to POLPX, a forward contract for baseload delivers equal amounts of energy in each hour of the supply period[3]. A forward contract for peakload includes supply in working days only for the hours from 7:00 am to 10:00 pm[4]. Figure 1 presents a graphical illustration of the baseload and peakload delivery structure on a particular day, while Table 2 presents a supply matrix.

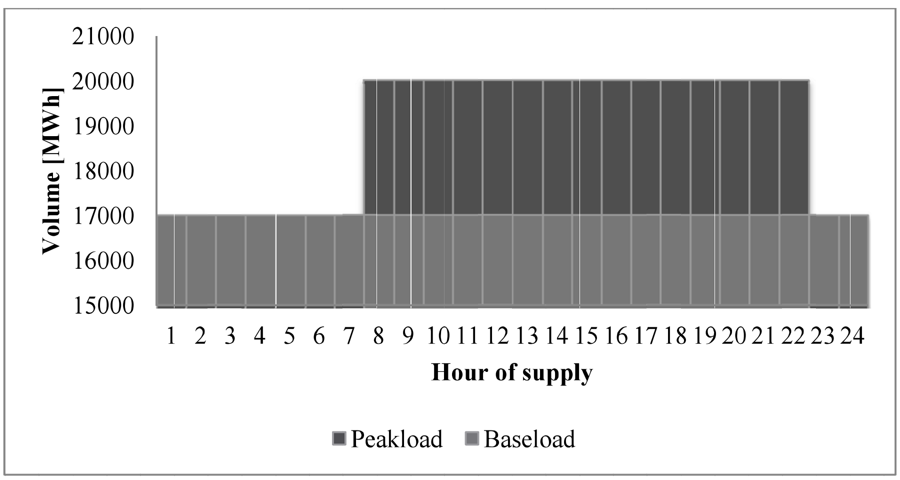


Figure 1. Baseload and peakload delivery structure

Source: Own elaboration using POLPX products definition.

2 For more information about POLPX visit: http://www.polpx.pl/en [23.03.2013].

3 http://www.polpx.pl/en/42/commodity-forward-instruments-market-with-physical-delivery-cfim [23.03.2013].

4 Polish Power Exchange website: http://www.polpx.pl/en/42/commodity-forward-instruments-market-with-physical-delivery-cfim [23.03.2013].

Table 2

Example of supply in baseload and peakload schedule

Schedule of supply [MW]												
Day/hour		5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16
2013-01-01	**Mon**	5	5	5	5	5	5	5	5	5	5	5
2013-01-02	**Tue**	5	5	10	10	10	10	10	10	10	10	10
2013-01-03	**Wed**	5	5	10	10	10	10	10	10	10	10	10
2013-01-04	**Thu**	5	5	10	10	10	10	10	10	10	10	10
2013-01-05	**Fri**	5	5	10	10	10	10	10	10	10	10	10
2013-01-06	**Sat**	5	5	5	5	5	5	5	5	5	5	5
2013-01-07	**Sun**	5	5	5	5	5	5	5	5	5	5	5

Source: Own elaboration using POLPX products definition.

3. The idea of hedging

The production company intending to buy electricity provides a schedule of future consumption to all interested retailers. The retailers present their offers as a feedback and the production company chooses the best offer. The retailers have to analyze the future consumption schedule for fitting in a structure of hedge. In general, hedge can be done in the DAM or in the CFIM segment. On the one hand, there is the highly heterogeneous structure of planned consumption (see Table 1), and there is also the very homogeneous structure of supply of market products (Table 2). Some surpluses and shortages occur in particular hours – these differences are called the open position volume.

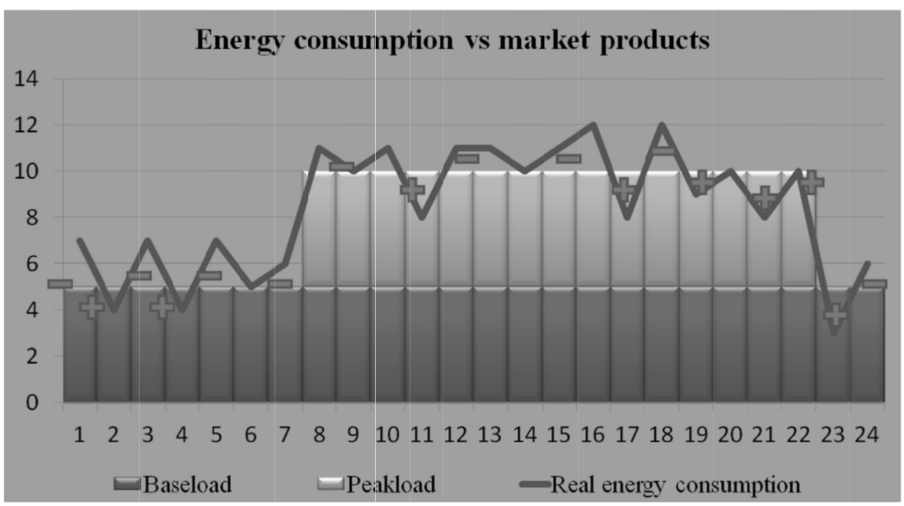


Figure 2. Consumption schedule and forward contracts

Source: Own elaboration.

The problem is to fit in a hedge as a combination of volume bought in the DAM and CFIM segments taking into account both market segments. The retailer is trying to hedge as much as possible in forward contracts because it is possible to hedge volumes for all supply periods at once. And, most importantly, the price of hedge is fixed and therefore the price risk is smaller. Hence, it is most important for the retailer to minimize the open position volume, while the consumer is interested only in the low price of the offer[5]. Concluding, the hedging problem can be formulated as a multicriteria optimization problem which minimizes the open position volume and offer price.

$$\underset{\substack{x_{base}\\x_{peak}}}{MIN}\left\{\sum_{i}\sum_{j}\left|\left(x_{base}\cdot b_{ij}+x_{peak}\cdot p_{ij}\right)-z_{ij}\right|\right\}$$

$$\underset{\substack{x_{base}\\x_{peak}}}{MIN}\left\{\sum_{i}\sum_{j}\left[\frac{c_{base}\cdot x_{base}\cdot b_{ij}+c_{peak}\cdot x_{peak}\cdot p_{ij}}{x_{base}\cdot b_{ij}+x_{peak}\cdot p_{ij}}\right]\right\}$$

where:

$$\begin{cases} x_{base}\le \max\limits_{i,j}\{(b_{ij}-p_{ij})z_{ij}\}\\ x_{base}\ge \min\limits_{i,j}\{(b_{ij}-p_{ij})z_{ij}\}\\ x_{peak}\le \max\limits_{i,j}\{p_{ij}z_{ij}\}\\ x_{peak}\ge \min\limits_{i,j}\{p_{ij}z_{ij}\}\\ x_{base},x_{peak}\in Int \end{cases}$$

$i=1,\dots,365$

$j=1,\dots,24$

Decision variables:

x_{base} – baseload power,

x_{peak} – peakload power.

Available data:

$Z_{i\times j}$ – future consumption schedule,

c_{base} – forward's baseload price,

c_{peak} – forward's peakload price,

i – day index, for example $i=1,\dots,365$ for supply in year 2013,

j – hour index in *i-th* day, $j=1,\dots,24$,

$B_{i\times j}$ – baseload supply matrix,

$P_{i\times j}$ – peakload supply matrix.

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[5] Energy retailer is fully responsible for every aspect of energy supply. That's why the consumer doesn't care about the volume – he's interested only in the price of energy.

Supply matrices are binary matrices. When there is supply in the *i-th* day and the *j-th* hour, the value is 1, otherwise the value is 0. Due to the definition of supply in baseload, the matrix $B_{i\times j}$ is filled with 1s. The matrix $P_{i\times j}$ is filled with 1s in the intersections of the rows representing the hours from 7 to 22 and working days. Criterion *(1)* is responsible for minimizing the open position volume as an absolute value: we want to minimize surpluses as well as shortages in the open position volume. Criterion *(2)* minimizes the volume weighed average price of forward contracts in hedge[6]. Constraint *(3)* defines the search range for the baseload power forward contract. Constraint *(4)* defines the search range for the peakload power forward contract.

We want to minimize surpluses as well as shortages in the open position volume; the price should be less than or equal to some specified upper level P_u. We can transform this basic model into a goal programming model[7].

$$\underset{\substack{x_{base}, x_{peak} \\ d_1^+, d_1^-, d_2^+}}{MIN} \quad \{d_1^+ + d_1^- + d_2^+\}$$

$$\begin{cases} \sum_{\mathrm{i}} \sum_{\mathrm{j}} \left(x_{base} \cdot b_{ij} + x_{peak} \cdot p_{ij} - z_{ij}\right) - d_1^+ + d_1^- = 0 \\ \sum_{\mathrm{i}} \sum_{\mathrm{j}} \left(\frac{c_{base} \cdot x_{base} \cdot b_{ij} + c_{peak} \cdot x_{peak} \cdot p_{ij}}{x_{base} \cdot b_{ij} + x_{peak} \cdot p_{ij}}\right) - d_2^+ + d_2^- = P_u \\ x_{base} \leq \max\limits_{i,j}\{(b_{ij} - p_{ij}) z_{ij}\} \\ x_{base} \geq \min\limits_{i,j}\{(b_{ij} - p_{ij}) z_{ij}\} \\ x_{peak} \leq \max\limits_{\mathrm{i,j}}\{\mathrm{p_{ij} z_{ij}}\} \\ x_{peak} \geq \min\limits_{\mathrm{i,j}}\{\mathrm{p_{ij} z_{ij}}\} \\ x_{base}, x_{peak} \in \mathrm{Int} \\ d_1^+, d_1^-, d_2^+, d_2^- \geq 0 \end{cases}$$

$$i = 1, \ldots, 365$$
$$j = 1, \ldots, 24$$

where:

d_1^+, d_1^- – overachieve and underachieve coefficients, respectively, for the open position volume,

d_2^+, d_2^- – overachieve and underachieve coefficients, respectively, for the offer price,

P_u – fixed upper price level specified by the decision maker.

6 We assume zero sales margin, so that offer price is equal to purchasing costs.

7 According to: Trzaskalik (red.) (2006, p. 39-40).

The advantage is that there is only one criterion consisting of overachieve and underachieve coefficients. Furthermore, we want to minimize only the surpluses of price criterion, so the variable d_2^- does not occur in the objective function. There is no need to employ sophisticated routines for nonsmooth functions[8].

4. Illustrative example

Let us consider a future consumption schedule for the first seven days of January 2013. The potential retailer has to hedge 90 GWh of energy. Consumption is higher in peak hours (see Figure 3). The average baseload power is 508 MW and the average peak power is 107 MW, for the total of 615 MW consumption in peak hours.

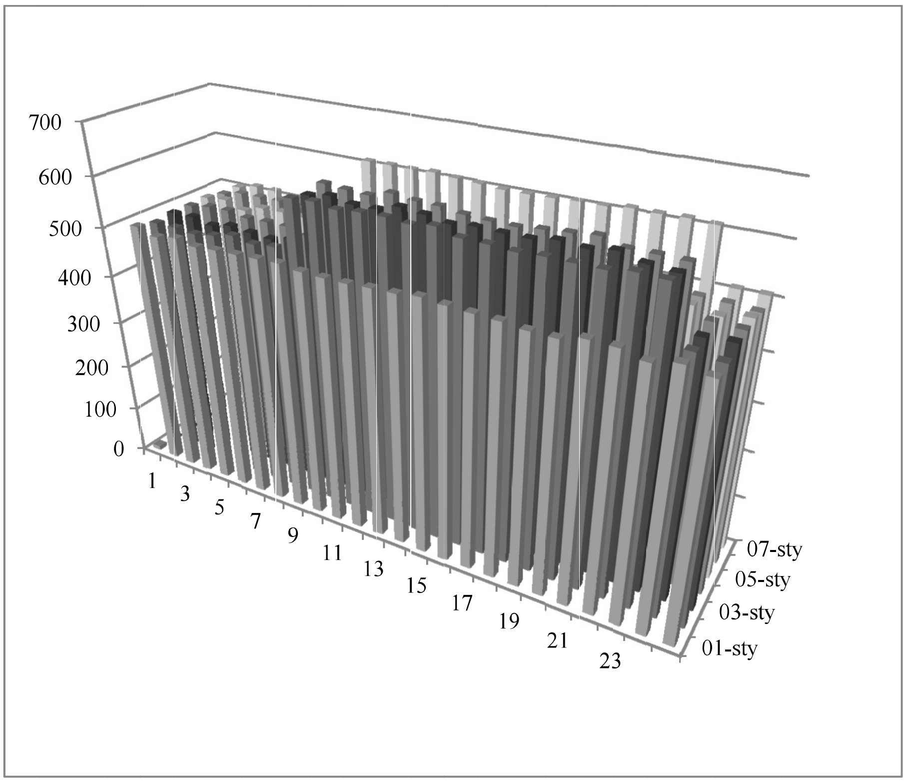

Figure 3. Graphical representation of consumption structure

Source: Own elaboration.

[8] The first criterion in the basic model includes absolute value – this makes it nonsmooth.

The forward contract price is 197,00 PLN/MWh for baseload and 213,00 PLN/MWh for peakload. We also assume that the upper price level P_u is equal to the peakload price of 213,00 PLN/MWh – we want the price of our hedge to be less than or equal to 213,00 PLN/MWh.

The results are presented in Table 3. One solution has been obtained by using the goal programming model (marked in bold). But offering to the potential customer one offer (solution) is not enough – there are no negotiation possibilities with only one offer. Therefore three additional solutions have been generated, which are very interesting because of their price. In the goal programming solution the open position volume is the least but the price is the largest; the consumer would probably not choose this offer. But the retailer should consider additional solutions, in which the open position volume is only 0,06%-0,20% higher and whose price is more attractive for the potential client.

Table 3

The results

Solution	OP [MWh]	Price [PLN/MWh]	Base [MW]	Peak [MW]	OP/Volume
Goal programming	**0,68**	**199,87**	**504**	**110**	**0,00%**
Additional	-59,32	199,85	504	109	0,06%
Additional	-119,32	199,82	504	108	0,13%
Additional	-179,32	199,80	504	107	0,20%

Source: Own elaboration.

5. Summary

Goal programming has been used to solve the electricity hedging problem consisting of two different criteria: open position volume and offer price. This multicriteria problem is more elastic than other such problems in the literature. The advantage is that both the retailer and the consumer can use it to calculate the parameters of a reference offer for the negotiation process. Another advantage is that the retailer has an effective tool for decision making during the negotiation process with which he can generate solutions including potential changes in the parameters of the model. The decision maker makes a decision about the trade-off between the open position volume and the price of the offer.

Goal programming is an effective way to simplify the basic energy hedging problem. Being a very convenient tool, it makes this model applicable in practice. Goal programming is also a very ingenious method for handling nonsmooth criteria indirectly. The goal programming approach has one important disadvantage: it generates only one solution at a time (in our paper additional solutions have been generated). Other methods provide a set of nondominated solutions which may be more useful for the decision maker.

References

Bunn W.D. (2004), *Modeling Prices in Competitive Electricity Markets*, John Wiley & Sons.

Deng S-J., Xu L. (2009), *Mean-risk Efficient Portfolio Analysis of Demand Response and Supply Resources*, Energy 34, Elsevier, p. 523-1529.

Galvani V., Plourde A. (2010), *Porfolio Diversification in Energy Markets*, Energy Economics 32, Elsevier, 257- 268.

Goldberg R., Read J., Altman A., Audouin R. (2007), *Delta Hedging Energy Portfolios: An Exploratory Study*, Proceedings of the 40th Hawaii Conference on System Sciences.

Gotham D., Muthuraman K., Preckel P., Rardin R., Ruangpattana S. (2009), *A Load Factor Based Mean-variance Analysis for Fuel Diversification*, Energy Economics 31, Elsevier, 249-256.

Huisman R., Mahieu R., Schlichter F. (2009), *Electricity Portfolio Management: Optimal Peak/offpeak Allocations*, Energy Economics 31, Elsevier, 169-174.

Jajuga K., Jajuga T. (2009), *Inwestycje. Instrumenty finansowe, ryzyko finansowe, inżynieria finansowa*, PWN, Warszawa.

James T. (2007), *Energy Market. Price Risk Management and Trading*, Willey.

Kaminski V. (2004), *Managing Energy Price Risk*, Risk Publications.

Kaminski V. (2005), *Energy Modeling. Advances in the Management of Uncertainty*, Risk Publications.

Liu M., Wu F. (2007), *Portfolio Optimization in Electricity Markets*, Electric Power Systems Research 77, Elsevier, 1000-1009.

Michalski D., Krysta B., Lelątko P. (2004), *Zarządzanie ryzykiem na rynku energii elektrycznej*, Instytut Doskonalenia Wiedzy o Rynku Energii, Warszawa.

Mielczarski W. (2000), *Rynki energii elektrycznej. Wybrane aspekty techniczne i ekonomiczne*, ARE S.A., Warszawa.

Oum Y., Oren S. (2009), *VaR Constrained Hedging of Fixed Price Load-following Obligations in Competitive Electricity Markets*, Risk and Decision Analysis 1, IOS Press and the authors, 43-56.

Toczyłowski E., Żółtowska I. (2009), *A New Pricing Scheme for Multi-period Pool-based Electricity Auction*, European Journal of Operational Research 197, 1051-1062.

Trzaskalik T. (red.) (2006), *Metody wielokryterialne na polskim rynku finansowym*, PWE, Warszawa.

Weron A., Weron R. (2000), *Giełda energii. Strategie zarządzania ryzykiem*, CIRE, Wrocław.