Assessment of Environmental and Economic Effects of Environmental Investment as a Decisions Problem

RENATA MYŠKOVÁ[1], OBRŠÁLOVÁ ILONA[2], ČENČÍK PETR[3], ŠATERA KAREL[2]
[1]Institute of Business Economics and Management, [2]Institute of Administrative and Social Sciences,
[3]Institute of Mathematics and Quantitative Methods
Faculty of Economics and Administration
University of Pardubice
Studentská 95, 53210 Pardubice
CZECH REPUBLIC
renata.myskova@upce.cz; ilona.obrsalova@upce.cz; petr.cencik@upce.cz; karel.satera@upce.cz;
http://www.upce.cz

Abstract: This paper discusses the decision-making on environmental investments. The chosen case study is the waste water treatment plant with a focus on the reed bed sewage plant as a natural cleaning process. There are described different types of sewage treatment plants which can be included in the so called small sewage treatment plants category. Special attention is devoted to valuation of the reed bed sewage treatment plant (further RBSTP) and their environmental effects with regard to the concept of LCA. Features and functions of different sewage treatments are analysed and advantages and disadvantages of the RBSTP and their utilisation opportunities are discussed. Concepts of multicriteria decision methods are compared to the traditional methods of the economic efficiency evaluation.

Key-Words: efficiency, environmental investment, environmental and economic effects, conventional and reed bed sewage treatment plants, multi-criteria decision making, Life Cycle Assessment.

1 Introduction

The EU has paid a great attention to water quality. Businesses and municipalities are under particularly strong pressure of legislation. The basic legislation of the European Parliament and of the Council that constitute a framework for Community action in the field of water policy are the Directive 2000/60/ES of The European Parliament and of The Council of 23 October 2000 that establish a framework for Community action in the field of water policy, and the Council Directive 91/271/EEC of 21 May 1991 that addresses the urban waste-water treatment. Water protection, use and rights to them then in the Czech Republic is primarily regulated by the Act Nr. 254/2001 Coll., Water Act, as amended. In the Czech Republic there are hundreds of small communities that will not be able, due to economical reasons, dispose their wastewater in the first term – i.e. until the end of 2015. Implementation of wastewater treatment plants or other means of the wastewater disposal in small communities must be acceptable to people living in that locality, especially socially.

Environmental protection strategies have many different forms. Their use changes with time and conditions. It is difficult to ensure a clean production without any end-of pipe equipment. Therefore environmental investments in sewage treatment plants are very common. A separate environmental investment is an interesting problem of the decision-making process because the investment can have both effects - positive and negative and all of these effects cannot be, at the current level of knowledge, transferred to a cost-benefit analysis. For all of these reasons it is essential to use multi-criteria decision making methods.

1.1 Traditional Sewage Treatment Plants

Traditional sewage treatment plants are mechanical or mechanical-biological. The goal is to simulate, regulate and intensify the processes and procedures of self-cleaning that are normally found in natural water environment. This process is based on the principle of oxidation-reduction reactions. These reactions are divided into aerobic and anaerobic.

Treatment plants can be divided into small, middle and large based on the number of inhabitants. The size of the treatment plant determines what technology will be used for individual steps of the treatment process.

1.2 Alternative Sewage Treatment Plants, Reed Bed STP

Natural methods of wastewater treatment represent an alternative to the conventional approach. They form the first or the second biological level of wastewater treatment. These methods include soil filters, reed bed treatment plants, stabilisation tanks (especially all groups of biological tanks), aquacultures, bio eliminators, irrigation with wastewater and with liquid stabilised wastes.

These ways of treatment simulate self-cleaning processes which normally take place in soil, water and wetland environment.

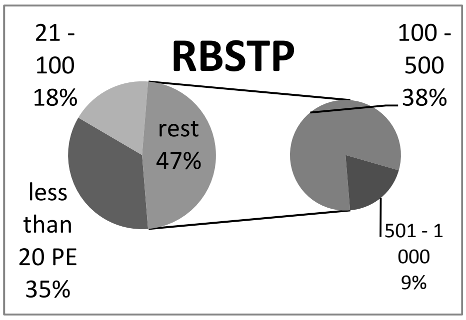
Vegetation takes a part in the cleaning process by creating favourable conditions for development of micro-organisms involved in the treatment process, utilisation and binding of vegetal nutrients, especially nitrogen and phosphorus, for creation of biomass, supplying oxygen to the root zone by macrophytes, producing oxygen by photosynthesis in biological tanks etc. [14, 16].

RBSTP have several variants like artificial wetlands with floating plants, artificial wetlands with submerged plants, and artificial wetlands with swamp plants.

Basically all RBSTP in the Czech Republic are proposed as plants with horizontal flow and mechanical pre-treatment.

The onset of RSTP was like in other countries slow, Currently it is built in the Czech Republic about 300 RBSTP, their size distribution is shown in Fig.1. The article deals with the categories into 50 PE.

Fig.1 RBSTP size distribution in the Czech Rep.



Source: [1, 14]

PE – Person Equivalent

The main *advantages* of reed bed sewage treatment plants are:

- Ecological (reed bed sewage treatment plants do not need electricity, clean water returns to Earth - the place where it was taken from, they create a new natural biotope in the garden or in surroundings of the municipality, they are quite, they prevent soil erosion.)
- Financial (higher investment but much lower operation cost when compared to conventional treatment plants, at least 2/3, an opportunity to get a funding from the EU, utilisation of by-products - weed, heat etc.).
- Aesthetic (reed bed treatment plants do not disturb the landscape; they provide habitant for wetland and moisture-loving plants).
- Other (minimum concrete constructions and use of technologies, root treatment plants are resistant to floods, can work discontinuously, they cope well with oscillation of sewage volume and quality, they require minimum regular maintenance, there is a lower risk of system breakdowns, they can be placed on otherwise hard-to-utilise land) [12,13].

Main *disadvantages* of reed bed sewage treatment plants may, according to some authors [1, 3, 4, 6, and 12], include:

- High land space requirements.
- Mechanical treatment can be managed and analysed more easily in case of problems (management software system) and corrective actions can be applied more easily.
- More ground works are needed.

- Decrease of treatment effect in non-vegetation (winter) period.
- Clogging the filter bed can lead to insufficient oxygen in the system, thus evolution of anaerobic processes, growth of sulphuric bacteria which, in combination with high-capacity septic tank, resolves in a negative odour effect.
- Inefficient elimination of nitrogen and phosphorus.

RBSPs efficiency depends on temperature, precipitation, humidity, latitude and altitude as well, which determine the length of the growing season. Also relevant are the local specificities such as population density, sewage network etc.

1.3 Comparison of Conventional and Reed Bed Sewage Treatment Plant

The data about reed bed treatment plants have been taken from [1, 3, 7, and 13], and the data on treatment efficiency of the mechanical-biological treatment plant have been taken from [1, 3, 4, and 12].

The available data can lead us to a conclusion that the treatment efficiency is sufficient all-year round. But the disadvantage of the reed bed treatment plant is that it has decreased treatment efficiency in the winter months.

Therefore it is generally recommended to build reed bed treatment plants especially at recreational objects and summer-house areas that are inhabited mostly in summer and where the small number of inhabitants does not cause high water pollution. Bigger agglomerations will have to cope with a problem how to find an area large enough for a reed bed treatment plant that would ensure sufficient treatment efficiency.

Conventional treatment plants do not require that much free space. Reed bed treatment plants are not further recommended for cleaning highly polluted industrial waters unless these had been previously sufficiently pre-cleaned.

Further, they are not recommended for places strongly polluted by one-type waste. Reed bed treatment plants also suffer from higher risk of leaking sewage into underground water (unless a thorough isolation of root field bed is done).

2 Evaluation of Sewage Treatment Plant

An example of recreational centre with capacity up to 50 PE was selected. The investor intends to purchase a sewage treatment plant. He can decide either for a septic tank, conventional type of treatment plant or, if he has enough land, alternative reed bed treatment plant.

To decide on the best option is necessary to evaluate the economic and environmental effects. It is possible to use e.g. a simple method of given criteria level and the progressive option selection based on beforehand set indicators and to find out which of these options are the most interesting. A suitable option has to respect valid legislative requirements.

The main problem lies in difficulties of monetization of environmental effects. We face the problem of not only referred inability of monetary evaluation, but also the definition of borders assessment. In the case of evaluation of environmental investments there are yet few studies devoted to the concept of LCA. In the contribution dedicated to this problem [16] authors give an inventory and assessment of the effects of both local and global. This method gives a more comprehensive view of the decision making process.

Effectiveness is a multidimensional concept that has different interpretations, and share inputs and outputs can be expressed in various ways according to a purpose. It can express the financial terms of financial efficiency and monitor whether and how long the activity can be sustainable in economic terms. This concept should be extended to other perspectives, not only economic.

2.1 Description of Evaluated Options

There are four basic options to be taken in consideration:

A. Septic Tank

Septic is an underground flow-through tank with several septa used for a partial cleaning of sewage with capacity up to 50 PE. Standalone septic is, due to its cleaning effects, suitable only as a component of a treatment mechanism, it should be accompanied by other levels of treatment. This set is a good solution for buildings which are not permanently inhabited, therefore also for recreational objects.

B. Mechanical - Biological Sewage Treatment Plant

Home sewage treatment plants (further HSTP) are intended for cleaning sewage from small sources of pollution which have no option of connecting to municipal canalisation. Treated water can be further utilized (e.g. for garden, lawn, greenhouse irrigation etc.).

B1 Mechanical - Biological Sewage Treatment Plant (another type) [2]

C. Reed Bed Sewage Treatment Plant

Reed bed treatment plant represents an alternative to conventional methods of sewage treatment. They are based on copying the self-treatment process when during gravitation flow through a suitably configured terrain and vegetation the culture of self-cleaning aerobic micro-organisms grows spontaneously.

The basic parameters were obtained for all available types of sewage treatment plants relevant for the capacity below 50 PE (total operating costs per annum, purchase costs and parameters of sewage treatment efficiency) [1, 3, 4, 7,13 and 14].

In order to complete the analysis it is also necessary to take into account the impact of individual options on the nature and environment as it has been described. The monetary expression is very limited. The verbal description and the evaluation on 5 -point scale (1 – the best, 2 – good, 3 – neutral, 4 – bad, 5 – the worst) has been used14 criteria were defined and were divided into 3 groups based on following:

I. Economic aspects

- total yearly operational cost (thousands CZK) – k_1
- purchase price (thousands CZK) – k_2

II. Aspects of sewage treatment efficiency

- parameter BOD_5 (%) – k_3
- parameter COD-Cr (%) – k_4
- parameter non-dissolved materials – NM (%) – k_5
- parameter ammoniac nitrogen – $N\text{-}NH_4$ (%) – k_6
- parameter phosphorus P–total (%) – k_7
- lifetime of sewage treatment plans (years) – k_{14}

III. Environmental aspects

- bad odour (RU) – k_8
- electricity need (RU) – k_9
- cleaning effect in winter (RU) – k_{10}
- positive side effects (RU) – k_{11}
- aesthetic aspect (RU) – k_{12}
- requirement on land occupation (RU) – k_{13}.

Where
RU is a relative unit for individual verbal numeric scale of particular criterion.

2.2 Valuation and Results

This contribution is focused on utilisation of multicriteria methods for investment evaluation and decisions. The MCDM (multi-criteria decision making) methods are used to solve problems with multiple attributes. There are variety techniques and models [5, 6, 8, 9 and 22].

One of the simplest methods is the method of specified criteria levels. This method belongs to a group of methods that approach modelling of criteria preference by aspiration levels, i.e. by determining the starting level of individual criteria that are acceptable for investors [13]. Others methods are based e.g. on a fuzzy approach [5, 6, 9].

In our case we have decided to use the TOPSIS (technique of order preference by similarity to ideal solution) which was introduced by Hwang and Yoon [6, 15].

In this method two alternatives are hypothesised – ideal and negative ideal. Based on the input criteria the TOPSIS selects the alternative that is the closest to the ideal solution and farthest from the negative ideal alternative [10]. The only subjective input needed is weights for criteria.

This method consists of several steps [15]:

1. Create a matrix based on priority scores $X = (x_{ij})_{n \times m}$, where x_{ij} is the score of the option i using the criterion j.

2. Normalize the scores:

$$r_{ij} = \frac{x_{ij}}{\left(\sum_{k=1}^{n} x_{kj}^2\right)^{0,5}};\ i = 1,....n;\ j = 1.....m. \quad (1)$$

3. Assign the weight w_j to the criterion j such that:

$$\sum_{j=1}^{m} w_j = 1 . \quad (2)$$

4. Multiply each column of the matrix by its associated weight:

$$v_{ij} = w_j r_{ij} \quad (3)$$

for $i = 1, \ldots, n; j = 1, \ldots, m$.

J is the set of benefit attributes or criteria (more is better),
J' is the set of negative attributes or criteria (less is better).

5. Determine the ideal solution $A^* = \{ v_1^*, \ldots, v_n^* \}$, where

$$v_j^* = \{\max_i (v_{ij}),\ j \in J; \min_i (v_{ij}),\ j \in J'\},$$

J is the set of benefit attributes or criteria (more is better),
J' is the set of negative attributes or criteria (less is better).

Determine the negative ideal solution (basal solution) $A' = \{ v_1', \ldots, v_n' \}$, where

$$v_j' = \{\min_i (v_{ij}),\ j \in J; \max_i (v_{ij}),\ j \in J'\},$$

6. Calculate the separation measures using the Euclidean distance:
For the separation from the ideal alternative:

$$S_i^* = \left[\sum_{j=1}^{m} (v_j^* - v_{ij})^2\right]^{1/2};\ i = 1,\ldots, n, \quad (4)$$

For the separation from the negative ideal alternative:

$$S_i' = \left[\sum_{j=1}^{m} (v_j' - v_{ij})^2\right]^{1/2};\ i = 1,....,n. \quad (5)$$

7. Calculate the relative closeness to the ideal solution R_i as follows:

$$R_i = S'_i / (S_i^* + S'_i),\qquad 0 < R_i < 1. \quad (6)$$

8. Select the option with Ri^* closest to 1.

In our case we have four alternatives – STP type A, B, B1, C, fourteen attributes/criteria k_1, k_2, $k_3 \ldots k_{14}$, from which k_1 and k_2 are the cost criteria (i.e. negative attributes), k_3-k_8 and k_{14} are performance parameters (i.e. benefit attributes), and k_9-k_{13} are the environmental parameters (i.e. negative attributes). For weights we have used two sets for comparison – equal weights (subjectivity is this way eliminated) and then weights in ratio 4:2:1 for cost criteria : performance parameters : environmental attributes. (To improve the reliability of the decision making process, a large team of experts can be used to determine the relevant attributes and their importance weights using a questionnaire about importance and ranking of all attributes, as in [15]).

Inputs, calculations and results are summarized in Tables 1 to 9. (Inputs were modified to obtain the decision matrix that had only benefit attributes [18]). – see the Table 2.

Table 1: Initial Decision Matrix

STP type	Criteria													
	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8	k_9	k_{10}	k_{11}	k_{12}	k_{13}	k_{14}
A	25	96.8	25	10	55	0	0	4	1	2	4	4	2	25
B	60	265	96	90	95	90	70	3	4	1	3	4	2	25
B1	50	180	97.2	93.6	97.1	99.4	80.2	3	3	1	3	4	2	25
C	10	700	86	76	85	34	40	3	1	4	1	2	5	50
Weight	a	a	b	b	b	b	b	b	c	c	c	c	c	b

Source: [2, 3, 4, 13, 14, 15, 18 and own valuation].

For equal weights is a=b=c= 0. 07143, for weights 4:2:1 is a= 0.1538; b= 0.07692; c= 0.0384.

Table 2: Modified Decision Matrix

STP type	Criteria													
	k_1^*	k_2^*	k_3	k_4	k_5	k_6	k_7	k_8	k_9^*	k_{10}^*	k_{11}^*	k_{12}^*	k_{13}^*	k_{14}
A	35	603.2	25	10	55	0	0	4	3	2	0	0	3	25
B	0	435	96	90	95	90	70	3	0	3	1	0	3	25
B1	10	520	97.2	93.6	97.1	99.4	80.2	3	1	3	1	0	3	25
C	50	0	86	76	85	34	40	3	3	0	3	2	0	50
Weight	a	a	b	b	b	b	b	b	c	c	c	c	c	b

*negative attributes were transformed to benefit attributes ($x_{ij}=x_{ij}$ - $\max_i(x_{ij})$, j=1,2,9,10,11,12,13)

Table 3: Normalized Scores

	Criteria													
STP type	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8	k_9	k_{10}	k_{11}	k_{12}	k_{13}	k_{14}
A	0.566	0.665	0.153	0.066	0.325	0.000	0.000	0.610	0.688	0.426	0.000	0.000	0.577	0.378
B	0.000	0.479	0.588	0.597	0.561	0.651	0.616	0.457	0.000	0.640	0.302	0.000	0.577	0.378
B1	0.162	0.573	0.595	0.621	0.573	0.719	0.705	0.457	0.229	0.640	0.302	0.000	0.577	0.378
C	0.808	0.000	0.526	0.504	0.502	0.246	0.352	0.457	0.688	0.000	0.905	1.000	0.000	0.756
Weight	a	a	b	b	b	b	b	b	c	c	c	c	c	b

Table 4: Normalized Scores Multiplied by Equal Weights and Ideal and Basal Solutions

	Criteria													
STP type	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8	k_9	k_{10}	k_{11}	k_{12}	k_{13}	k_{14}
A	0.040	0.047	0.011	0.005	0.023	0.000	0.000	0.044	0.049	0.030	0.000	0.000	0.041	0.027
B	0.000	0.034	0.042	0.043	0.040	0.046	0.044	0.033	0.000	0.046	0.022	0.000	0.041	0.027
B1	0.012	0.041	0.043	0.044	0.041	0.051	0.050	0.033	0.016	0.046	0.022	0.000	0.041	0.027
C	0.058	0.000	0.038	0.036	0.036	0.018	0.025	0.033	0.049	0.000	0.065	0.071	0.000	0.054
Weight	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071
Ideal	0.058	0.047	0.043	0.044	0.041	0.051	0.050	0.044	0.049	0.046	0.065	0.071	0.041	0.054
Basal	0.000	0.000	0.011	0.005	0.023	0.000	0.000	0.033	0.000	0.000	0.000	0.000	0.000	0.027

Table 5: Separation from Ideal and Negative Ideal - equal weights

STP type	Separation from ideal	Separation from negative ideal	Relative closeness to ideal solution (R_i)
A	0.1363	0.0951	0.4110
B	0.1175	0.1105	0.4846
B1	0.1051	0.1199	0.5328
C	0.0898	0.1362	0.6027

Table 6: Final ranking - equal weights

Ranking	STP type	R_i
1	C	0.6027
2	B1	0.5328
3	B	0.4846
4	A	0.4110

R_i - the relative closeness to the ideal solution

Table 7: Normalized Scores Multiplied by 4:2:1 Weights and Ideal and Basal Solutions

	Criteria													
STP type	**k_1**	**k_2**	**k_3**	**k_4**	**k_5**	**k_6**	**k_7**	**k_8**	**k_9**	**k_{10}**	**k_{11}**	**k_{12}**	**k_{13}**	**k_{14}**
A	0.087	0.102	0.012	0.005	0.025	0.000	0.000	0.047	0.026	0.016	0.000	0.000	0.022	0.029
B	0.000	0.074	0.045	0.046	0.043	0.050	0.047	0.035	0.000	0.025	0.012	0.000	0.022	0.029
B1	0.025	0.088	0.046	0.048	0.044	0.055	0.054	0.035	0.009	0.025	0.012	0.000	0.022	0.029
C	0.124	0.000	0.040	0.039	0.039	0.019	0.027	0.035	0.026	0.000	0.035	0.038	0.000	0.058
Weight	0.154	0.154	0.077	0.077	0.077	0.077	0.077	0.077	0.038	0.038	0.038	0.038	0.038	0.077
Ideal	0.124	0.102	0.046	0.048	0.044	0.055	0.054	0.047	0.026	0.025	0.035	0.038	0.022	0.058
Basal	0.000	0.000	0.012	0.005	0.025	0.000	0.000	0.035	0.000	0.000	0.000	0.000	0.000	0.029

Table 8: Separation from Ideal and Negative Ideal - weights 4:2:1

STP type	Separation from ideal	Separation from negative ideal	Relative closeness to ideal solution (R_i)
A	0.1197	0.1401	0.5392
B	0.1416	0.1205	0.4598
B1	0.1158	0.1380	0.5437
C	0.1178	0.1514	0.5623

Table 9: Final ranking - weights 4:2:1

Ranking	STP type	R_i
1	C	0.5623
2	B1	0.5437
3	A	0.5392
4	B	0.4598

R_i - the relative closeness to the ideal solution

3 Conclusion

The issue of efficiency evaluation of environmental investments has not been solved in a satisfactory way yet especially because of problems with the environmental impact valuation and its inclusion in a cost–benefit analysis. For the evaluation of the eco-efficiency it is necessary, in addition to the costs of the environmental protection, to express it as revenues and in this case as environmental benefits. This is a problematic part of the calculation and for this reason it is in many cases impossible to proceed with the evaluation of benefits in monetary units.

The list of criteria is open and it is possible to add e.g. social aspects. Some important criteria are missing due to lack of information about the problem.

Currently, there are a number of methods that can evaluate investment options in terms of purely economic parameters (e.g. Internal Rate of Return - IIR, Net Present Value, Return of Investment - ROI, Pay Back Method). Again, these methods do not provide consistent results for alternative decisions and they do not address the need for further analysis [11, 12, 13 and 19]. The purely economic evaluation would rate RBSTP unfavourably.

Enforcing a wider use of this treatment technology is complicated and opinions on the use and effectiveness are different. Multicriteria methods can reflect many aspects in the decision making process. The described method of evaluation can usefully complement various approaches to the decision making process, in this case economic and environmental.

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