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Economic Feasibility Study for Phosphorus Recovery Processes

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Abstract

Phosphorus recovery from wastewater has become a necessity for sustainable development because phosphorus is a non-renewable essential resource, and its discharge into the environment causes serious negative impacts. There are no economic incentives for the implementation of phosphorus recovery technologies because the selling price of rock phosphate is lower than phosphorus recovered from sewage. The methodologies used to determine the feasibility of such projects are usually focused on internal costs without considering environmental externalities. This article shows a methodology to assess the economic feasibility of wastewater phosphorus recovery projects that takes into account internal and external impacts. The shadow price of phosphorus is estimated using the directional distance function to measure the environmental benefits obtained by preventing the discharge of phosphorus into the environment. The economic

feasibility analysis taking into account the environmental benefits shows that the phosphorus recovery is viable not only from sustainable development but also from an economic point of view.

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Notes

1. $\text{SSP}_t = \overline{\text{SSP}}_t * \left(1 + d\right)^{-t}$ where: SSP_t = present selling price of recovered phosphorus; $\overline{\text{SSP}}_t$ = nominal selling price of recovered phosphorus; d = discount rate and t = year.

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Appendix

Given the directional vector $g = (1,1)$ and assuming $k = 1, \dots, K$ treatment plants operating in a period, the quadratic directional distance function for WWTP k is expressed as

$$\begin{aligned}
 & \text{\$\$} \begin{gathered} D_0(x_k, y_k, b_k; 1, 1) = \alpha + \\
 & \sum_{n=1}^N \alpha_n x_{nk} + \sum_{m=1}^M \beta_m y_{mk} + \sum_{j=1}^J \gamma_j b_{jk} + \\
 & \frac{1}{2} \sum_{n=1}^N \left(\sum_{\{n' = 1\}}^N \alpha_{n'} x_{nk} \right) \hfill + \frac{1}{2} \sum_{m=1}^M \left(\sum_{\{m' = 1\}}^M \beta_{m'} y_{mk} \right) \\
 & y_m y_{\{m' = 1\}} + \frac{1}{2} \sum_{j=1}^J \left(\sum_{\{j' = 1\}}^J \gamma_{j'} b_{jk} \right) b_{\{j' = 1\}} + \\
 & \sum_{n=1}^N \left(\sum_{\{n' = 1\}}^N \alpha_{n'} x_{nk} \right) \hfill + \sum_{m=1}^M \left(\sum_{\{m' = 1\}}^M \beta_{m'} y_{mk} \right) \\
 & y_m y_{\{m' = 1\}} + \frac{1}{2} \sum_{j=1}^J \left(\sum_{\{j' = 1\}}^J \gamma_{j'} b_{jk} \right) b_{\{j' = 1\}} + \\
 & \sum_{n=1}^N \left(\sum_{\{n' = 1\}}^N \alpha_{n'} x_{nk} \right) \hfill + \sum_{m=1}^M \left(\sum_{\{m' = 1\}}^M \beta_{m'} y_{mk} \right) \\
 & y_m y_{\{m' = 1\}} + \frac{1}{2} \sum_{j=1}^J \left(\sum_{\{j' = 1\}}^J \gamma_{j'} b_{jk} \right) b_{\{j' = 1\}} \end{gathered} \text{\$\$} \\
 & (8)
 \end{aligned}$$

Equation 8: Quadratic directional distance function.

$$\begin{aligned}
 & \text{\$\$} \begin{aligned} \text{Min} = \sum_{k=1}^K \left[D_0(x_k, y_k, b_k; 1, 1) - 0 \right] \quad & \& s.t. \quad t_i . i = 1, \\
 & D_0(x_k, y_k, b_k; 1, 1) \geq 0, \quad k = 1, \dots, K \quad & \& \dots, \\
 & \frac{\partial D_0}{\partial b_k}(x_k, y_k, b_k; 1, 1) = 0, \quad k = 1, \dots, K \end{aligned} \text{\$\$}
 \end{aligned}$$

$$\begin{aligned}
& ;1,1} \right) \} \} \{ \{ \partial b_{\{j\}} \} \} \geq 0, \forall j = 1, \dots, K \} \& \\
& (\{\text{iii}\}) \& , \frac{\partial D_0}{\left(x_k, y_k, b_k; 1, 1 \right)} \} \\
& \{ \{ \partial y_m \} \} \leq 0, \forall m^{\prime} = 1, \dots, M, \forall k = 1, \dots, K \} \& \\
& (\{\text{iv}\}) \{ \frac{\partial D_0}{\left(x_k, y_k, b_k; 1, 1 \right)} \} \\
& \{ \{ \partial x_n \} \} \geq 0, \forall n = 1, \dots, N, \& (\{\text{v}\}) \& \\
& \sum_{m=1}^M \beta_m - \sum_{j=1}^J \gamma_j = -1 \} ; \sum_{\{m^{\prime} = 1\}}^M \beta_{mm^{\prime}} \} - \\
& \sum_{j=1}^J \mu_{mj} = 0; \forall m = 1, \dots, M; \& \quad \\
& \sum_{\{j^{\prime} = 1\}}^J \gamma_{jj^{\prime}} = 1 \}^J \{ \gamma_{jj^{\prime}} \} \} - \\
& \sum_{m=1}^M \mu_{mj} = 0; \forall j = 1, \dots, J; \sum_{m=1}^M \delta_{nm} \} - \\
& \sum_{j=1}^J \eta_{nj} = 0; \forall n = 1, \dots, N; \& (\{\text{vi}\}) \& , \alpha_{nn^{\prime}} = \alpha_{n^{\prime}n} ; \\
& \beta_{mm^{\prime}} = \beta_{m^{\prime}m}; m \neq m^{\prime}, \gamma_{jj^{\prime}} = \gamma_{j^{\prime}j} ; \\
& \end{aligned}
\end{math>$$

(9)

Equation 9: Nonlinear program to minimize the sum of the distance between the production frontier and individual observations.

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