Methods for Evaluation of WWTPs Environmental Impacts: A Review

J Turková and J Korytárová

Institute of Structural Economics and Management, Faculty of Civil Engineering, Brno University of Technology, Veveří 331/95, 602 00 Brno, Czech Republic
turkova.j@fce.vutbr.cz

Abstract. Wastewater treatment processes are designed to achieve improvements in the quality of wastewater, however, it also brings both positive and negative environmental impacts (on ecosystem quality, on human health and on resource use). This issue raises many questions. Is it possible to assess these impacts? Which method is the most suitable for assessing the impact on the environment? This paper reviews articles dealing with a methodology for accessing environmental impacts of wastewater treatment plant (WWTP). Analysis of the published papers has indicated that the most frequently used evaluation tools is Life Cycle Assessment (LCA) or methods based on LCA, Cost-benefit Analysis (CBA) and Data Envelopment Analysis (DEA) in combination with other methods. These methods were described with their characteristics and weaknesses in evaluating. Selecting the appropriate assessment tool is the first step in the decision-making process. It is also necessary to take into account some key aspects: focus point, data that is required, obtained result as well as regulation and direction aspects. Based on extensive research and comparison of assessment methods, especially CBA method in the ex-ante evaluation and DEA method as a suitable supplement in the ex-post evaluation have been recommended for WWTP project evaluation by the authors.

1. Introduction

Authorities of the majority of the world countries adopted as a goal achieving sustainable development because of the emergence of global environmental issues and deepening of sustainable development trends [1]. Concept of sustainable development, where economy, environment, and well-being can no longer be separated, have many definitions [2]. One of the best-known definitions [3] is that adopted by the World Commission on Environment and Development in 1987 [4], “Sustainable development is development that meets the needs of present generation without compromising the ability of future generations to meet their own needs”. The key issue of sustainable development is utilization of water resources [5], representing one of the fundamental conditions of human life, as clean water supply and sanitation remain major problems in many parts of the world [6].

The United Nations Environment Programme (UNEP) [7], which develops international and national environmental instruments, claims that nowadays 450 million people in 29 countries suffer from water shortages. Consequences of this mean that approximately 2 million people die every year due to water-borne diseases as a result of the faecal pollution of surface water. However, water consumption has been constantly rising. According to the World Development Indicators, the total annual freshwater consumption was 3,906.74 billion cubic meters in 2013. The highest freshwater
consumption, for instance, was in India (761 billion m$^3$), in China (554.1 billion m$^3$) and in the United States (478.4 billion m$^3$).

The 2000/60/EC Directive of the European Parliament and of the Council declared that “Water is not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such”. In this context, wastewater treatment has become one of the most important environmental issues. The United Nations set global goals and targets for sustainable development and the political declaration on the post-2015 development Agenda, which comprises, among others, the aim to halve the point and nonpoint pollution, and untreated wastewater discharges into water sources, and to double recycling and safe reuse of wastewater by 2030 [7].

Each area of human activity has either positive or negative environmental impacts. This issue raises many questions. Is it possible to assess these impacts? Which method is the most suitable for assessing the impact on the environment? This paper focuses on methodology for assessing environmental impacts of wastewater treatment as this evaluation is often crucial when making decisions about the projects. A literature review was conducted using scientific search engines in journals indexed in recognized databases (e.g., Scopus). The reviewed studies were published during 2000–2018. The available methodologies were organized in thematic areas. Firstly WWTPs review of evaluation methodologies used for wastewater management was described. Secondly, Life Cycle Assessment (LCA) and Cost-benefit Analysis (CBA), two most frequently used methods, with their advantages and weaknesses were described. Finally, obtained data was analysed in Discussion and Conclusion chapters.

2. Methodology
Methodology is based on the following steps. Firstly the detailed analysis of WWTP environmental impact was carried out. Then, the most widely used assessment tools for evaluating environmental impacts of WWTPs were identified and analysed. Consequently key aspects of the investigated methods were presented and finally recommendations were formulated.

3. WWTP environmental impact
Sustainable development is based on three basic pillars: economy, society, and environment [8], this also applies in the field of wastewater treatment. However, each such project also brings environmental impacts with potential effects on ecosystem quality, on human health and resource use [9]. These changes affecting the environment can be either positive or negative [10]. Therefore, in recent years there is an effort to focus on examining the causes and consequences of these impacts [11]. Dixon et al. [12] state that for minimization the WWTP environmental impacts, it is necessary to pay attention to the design and to consider the whole life cycle of the system.

Drinking water supply systems were developed many centuries ago when people were storing and distributing water. Significant boom of this industry was recorded after the end of the World War II, especially in the United States and in the United Kingdom. Since 1950 water quality limits and standards for decision-making on sewage and wastewater treatment have been strictly monitored and followed. There are three levels of wastewater treatment: primary (mechanical), secondary (biological) and tertiary (phosphates and nitrates removal) [13]. All of these processes are responsible for reducing dissolved solids, pathogenic bacteria, nutrients and biodegradable organic materials. An essential purpose of wastewater treatment processes is to achieve improvements in the quality of water in natural water systems and to minimize the environmental impact [14] which is caused, for example, by energy consumption, sludge production or environmental emissions [15]. However, water purification is not the only function of WWTPs they are also beginning to be considered as a renewable resource from which water, materials, and energy can be recovered [16–17]. Utilization of sludge is very common, sludge is obtained during wastewater treatment and the goal is to prevent its adverse effects on the environment and human health. There are several options available for energy recovery from waste sludge as well [18].
Guide to Cost-benefit Analysis for Investment Projects is an important document for evaluating environmental impacts. The section focused on the water supply and sanitation describes main objectives that should be implemented in this area, such as improving water quality, increasing the efficiency and effectiveness of existing water supply services and wastewater treatment. The document (usually used for CBA methods) defines typical cost/benefit examples that may arise in the field of water management: improvement of drinking water quality, health impacts, cost savings on resources, etc. [19].

4. Review of evaluation methodologies

The main goal of this paper is to find and analyse the most widely used assessment tools for evaluating environmental impacts of WWTPs. In the following text, scientific articles from the 2000–2018 period are listed. All articles were gained by scientific search engines from journals indexed in recognized databases e.g., Science Direct or Scopus. The search was focused on fields of water management, namely the projects of wastewater treatment. The following key words were used: environmental impact of WWTP, environmental assessment, economic evaluation of WWTP, etc. Based on the review, the most frequently used methods were LCA which is one of the most accepted tools in the framework of sustainability [20] and other methods based on LCA, furthermore CBA, the most frequently used tool for evaluating economic efficiency of projects [21] and other methods or combination of different methods. More detailed analysis of the results is presented in the Discussion and Conclusion chapters. The impact assessment review papers were also examined. According to the article review, [22] 11,231 environmental papers were published in 2009 (in Web of Science) whereas only 807 in 1990. Growing interest in this issue is apparent.

The reviewed papers were focused either on the exploration of one method [2, 10, 22–26], on highlighting knowledge gaps among LCA, LCC (Life Cycle Costing) and CBA [27] or on the clarity provision in the combination of several methods for their most effective use [8, 28]. None of the articles contained comparison of methods for wastewater treatment plants from the general point of view.

4.1. Life Cycle Assessment (LCA)

Life cycle assessment (LCA) is a technique for assessing environmental aspects and potential impacts throughout a product life from raw material acquisition through production, use, and disposal of the waste generated [29]. It has been applied at wastewater treatment issues since 1990 [26]. It is regulated by ISO 14040: 2006, even though LCA was developed in the 1960s [23], the standardization process was initiated in 1990s [8, 23]. For applying the LCA method, it is necessary to set the definition of targets and scope (ISO 14040), then Life Cycle Inventory Analysis (LCI, ISO 14041), Life Cycle Impact Assessment (LCIA, ISO 14042) and finally the Life Cycle Assessment and Interpretation (LCAI, ISO 14043) of gained results [30].

Selected articles published in 2000–2018 period, focused on the LCA method, were examined in this paper. Authors or groups of authors from different parts of the country agree that this method is an effective tool for assessing environmental impacts but its application is really demanding on input data. Wide application of this method in wastewater management area is supported by numerous scientific articles. For instance there are papers on the evaluation of WWTP [9, 16, 31–34], on small-scale WWT [12, 35], on wastewater urban sludge [36], on urban wastewater systems [9, 14], and on metropolitan water systems planning [37]. Corominas et al. [23] published the critical review paper where they purposed the challenges for LCA applied to wastewater treatment. Nevertheless, application of LCA is still in progress [25]. Study results are always related to a functional unit which can be available, for instance specific quantities of population equivalent (p. e.) per year [38–40], or per day [9, 41], quantities of treated water in m³ per specific period [33, 42] or the removed nutrients [43].

A critical point in the application of LCA method seems to be the third step which is called Life cycle impact assessment (LCIA). This part aims at exploring the system impacts on the environment
of the product to help impact category [29, 44]. These impact indicators operate on two principles: midpoint indicator or endpoint indicator [45]. The impact (on the level of midpoint, endpoint or both) is evaluated by the specified methodology. From the reviewed studies, CML methodology was performed in 9 papers [14–15, 30, 39, 42–43, 46] and ReCiPe in 3 papers [9, 47–48]. Renou et al. [33] and Li et al. [49] applied more assessment methods (CML, ReCiPe, Eco Indicator 99 etc.) and others that were not specified.

Similarly to all assessment tools, also LCA has strengths and weaknesses. The results may be sometimes unexpected or difficult to anticipate. Finnveden et al. [29] describe many uncertainties in LCA which are related to data, variability, model etc. It implies that the input data requires a lot of high quality [12]; which means that data collection is time and labour consuming [50]. It is very difficult to quantify it, because of the impact on human health, biodiversity [8, 12], aesthetics [12], different stakeholders or geographic location [51]. On the other hand, LCA is a powerful set of tools [1] which gives a more accurate [50] picture of the true environmental trade-offs in technology or process selection [20]. Resulting from the review of scientific literature, the method should be combined with other tools, for instance, PSO-LCA method [51], LCA with DEA [52], Net Environmental Benefit (NEB) [53], and LCC [54] or with Dynamic Modelling (DM) [16].

4.2. Cost-benefit Analysis (CBA)

Cost-benefit analysis is known as the most widely used tool for evaluating the economic efficiency of projects, a number of authors agree on this claim [21, 55–57]. Among others, this method is also used to quantify the losses on human health and the environmental damage and it identifies the most efficient way to reduce those [58–60]. CBA includes financial analysis for predicting the development of all real financial flows of the project in the future and to establish the viability of the project and return on investment [61]. The second part of the method is an economic analysis which assesses the contribution of the project to the general economic wealth of the region or state. According to [19], typical benefits/cost in the part of the economic analysis for water supply and sanitation are: improved quality of drinking water or improved reliability of water sources, health impacts, increased availability of drinking water etc. It is also a recommended evaluation method for listed impacts. This article also presents research articles which dealt either with CBA or with part of this method: Contingent valuation method (CVM), Total economic value (TEV) or Distance function (DF). The innovative software for WWTP design - Environmental Decision Support System (NOVEDAR_EDSS) was used in one of them [10]. Some authors search for other possible alternatives of using the CBA for instance Carolus et al. [62] introduced alternative “bottom-up” approach which is based on a search into an environmental problem.

Wastewater treatment process brings associated environmental benefits and costs that are not often quantified [63]. These monetary evaluations of unpriced environmental impacts are a very important feature of CBA [59]. Layard and Glaister [64] state that for market values of social costs and benefits, shadow prices are used in the CBA. They concern unpriced goods that would be achieved in a perfectly competitive market. A Contingent Valuation Method (CVM), Total economic value (TEV) or Distance function (DF). The paper published by Molinos-Senante et al. [57] presents Environmental Decision Support System (EDSS) which was developed under the NOVEDAR program. This new innovative software for WWTP design was applied at nine different technologies with the target to evaluate the environmental, economic and social issue, specifically through CBA. Arroyo and Molinos-Senante [60] also used the CBA approach for selecting the most-appropriate WWT technology which is, from their point of view, transparent.
The framework of CBA is explicitly required for major projects where the cost exceeds EUR 50 million [19]. The main strength of this method is monetizing the costs and benefits, which can help project managers with decisions-making process. The disadvantages are hidden in the uncertainty of the calculation of environmental and social costs [50]. Quantification of the internal costs of wastewater treatment process is usually straightforward. According to Molinos-Senate et al. [10, 57, 72] and Hernández-Sancho et al. [63] the costs are associated with treatment process and established in €/year (energy, staff, maintenance, reagents and waste management). Garcia & Pargament [74] also calculate with investment costs. The income from the sale of water is considered as an internal benefit [75]. However, many authors focusing on CVM or distance function method dealt just with a valuation of non-market environmental benefits. External costs and benefits are measured in monetary terms through the concept of individuals willing to pay, based on a survey [65, 68]. For complete analysis, it is necessary to use evaluation of various indicators, for instance, Net Present Value, (NPV), Benefit–Cost Ratio (BCR), [71] or Internal Rate of Return (IRR) [74, 76].

4.3. Other methods
A total of 11 research articles were focused on the different methodology or on the combinations with LCA. As discussed above, LCA and CBA are the most used evaluation tools for wastewater management. Nevertheless, literature knows also other evaluation tools, for instance, Data Envelopment Analysis (DEA), a nonparametric method which is based on a linear programming [77–78]. It measures the comparative productive efficiency of multiple similar units [79]. The main goal of this methodology is to decrease the input per unit output. This can lead to improved eco-efficiency [79]; therefore DEA seems to be a very useful tool which contributes to the environment field [80]. Sala-Garrido et al. [20] present the first techno-economic efficiency comparison through the metafrontier model of different wastewater treatment technologies. The calculation with multi-input or multi-output application in many industries [81] and grouping of indicators into a single performance index [20] are the main advantages of DEA.

Additional studies also analyzed a combination of LCA with other methods. Lorenzo-Toja et al. [52] connect DEA with LCA for 113 WWTPs in Spain and the obtained result showed a poorer environmental profile for large WWTPs than for small and medium WWTPs. On the other hand, Godin et al. [53] introduce a new concept for LCA which is called Net Environmental Benefit (NEB). This concept illustrates comparison between a zero option and a wastewater treatment option through LCA. D’Inverno et al. [78] compared non-radial (as in DEA) and AHP-non-radial models, where efficient units were the same, but resulting environmental indices were different.

5. Discussion
Evaluation tools presented in this paper provide a review of the methods used for assessing environmental impacts of WWTPs. The following Table 1 shows a summary of the most widely used methods: LCA, CBA, and DEA. Selecting an appropriate method is not always easy. There are some key aspects that have to be taken into account during decision-making process. The focus point; LCA aims, for instance, at minimizing the environmental impact, whereas CBA presents socio-economic impacts. DEA is focused on economic efficiency and it is not used directly for evaluation of environmental impact but rather in combination with other methods. Data that is required; input data as the cost of energy, staff, maintenance, waste management etc. is needed for CBA or DEA methods, the desirable output is water being treated and undesirable data for the CBA method relates to removing pollutants from wastewater.

LCA method is based on assessing environmental aspects and potential impacts of product, service or process from cradle-to-grave perspective [23]. All processes and operations involved in the different phases of the product lifecycle form one unit (the product system) which contains many inputs (materials, energy) and outputs (substances which are incorporated into the environment during its production, consumption, and disposal). As the obtained result, for example, CBA comprises the calculation of socio-economic efficiency through the criterion indicators (NPV, IRR, etc.); LCA
brings the set of positive or negative environmental impacts and their interpretation. Regulation and direction aspects, according to the article no. 40 in the Council Regulation (EC) no. 1083/2006 is also required by a cost-benefit analysis for decision-making process about the co-financing of major projects (where the total eligible cost exceeds EUR 50 million) [19]. LCA is regulated by the ISO 1400 and DEA has no legal framework.

Table 1. Key aspects of the most widely used assessment methods.

| LCA | CBA | DEA |
|-----|-----|-----|
| **Purpose** | Minimize the environmental impact | Maximize the utility for the society | Measure productive efficiency of decision-making units |
| **Time scope** | Depends on time horizons of impact categories | The project’s time horizon | Time factor is not included |
| **Territorial scope** | Global | Usually national (broader if there are international or other reasons) | Related just to function units |
| **Focus** | Environmental impact | Socio-economic impact | Economic efficiency |
| **Required data** | Input: material, energy. Output: substances incorporated into the environment during its production, consumption, and disposal. | Input: Energy, staff, maintenance, waste management etc. Desirable output: treated water. Undesirable output: pollutants | Input: energy, staff, maintenance, waste management etc. Output: pollutants |
| **Principle** | Assessing the environmental aspects and potential impacts throughout a product life from raw material acquisition through production, use, and disposal of the waste generated. | Evaluating the costs and benefits to the human well-being of a project with the same monetary units. Future cash flows are discounted to their present value and subsequently included in the calculation of criterion indicators. | Linear programming based on comparing the efficiency of a set of units in need of inputs and production of outputs. Determines the production frontier. |
| **Result** | Set of environmental impacts | Socio-economic efficiency determined through the criterion indicators (NPV, IRR, etc.) | Effectiveness in a percentage of each reporting unit |
| **Sensitivity analysis** | Obligatory | Recommended | Not performed |

6. Conclusion and recommendation

Protection of nature and natural resources currently represents issues concerning all states worldwide. As a consequence of this interest, a wide range of methods for evaluating the environmental impact have been developed. These include not only LCA and CBA (discussed above), but also the Strategic Environmental Assessment (SEA), Environmental Impact Assessment (EIA), Environmental Risk Assessment (ERA), Material Flow Analysis (MFA) and the Ecological Footprint, etc. The review shows that methods that are not traditionally used for socio-economic impact assessment, such as DEA, can be successfully applied to wastewater treatment projects as well. Despite weaknesses or
difficult application of these methodologies, economic and social assessment is necessary for preservation of the goals of sustainable development. Worldwide interest in this issue is supported by numerous scientific articles and by the regulations of the majority of states. Based on extensive research and comparison of assessment methods, especially CBA method for investment decisions and DEA method to be used as a suitable supplement in the ex-post evaluation have been recommended for WWTP projects.

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