ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume LIX 39 Number 7, 2011

MODEL OF COST AND PRICE RELATIONSHIPS FOR MUNICIPAL WASTE MANAGEMENT OF THE CZECH REPUBLIC

J. Soukopová, J. Hřebíček

Received: August 31, 2011

Abstract

SOUKOPOVÁ, J., HŘEBÍČEK, J.: *Model of cost and price relationships for municipal waste management of the Czech Republic.* Acta univ. agric. et silvic. Mendel. Brun., 2011, LIX, No. 7, pp. 371–378

Presented paper *Model of cost and price relationships for municipal waste management of the Czech Republic* introduces an integrated waste management model of the Czech Republic which was developed as a balanced network model for a set of sources (mostly municipalities) of municipal solid waste (MSW) connected with a set of chosen waste treatment facilities processing their waste. Model is implemented as a combination of four models including environmental and economic point of view. It enables to formulate the optimisation problem in a concise way and the resulting model is easily scalable. It can be used for waste management planning as a decision support tool. In this case, aggregated emissions of greenhouse gases expressed as CO_2 equivalent have been minimised. Model involves composting energy utilization, material recycling, and landfilling. Its size (number of sources and facilities) depends only upon available data. Its application was used as a decision support tool in the case study of optimizing the planning allocation of potential facilities of waste management of the Czech Republic.

waste management, municipal solid waste, integrated waste management model, cost modelling

Waste is an unavoidable by-product of human activities. Economic development, urbanization and improved living standards in cities increase the quantity and complexity of generated municipal solid waste (MSW). The decisions in the area of MSW management are not only very capital intensive, but also difficult from environmental and social points of view. There is the need to develop, master and implement simple, but reliable tools that will help to the decision makers in the analysis of waste management processes. This paper discuses an model of integrated solid waste management to assist in identifying alternative solid waste management strategies and plans that meet cost, material, energy, and environmental emissions objectives of European Union (EU).

The MSW is considered as all waste generated within the community (as well as the source MSW) by the activities of inhabitants (households) and businesses (e.g. trade waste), which is separated into its components and transported to waste treatment facilities. The MSW normally contains the remains of food and vegetables, paper, plastic, glass and metal containers, printed matter (newspapers, magazines, and books), destroyed products, ashes and rubbish, used or unwanted consumer goods, including shoes and clothing. Chosen components of MSW are collected separately and thus they are balanced separately. The waste (or its components) can be composted, used as raw material (paper, plastic, glass, and metals), used in the biogas, energy recovery (incineration) plants or land filled. The separation of its components may take place at the source (separate collection in the municipalities) or in the facilities. Biodegradable waste can be separated at source and composted at home or in a municipality (municipal composting plant). So we define the individual waste streams, which are mass balancing.

METHODS AND MATERIALS

At the beginning of the development of models of waste management has moved towards the *integrated model waste management* (IMWM), which is designed to minimize the economic costs and / or environmental impacts, see Berger *et al.* (1999), Wang (2001), Yeomans (2006). It already requires the use of optimization procedures for finding minima appropriately defined objective function (total cost, emissions, etc.), Haigh (2006).

Consider the IMWM discussed by Hřebíček *et al.* (2009) which consists of the set of MSW sources (municipalities) of the Czech Republic connected by the road network with the set of waste treatment facilities (composting, biogas, mechanical-biological treatment and pre-treatment of recyclable waste plants, incinerating plants with energy recovery and landfills), where MSW (or its components separated at source) is transported to selected facilities for recovery or final disposal. The material balance is examined in terms of material flows between MSW sources and waste treatment facilities. The waste treatment facility technologies depend on both the operators (voluntary cooperation, market) and the regulator (government). The regulator is able to use the operating permits or economic instruments (charges), so that the waste management will show a minimal impact on the environment in socially viable cost for the most of communities.

In developing IMWM of the Czech Republic, we came out of the models available in literature. Since the early 1990s a number of IMWM has been developed which were based on life cycle analysis i.e. materials and energy balances, see McDougall *et al.* (2009) and Solano *et al.* (2002). Most available models are static, respectively deterministic and quantify the uncertainty of estimates due to random nature of input values. Another disadvantage of models based only on the LCA is that they do not allow optimizing the allocation of waste treatment facilities from sources and/or quantifying the transport emissions. We tried to reduce the greatest uncertainty of our model by the estimation of the composition of municipal waste, waste separation, varying the proportion of resources, varying quantities of trade waste and the like.

The developed IMWM of the Czech Republic consists of the combination of four sub-models, where we used following tools (Hřebíček, Soukopová, 2010):

a) The geographic information system (GIS) *ArcMap,* which computed a transport matrix linking the sources MSW and waste treatment facilities and the simple model, which generated emissions from the transport of MSW and enable to find the closest facility.
b) The sophisticated model of Hejč *et al.* (2008) for the determination of the quantity and composition of MSW from every source (municipality) or data from annual waste reports of municipality of the quantity and separated components of MSW.
c) The cost economic sub-models of every type of waste treatment facility including the generation of the emissions of MSW treatment.
d) The software *LINGO* for the carbon emissions optimization of allocated waste treatment facilities with the choice of either economic or environmental point of view.

RESULTS

1. Transport network model

Consider the MSW flows at the Czech Republic among all sources (municipalities) S_i, where (i =1,…, N), N = 6245 and all waste treatment facilities F_j, (j = 1,…, M), M = 307, where ML = 237 is the number of landfills (figure 1).

Consider these MSW flows in a continuous manner and mass balance between sources (municipalities) and facilities carried out over a longer period of time (annual reporting).

If we model the allocation of existing N sources S_i and M facilities F_j in the Czech Republic then we built the transport matrix $\boldsymbol{D} = \{d_{ij}\}$, ($NxM$), of real transport distances d_{ij} (e.g. road maps) among all sources S_i and all facilities F_j and the vector of the distance $\boldsymbol{dc} = \{dc_i\}$ (Nx1) of the source S_i from its closest landfill F_c, c {1, …, M}.

We have used the GIS program *ArcMap* 9.2 with its extension *Network Analyst* 9.2[1] from ESRI for the analysis of the closest facility (e.g. landfills) to the individual sources (municipalities). With using *ArcGIS Network Analyst*, we have created simple applications that provide us transport distances among all M sources and N facilities, find closest facilities, and create the distance matrix $\boldsymbol{D}$ and the vector $\boldsymbol{dc}$.

Networks used by *ArcGIS Network Analyst* are stored as network datasets. A network dataset is created from the feature source or sources that participate in the network. We used municipalities and roads layers of the Czech Republic for *ArcGIS Network Analyst* from the open-source project *FreeGeodataCZ data package*. It incorporates an advanced connectivity transport model that can represent complex scenarios, such as multimodal transportation networks.

2. Model of quantity and composition of MSW

The developed model of quantity and composition of MSW is based on the production of

1 *Network Analyst* program enables to implement networking analysis – finding the shortest path between two points, finding time to travel between two points, etc. Users can create and maintain network data sets in shape file, personal geodatabase, and enterprise geodatabase formats.

1: *Map of 237 landfills of the Czech Republic*

MSW in each municipality of the Czech Republic and was published by Hejč and Hřebíček (2008). They described formally the simple model of MSW production as the function of appropriate variables taking into account specific waste production, and local demographic, socio-economic influences:

$$P = inh \times spec \times std \times sz \times unemp \times hsg \times heat/1\,000, \quad (1)$$

where:

P......... is the amount of the MSW production of municipality per year in tons [t],
inh..... is the number of inhabitants of municipality,
spec... is the specific waste production coefficient (reference values of other coefficients), measured in tons [t],
std...... is the standard of living coefficient,
sz....... is the size of the community coefficient,
unemp is the unemployment rate coefficient,
hsg..... is the type of housing (recreation, blocks of flats, empty houses…) coefficient and
heat... is the type of heating coefficient.

The model (1) came with a finer division of demographic, socio-economic impacts on production and treatment of MSW into the level of individual municipalities. For those above-mentioned values of adjustable variables where is evidence that uncertainty must be estimated with an appropriate stochastic evaluation and Monte-Carlo simulation. It enables to meet the conditions required by the Ministry of Environment (MoE) to hit the regional dimensions (at least at district level) and therefore to meet different impacts on relative prices of waste management in different regions of the Czech Republic, see Hřebíček *et al.* (2009). This model was investigated and verified for three years in South Moravia region of the Czech Republic, where were optimized some above-mentioned variables by Hejč *et al.* (2008), Hejč and Hřebíček (2008) with the simple expression:

$$x = (act/ref) \times cx,$$

where:

x .... means a variable from {*std, sz, unemp, hsg, heat*},
ref... means a reference value from three year investigations,
act... an actual value from given year and
cx.... is the compensator (given by optimization process) of the considered variable *x*.

The above-mentioned model (1) calculates the production P_i of MSW in each municipality S_i based on the adjusted number of inhabitants inh_i, the specific waste production coefficient *spec* and specific demographic data reflecting the population behaviour with respect to MSW management (i.e. the type of housing hsg_i and other variables std_i, sz_i, $unemp_i$, $heat_i$ of municipality S_i), ($i = 1…N$). These data are downloaded from publicly accessible registers of the Center for Regional Development of the Ministry for Regional Development of the Czech Republic and the Czech Statistical Office. They are updated annually from all municipalities of the Czech Republic. Therefore, the model enables to calculate the production of MSW for the given year with actual variables in (1) and predict waste production with using the linear model of the Waste Management Plan of the Czech Republic. We were able to calculate waste production MSW for 2008 year and predict the increase of the production of MSW in 2016 and 2020 years.

The validation and optimization of the model (1) outputs – the production P_i of MSW – was done with the available data from the annual reports of municipalities S_i of the South Moravia region. However, annual reports of MSW of S_i bear some error, which issued from their different data quality. The process of the improvement of the data quality of municipalities S_i of the South Moravia region lasted several months. The data from the annual reports of all municipalities about their waste production are collected by the *Information System of Waste Management* (ISWM) of the Czech Republic. We used these but we had to solve the problem with incompleteness of these data because more than 500 municipalities of the Czech Republic did not report their annual MSW production to ISWM. So we had to use the model (1) for the calculation of their missed MSW production in 2008 and the prediction of their MSW production in 2016 and 2020 years.

We have to estimate of MSW composition for the calculation of the amount of separated components of MSW at each municipalities S_i to obtain the rest PD_i of MSW P_i after the separation of recyclable components. We have used for this estimation values listed in the Table I, which are based on the results of research of Benešová *et al.* (2009).

We have considered values from Table I to estimate real quantity of a disposable production PD_i of MSW from the municipality S_i to waste treatment facilities (new ones or available ones) after separation of recyclable components of MSW, which was estimated by Hejč *et al.* (2008), Hřebíček and Soukopová (2010):

$$PD_i = (1 - sep_i \times will_i)\, P_i, \qquad (2)$$

where:

sep_i .... is the ratio of separation at source S_i,

$will_i$.... is willingness to separate MSW (paper, glass, metals, textile and bio-waste) at municipality S_i ($i = 1\ldots N$).

Coefficients sep_i and $will_i$ came from data of the investigation of the MoE and were validated in South Moravia region by Hřebíček and Soukopová (2010).

The model (2) help us to solve some uncertainties which issued from the different state of population awareness about MSW management and estimate the amount of disposable production PDi of MSW from the municipality S_i to appropriate waste treatment facilities. The Ministry of Environment has used this model since 2009 after several months reviewing process.

3. Economic models for facilities

We developed cost economic models for all types of facilities F_j ($j = 1\ldots M$), including composting, biogas, and mechanical biological treatment (MBT) plants, incineration plants with energy recovery (ERP) and landfills. These models are similar and we introduced this economic model for a generic facility *F*.

Calculate the price *p* of one t of the waste treatment at a new composting, biogas, MBT and ERP plant *F*. This calculation is based on the financial and economic analysis and financing methods for the measuring the efficiency of investment, see Levy and Sarnat (1999), Valach (2006), Soukopová *at al.* (2011) etc. We used the *Net Present Value* (*NPV*) as the basic calculation method for the price *p*.

$$NPV = -I + \sum_{i=1}^{n} \frac{CF_i}{(1+r)^i}, \qquad (3)$$

where

I.......... means an investment expenditures in facility *F*,

CF_i .... means a cash flow generated in the period *i*,

r.......... means the discount rate and

n......... means the lifetime of facility.

To calculate the price *p* is assumed that the *NPV* must be at the time of return positive. Thus the basic assumption was that we set the maximum

I: *MSW composition at the Czech Republic (weight %)*

Material	The share of material groups in waste (% by weight), average			
	Housing estates of big cities	Housing estates of small cities	Mix housing estates of cities	Rural area
Paper	22.7	22.2	25.6	7.6
Plastics	13.8	16.8	18.0	9.0
Glass	8.7	6.7	7.6	8.9
Metals	3.4	3.0	3.1	4.5
Bio-waste	18.2	19.6	17.3	6.3
Textile	5.6	6.6	5.1	2.2
Energy recovery waste	12.4	6.7	7.0	6.2
Under 20 mm	9.7	8.1	8.2	45.8
Other	5.5	10.3	5.1	9.5
Totally	100.0	100.0	100.0	100.0

Source: authors

acceptable *payback* period of investment I in the facility F_j, ($j = 1,\ldots, N$).

Then n = *lifetime* = *payback* in formula (3). If we assume that

$$CF_i = pK + B_i - C_i - u_i - j_i - E_i - T_i \ , \tag{4}$$

where

$$T_i = t \times (pK + B_i - C_i - u_i - j_i - E_i - O) \ , \tag{5}$$

where

CF_i.means a cash flow generated in the period i,
K.....means the capacity of the facility,
p......means the price,
B_i....is the total revenue generated from the facility in the period i,
C_i....is the total operating costs arising from the facility during the period i,
u_i ... means the interest due on loans for the period i,
j_i..... means repayment of principal on loans for the period i,
$_i$........means the costs of emission allowances for the period i,.
T_i .. means an income tax arising from the facility during the period i,
t.......means the tax rate on corporate income,
i.......means the period (year) from 0 to n and
n......means lifetime and also payback of the facility.

Then price p is defined as

$$p = \frac{\dfrac{I}{(1-t)\sum_{i=1}^{n}\dfrac{1}{(1+r)^i}} - B + C + \dfrac{\sum_{i=1}^{n}(u_i + j_i + E_i)}{\sum_{i=1}^{n}\dfrac{1}{(1+r)^n}} - \dfrac{tO}{1-t}}{K} \ . \tag{6}$$

It is clear that different facilities will have different costs, incomes, investments, etc. For each-mentioned facilities F_j (composting, bio-gas, MBT and ERP plants, and landfills) were developed the economic sub-models for the construction of the price p_j of given facility F_j ($j = 1\ldots M$). These models were based on the real level of investment, operating expenses, operating incomes, interest on loans, capacity of facility and emissions. The economic model of landfill was evaluated from prices for all landfills of the Czech Republic, as the average for the whole country, because the standard deviation of prices was less than 10%.

4. Carbon emission model

Reducing greenhouse gas emissions is the important socially topic in the Czech Republic. Particularly the suppression of landfill methane emissions, total emissions of CO_2 equivalent will have to be significantly reduced in the waste management sector. In developing the carbon emission model we have confined ourselves to minimize greenhouse gas emissions in the transportation, composting, incineration and landfilling MSW. Modelling of these emissions is a standard part of the LCA models of municipal waste management, so that in Solano *et al.* (2002), there are emission factors. This means that the emission factors, unit fuel consumption, energy prices, waste categorization and other parameters are fixed set according to the Czech Republic where the integrated model of waste management was constructed (Hřebíček and Soukopová, 2010). Moreover, users are not accessible to balance relationships, the above-mentioned developed models do not optimize traffic and are strictly deterministic (do not take into account random variations of input data and uncertainty of adjustable parameters). Besides the mass-flow models, there are also above-mentioned economic models that can describe the system of unit costs and examine the impact of economic instruments. Therefore, the carbon emission model was simply transformed into the above economic model by replacing the unit cost of emission factors. Because the model allows you to insert individual emission factors, which depend on the waste treatment technology and its optimal use is possible by analogy to the economic optimization with regard to the cost of waste treatment facilities. However, the data of new facilities are not available to the regulator (MoE) and can be obtained only from the operators (or potential investors at prepared facilities).

DISCUSSION

The above-mentioned chapters introduced shortly four developed different sub-models necessary for the regulation of waste management of the Czech Republic and a decision support of the allocation of subsidies from EU. We used properties of the *MS Excel* spread-sheet for the integration of above sub-models into one IMWM of the Czech Republic to evaluate cost and price relationships for the municipal waste management of the country.

This implementation of IMWM enables the central option of the set of the input economic parameters of the model at the single control sheet of the MS Excel with interconnected sheets, where we implemented above sub-models:

1) the sheet (table) of socio-demographic variables inh_i, std_i, sz_i, $unemp_i$, $heat_i$, hsg_i, sep_i, $will_i$ of all municipalities S_i of the Czech Republic needed to calculate the outputs P_i and PD_i, ($i = 1\ldots N$), of the model (1), (2),
2) the sheet with the dynamically calculated the vector ***dc*** of the distance dc_i of source S_i from the closest landfill F_c by *Network Analyst* program, and the cost CTF_i of waste treatment of PD_i at the landfill F_c together with the cost CTE_i of transport to this facility including carbon emissions cost, ($i = 1\ldots N$),

3) the sheets of economic models (5) of (planned and current) waste treatment facilities F_j^1 with dynamically calculated prices p_j including costs of carnon emission, (j = 1…M),
4) the sheet with dynamically calculated a potential amount of MSW from "the collecting waste area" of the facility F_j (j = 1…M), where the collecting waste area consists of the municipalities, where are cheaper costs (CTF_i + CTE_i) to the closest appropriate facility than ones to the closest landfill,
e) the sheet of main communication interface the IMWM, where the input economic variables together with the allocation of new facilities are set up with further options required for the model.

The implemented IMWM compares the costs for processing MSW for each municipality in the Czech Republic based on prices at the nearest treatment facilities and landfills ERP / MBT, even including shipping costs and carbon emission costs. If the cost of MSW treatment in the ERP / MBT facility is less than the cost of landfilling, it is assumed that the MSW from the municipality will be treated in an appropriate ERP / MBT facility. If costs are higher it is assumed that either the MSW disposed of in the nearest landfill.

Decisions makers of the MoE were able to use this IMWM to allocate subsidies from EU to investors of potential facilities to decline MSW from landfills to new facilities (ERP and MBT). They could choose inputs: *the list of K planned facilities* F_s (s = 1…K) (they are connected with their economic models); *their common payback; common value-added tax; chosen percentage of subsidy; charge of landfilling* and *landfill reclamation*. They obtained outputs of this model, where were *prices* p_s *of waste treatment* in planned *facilities* F_s, and calculated prices CT_i = (CTF_i + CTE_i) for all municipalities S_i, (i = 1…N) of the Czech Republic which will pay for the treatment of MSW.

We will illustrate the IMWM application to monitor total cost and pricing relationships in the waste management of the Czech Republic. We model:

- total planned EU subsidies to new allocated facilities (ERP and MBT),
- the quantity of MSW which is available for each facility in comparison with its planned capacity and
- *the financial burden per capita (minimum, average and maximum) of MSW treatment for the Czech Republic.*

The Table II shows the outputs of the model, i.e. prices (in CZK – Czech Crowns) of 1 ton of waste treatment at planned facility (ERP and MBT) of given capacity with respect to EU subsidies.

The table shows that amount of EU subsidy affect more facilities ERP prices of ton of waste treatment. It also shows that as the maximum EU subsidy for the ERP facility is 30% while the MBT facility is 50%. For the comparison of the facility price would be optimal to combine the amount of subsidy, e. g. 30% for the ERP and 40% for the MBT.

II: *Prices of 1 ton of waste treatment at facility and average financial burden per capita*

EU subsidy	ERP capacity per year			MBT capacity per year			burden per capita
	100 kt	150 kt	200 kt	50 kt	80 kt	100 kt	average
20%	1 624	1 471	1 285	1 861	1 758	1 717	888
30%	1 422	1 272	1 093	1 723	1 626	1 585	872
40%	1 202	1 073	901	1 536	1 446	1 404	848
50%	975	873	709	1 491	1 408	1 365	819

Source: authors

SUMMARY

The integrated waste management model of the Czech Republic is introduced in the paper. The model was implemented with using *MS Excel* as the combination of the tools GIS Network Analyser, sophisticated sub-model calculating MSW production and separation of its component at all municipalities and cost economic sub-models of all facilities including carbon emission.

It enables to optimise environmental impacts (landfilling and greenhouse emissions). Its application was used as the decision support tool of the MoE for optimizing EU subsidies to the planning allocation of new waste treatment facilities (ERP and MBT) with respect to expenses per capita of waste management of the Czech Republic.

The concept of the model is very general, and other additions and modifications of the model (e.g. addition of other relevant waste streams) will be performed for the future needs of its users. It can be used for modelling:

- the percentage of EU subsidy for various types of facility with respect to the total planned EU subsidies,

2 We have modelled capacity of potential facilities – 100 and 200 kt for ERP

- the fee for landfilling and incineration,
- the number and location of facilities with regard to the quantity of MSW which is available for each facility in comparison with its planned capacity,
- the MSW treatment financial burden per capita (minimum, average and maximum) etc.

REFERENCES

ArcMap 9.2, [online], quoted 30.04.2010, <http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=welcome, last access>.

BENEŠOVÁ, L., HNAŤUKOVÁ, P., ČERNÍK, B. and KOTOULOVÁ, Z., 2009: Municipal Waste – Environmental and Social Problems in Future. In: *The Twenty-Fourth International Conference on Solid Waste Technology and Management*, Philadelphia, PA, U.S.A. (15.–18. 3. 2009). [online], quoted 30.04.2010, <http://komunalniodpad.eu/index.php?str=konference, last access >.

BERGER, C., SAVARD, G., WISERE, A., 1999: EUGENE: An Optimisation Model for Integrated Regional Solid Waste Management Planning, *International Journal of Environment and Pollution*, 12(2/3), 280–307. ISSN 0957-4352.

FreeGeodataCZ, [online], quoted 30.04.2010, <http://grass.fsv.cvut.cz/wiki/index.php/FreeGeodataCZ, last access 30.04.2010>.

HAIGH, M. et al., 2006: *EPIC/CSR Integrated Waste Management Tool: Environmental Analysis Model*, Environment and Plastics Industry Council and CSR: Corporations Supporting Recycling, Version: Release 2.0.6.

HEJČ, M., HŘEBÍČEK, J., 2008: Primary Environmental Data Quality Model: Proposal of a Prototype of Model Concept. In: *Proceedings of the iEMSs Fourth Biennial Meeting: International Congress on Environmental Modelling and Software* (iEMSs 2008). Barcelona, Catalonia: International Environmental Modelling and Software Society (iEMSs), pages 83–90, ISBN 978-80-210-4333-6.

HEJČ, M., HORSÁK, Z., HŘEBÍČEK, J., 2008: Information Tools for Supporting Implementation of Integrated Waste Management System in the Framework of the Czech Republic. In: *EnviroInfo 2008*. Environmental Informatics and Industry Ecology. Aachen, Germany: Shaker Verlag, pages 637–640, ISBN 978-3-8322-7313-2.

HŘEBÍČEK, J. et al., 2009: *Integrated waste management system at regional level* (in Czech), Brno: Littera, ISBN 978-80-85763-54-6.

HŘEBÍČEK, J., SOUKOPOVÁ, J., 2010: Modelling Integrated Waste Management System of the Czech Republic. In: *14th WSEAS International Conference on Systems. Latest Trends on Systems.* Vol. II. USA: WSEAS Press, ISBN 978-960-474-214-1.

ISWM, [online], quoted 30.04.2010, http://isoh.cenia.cz/groupisoh/, last access 30.04.2010.

MCDOUGALL, F., WHITE P., FRANKE M., HINDLE P., 2009: *Integrated Solid Waste Management: Life Cycle Inventory:* 2nd Edition, Oxford, United Kingdom: Blackwell Science, ISBN 0-632-05889-7

RIS, Internet: http://www.risy.cz/index.php?pid=402&language=en, last access 30.04.2010.

RATHI, S., 2007: Optimisation model for integrated municipal solid waste management in Mumbai, India. *Environment and Development Economics,* 12(1), 105–121.

SOLANO, E., RANJITHAN, S. R., BARLAZ, M. A. and BRILL, E. D., 2002: Life-Cycle-based Solid Waste Management. In: Model Development. *Journal Environmental Engineering,* 128(10), 981–992.

SOUKOPOVÁ, J. et al., 2011: *Municipal environmental public expenditures and their efficiency* (in Czech), Brno: Littera, ISBN 978-80-85763-60-7.

SHMELEV, S. E., POWELL, J. R., 2006: Ecological-economic modelling for strategic regional waste management systems, *Ecological Economics*, 59 (1), 115–130.

VALACH, J., 2006: *Investment decisions and long-term financing* (in Czech), Praha: Ekopress.

WANG F. S., 2001: Deterministic and stochastic simulations for solid waste collection systems – A SWIM approach, *Environmental Modelling and Assessment*, 6(4), 249–260.

WMP, Waste Management Plan of the Czech Republic, Internet: http://www.mzp.cz/www/zamest.nsf/0/9948146215721cf0c1256e54004b698b?OpenDocument, last access 30.04.2010.

YEOMANS, J. S., 2006: Application of Simulation-Optimisation Methods in Environmental Policy Planning Under Uncertainty, *Environmental Informatics Archives*, 4, 167–185.

Address

Mgr. Ing. Jana Soukopová, Ph.D., Katedra veřejné ekonomie, Ekonomicko-správní fakulta, Masarykova univerzita, Lipová 41a, 602 00 Brno, Česká republika, prof. RNDr. Jiří Hřebíček, CSc., Institut biostatistiky a analýz, Kamenice 126/3, 625 00 Brno, e-mail: soukopova@econ.muni.cz, hrebicek@iba.muni.cz