Decision making tools for selecting sustainable wastewater treatment technologies in Thailand

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Abstract. Wastewater consists of valuable resources that could be recovered or reused. Still it is under threat because of ineffective wastewater management and systems. In Thailand, less than 25% of wastewater generated may be treated while the rest is inadequately treated and sent back directly into waterbodies or the environment. Furthermore, the technologies that have been applied may be inefficient and unsustainable. Efficiency, sustainability, and simplicity are important concepts when designing an appropriate wastewater treatment system in developing countries. The objectives of this study were to review and evaluate wastewater treatment technologies and propose a method to improve or select an appropriate technology. An expert system in Excel® program was developed to determine the best solution. Sensitivity analysis was applied to compare and assess uncertainty factors. Due to the different conditions of each area, the key factor of interest was varied. Furthermore, Robust Decision Making tool was applied to determine the best way to improve existing wastewater treatment facility and to choose the most appropriate wastewater treatment technology.

1. Introduction
Wastewater is one of today’s most important environmental issues that causes severe problems to humans, animals, and the environment by improper management and technologies. Wastewater is a combination of domestic, commercial, industrial, and agricultural discharge. It contains pollutants and contaminants, including nutrients, microorganisms, chemicals and other toxins. These pollutants can cause health and environmental problems when wastewater is released into body rivers improperly [1]. However, wastewater also contains reusable resources such as water, carbon and nutrients that could be recovered or reused [2]. Therefore, wastewater should be appropriately treated for removal of pollutants to meet the effluent regulatory standards. Moreover, the processes should focus on resource recovery to minimize carbon footprint, and to be self-sustainable [3].

1.1. Objectives
Since wastewater issue is critical, many engineers and scientists have been developing new technologies to investigate an efficient system to solve this problem. Basic wastewater treatment systems reduce organic compounds and suspended solids to meet the effluent permit standards [4]. The advancement of technology has developed treatment processes, which can remove dissolved organic matter and toxic substances. At present, an improvement of scientific knowledge and consciousness about the environment led to new technologies and systems, which can reduce pollutions in wastewater and recycle energy with the goal of zero discharge of pollutants [5].
However, developing countries still have problems with wastewater treatment systems because of insufficient regulations, improper management, economic situation, and selecting unsuitable technologies. Thus, the primary objective of this research paper was to determine appropriate wastewater technologies to be used in Thailand. In addition, it also suggested new methods and sustainable practices that can be used long-term to improve the overall wastewater treatment systems in the country.

1.2. Research scope
The scope of this study was to select an appropriate wastewater treatment technologies by using different methods as depicted in Figure 1. First step is to evaluate the existing wastewater facilities in Thailand by focusing on three important criteria, performance, cost, and sustainability. Performance includes two important factors, reliability and simplicity. Cost includes an initial cost and operation and maintenance costs. Resource recovery, energy management, and solid volume reduction are three main concepts of sustainability. After considering these three main factors, the study will analyse sustainable alternative wastewater technologies and develop an expert system to select the most suitable wastewater process.

![Figure 1. Research scope](image)

2. Thailand wastewater treatment systems
There are several types of wastewater treatment systems in Thailand. The most common system is stabilization pond, which is commonly used in rural areas. Aerated lagoon and oxidation ditch, which are one type of activated sludge processes are also common processes used in Thailand’s rural areas [6]. In urban areas, such as Bangkok, Pattaya, the typical system is the activated sludge process. There are other processes such as constructed wetland, rotating biological contactor (RBC), fixed film activated sludge, sequencing batch reactor (SBR) and, modified sequencing batch reactor (MSBR). Figure 2 shows the fraction of the amount of wastewater treatment systems in Thailand.
Figure 2. The percentage of the amount of wastewater treatment systems. OD: Oxidation ditch; AL: Aerated lagoon; SP: Stabilization pond; CW: Constructed wetland; AS: Activated sludge.

3. Case studies in Thailand
In this section, some examples of wastewater treatment systems in Thailand are reviewed by choosing different types of technologies and compared the efficiency and cost of the systems. Table 1 shows five different types of wastewater treatment commonly used in Thailand, which are stabilization pond, sequencing batch reactor, aerated lagoon, oxidation ditch, and activated sludge. This table provides the capacity of the plants, the actual inflow to the plant, the construction cost, the operation and maintenance costs, and BOD and SS removal ratio.

Table 1. The efficiency of examples of wastewater treatments in Thailand

| Province    | Type of treatment    | Design Capacity (m³/d) | Inflow (m³/d) | Costs (million baht) | BOD (mg/L) | Removal Ratio (%) | SS (mg/L) | Removal Ratio (%) |
|-------------|----------------------|------------------------|--------------|---------------------|------------|-------------------|-----------|------------------|
| Subdistrict | Stabilization pond   | 8400                   | 11413        | 227                 | 4.8        | 4.4               | 8.33      | 220              |
| Lamphun     | SBR                  | 10900                  | 4599         | 583                 | 6.96       | 3197              | 21.65     | 46.9             |
| Ang Thong   | Aerated lagoon       | 8200                   | 1000         | 183                 | 6.95       | 5977              | 19.23     | 47.8             |
| Lam Phang   | OD                   | 25000                  | 1651         | 194                 | 6.48       | 1238              | 14.94     | 52.1             |
| Si Phraya   | AS                   | 30,000                 | 18,211       | 464                 | 10.64      | 56                | 90.5      | 189              |

4. Alternative sustainable wastewater treatment systems
The study focuses on resource recovery from wastewater sector including water reuse, energy recovery, and nutrient recovery. The future goal for wastewater treatment of domestic wastewater should have a minimal carbon footprint, and be 100% self-sustainable with regards to energy, carbon, and nutrients, while achieving a discharge or reuse quality that preserves the quality of the receiving waters [7]. The goal of sustainable wastewater processes should be changed into recycling treatment to promote the conservation of water resources. This following section provides many case studies on alternative sustainable wastewater technologies, which are very useful to apply to this research.

4.1. Case studies

4.1.1 Technology roadmap for sustainable wastewater treatment plants in a carbon-constrained world.
‘Resources end up in wastewater through inefficient consumption. As a result, wastewater contains potentially reusable water, carbon (energy), and nutrients (nitrogen, phosphorus, and sulfur) that could be recovered. Meanwhile, current wastewater treatment objectives are primarily to produce an acceptable quality of treated water at the lowest life cycle cost (LCC). Most current treatment processes manage carbon and nutrients as wastes to be removed, and do not attempt to capitalize on the resources inherent in wastewater’ [7]. The future goal for wastewater treatment of domestic
wastewater should be to have a minimal carbon footprint, and to be 100% self-sustainable with regards to energy, carbon, and nutrients, while achieving a discharge or reuse quality that preserves the quality of the receiving waters [7].

According from the article, the author presents treatment processes and pathway to improve wastewater technology.

Treatment process category are:
• Further reliance on biotechnology
• Optimization of carbon to energy within liquid and solids treatment processes
• Fixed film processes
• Nutrient recovery processes for nitrogen (N), phosphorus (P), and sulfur (S)
• Enhanced primary treatment for increased carbon diversion to solids processing
• Membrane equipment and process improvements to allow broader application
• Microconstituents/micropollutants – fate and effects research
• Develop and use new thermal sludge processes (pyrolysis and gasification)
• Control or capture air and GHG emissions

Equipment category are:
• Heat recovery from sidestreams and plant effluent
• Better aeration systems

Other category is:
• Better disinfection processes and equipment

Technology Pathways are to:
• Define whole plant treatment concepts that are energy neutral, including multi-sludge systems and sidestream treatment processes;
• Extract nutrients in forms that are amenable for agricultural reuse with minimal perception of risk to public health;
• Improve the use of biogas to produce energy;
• Identify and develop those emerging biosolids-to-energy technologies that show the greatest promise so that utilities can cost-effectively use them; and
• Explore new concepts that extract energy from wastewater, such as microbial fuel cells, or that produce or use other energy byproducts from wastewater such as hydrogen or nitrous oxide.

4.1.2. Sustainable wastewater management in developing countries

The authors presented reflections and stories about appropriate and sustainable wastewater management systems in developing countries. They also provided case studies and the implications and application. The objectives were to reflect on, discuss, and provide examples a broader use of robust, reliable, cost-effective, and efficient wastewater management systems that work in practice [8]. Basic concepts from this book were summarized below.

The authors described the sustainable ecosystem approach as follows:
1. Not about large-scale, centralized wastewater management but about appropriate, sustainable on-site systems.
2. Focus on on-site systems but improve linkages to cluster and centralized systems.
3. Not about discharge point, but about land-based wastewater management systems.

Local context lessons were as follows:
1. Local objectives, not (environmental) standards
2. Success and failure constantly interchange, producing a rather difficult context for predictions and lessons learned
3. Tales from the field as starting points for reflections
4. Cases of sense and simplicity – the ultimate way forward

5. Methodology

5.1. Robust Decision Making (RDM)
Robust Decision Making (RDM) is the adaptive or flexible decision method that can be used in the uncertain conditions [9]. Since future is uncertain and unpredictable, robust options tend to be more recommended than optimal options. On the other hand, the best option is more suitable when the future can be predicted. The purpose of RDM is to identify robust strategies, which can adapt or perform well under uncertain situations in the future. The method is helpful for decision makers in long-term consequences. The fundamental steps for Robust Decision Making are to: (1) identify the issues and set a goal; (2) select a robust strategy through investigating information, strategies, and risks; (3) take an active action towards the goals; (4) determine whether the strategy is effective; and (5) update and resolve the strategy. The last step is an essential one because if the strategy is not effective, decision makers can change strategies until they meet their goals. Figure 3 illustrates the steps of Robust Decision Making [10].

![Figure 3. The Steps for Robust Decision Making.](image)

5.2. Sensitivity Analysis (RDM)
Developing an expert system in Excel® program, setting the criteria and then weighting and ranking are important method to determine overall processes. The weights depend on an area and local conditions. Sensitivity analysis was used to evaluate the impacts of efficiency, simplicity, operation and maintenance costs, and energy efficiency on determining sustainable wastewater treatment. Common wastewater systems used in Thailand will be evaluated by selecting different factors that affect wastewater technologies selection. Figure 4 illustrates important results. When wastewater treatment facilities concern the cost as the most important factor, stabilization pond would be the best option. However, the result is the system would be very low efficiency. This means if the wastewater treatment facilities want to produce higher wastewater treatment quality, the facilities should modify to other systems such as activated sludge or aerated lagoon. The facilities should also adapt to new alternative wastewater treatments, which are provided section 4, alternative sustainable wastewater treatment systems, in order to reuse or recycle reusable resources in wastewater. This will lead to lower their energy consumption, produce valuable resources, or even produce their own energy.
6. Proposal of sustainable wastewater treatment
Selecting the most appropriate wastewater treatment technology is not only about implementing the best technical solution at the lowest cost, but also about sustainability including social and environmental considerations [11]. Wastewater treatment technologies in Thailand are ineffective because ease of operation and low costs were the top priorities [12]. However, one of the most important factors is effectiveness because it directly affects public health and the environment. Stabilization pond, construct wetland or other natural processes are easy to operate, but the quality of effluent and reliability of the systems tend to be poor.

6.1. An expert system in Excel® program.
An expert system was developed in Excel® program to aid in selecting the most sustainable wastewater treatment processes for a wastewater treatment plan of interest and/or comparing existing wastewater treatment technologies by a weighting and ranking system. Moreover, sensitivity analysis can be implemented to compare the technologies by changing weighting factors. Figure 5 shows the flowcharts of the developed expert system.

7. Conclusions
The selection of wastewater treatment systems must be based on sustainability. The significant factors such as efficiency, simplicity, operation and maintenance costs, and energy efficiency were considered to determine the most sustainable wastewater systems. Thailand wastewater treatment systems were
analyzed using the developed expert system. The key problems of wastewater in Thailand and possible solutions are described. In addition, the recommendation and future study are also stated in this chapter.

7.1. Problems and solutions
One of the major problems of wastewater treatment systems in Thailand is the lack of wastewater facilities to treat all wastewater produced from sources. Furthermore, the common systems used in Thailand are natural treatments, especially in rural area resulting in the low quality of treated water. One solution is that the government should focus on improving wastewater treatment sector in Thailand. The water quality can impact overall people’s health and the environment. Thus, it is necessary to build more wastewater treatment systems.

An expert system in Excel® program was developed to provide a robust solution for any wastewater treatment plant and to aid in improving or solving a problem in the facility. Sensitivity analysis is applied in order to evaluate the uncertainties of choosing wastewater treatment technologies. The local condition affects the decision significantly. Thus, a Robust Decision Making tool was adopted to determine the way to improve existing wastewater treatment facility and to choose the most appropriate wastewater treatment system. It can aid in identifying issues, finding options, implementing strategies, monitoring results, and improving the systems efficiency.

In developing countries, local conditions, efficiency, sustainable and simplicity are important concepts when designing a wastewater treatment system [13]. Local conditions including finance, government, citizens, and the community. Efficiency of wastewater technology is also very significant. Any wastewater treatment plant should meet the regulatory standard.

Thailand wastewater treatment facilities can use anaerobic digesters to produce electricity and heat. This can reduce energy demand and lower the operational cost. Furthermore, they can recycle their sludge produced from the treatments to be used as a fertilizer. The most important production in Thailand is rice. Thus, it will be very useful and sustainable if biosolids produced from wastewater treatment plants are used as a fertilizer. This can help both the wastewater facilities and farmers.

Lastly, simplicity is one of the important concepts of choosing appropriate wastewater treatment technologies. Simplicity means simplicity of the management, the technology, and the details. Simplicity is reducing the level of complexity as much as possible and cutting the number of elements that could eventually lead to the failure of the system [8], [14].

7.2. Suggestion and future study
One of the key factors in constructing a wastewater treatment plant is the community participation. Most people who live in poor rural area may not get the good water quality like the people who live in urban areas. They should call for their right to get the appropriate wastewater treatment and water quality and improve their lives. Furthermore, education on wastewater problems and management to public is an important activity. For example, a community can initiate cleaning activities by raising public awareness and strengthening community participation.

The future study should investigate about related factors that might affect wastewater activity such as social involvement, public participation, and government support. The knowledge and policy that related to wastewater management should be gathered and analyzed in order to determine the most appropriate wastewater treatment technologies.

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