ISSN: 18158129 E-ISSN: 18151027
Volume 20, Issue 02, February, 2024

# Research and Development Impacts of the Nature-by-Nature Process for Wastewater Treatment

Witsarutpon Supapipat[1*], Kampanat Vijitsrikamol[1], Onanong Phewnil[1], Suwanna Praneetvatakul[1]

Department of Agricultural and Resource Economics kasetsart university Thailand[1]

Corresponding Author: 1*

**ABSTRACT**— Research on the Nature-by-Nature Process for wastewater treatment can provide significant economic, social, and environmental benefits to the Laem Phak Bia Environmental Research and Development Project. The project has been on-going since 1991, but there has not yet been any meaningful quantitative studies of the aforementioned benefits, particularly those focusing on potential contributions to making management of the project (budgetary management or implementation of the stated policy goals) more efficient, or to assess its impacts. Generally, comprehensive quantitative evaluation of the impacts of research is crucial to determine the success of research investments. Consequently, the over-arching objective of this study was to assess the impact of this research work based on the benefits derived from the project. The benefits were categorized and aligned by user group: Phetchaburi Municipality, Laem Phak Bia Environmental Research and Development Project, the local community and immediately surrounding area, residents within the project area, and individuals interested in learning about wastewater treatment systems. Evaluation of the research benefits evidenced a net present value of approximately 155 million THB (Thai baht), with a 2.02 ratio of benefit to cost, and 36% internal rate of return. Although this assessment focused on benefits within one province within Thailand, this type of research project has global significance and value.

**KEYWORDS:** Value of Impact / Laem Phak Bia Environmental Research and Development Project / Nature-by-Nature Process for Wastewater Treatment

## 1. INTRODUCTION

Large areas within the Province of Phetchaburi, Thailand, often face domestic wastewater issues, largely because of its topography and natural physical characteristics—the region has low-lying plains, within riverine areas that drain into the Gulf of Thailand. Phetchaburi River flows through the municipality, making the central urban area susceptible to the discharge of wastewater (Laem Phak Bia Environmental Research and Development, 2022).

Over many years, the physical characteristics of the Phetchaburi River has changed. The waterway has become mired with dense vegetation that has grown denser as transportation patterns have changed due to the more modern, urban society, and activity on the waterway has declined as land-based transportation has increased. Additionally, the covert discharge of wastewater from agriculture and industry into the Phetchaburi River has exacerbated changes to the water's quality. In recent times, approximately 3,500–4,500 cubic meters of wastewater is released daily into Phetchaburi River, causing deteriorate to the point where it cannot be used for consumption and other daily activities that has traditionally relied on the water. This has significantly harmed the quality of life for the local population, with ongoing repercussions as evidenced by the recorded statistics. According to Phetchaburi municipal officials, urban residents release approximately 200 liters of wastewater per person per day as part of their daily activities, which is significantly higher than the rural

population, which releases about 60 liters of wastewater per person per day from similar activities (Laem Phak Bia Environmental Research and Development, 2022).

The wastewater problem has had multifaceted negative impacts on the Province of Phetchaburi. Although denigration of the river's water quality has rendered it unsuitable for consumption and daily use, and undermined the fertility of the river's ecological system over multiple generations, initiatives focusing on investment in water purification has been scant. Environmental constraints and limited available physical space within the municipal area of Phetchaburi has curtailed efforts to invest in water improvement.

A first initiative to address the problem was launched on 12 September 1990 by His Majesty King Bhumibol Adulyadej, who graciously initiated a collaborative effort involving the Chai Pattana Foundation, the Department of Royal Irrigation, and Kasetsart University which undertook to study and address the environmental issues related to wastewater in community areas. This Petchaburi initiative was conducted under the auspices of the "Laem Phak Bia Environmental Research and Development Project: Nature-by-Nature Process for Wastewater Treatment." On-going since 1991, the project has been implemented in the public interest within the Laem Phak Bia Subdistrict of Ban Laem District, Phetchaburi Province, covering an area of 642 acres [6].

The Laem Phak Bia Project treats wastewater from the municipal area of Phetchaburi by collecting it into a wastewater sump located in the Klong Yang Subdistrict. This sump serves the purpose of collecting and settling solid materials, such as sediment and sand, from the wastewater. The wastewater continuously flows through a pressurized conduit which transports it approximately 18.5 kilometers to enter the wastewater treatment system at Laem Phak Bia [7].

Since its inception in 1991 until 2022, the Chaipattana Foundation has invested in various aspects of the project, including research, facility maintenance, and project implementation. The annual average cost for these activities has been US$ 650,000–700,000 per year. The budget is supposed to be allocated to provide adequate resources and to ensure cost-effectiveness of the project, which encompass wastewater treatment system maintenance, knowledge dissemination and training programs, as well as management and preservation of mangrove forests within the project area (Laem Phak Bia Environmental Research and Development, 2022).

The success of the Laem Phak Bia Project: Nature-by-Nature Process for Wastewater Treatment, goes beyond providing beneficial wastewater treatment to the Phetchaburi municipal, resulting in cost savings in the treatment process and ultimately benefiting the public. It also involves the dissemination of technological knowledge and training for individuals interested in wastewater treatment, whether for community-based treatment or cost reduction in wastewater treatment processes (Laem Phak Bia Environmental Research and Development, 2022).

During the 20 years that the project has been in operation, treated wastewater has been consistently released onto Laem Phak Bia Beach which has resulted in a noticeable increase in the sea's coastal area near the Laem Phak Bia Environmental Research and Development Project. This expansion in the coastal area, attributed to the efforts of this Royal Initiative, has increased the mangrove forest area by approximately 3.7 hectares annually [1]. In turn, the expanding coastal area has led to a larger population of various aquatic animals such as crabs and mudskipper, within the project area. This increase is of significant benefit to local fishermen in Phetchaburi Province and neighboring provinces, as they can now harvest from these enhanced resources (Satienpong et al., 2016; Jitthaisong et al., 2012; Chunkao et al., 2014; [5].

ISSN: 18158129 E-ISSN: 18151027
Volume 20, Issue 02, February, 2024

The mentioned successes have provided clear and tangible economic, social, and environmental benefits to various aspects of the community. However, up to this point, there has not been a quantitative evaluation of the project's impacts to illustrate these effects.

This quantitative evaluation is undertaken because it is important to optimize the allocation of research funding and achieve the highest level of efficiency for this project ... and for future similar projects. The main objective of this study is to evaluate the value derived from the impacts of the project over the course of its operation, from its inception to the present. Specifically, the project can use the results of this study and evaluation to more efficiently manage its budget. Looking forward, the findings provide key data to shape policies and plan the project's future operations, in ways that optimally benefit the local society and the country. Indeed, this impact evaluation can be applied to other significant environmental research and development projects, with impacts worldwide.

## 2. Methodology

This study evaluated the marginal net benefits gained from the investments and technological advancements in the research, focusing on economic changes or surplus. The Laem Phak Bia Environmental Research and Development Project: Nature-by- Nature Process for Wastewater Treatment, was initially conceived as an effort to resolve wastewater problems within this region. The scope of the study included an evaluation of any reduction in the water treatment costs benefiting the municipal government of Phetchaburi Province and its residents. It also encompassed a study of the benefits provided by training local entrepreneurs and the potential income generated by people in the project area. On a more global scale, the study sought to determine whether the project had significant impacts on Thailand's economy, society, and environment, and to collect data that could be used to plan the direction of future research initiatives, as summarized in the conceptual framework shown in Figure 1.

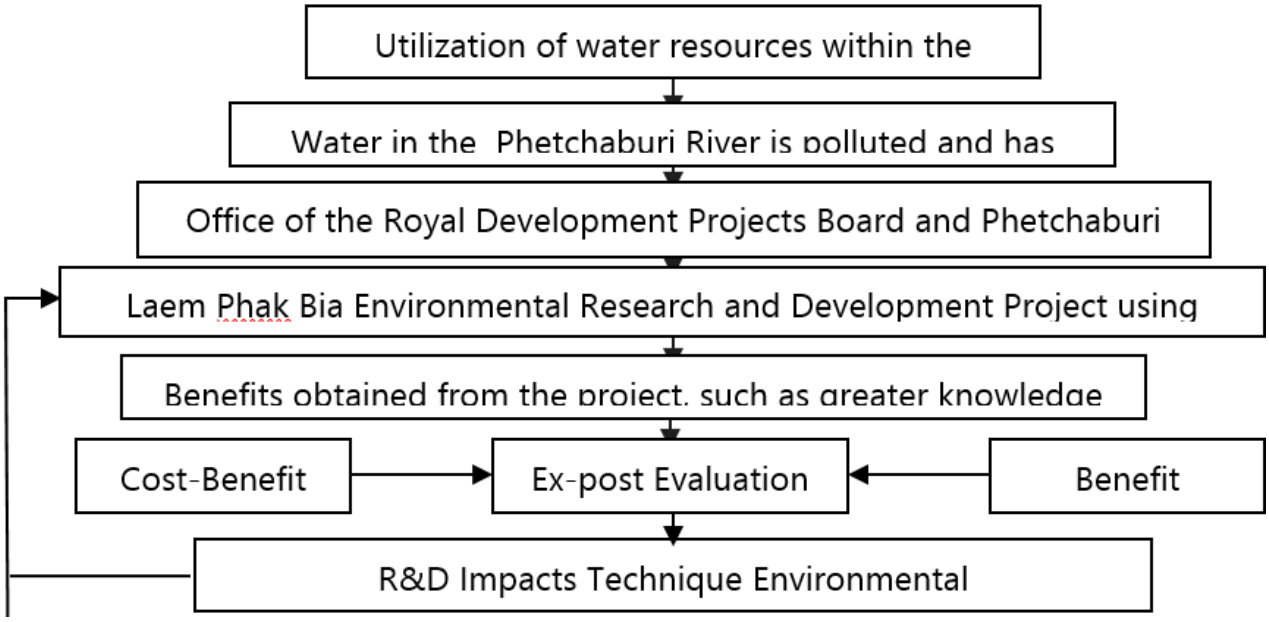


**Figure 1** Conceptual Framework

In this context, the research methodology consists of six main points (2.1 to 2.6). Point 2.1 explains the principles of Nature-by-Nature Process for Wastewater Treatment, while points 2.2 to 2.6 evaluate and assess market and non-market value of impacts.

### *2.1 Nature-by-Nature Process for Wastewater Treatment*

The Nature-by-Nature Process in the Laem Pak Bia project involves four methods to treat the wastewater: lagoon system, submerged plant, artificial wetlands, and mangrove forest filtration. The lagoon system serves as the project's main water treatment method.

A lagoon system relies on natural processes driven by microorganisms, in conjunction with key environmental factors such as sunlight and air, which naturally break down organic substances present in incoming wastewater, before releasing the treated water back into the natural water source (Laem Phak Bia Environmental Research and Development, 2022).

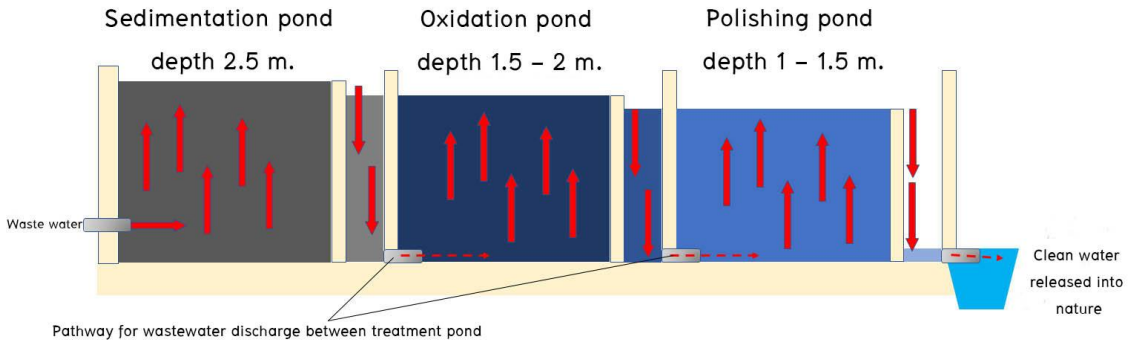


**Figure 2** Lagoon System Concept

### *2.2 Impact pathway*

Evaluating the impact pathway provides an analysis of the relationship between research investments and resulting impacts. The pathway to impact illustrates how research outputs can generate benefits when they are utilized by the intended beneficiaries, transferred to other users, or when they contribute to further research. Research outcomes specifically relate to changes resulting from the use of research outputs, such as changes in policies or behaviors, that have economic, social, and environmental impacts. The analysis of benefits involves an assessment of the economic value of changes in producer and consumer welfare, in a positive direction [10].

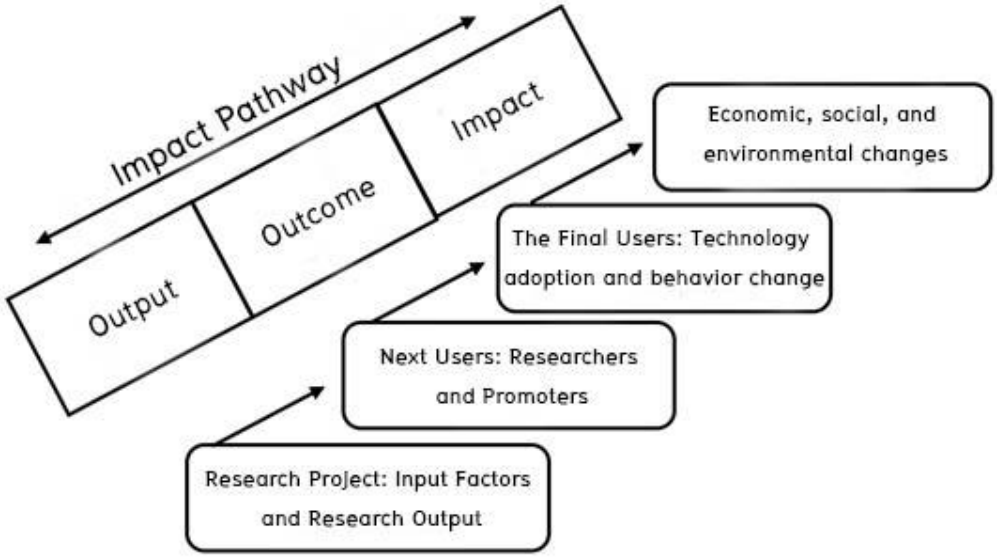


**Figure 3** Impact Pathway Concept

Source: Modified from Praneetvatakul, 2021 citing Templeton, 2006.

ISSN: 18158129 E-ISSN: 18151027
Volume 20, Issue 02, February, 2024

### *2.3 The evaluation of impacts according to the principle of "Net Change"*

Changes resulting from research and development work, or the application of technology or innovations, have a value that serves as the basis for measuring the "Net Change" principle. This principle involves analysis of the change in value that results when research and related developments are used for beneficial purposes. The analysis of value should consider the inherent characteristics of the beneficiaries within the zone of this impact, assessing what has changed from the original status of the beneficiaries (status before the project began). However, proper analysis also requires comparisons of changes that have occurred without the research project and any related developments. Indeed, "Counterfactual" is a key concept that evaluators must keep in mind during the impact evaluation process [11], [2].

There are two dimensions of this analysis:

1) Benefits derived from a situation with research work, compared to benefits in a situation without research (with vs. without research)
2) Benefits gained by the target user group, before and after the research work (before vs. after research)

The 'Net Benefit' is calculated by subtracting the values of the two dimensions of change, before and after. Analyzing the difference in both dimensions is referred to as 'Double Differences' analysis.

**Table 1** Impact evaluation according to the principle of 'Double Differences'

| Dimensions of Impact | With | Without | |
|---|---|---|---|
| Before | A | B | |
| After | C | D | Net Change |
| Change | (C-A) = $\Delta_1$ | (D-B) = $\Delta_2$ | = $\Delta_1$ - $\Delta_2$ |

Source: [10].

### *2.4 Assessing impact within the timeframe of 'Impact Occurrence': Ex-ante vs. Ex-post Evaluation*

When assessing the research impacts, the evaluator should consider the time frame of the evaluation taking into account the objectives of the project and the timing of benefits or impacts generated. In this context, ex-ante evaluation refers to assessing impacts in the future, while ex-post evaluation refers to impacts that occurred in the past yet with effects in the present [11], [8].

### *2.5 Impact evaluation of economic indicators*

Research and development impact evaluation relies on analytical principles similar to those used in general business investment evaluation but differ in how costs and benefits are calculated and calibrated. That is, costs are plugged into the calculation as a lumpsum of the research and development budget; benefits are calculated to determine net incremental benefit values taking into account any counterfactual schemes, using the double-difference evaluation (with & without, before & after project implementation).

Research investments can be assessed for societal impacts generated to determine whether the research work should receive ongoing support. Economic impact evaluation involves calculating the value of benefits generated by the research work and the measurable research costs, both at market prices and non-market prices [10].

1) Net Present Value (NPV) is defined as the value of benefits less the sum of current costs. An investment with NPV values above zero indicates a minimum recovery of the capital investment.
2) Benefit-Cost Ratio (BCR) is the ratio of the present value of revenues to the present value of costs at

a given discount rate. A ratio of BCR greater than one indicates a feasible project—less than one indicates a non-profitable project. The most viable project has the highest BCR ratio.

3) Internal Rate of Return (IRR) is the interest rate where total costs equal the benefits obtained during a certain period of business operations. A project is considered financially viable when the IRR is equal to, or higher than, the interest rate that could be received from alternative financial investments (Ewumi, 2023).

### *2.6 Benefit Transfer*

Benefit Transfer is a method of economic valuation that involves taking economic values obtained from one context ("source context") and applying them to another context ("target context"). For example, the benefit value might involve using the economic value data for using a specific public park obtained from one specific research study (source context) to estimate the economic value for using another public park (target context) [11].

Generally, there are three benefit transfer methods—Value Transfer, Function Transfer and Meta-Analysis: Value Transfer uses research results from pre-existing monetary valuation studies at one or more sites or policy contexts to predict value estimates, or other related economic information, for other sites or policy contexts. Two main approaches have commonly been used with two common variations within each [4].

## 3. Data collection

The data collection for data analysis can be divided into two methods as follows.

3.1 Collecting data from project documents and relevant academic materials, with the presentation of data items, data types, and data resources shown in Table 2.

**Table 2** Collecting data from project documents and relevant academic materials

| Data items | Data types | Data resources |
|---|---|---|
| Administrative budget and funding sources | Annual budget (1991-2022) | |
| Visitor statistics | Number of participants in the project training (1991-2022) | Laem Phak Bia Environmental Research and Development Project |
| The increasing characteristics of mangrove forests | Mangrove forest quantity (1991-2022) | |
| Amount of treated water | The quantity of water sent by the municipal authority of Phetchaburi for treatment (1991-2022) | Phetchaburi Municipality |

3.2 Collecting data through in-depth interviews entails seeking detailed information from knowledgeable individuals or relevant personnel, with the specifics to be documented in Table 3.

**Table 3** Collecting data through in-depth interviews

| Data items | Data types | Data resources |
|---|---|---|
| Costs for wastewater treatment training | Details of expenses for the training course, including accommodation costs (1991-2022) | Officials from Laem Phak Bia Environmental Research and Development Project |

ISSN: 18158129 E-ISSN: 18151027
Volume 20, Issue 02, February, 2024

| | | |
|---|---|---|
| Information on activities within the project | Income and expenses generated from various activities within the project on an annual basis (1991-2022) | |
| Statistics of residents within the project area. | The number of people benefiting from the mangrove forest each year (1991-2022) | The village head in each district around the project area |

## 4. Data analysis

To assess the impact value of the project, an ex-post evaluation tool is employed. This tool involves calculating the net benefits obtained from a comparative analysis and utilizes the impact pathway of the research project. It is complemented by an economic impact evaluation to evaluate the economic viability of the research work. Data used in this analysis are adjusted for value transfer when there were variations in the research years.

### *4.1 Economic impact evaluation [10].*

#### *4.1.1 Net Present Value (NPV):*

$$NPV = \sum_{t=1991}^{T=2022} \frac{(B_t - C_t)}{(1+r)^t} \geq 0$$

#### *4.1.2 Benefit-Cost Ratio (BCR):*

$$BCR = \frac{\sum_{t=1991}^{T=2022} \frac{B_t}{(1+r)^t}}{\sum_{t=1991}^{T=2022} \frac{C_t}{(1+r)^t}} \geq 1$$

#### *4.1.3 Internal Rate of Return (IRR):*

$$\sum_{t=1991}^{T=2022} \frac{(B_t - C_t)}{(1+IRR)^t} = 0$$

Specify $B_t$ = net benefits per year when compared to the baseline (US$/year)

$C_t$ = budget of the project related to treatment, activities, and maintenance at year t.

$r$ = discount rate of 5%.

$t$ = time period (years) from the start in 1991 to the end in 2022.

### *4.2 Value Transfer [9]*

$$\mathrm{WTP_j} = \mathrm{WTP_i} \times \left(\frac{GDP,PPP_j}{GDP,PPP_i}\right) \times \left(\frac{CPI_{j0}}{GCPI_{js}}\right)$$

Specify WTPj = willingness to pay for the target context, which in this case is willingness to pay for the increased mangrove forest

WTPi = willingness to pay for the initial context, which in this case refers to willingness to pay for the referenced research

GDP,PPPj = Gross Domestic Product per capita adjusted for the purchasing power parity of the target country j in the year of impact evaluation

GDP,PPPi = Gross Domestic Product per capita adjusted for the purchasing power parity of the target country i in the year of impact evaluation.

$CPIj_0$ = Consumer Price Index of the target country j in the base year

CPIjt = Consumer Price Index of the target country j in the year for which the impact value evaluation is conducted

**5. Results**

5.1 The Impact pathway of Laem Phak Bia Environmental Research and Development Project: Nature by Nature Process for Wastewater Treatment includes the following components:

***5.1.1 Inputs:***

(1) Research budget supported by the Chaipattana Foundation (1991– 2022)
(2) Budget for activities related to corporate social responsibility
(3) Maintenance and upkeep costs for wastewater treatment ponds

***5.1.2 Outputs:***

(1) Nature-by-Nature Process for Wastewater Treatment
(2) Manual on wastewater treatment methods
(3) Training course on wastewater treatment know-how
(4) Patents from research work

***5.1.3 Outcomes:***

User 1 Phetchaburi Municipality
User 2 Laem Phak Bia Project
User 3 Local community and surrounding area
User 4 Residents within the project area
User 5 Individuals interested in learning about wastewater treatment systems

***5.1.4 Impacts:***

Economic benefits:

- Phetchaburi Municipality has reduced wastewater treatment expenses
- Laem Phak Bia Project generates profits from selling souvenirs
- Individuals interested in learning about wastewater treatment systems save on educational expenses
- Residents within the project area benefit by utilizing the mangrove forest area and participating in project activities
- Reduced damage from alternative water treatment methods that use chemicals

Social benefits:

- Strengthened community networks among residents in the project area
- Dissemination of knowledge to individuals who are eager to learn about wastewater treatment systems and to support similar developments in communities in other regions

Environmental benefits:

ISSN: 18158129 E-ISSN: 18151027
Volume 20, Issue 02, February, 2024

- Reduced water pollution
- Increased green spaces, largely due to mangrove forest expansion

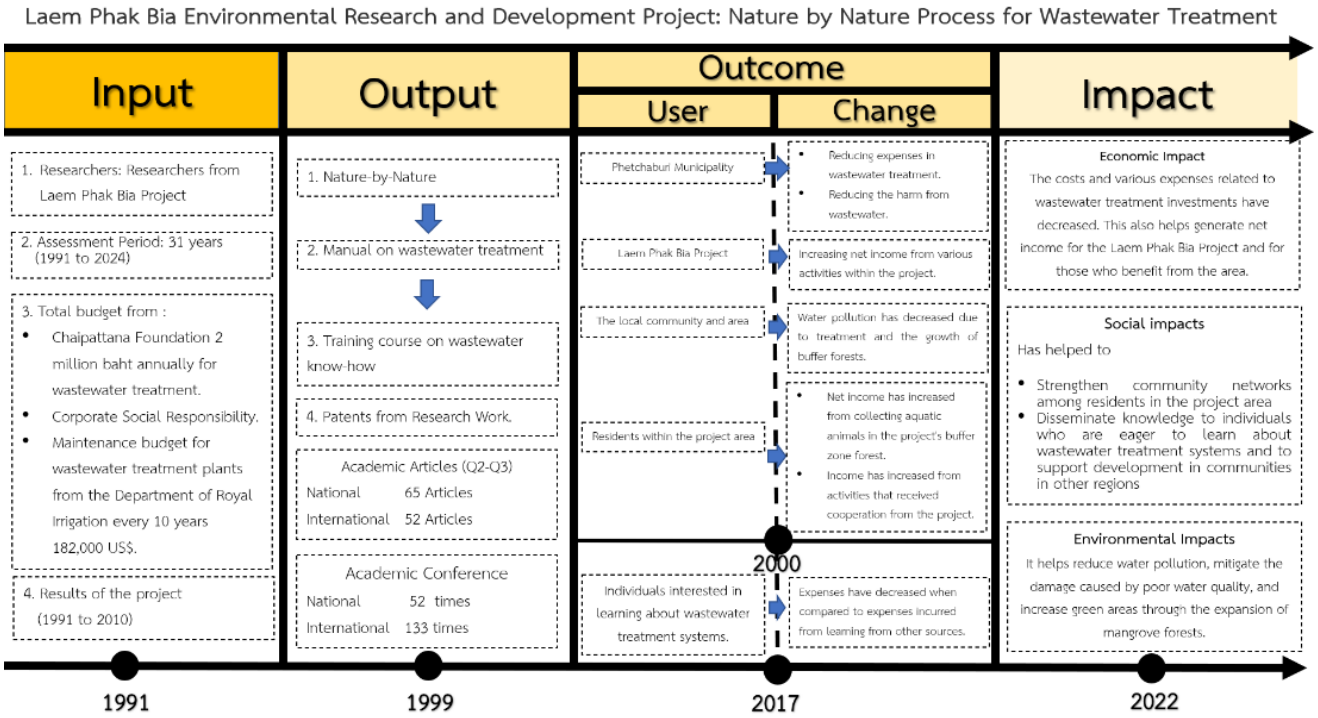


**Figure 4** Impact pathway of Laem Phak Bia Environmental Research and Development Project: Nature-by-Nature Process for Wastewater Treatment

### *5.2 Economic impact evaluation of research project investments*

When the Phetchaburi Municipality utilizes the benefits from the project by sending wastewater for treatment, it uses the data to estimate the level of acceptance of wastewater treatment. In the other words, this amount of wastewater is considered as the adoption level of the project. This estimation covers the entire process, starting from the initial implementation of the treatment system to the utilization of various benefits derived from the treatment process. For example, Laem Phak Bia Environmental Research and Development Project initiated experimental studies from 1991 to 1999, and full-scale wastewater treatment began in 2000. Additional benefits derived from the treatment process have been utilized, such as allowing the local community to collect and sell aquatic animals in the project area, establishing a laboratory for water quality analysis and monitoring in 2007, and creating various community-oriented activities starting in 2017 which continue. These trends are analyzed in terms of the wastewater treatment process.

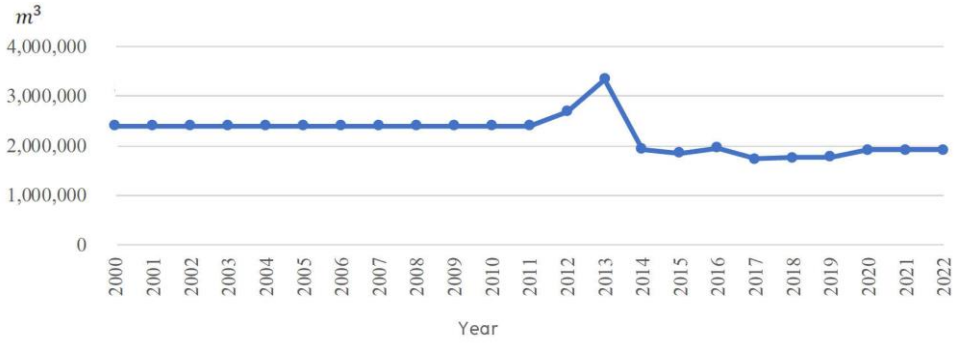

**Figure 5** Amount of wastewater (adoption level) sent from Phetchaburi Municipality to Laem Phak Bia Environmental Research and Development Project, 1991 to 2022

The costs and benefits that can be quantified conventionally and benefits that can be quantified through value transfer are calculated to determine their importance in finding the net value, which is crucial for conducting a cost-benefit analysis, as shown in Table 2.

**Table 2** Costs and benefits generated by the Laem Phak Bia Environmental Research and Development Project

| List | Calculation method | US$/year |
|---|---|---|
| **Costs** | | |
| 1) Budget for wastewater treatment | 10% of the budget from the Chaipattana Foundation | 55,000 (32 years) |
| 2) Budget for activities related to Corporate Social Responsibility | Yearly statistics based on actual numbers | 330 (5 years) |
| 3) Maintenance and upkeep costs for wastewater treatment ponds. | Yearly statistics based on actual numbers | 182,000 (3 years) |
| **Benefits** | | |
| 1) Benefits to Phetchaburi municipality | | |
| • Benefits from water treatment | Reduced treatment costs compared to Wastewater treatment service fees in Tha Yang District | 170,000 (23 years) |
| • Benefits from preventing damage from wastewater in the community | Value of preventing damage from wastewater in the community, adjusted using the base year 2009 | 280,000 (23 years) |
| **2)** Benefits of the Laem Phak Bia Project | | |
| • Benefits from promoting activities within the mangrove forest area in collaboration with CSR and the local community | Average profit per individual from the activities | 775 (6 years) |
| • Benefits from selling fish from the wastewater treatment system | Profit gained from selling fish | 37,500 (2 years) |
| • Benefits from quality analysis of the project | Reduced quality inspection costs compared to external water quality inspection costs outside the project | 78,210 (16 years) |
| • Benefits from short-term training | Training cost per day | 3,046 (7 years) |
| 3) Benefit to local community and area | | |
| • Benefits from having a mangrove forest | Increased value of mangrove forests, adjusted using the base year 2019 | 42,460 (32 years) |
| 4) Benefit to residents within the project area | | |
| • Benefits from Group 1. | | 620 (32 years) |

ISSN: 18158129 E-ISSN: 18151027
Volume 20, Issue 02, February, 2024

| | | |
|---|---|---|
| • Benefits from Group 2 | Average income from utilizing resources in project area using value transfer, adjusted using the base year 2022 | 4,133 (32 years) |
| 5) Benefit to individuals interested in learning about wastewater treatment systems | Reduced training costs compared to the training costs of the Thai Environmental Institute | 20,223 (5 years) |

Cost-benefit analysis of the research project involves a financial analysis that starts with the research support budget established by the Chaipattana Foundation, which is considered as the research project cost. The analysis aims to determine the value of benefits derived from impacts of the research project. It calculates values using three key indicators: NPV, BCR, and IRR. A discount rate of 5% is used in the calculations.

**Table 3** Impact evaluation of the Research and Environmental Development Project at Laem Phak Bia: Natural-by-Nature Treatment Process for Wastewater

| Indicators | Evaluation results |
|---|---|
| Net Present Value (NPV): US$ | 4,259,836.86 |
| Benefit Cost Ratio (BCR) | 2.02 |
| Internal Rate of Return (IRR): % | 36.00 |

Note: The discount rate is set at 5%

Analysis of the value of the impact evaluation for this research project, using three indices (NPV, BCR, and IRR), it was determined that the investment in this research project can generate an additional income up to US$ 4,259,836.86. That is, the BCR indicates that for every US$ 1 invested, it can yield a return of US$ 2.02, that is, 2.02 times the investment of the funding agency.

### *4.3 Impact Shares*

1) Market and non-market impacts

When analyzing the value of benefits for the entire duration of the project (Figure 6), the majority of the market value benefits are economic benefits experienced by the Phetchaburi municipality; the value of these economic benefits with other economic benefits account for 90% of the total benefits.

In contrast, all of the non-market values benefit the local community and surrounding area, primarily in the form of social and environmental benefits, particularly due to the expansion of the mangrove forest, which accounting for 10% of the total benefits.

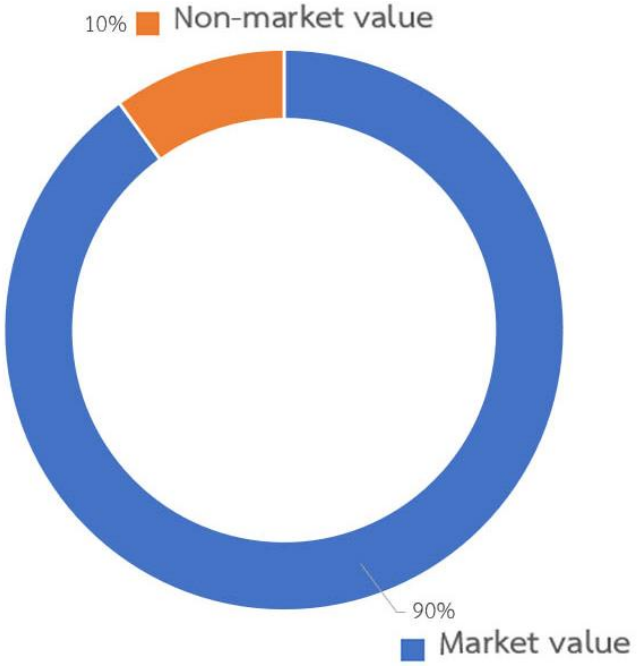


**Figure 6** The impact proportion of market value and non-market value

2) The impact proportion based on beneficiary group

When analyzing the proportion of benefits for the entire duration of the project (Figure 7), the proportion of benefits flowing to the Phetchaburi municipality increased by as much as 78%. This is because the municipality has been the primary beneficiary of the project since its inception. Other benefits or activities occur as the project has been implemented, or new benefits have arisen due to the wastewater treatment carried out by Phetchaburi municipality. Specifically, benefits to individuals interested in learning about wastewater treatment systems, which have resulted from activities newly introduced in 2017, have received the smallest proportion of the beneficial impacts (only 1%). However, as the project has progressed, by 2022 the proportion of the benefits increased to 3%.

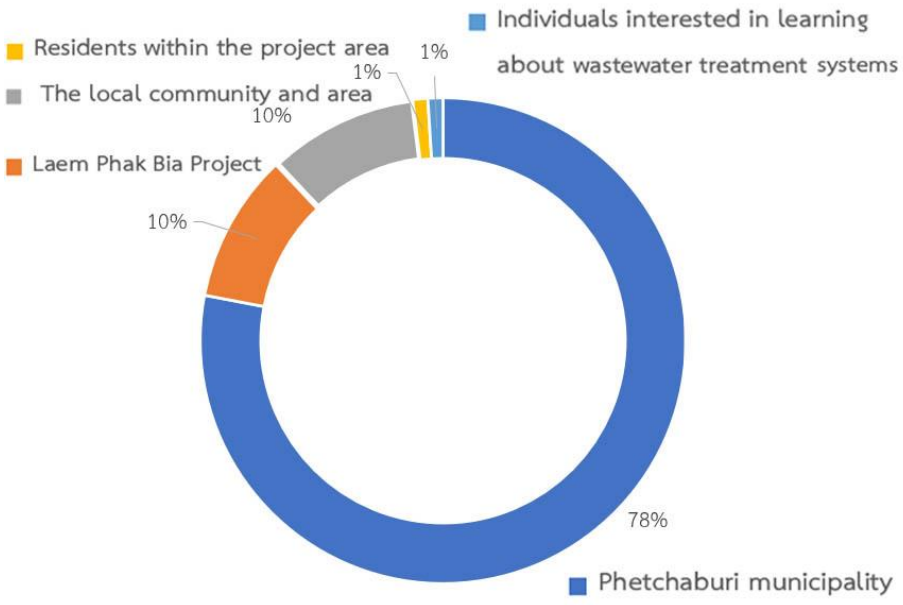


**Figure 7** The impact proportion based on beneficiary group

ISSN: 18158129 E-ISSN: 18151027
Volume 20, Issue 02, February, 2024

## 5. Discussion and conclusions

This analysis focused on the impacts resulting from the Laem Phak Bia Environmental Research and Development Project: Nature-by-Nature Process for Wastewater Treatment, which was implemented primarily to address critical domestic wastewater problems. The study, using a cost and benefit analysis, assessed impacts from the project's inception in 1991 to 2022. Overall, an Ex-post Cost-Benefit Analysis, with a discount rate of 5%, indicated that the project has been successful, with significant positive impacts, in terms of economic, market-value impacts, as well as in social and environmental, non-market value impacts.

This Phetchaburi study can be compared to a similar study, which used an economic analysis of waste heat recovery and utilization in data centers, and considered environmental benefits [12]. The Zhang study used the same research methods (focusing on NPV, BCR, and IRR) to evaluate the impacts of that project. In that research, NPV equalled US$ 1.5 million, BCR was 1.15, and IRR was 16.54.

Overall, this assessment and evaluation supports the Nature-by-Nature Process for Wastewater Treatment Project. The research and activities conducted by that project have proved to be efficient, and the developments resulting from the project have provided significant economic, social, and environmental impacts that benefit Thailand and the global society.

## 6. References

[1] Chunkao, Kasem. and Nimpee, Chatri. (2007) 'A study to investigate the coastal land expansion in the vicinity of the environmental research and development project at Laem Phak Bia resulting from royal initiatives', Laem Phak Bia Environmental Research and Development Project, pp. 1-9.

[2] Davis, J., Gordon, J., Pearce, D., & Templeton, D. (2008) 'Guidelines for assessing the impacts of ACIAR's research activities', ACIAR Impact Assessment Series, 58.

[3] Folorunso, E. A., Schmautz, Z., Gebauer, R., & Mraz, J. (2023). 'The economic viability of commercial-scale hydroponics: Nigeria as a case study', Heliyon, 9(8). doi: 10.1016/j.heliyon.2023.e18979

[4] Grammatikopoulou, I., Badura, T., Johnston, R. J., Barton, D. N., Ferrini, S., Schaafsma, M., & La Notte, A. (2023) 'Value transfer in ecosystem accounting applications', Journal of Environmental Management, 326, 116784. doi:10.1016/j.jenvman.2022.116784

[5] Khowhit, S., & Chunkao, K. (2017) 'Influence of Treated Domestic Effluenton Concentration of Heavy Metals (As, Cd, Cr, Hg, Ni, Pb) in Hard Clams (Meretrix spp.) Living withinin New Mudflat Areas of Laem PhakBia: The King's Royally Initiated Laem Phak Bia Environmental Research and Devel', Burapha Science Journal, 1-16.

[6] Office of the Royal Development Projects Board area 1. (2021) 'Laem Phak Bia Environmental Research and Development Bang Laem District, Phetchaburi Province', Laem Phak Bia Environmental Research and Development Project.

[7] Pongput, K. (2021) 'Wastewater treatment in accordance with the royal initiative Laem Phak Bia project', Kasetsart University, pp. 1-28.

[8] Reed, Mark S. (2018) 'The Research Impact Handbook', 2^nd Editon, Fast Track Impact.

[9] Sinphurmsukskul, N. (2023) 'Social and environmental impact assessment from social and environmental research', Kasetsart University.

[10] Vijitsrikamol, K. (2021) 'Evaluating Research and Development Impacts: Basic Principles and Practical', Bangkok: Knowledge Network Institute of Thailand.

[11] Vijitsrikamol, K. (2022) 'Social and Environmental Engineering Impact evaluation Project for a Sample Group of Research Projects in the Circular Economy Cluster Plan, Office of National Higher Education Science Research and Innovation Policy Council (NXPO), Fiscal Year 2021', Office of National Higher Education Science Research and Innovation Policy Council (NXPO).

[12] Zhang, C., Luo, H., & Wang, Z. (2022). An economic analysis of waste heat recovery and utilization in data centers considering environmental benefits. Sustainable Production and Consumption, 31, 127-138. heat recovery and utilization in data centers considering environmental benefits' Sustainable Production and Consumption 31, pp. 127-138. Doi: 10.1016/j.spc.2022.02.006