CZASOPISMO TECHNICZNE Ch
WYDAWNICTWO POLITECHNIKI KRAKOWSKIEJ

z. 2-Ch/2008
ISSN 0011-4561
ISSN 1897-6298

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COSTS AND COST-EFFECTIVENESS OF WASTE RECYCLING

KOSZTY ORAZ EFEKTYWNOŚCI EKONOMICZNE RECYKLIGU

Abstract

Costs of recycling are difficult to assess and compare due to differences in the costs factor included in the assessments. For example, some recycling costs are not separated from the general costs of waste management, some schemes include the income from the sale of the recycled materials with the costs of collection, others do not; and some report the costs of collection only. In this paper, with the aid of the mathematical model, we consider the economic cost-effectiveness of recycling depending whether the recycling plant will pay for the provided waste or not. In the model, the unit price of the provided waste is represented by (p). It means that if the recycling plant pays for waste, then p will be $p > 0$. If the plant does not pay for the provided waste, p will equal $p = 0$, if the producer pays for the utilization of waste, then $p < 0$. Besides, in this model the emphasis is put on the economic conditions of the recycling plant containers. Those conditions will be discussed depending on: capital costs, ecological unit cost of the recycling plant, unit costs of the processing of recycling, the amount of work allocated for the production in fixed units, fixed costs, the amount of raw material/waste modified, etc. In the paper the costs of recycling and cost-effectiveness of MSW recycling were discussed in the case when the recycling plant paid for waste.

Keywords: costs, cost-effectiveness, waste, municipal, recycling

Streszczenie

Ze względu na różnice w czynnikach kosztów, koszty recyklingu są trudne do oszacowania i porównania. Przykładowo, niektóre koszty recyklingu nie są oddzielone od kosztów gospodarki odpadami. W niektórych przypadkach dochód ze sprzedaży recyklowanych materiałów oraz koszty zbiórki i regeneracji łączono ze sobą, a w niektórych nie. Za pomocą modelu matematycznego możemy rozważyć opłacalność ekonomiczną zakładu recyklingu, w przypadku gdy zakład zapłaci za dostarczone odpady albo nie. W rozpatrywanym modelu jednostkowe koszty za dostarczone odpady wynoszą (p). Oznacza to że, jeżeli zakład zapłaci za dostarczone odpady, wówczas $p > 0$. Natomiast jeżeli dostawca odpadów zapłaci za ich unieszkodliwienie, wtedy $p < 0$. W modelu rozpatrzono warunki ekonomiczne zakładu w zależności od: kosztów kapitałowych, kosztów ekologicznych, kosztów produkcji, ilości pracy, ilości produkowanego surowca wtórnego itp. W artykule przedstawiono koszty oraz efektywności ekonomiczne recyklingu, w przypadku gdy zakład zapłaci za dostarczone odpady.

Słowa kluczowe: koszty, efektywność ekonomiczna, odpady, recykling

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1. Introduction

Both the costs and economic cost-effectiveness of waste recycling depend on various costs. These costs include the costs borne by the waste supplier, namely: the costs of gaining waste, transporting it to segregation plants, and costs of segregation. On the other hand, recycling plants, which use waste as raw materials, bear the costs of waste processing and their clearance. In addition, we need to take into consideration those costs which are destined for amortization, equipment maintenance, waste storage and salaries.

Most studies on waste management and recycling technology have been done throughout the world to determine the economic and ecological profitability of waste management in the substitution of raw materials. Research has been done by such authors as Giuseppe Di Vita, A. Haque, et al., and Yunchang Jeffrey Bor, et al. [1, 3]. Few studies deal with cost-benefit analysis of waste recycling presented by the pioneer research in analyzing cost-benefit of recycling. Xavier Duran, et al. developed a model for assessing the economic viability of construction and demolition of waste recycling — the case of Ireland. The model developed in the research was based on the potential decisions that the waste producer and the aggregate user were facing. Once the model is developed and the underlying assumptions outlined and analysed, the paper then proceeds to assess the impact of the imposition of environmental taxes and the use of subsidies on the economics of Construction and Demolition Waste (C&DW) recycling. Conclusions were presented which suggested that economic viability is likely to occur when the cost of landfilling exceeds the cost of bringing the waste to the recycling centre and the cost of using primary aggregates exceeds the cost of using recycled aggregates [4].

Doron Lavee presented a study conducted in Israel in the years from 2000 to 2004. The economic analysis shows that if municipality efficiently adopts recycling, it can take advantage of anticipated reduction in the quantity of waste directed to landfills and thus reduce overall waste management costs by average 11%.

The results show that for most municipalities in Israel (51% of the municipalities), it would be efficient to adopt recycling and that the optimal amount of waste recycling in Israel is 27.7% (excluding organic waste) of all the municipal solid waste. The analysis reveals that recycling is very advantageous for the large municipalities (recycling is efficient in 87% of all such municipalities) and much less advantageous for the regional municipalities (recycling efficient in 25%) [5].

Other research on cost-benefits of recycling was presented by many authors. Vivian W.Y. Tam in his pioneering work studied the cost and benefit on the current practice in dumping the construction waste to landfills and producing new natural materials for new concrete production, and the proposed concrete recycling method to recycle the construction waste as aggregate for the new concrete production. With the advent of the cost on the current practice, it is found that the concrete recycling method can result in a huge sum of saving. The benefits gained from the concrete recycling method can balance the cost expended on the current practice. Therefore, recycling concrete waste for new production is a cost-effective method that also helps protecting the environment and achieves construction sustainability [6].

With the aid of the mathematical model, we consider the economical cost-effectiveness of recycling dependence whether the recycling plant will pay for the provided waste.

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2. Application of multiplicative and additive functions for cost-effectiveness maximization

The multiplicative and additive functions typical of the recycling plant are commonly used.

The multiplicative function has a form

$$f_2(x_1 \cdots x_n) = ax_1^{\alpha_1} ax_2^{\alpha_2} ax_3^{\alpha_3} \cdots ax_n^{\alpha_n} \tag{1}$$

where $a > 0$, $\alpha_i > 0$, for $i = 1, \ldots, n$, $\alpha_1 + \alpha_2 + \alpha_3 + \cdots \alpha_n = \alpha \langle 1$

The additive function has a form

$$f_3(x_1 \cdots x_n) = a_1 x_1^{\alpha} + a_2 x_2^{\alpha} + a_3 x_3^{\alpha} \cdots + ax_n^{\alpha} \tag{2}$$

where: $\alpha > 0$, $\alpha \in (0, 1)$

The aforementioned functions are both homogeneous of degree α and concave of many variables $x = (x_1, x_2, \ldots, x_n)$.

In the paper [7], the system of forming equation has been obtained

$$\frac{\partial f}{\partial x_i} = \frac{\alpha}{K} f(x_1, \ldots, x_n) \cdot q_i, \quad i = 1, \ldots, n \tag{3}$$

On the basis of the system of equation (3), we will examine the issue of cost-effectiveness maximization for multiplicative and additive functions.

2.1. Application of multiplicative function for cost-effectiveness maximization

Owing to the fact that $\frac{\partial f_2}{\partial x_i} = \left(ax_1^{\alpha 1} \ldots a_i x_i^{\alpha_i - 1} \ldots x_n^{\alpha_n}\right) = \frac{a\alpha_i}{x_i} f_2(x_1, x_2, \ldots, x_n)$, the system of equations (3) is as follows

$$\frac{\alpha_i}{x_i} f_2(x_1, x_2, \ldots, x_n) = \frac{\alpha}{K} f_2(x_1, x_2, \ldots, x_n) q_i, \; i = 1, 2, \ldots, n \tag{4}$$

Hence $x_i = \frac{\alpha_i K}{\alpha q_i}$, $i = 1, 2, \ldots, n$.

In order to achieve the maximal profit from the production, the distribution of the sum K on the particular means of production is displayed by the following vector $\bar{x}_2 = \frac{K}{\alpha}\left[\frac{\alpha_1}{q_1}, \frac{\alpha_2}{q_2}, \ldots, \frac{\alpha_n}{q_n}\right]$.

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Then, the maximal profit amounts to

$$Z_2(K) = pf_2(\bar{x}_2) - K = p\left(\frac{K}{\alpha}\right)^{\alpha} f_2\left(\frac{\alpha_1}{q_1}, \frac{\alpha_2}{q_2}, \ldots, \frac{\alpha_n}{q_n}\right) - K \tag{5}$$

Substituting $\frac{p}{\alpha^{\alpha}} f_2\left(\frac{\alpha_1}{q_1}, \frac{\alpha_2}{q_2}, \ldots, \frac{\alpha_n}{q_n}\right) = R_2$ we get $Z_2(K) = R_2 K^{\alpha} - K$. The production will bring the profit if $Z_1(K) > 0$. Therefore, we have the condition $K < R_2^{\frac{1}{1-\alpha}}$ given. We are going to investigate which values *K* have to be involved for the profit to be maximal.

We have $Z_2'(K) = \alpha R_2 K^{\alpha-1} - 1 = 0$. The course of the function is as follows:

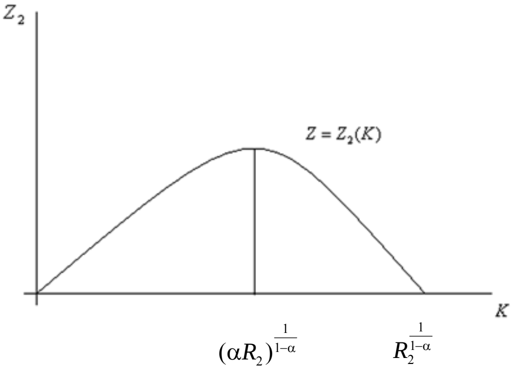

Fig. 1. The course of the profit function with regard to the invested capital *K*

Rys. 1. Przebieg funkcji zysku w zależności od zainwestowanego kapitału *K*

The production makes the profit if we invest the sum *K*, which is destined for the production. $K \in (0, (\alpha R_2)^{\frac{1}{1-\alpha}}\rangle$, the profit is the highest for $K = (\alpha R_2)^{\frac{1}{1-\alpha}}$.

2.2. Application of additive function for cost-effectiveness maximization

The issue of profit maximization for the additive production function (2) will be examined.

Considering the fact that $\frac{\partial f_3}{\partial x_i} = a_i \alpha x_i^{\alpha-1}$ the system of equations (3) is as follows:

$a,\alpha_i^{\alpha-1} = \frac{\alpha}{K} q_i f_3(x_1, x_2, \ldots, x_n),\ i = 1, 2, \ldots, n$. After rearranging, it has a form

$$\frac{a_i K}{q_i} = x_i^{1-\alpha} f_3(x)\ ,\ i = 1, 2, \ldots, n \tag{6}$$

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In order to solve the system of equations (3), certain modifications need to be applied. We raise both sides of the equation (6) to the power of $\frac{\alpha}{1-\alpha}$; hence, we get

$$\left(\frac{a_i K}{q_i}\right)^{\frac{\alpha}{1-\alpha}} = x_i^{\alpha}\left[f_3(x)^{\frac{\alpha}{1-\alpha}}\right],\ i = 1, 2, \ldots, n \tag{7}$$

We have to multiply the equations (7) by $a_{i,}$ respectively and then add the members of the equations up. Consequently, we get $K^{\frac{\alpha}{1-\alpha}}\sum_{i=1}^{n} a_i\left(\frac{a_1}{q_1}\right)^{\frac{\alpha}{1-\alpha}} = \left[f_3(x)^{\frac{\alpha}{1-\alpha}}\right]\sum_{i=1}^{n} a_i x_i^{\alpha}$.

Marking $\sum_{i=1}^{n} a_i\left(\frac{a_1}{q_1}\right)^{\frac{\alpha}{1-\alpha}} = U$ we get $K^{\frac{\alpha}{1-\alpha}}\,U = \left[f_3(x)^{\frac{\alpha}{1-\alpha}}\right]f_3(x)$. Therefore, $f_3(x) = K^{\alpha}\,U^{1-\alpha}$. Substituting (7) to (6) we have

$$x_i = \frac{K}{U}\left(\frac{a_1}{q_1}\right)^{\frac{1}{1-\alpha}},\ i = 1, 2, \ldots, n \tag{8}$$

Hence, the vector $\bar{x}_3 = \frac{K}{U}\left[\left(\frac{a_1}{q_1}\right)^{\frac{1}{1-\alpha}}, \left(\frac{a_2}{q_2}\right)^{\frac{1}{1-\alpha}}, \ldots, \left(\frac{a_n}{q_n}\right)^{\frac{1}{1-\alpha}}\right]$ presents the distribution of the sum K on the particular means of production. Then, the maximal profit amounts to $Z_3(K) = pf_3(\bar{x}_3) - K = p\left(\frac{K}{U}\right)^{\alpha} f_3\left[\left(\frac{a_1}{q_1}\right)^{\frac{1}{1-\alpha}}, \left(\frac{a_2}{q_2}\right)^{\frac{1}{1-\alpha}}, \ldots, \left(\frac{a_n}{q_n}\right)^{\frac{1}{1-\alpha}}\right] - K$.

Marking $\frac{p}{U^{\alpha}} f_3\left[\frac{K}{U}\left(\frac{a_1}{q_1}\right)^{\frac{1}{1-\alpha}}, \left(\frac{a_2}{q_2}\right)^{\frac{1}{1-\alpha}}, \ldots, \left(\frac{a_n}{q_n}\right)^{\frac{1}{1-\alpha}}\right] = R_3$ we obtain $Z_3(K) = R_3 K^{\alpha} - K$.

We obtain the same results for the multiplicative function. The production brings the profit for $K < R_3^{\frac{1}{1-\alpha}}$, $K \in (0, (\alpha R_3)^{\frac{1}{1-\alpha}}\rangle$. However, the profit is the highest for $K = (\alpha R_3)^{\frac{1}{1-\alpha}}$. For more details see Fig. 1.

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3. Summary

Any product has a possibility of turning into waste when it loses its economic value with the passing of time (Shinichiro Nakamura, 1999). Waste accumulates over time unless decomposed in the ecosystem or recycled. Today, the accumulation of waste has reached such magnitude that it can become a real threat to the existence of the whole ecosystem.

The excessive number of waste is a result of improper economy. Consequently, there is an increase in environmental contamination. Both human life and health, as well as destroyed landscape, are under threat. By and large, waste is landfilled. Only a small amount of waste is subjected either to recovery or to recycling. In Poland sufficiently good solutions which would permit complex planning, management and control of the elementary processes of recycling and neutralizing of waste in order to minimize the waste streams directed to landfills and diminution of environmental contamination have not been developed. The deficiency in such solutions impedes the work of groups of specialists in various fields at rational planning of recycling. The proposed mathematical model can help to analyse these processes.

Looking at the model we may deduce that if we invest the sum K for the production $K \in (0, (\alpha R_2)^{\frac{1}{1-\alpha}}\rangle$, the recycling plant will make the profit; nevertheless, the profit is the highest for $K = (\alpha R_2)^{\frac{1}{1-\alpha}}$.

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