Software provided waste management sustainability assessment

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***Abstract*— Principles of sustainable development are currently an integral part of any advanced way of thinking either in the development of society in general, the development of an economy or an engineering practice. The problem lies in the complexity of such a mindset. In order for a system to be sustainable it must be at least economically justified, not to have a negative impact on the environment and to be acceptable to the society. In addition, very often, it is necessary to consider the political consequences of certain phenomena, technological solutions, and other aspects. The development of software solutions that offer the possibility of including a lot of parameters (indicators) and their analysis are of crucial importance. This paper presents the principle of a software package application that provides the possibility of comparing the sustainability of certain methods of waste management on the territory of the local community. For this purpose three scenarios were taken into consideration: basic as usual, aerobic process and anaerobic process, together with the relevant pretreatment. For the assessment of their sustainability, economic, environmental and social indicators were taken into account. The procedure of multi-criteria analysis using the AHP method and pair-wise criteria, performed with the Expert Choice 11 software, was used. The results obtained by using the AHP method and a sensitivity analysis showed that, according to the selected indicators, it is possible to rank the scenarios and choose the best sustainable waste management scenario (the scenario which involves resource recovery through recycling inorganic waste and composting organic waste).**

I. Introduction

The problem of waste management is not new, but has become current with population growth, economic development and recognition of the negative effects of waste on the environment. In recent decades, research has been done in the field of waste management, from finding different waste management methods, and the utilization of energy from waste, to the election of the most optimal method of waste management for specific local requirements.

From the moment that sustainable development became current in different areas, the attention has been focused on sustainable waste management and the search for sustainable waste management scenarios. Different research was done [1-3] in order to determine a sustainable decision making model for waste management scenarios.

Sustainability has been appealed sometime as the revolution of the 21st century, having the environmentalism the precursor of this new wave of thinking. In the vast scientific literature on sustainability, a huge number of different definitions and interpretations of this concept have been proposed, so that it is really difficult to have an unique clear-cut understanding of it.

Several models of waste management were developed: models based on cost-benefit analysis, models based on life cycle analysis, and models based on the use of multi-criteria analysis [4]. Each of them has different approaches, benefits and limitations: for models based on the cost benefit analysis all criteria for assessing scenarios translate into a monetary measurement, for models based on life cycle assessment scenario the analysis is carried out on the basis of the analysis of environmental impact of all phases of a product that lead to the creation of waste, and for models based on the multi-criteria analysis the assessment and selection of scenarios is carried out on the basis of a number of selected, usually conflicting criteria.

There are different models used in research depending on the chosen criteria and criteria weight for the selection of optimal and sustainable waste management scenarios. In the case where economic criteria are the preferred choice, cost-benefit analysis is commonly used [5,6]. If environmental criteria are recognized as a priority, life cycle analysis is used [7,8].

When assessing the sustainability of waste management scenarios according to three types of sustainable development indicators (environmental, economic and social), the best results can be provided by multi-criteria analysis. "For a waste management system to be sustainable, it needs to be environmentally effective, economically affordable and socially acceptable" [4]. The benefit of multi-criteria analysis in assessing the sustainable scenario is that it allows the use of both qualitative and quantitative criteria (sustainable development indicators). It also allows for the participation of different groups of decision-makers even with opposing goals in defining indicators and decision-making.

In literature [9,10] there are a number of multi-criteria methods applied in the assessment of the sustainability of a waste management scenario. Depending on particular problems, AHP, ELECTRE or PROMETHEE methods are commonly used in literature [11-13].

In this paper the principle of a software package application that provides the possibility of comparing the sustainability of certain methods of waste management on the territory of the local community is presented. For this purpose three scenarios are taken in the consideration: business as usual, aerobic process and anaerobic digestion, both with relevant pretreatment. For assessment of its sustainability economic, environmental and social indicators were taken into account. The procedure of multi-criteria analysis using the AHP method and pair-wise criteria, performed with the Expert Choice 11 software was used.

II. The Analytic Hierarchy Process (AHP) and Expert Choice

The Analytic Hierarchy Process (AHP) is a multi-criteria decision making technique, quite often used to solve complex decision making problems in a variety of disciplines [13–15].

The AHP hierarchical structure allows decision makers to easily comprehend problems in terms of relevant criteria and sub-criteria. Additional criteria can be superimposed on the hierarchical structure. Furthermore, if necessary, it is possible to compare and prioritize criteria and sub-criteria in the AHP practice, and one can effectively compare optimal solutions based on this information.

The decision procedure using the Analytic Hierarchy Process (AHP) is made up of four steps:

“1) define the problem and determine the kind of knowledge sought.

2) structure the decision hierarchy according to the goal of the decision – in the following order: the objectives from a broad perspective, through the intermediate levels (criteria on which subsequent elements depend) up to the lowest level (which usually is a set of the alternatives).

3) construct a set of pair-wise comparison matrices. Each element of the matrix in the upper level is used to compare elements in the level immediately below.

4) use the priorities obtained from the comparisons to weigh the priorities in the neighboring level. Do this for every element. For each element in the level below add its weighed values and obtain its overall or global priority. Continue this process of weighing and adding until the final priorities of the alternatives in the bottom most level are obtained.” [16].

Expert Choice, the user-friendly supporting software, has certainly largely contributed to the success of the AHP method. It incorporates intuitive graphical user interfaces, automatic calculation of priorities and inconsistencies and several ways to process a sensitivity analysis [17].

A. *The adopted AHP model*

The most important step of these decision-making processes is a correct pair-wise comparison, whose quantification is the most crucial step in multi-criteria methods which use qualitative data. Pair-wise comparisons are quantified by using a scale. Such a scale is a one-to-one mapping between the set of discrete linguistic choices available to the decision maker and a discrete set of numbers which represent the importance, or weight, of the previous linguistic choices.

The pair-wise comparisons in the AHP are determined in line with the scale introduced by Saaty [16]. According to this scale, the available values for the pair-wise comparisons are: {9, 8, 7, 6, 5, 4, 3, 2, 1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9}.

Figure 1. shows the hierarchical structure considered in the selection of a sustainable scenario for waste treatment, based on selected indicators of sustainable development and Figure 2. shows the hierarchical structure presented in Expert Choice software.

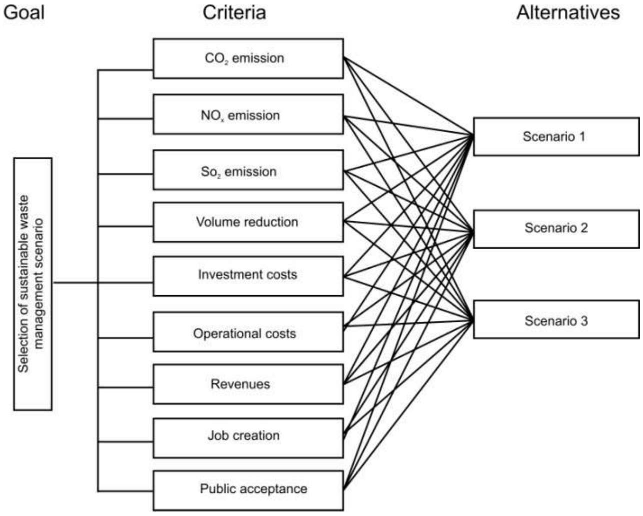

Figure 1. The hierarchical structure for selection and evaluation of a sustainable waste management scenario.

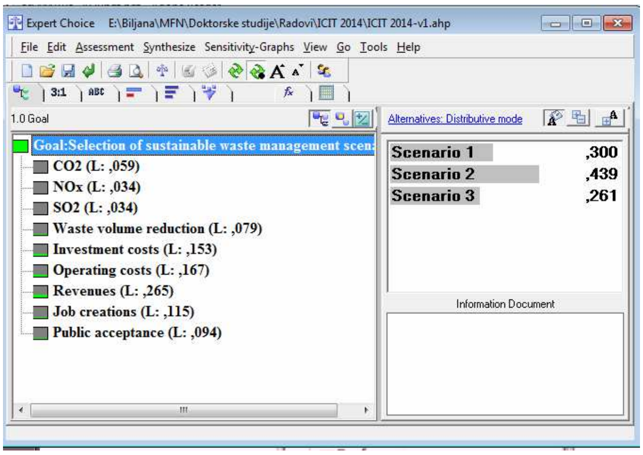

Figure 2. The hierarchical structure presented in Expert Choice software

III. Experimental Research

A. *Scenario*

The data on generated waste used in the considered scenarios were taken from the Waste Management Plan of the city of Niš in the period up to 2015 and other previously published papers [18].

In this paper, three scenarios were developed: business as usual, aerobic process and anaerobic digestion. Main variation factors (annual distance driven by trucks, fuel efficiency, energy consumption, energy efficiency) of each scenario are given in order to evaluate environmental indicators.

Scenario 1 – business as usual: Most of waste (68,440 t) is disposed to the landfill, only small amount of metal and glass (3560 t) is recycled. Annual distance driven by collection trucks is 118400 km. Trucks use diesel fuel, with fuel efficiency of 2.5 km/l. Energy consumed by landfill operation: diesel 0.22 l/t. Energy consumption at materials recovery facility: electricity 25 kWh/t, natural gas 0.264 m^3/t.

Scenario 2 – aerobic process: Inorganic waste (28,840 t) is recycled (plastic, glass, paper and metal). Organic waste (31,790 t) is sent to in-vessel composting plant. Other waste (11,464 t) is disposed of in the landfill. Annual distance driven by collection trucks is 112,596 km. Energy consumption in composting process: electricity 21 kWh/t.

Scenario 3 – anaerobic digestion: Recyclable waste – glass, metal and plastic (17,809 t) are recycled. Other waste (54,291 t) is sent to anaerobic digestion plant for the purpose of electricity generation. Annual distance driven by co-mingled trucks is 108150 km. Composition of biogas produced: $C0_2$ 45%, CH_4 55%. Energy efficiency in anaerobic digestion process: 20%. Facility energy consumption: 22% of energy produced.

B. Evaluation of indicators

Nine sustainable development indicators were selected in order to carry out the research (which will be used to rank the considered scenarios). Environmental indicators: GHG emissions (CO2 Equivalents), acid gases emissions (NOx and SO2), waste volume reduction. Economic indicators: investment costs, operational costs, revenues. Social indicators: job creation, public acceptance.

GHG and acid gases emissions: Amounts of carbon dioxide, nitrogen oxides and sulphur dioxide emitted to the atmosphere were estimated using the data from the previous paper [18] in which the amount of gas emissions is determined based on the composition of waste using the Integrated Waste Management Model [19]. In assessing the emissions, this model takes into account the emissions from the point at which a material is discarded into the waste stream to the point at which it is either converted into a useful material or finally disposed of. The model does not evaluate the energy and emissions associated with the production of infrastructure (e.g. collection vehicles, waste management facilities, etc). Emissions during transportation of waste, consumption of fossil fuels and electricity for the treatment of waste, and emissions during incineration were considered.

Waste volume reduction: The amount of waste that remains after treatment for landfill disposal, is also estimated by the Integrated Waste Management Model [19].

Investment and operational costs: Evaluation of investment and operational costs for the defined scenarios was performed on the basis of the data that are valid in the European Union for landfill, composting, anaerobic digestion and incineration [20,21]. For this purpose, the data for Germany were taken, shown in Table 4. Evaluation of investment and operational costs for recycling used the data from literature [22-24]. For evaluating the investment costs, land costs, the costs of design and construction of landfills, facilities and waste treatment facility, and the transportation vehicles costs were all taken into account. To evaluate the operational costs, maintenance costs, labor, energy costs and other operating costs were also taken into account.

Revenues: Evaluation of revenues was made on the basis of the data from literature [20] for waste treatment: composting (taking into account the market price of composting), incineration (taking into account the price of electricity produced) and anaerobic digestion (taking into account the price of electricity produced). Assessment of income from recycling was done on the basis of the market price of recycled materials (paper, metal, glass, compost), where the recovery rate taken into account was based on the data from literature [25].

Job creation: Evaluation of new jobs created was done on the basis of the data from literature [26,27], as shown in Table 5. The number of new jobs in waste management depends on waste treatment. Regardless of the different information that can be found in the literature related to the level of employment in terms of tonnes of waste per job, it can be concluded that for the more labor-intensive activities such as hand sorting and collecting waste, the level of employment is less than 500 tonnes of waste per job, while the less labor-intensive activities, such as dumping, incineration and composting, the level of employment is over 1000 tonnes of waste per job. The level of employment in the recycling is between these two extremes, depending on the type of materials that are recycled and recycling methods [28].

Table 1. shows the evaluation of indicators.

TABLE I. EVALUATION OF INDICATORS

	Scenario 1	Scenario 2	Scenario 3
GHG emission (CO_2 Equivalents) (kg/t)	701.48	-1184.35	-966.55
NOx emission (kg/t)	-0.035	-1.793	-1.550
SO_2 emission (kg/t)	-0.047	-2.422	-1.982
Volume reduction (%)	4.65	80.59	95.69
Investment costs (€/t)	8.90	16.70	24.40
Operational costs (€/t)	14,20	45.90	70,20
Revenues (€/t)	0,60	51,50	28,20
Job creation	368	450	488

Public acceptance: Public acceptance is a qualitative criterion which cannot be measured, therefore, 9 levels scale established in the AHP method [16] (1 - Worst, 9 - Best) was used for the assessment of this criterion.

IV. RESULTS AND DISCUSSION

After making hierarchal structure and evaluating of indicators, the procedure of multi-criteria analysis using the AHP method pair-wise criteria (compare the relative preference with respect to goal) was carried out, performed with the Expert Choice 11 software. Figure 3. shows comparison the relative preference with respect to goal.

Compare the relative preference with respect to: Goal:Selection of sustainable waste management scenario

	CO2	NOx	SO2	Waste volu	Investment	Operating	Revenues	Job creatio	Public acce
CO2		3,0	3,0	2,0	3,0	3,0	4,0	3,0	2,0
NOx			1,0	3,0	4,0	3,0	5,0	4,0	3,0
SO2				3,0	4,0	3,0	5,0	4,0	3,0
Waste volume reduction					2,0	3,0	4,0	2,0	1,0
Investment costs						1,0	2,0	1,0	3,0
Operating costs							2,0	2,0	3,0
Revenues								3,0	4,0
Job creations									2,0
Public acceptance	Incon: 0,04								

Figure 3. Comparison the relative preference with respect to goal.

Following the pair-wise criteria, the criteria weight with respect to the goal is obtained and shown in Figure 4.

Figure 4. Criteria weight

The normalized performance of scenarios against the criteria is presented in Table 2.

TABLE II. NORMALIZED PERFORMANCE OF SCENARIOS AGAINST THE CRITERIA (SUSTAINABLE DEVELOPMENT INDICATORS)

	Scenario 1	Scenario 2	Scenario 3
GHG emission (CO_2 Equivalents) (kg/t)	0,003	0,031	0,019
NOx emission (kg/t)	0,004	0,016	0,012
SO_2 emission (kg/t)	0,002	0,019	0,009
Volume reduction (%)	0,004	0,015	0,039
Investment costs (€/t)	0,07	0,042	0,028
Operational costs (€/t)	0,096	0,038	0,019
Revenues (€/t)	0,016	0,044	0,072
Job creation	0,008	0,039	0,022
Public acceptance	0,011	0,15	0,068

Following the procedure, software provides graphical representation scenarios ranking in different ways.

Figure 5. shows the ranking of scenarios after criteria (sustainable development indicators) weighting. According to the obtained results it can be concluded that the best ranking is Scenario 2, which includes recycling of waste (plastic, glass, paper and metal) and composting of organic waste. Scenario 1, which corresponds to business as usual scenario, ranked the last.

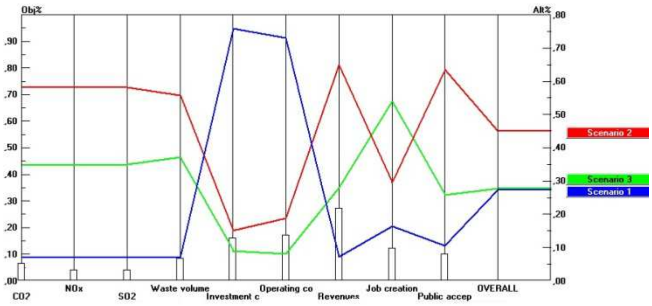

Figure 5. Scenario ranking for evaluated indicators weight – performance presentation

In order to carry out sensitivity analysis, software provides over dynamic representation and change the criteria weight, as shown in Figure 5. The last step of the decision process is the sensitivity analysis, where the input data are slightly modified in order to observe the impact on the results. If the ranking does not change, the results are said to be robust [17]. The sensitivity analysis is best performed with an interactive graphical interface. Expert Choice allows different sensitivity analyses, where the main difference is the various graphical representations as shown in Figure 6.

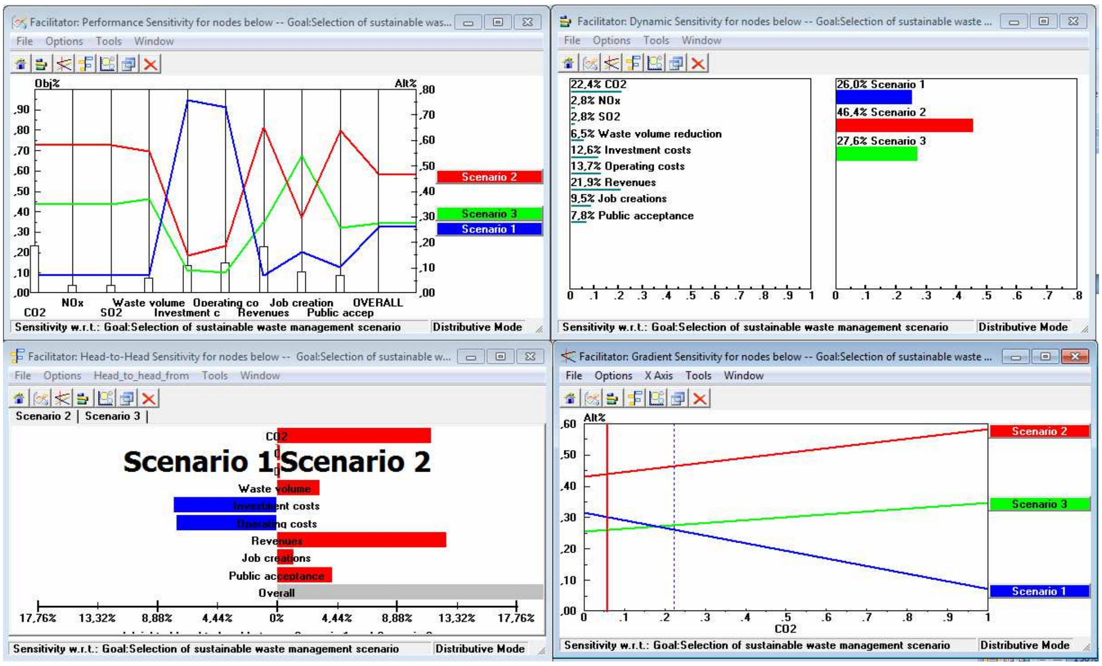

Figure 6. An example of four possible graphical sensitivity analyses in Expert Choice.

V. CONCLUSION

In this paper, the multi-criteria analysis AHP method is applied to assessing the sustainability of waste treatment scenarios. The selection of indicators of sustainable development was performed as a result of the recognized priorities in environmental, economic and social criteria.

Software Expert Choice based on AHP method is presented and used for forming hierarchical structure, pair-wise comparison, criteria and weighting scenario ranking according to the goal - selection of a sustainable waste management scenario.

The results obtained by using the Expert Choice software showed that, according to the selected indicators, the best sustainable waste management scenario is Scenario 2, recycling inorganic waste (plastic, glass, paper and metal) and composting organic waste (yard and food waste). The scenario which proved to be the least sustainable is Scenario 3 (combination of recycling inorganic waste parts and incineration of the remaining waste) due to high costs and negative public acceptance.

REFERENCES

[1] Wilson E.J., McDougall F.R., Willmore J., “Euro-trash: searching Europe for a more sustainable approach to waste management”, *Resources, Conservation and Recycling*, vol. 31, pp. 327–346, 2001.

[2] Costi P., Minciardia R., Robba M., Rovatti M., Sacile R., “An environmentally sustainable decision model for urban solid waste management”, *Waste Management*, vol. 24, pp. 277–295, 2004.

[3] Hung M.-L., Ma H.-W., Yang W.-F., “A novel sustainable decision making model for municipal solid waste management”, *Waste Management*, vol. 27, pp. 209–219, 2007.

[4] Morrissey A.J., Browne J., “Waste management models and their application to sustainable waste management”, *Waste Management*, vol. 24, pp. 297–308, 2004.

[5] Beguma R.A., Siwara C., Pereira J.J., Jaafar A.H., “A benefit–cost analysis on the economic feasibility of construction waste minimisation: The case of Malaysia”, *Resources, Conservation and Recycling*, vol. 48 (1), pp. 86–98, 2006.

[6] Jamasb T., Nepal R., “Issues and options in waste management: A social cost–benefit analysis of waste-to-energy in the UK”, *Resources, Conservation and Recycling*, vol. 54 (12), pp. 1341–1352, 2010.

[7] Den Boer J., Den Boer E., Jager J., “LCA-IWM: A decision support tool for sustainability assessment of waste management systems”, *Waste Management*, vol. 27, pp. 1032–1045, 2007.

[8] Ekvall T., Assefa G., Bjorklund A., Eriksson O., Finnveden G., “What life-cycle assessment does and does not do in assessments of waste management”, *Waste Management*, vol. 27, pp. 989–996, 2007.

[9] Chenga S., Chana C.W., Huangb G.H., “Using multiple criteria decision analysis for supporting decisions of solid waste management”, *Journal of Environmental Science and Health*; vol. 37 (6), pp. 975-990, 2002.

[10] Roussat N., Dujet C., Mehu J., “Choosing a sustainable demolition waste management strategy using multi-criteria decision analysis”, *Waste Management*, vol. 29, pp. 12–20, 2009.

[11] Karagiannidis A., Moussiopoulos N., “Application of ELECTRE III for the integrated management of municipal solid wastes in the Greater Athens Area”, *European Journal of Operational Research*, vol. 97, pp. 439-449, 1997.

[12] Karagiannidis A., Papageorgiou A., Perkoulidis G., Sanida G., Samaras P., “A multi-criteria assessment of scenarios on thermal processing of infectious hospital wastes: A case study for Central Macedonia”, *Waste Management*, vol.30, pp. 251–262, 2010.

[13] Herva M., Roca E., “Ranking municipal solid waste treatment alternatives based on ecological footprint and multi-criteria analysis”, *Ecological Indicators*, vol. 25, pp.77–84, 2013.

[14] Triantaphyllou E., Mann S. H., “Using the analytic hierarchy process for decision making in engineering applications: some challenges”. *International Journal of Industrial Engineering: Applications and Practice*, vol. 2 (1), pp. 35-44, 1995.

[15] Samah M.A.A., Manaf L.A. and Zukki N.I.M., “Application of AHP Model for Evaluation of Solid Waste Treatment Technology”, *International Journal Engineering Techniques*; vol. 1(1), pp. 35-40, 2010.

[16] Saaty, T.L., “Decision making with the analytic hierarchy process”, *International Journal Services Sciences*, vol.1 (1), pp. 83–98, 2008.

[17] Ishizaka A, Labib A. “Analytic hierarchy process and expert choice: benefits and limitations”. *ORInsight*, vol. 22, pp. 201-220, 2009.

[18] Stefanović G., Marković D., “Life cycle assessment of municipal solid waste management: case study of Nis, Serbia”, *The 24th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Systems*, pp 3930-3937, Novi Sad, Serbia 4-7 july 2011, ISBN 978-86-6055-015-8.

[19] Integrated Waste Model – Available at: </http://www.iwm-model.uwaterloo.ca/> [accessed 10.1.2013].

[20] Costs for Municipal Waste Management in the EU, Final Report to Directorate General Environment, European Commission – Available at: <http://ec.europa.eu/environment/waste/studies/eucostwaste_management.htm> [accessed 20.1.2013].

[21] Tsilemou K., Panagiotakopoulos D., “Approximate cost functions for solid waste treatment facilities”, *Waste Management & Research*, vol. 24, pp. 310–322, 2006.

[22] Cascadia, Recycling and Economic Development: A Review of Existing Literature on Job Creation, Capital Investment, and Tax Revenues, 2009 – Available at: <http://your.kingcounty.gov/solidwaste/linkup/documents/recycling-economic-development-review.pdf> [accessed 5.2.2013].

[23] The Costs of Recycling and Composting, Waste prevention, Recycling and Composting Option: Lessons from 30 US Communities – Available at: <http://www.epa.gov/osw/conserve/downloads/recy-com/chap08.pdf> [accessed 7.2.2013].

[24] <http://www.letsrecycle.com/prices/> [accessed 8.2.2013].

[25] U.S. Environmental Protection Agency – Available at: <http://www.epa.gov/epawaste/nonhaz/municipal/index.htm> [accessed 7.2.2013].

[26] Employment Effects of Waste Management Policies, Final Report – January 2001, Risk & Policy Analysts Limited – Available at: <http://ec.europa.eu/environment/enveco/waste/index.htm> [accessed 8.2.2013].

[27] Robin Murray, Creating wealth from waste, 1999 – Available at: <http://www.demos.co.uk/files/Creatingwealthfromwaste.pdf> [accessed 8.2.2013].

[28] Friends of the Earth, Report: More jobs, less waste, 2010 – Available at: <http://www.foe.co.uk/resource/reports/jobs_recycling.pdf> [accessed 8.2.2013].