E-PROCEEDINGS

ENRIC 2024

THE 5TH ENVIRONMENT AND NATURAL RESOURCES INTERNATIONAL CONFERENCE

NET ZERO NOW : ACTION FOR A SUSTAINABLE WORLD

14 - 15 NOVEMBER, 2024

ARNOMA GRAND HOTEL, BANGKOK, THAILAND

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Plenary Speech on
"How can Thailand achieve its net zero goal?"

Dr. Somkiat Tangkitvanich, TDRI: Thailand Development Research Institute
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Dr. Somkiat Tangkitvanich is the research director (Information Economy), Science and Technology Development Program, Thailand Development Research Institute (TDRI).

Area of Expertise:

- Media and Telecommunication Policy
- Economic Analysis of Laws
- International Trade and Investment Policy
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Education:

- 1991-1994 Ph.D., Computer Science, Tokyo Institute of Technology, Japan
- 1989-1991 M.S., Computer Science, Tokyo Institute of Technology, Japan
- 1984-1988 B.E. (summa cum laude with Gold Medal) Computer Engineering, Chulalongkorn University, Thailand

Work Experience:

- 2000-2012 Research Director (Information Economy), Science and Technology Development Program, Thailand Development Research Institute (TDRI), Bangkok, Thailand
- 2012-present President, Thailand Development Research Institute (TDRI)
- 1996-2000 Industrial Policy Specialist, Sectoral Economics Program, Thailand Development Research Institute (TDRI), Bangkok, Thailand
- 1996 Research Fellow, President Office, Thailand Development Research Institute (TDRI), Bangkok, Thailand
- 1995-1996 Senior Researcher, Information Technology Research Department,Nomura Research Institute, Japan
- 1994-1995 Researcher, Advanced Information Technology Research Department, Nomura Research Institute, Japan

Awards:

2006	Outstanding research (Trade Policy), awarded by Thailand Research Fund
2004	Thailand Anti-corruption Award, awarded by Anti-corruption Network
2003	Man of the Year, selected by Than Sethakit Newspaper
2000	Outstanding research (E-Commerce Policy), awarded by Thailand Research Fund

Mahidol University
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Plenary Speech on

"Environmental and Resource Impacts from an Aggressive Regionalized Carbon Peak Policy"

Associate Professor Dr. TIAN Xu
Shanghai Jiao Tong University, P.R. China
E-mail: tianxu@sjtu.edu.cn

Dr. Xu Tian, Associate professor at the School of International and Public Affairs, Shanghai Jiao Tong University, graduated from the University of Chinese Academy of Sciences and conducted postdoctoral research at Shanghai Jiao Tong University and University College London. Her main research areas include resource and environmental management, sustainable trade, and carbon policy analysis. He has published over 60 academic works in international journals on resources and the environment, such as Nature, Nature Climate Change, and Environmental Science and Technology.

Plenary Speech on

"Net Zero Now Action for a Sustainable World"

Dr. Porakrit Leophairatana, Director,
TPI Polene Public Company Limited

Dr. Porakrit Leophairatana currently serves as the Executive Vice President of Business Development at TPI Polene Power PLC and previously held the position of Assistant Vice President in the Specialty Polymers Division at TPI Polene PLC. At the TPI group, adhering to good environmental, social, and governance (ESG) principles, he has led the development of various projects, including new investments in green and renewable energy, such as solar, wind, and waste-to-energy; the development of specialty plastic resins and encapsulant films for photovoltaic and safety-glass applications; as well as the implementation of various electrification projects. He also serves on the board of directors for 15 companies across various industrial sectors, including renewable energy, pharmaceuticals, healthcare, petrochemicals, construction materials, and life insurance.

Dr. Leophairatana obtained a doctorate and a master's degree in chemical engineering from Columbia University in 2017 and 2015, respectively. He also received a bachelor's degree in chemical and biological engineering from Tufts University in 2013. Based on his doctoral and post-doctoral research work specializing in polymer physics and chemistry, he also co-founded a drug delivery company in New York City where he served as the CTO from 2017-2018.

The 5th Environment and Natural Resources International Conference (ENRIC 2024): Net Zero Now: Action for a Sustainable World

14 - 15 November, 2024, Arnoma Grand Hotel, Bangkok, Thailand

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18. Yutthapol Pongpleesal

Tentative Program

Day 1: 14 November, 2024

Time	Event
Room: Arnoma Grand Ballroom 2-3	
08.00 - 09.00	Registration
09.00 - 09.30	**Opening Ceremony** Mahidol University's Audio-Visual Presentation Faculty of Environment and Resource Studies's Audio Visual Presentation The Environment and Natural Resources International Conference (ENRIC)'s Audio Visual Presentation Conference Report by Associate Professor Dr. Kitikorn Charmondusit, Dean of the Faculty of Environment and Resource Studies, Mahidol University Welcome Speech and Conference Opening Remarks by Prof. Piyamitr Sritara, MD. FRCP, President of Mahidol University Presentation of Souvenir to the Sponsor, Keynote Speaker and Honored Guest Group Photograph
09.30 - 10.10	**Keynote Speaker** **"How can Thailand achieve its net zero goal?" by** **by Dr. Somkiat Tangkitvanich, TDRI: Thailand Development Research Institute**
10.10 - 10.45	**Keynote Speaker** **"Environmental and Resource Impacts from an Aggressive Regionalized Carbon Peak Policy"** **by Associate Professor Dr. TIAN Xu, Shanghai Jiao Tong University, P.R. China**
10.45 - 11.00	**Break**
11.00 - 11.30	**"Net Zero Now Action for a Sustainable World"** **by Dr. Porakrit Leophairatana, Director, TPI Polene Public Company Limited**
11.30 - 12.00	**Poster Session**
	No. 2024-11 Rearing Potential of Yellow Mealworm (Larvae of *Tenebrio molitor L.*) on Food wastes Keita Kidera, Toru Kobayashi, Kai Hashizume, and Mitsuru Hattori

Time	Event
	No. 2024-21 Environmental Impact of Prior Pesticides Occurring in Wetland Ecosystems Yurin Choi, Daeho Kang, and Junho Jeon
	No. 2024-22 Identification of Water-Soluble Chemicals in Leachate of Plastics and Their Kinetics Enhanced Under Photooxidative Conditions Doyeon Kim, Heewon Jang, and Junho Jeon
	No. 2024-23 Deletion of Glycine Betaine Transporter Gene Confers Increased Ectoine Accumulation in the Moderately Halophilic *Halomonas elongata* Yukino Baba, Ryo Kawamoto, Hiroyuki Tamino, Hanna Mitsunaga, Pulla Kaothien-Nakayama, and Hideki Nakayama
	No. 2024-24 Cell Surface Engineering as a Tool to Transform the Moderately Halophilic *Halomonas longata* into a Nutritious Single-Cell Eco-Feed Pattaranon Suklerd, Mei Shiota, Pulla Kaothien-Nakayama, and Hideki Nakayama
	No. 2024-29 Esterification of Acetic Acid and Ethanol for Ethyl Acetate Production by Vanadium Catalyst on Biochar Support Viputthawat Suwannaphan and Bunjerd Jongsomjit
	No. 2024-34 Plant-Based Solutions to Air Pollution in Bangkok: The Role of Urban Green Spaces Anh Tuan Ta, Nantikan Promchan, and Nguyen Tan Thong
	No. 2024-38 Phenological Changes in Seaweed Community Structure and the Diversity of Fish Communities in Seaweed Eecosystems Tomoyuki Aota, Hiroto Tateishiand, and Gregory N. Nishihara
	No. 2024-46 Assessing the Influence of Climate Change and Its Relationship on Mass Culture of Live Feed (Microalgae) in Outdoor System Conditions Wasana Arkronrat, Chonlada Leearam, and Vutthichai Oniam

Time	Event
	No. 2024-49 Impact of Rising Air Temperatures on the Growth and Water Quality of Blue Swimming Crab (*Portunus pelagicus*) Culture in Grow-Out Ponds: A Comparative Study of 2022 and 2023 Vutthichai Oniam, Wasana Arkronrat, and Rungtiwa Konsantad
	No. 2024-55 Hydrochar Production from Lignocellulosic Biomass and Evaluating Its Value Added Utilization HoLim Song and Jongkeun Lee
	No. 2024-56 Effects of Hydrothermal Pretreatment Temperature on Product Properties and Biogas Producing Potential Using Lignocellulosic Biomass JinHo Baek and Jongkeun Lee
	No. 2024-57 Electrochemical Water Treatment and Hydrogen Production Using a PEM Electrolysis Cell Yeji Seo and Jongkwan Park
	No. 2024-59 Effect of Non-Thermal Plasma on Post-Harvest Quality of Tomato Aishwarya Pant and Jirarat Anuntagoo
	No. 2024-62 Evaluation of Ventilation Effectiveness After Kitchen Renovation in Schools of Gyeongsangnam-do Province Jongwon Son and Taehyeung Kim
	No. 2024-65 Analysis of Urban Microclimate Characteristics Using ENVI-Met Modeling Jeong Da-Eun, Park Kyung-Hun, and Kim Tae-Gyeong
	No. 2024-66 Analysis of GHG Reductions in Energy Transition Sector Based on National New and Renewable Energy Plan Scenarios in Korea Haneul Kim and Teahyeung Kim

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	No. 2024-68 Analyzing the Relationship Between Local Climate Zones (LCZ) and Land Surface Temperature (LST) Focusing on Impervious Surfaces Kim Tae-Gyeong, Moon Byung-Hyun, Park Kyung-Hun, Son Jong-Won, and Jeong Da-Eun	
12.00 - 13.30	**Lunch**	
13.30 - 16.30	**Oral Presentation**	
13.30 - 14.45	Session 1: Impact of Climate Change and Pollution Chair: Associate Professor Dr. Dae-Woon Jeong Co-chair: Associate Professor Dr. Kritana Prueksakorn Room: **Arnoma Grand Ballroom 2-3**	Session 2: Mitigation, Adaptation, Policy and Governance Research Chair: Associate Professor Dr. Kitikorn Charmondusit Co-chair: Dr.Shreema Rana Room: **Arnoma Grand Ballroom 1**
13.30 - 13.45	No. 2024-05 Application of Geographic Information System for $PM_{2.5}$ Risk Assessment in Din Daeng District, Bangkok Allan Sriratana Tabucanon, Jirutchaya Mingkaew, Wimolsiri Tiemrak, Pronpairin Moonaudom, and Wenchao Xue	No. 2024-01 Corporate Social Responsibility in Green Logistics Considering Climate Change Kinga Biró and Mária Szalmáné Csete
13.45 - 14.00	No. 2024-10 Carbon Footprint of Rice Straw Paper Plate Monthira Yuttitham, Punnisa Thongnueaoon, Ganokwan Noppradich, Nafeesa Mahamad, and Harin Sachdev	No. 2024-08 An Empirical Study on Carbon Tracking for Thai Hotel Operation Amphai Wejwithan, Pittha Phongpradist, and Tanawan Sintunawa
14.00 - 14.15	No. 2024-35 Diversity of Urban Spontaneous Vegetation on Roadsides in Chaing Mai, Thailand Nadchawan Charoenlertthanakit and Pimonrat Tiansawat	No. 2024-15 Soil Carbon Sequestration Assessment in Major Cropping Patterns of the City of Batac, Philipines Dionisio S. Bucao, Arlene L. Gonzales, Aprilyn D. Bumanglag, Kenneth P. Tapac, and Arlene Mia G. Ruguian
14.15 - 14.30	No. 2024-37 Exploring the Impact of Marine Debris on *Zostera marina* Ecosystem Productivity	No. 2024-28 Project Efficiency Assessment for Eco-Industrial Area **Change to Poster Session** Methavee Siangrai, Ratchaphong Klinsrisuk and Allan Sriratana Tabucanon*

Time	Event	
	Alifro Maldini, Makoto Kabeyama, Shigetaka Matsumuro, Kaho Yamaha, Taishun Kobayashi, Yoshiki Matsushita, Nozomu Takashima, and Gregory N. Nishihara	
14.30 - 14.45	No. 2024-39 Do *Undaria pinnatifida* Seaweed Farms Have Potential to Sequester Carbon? Taishun Kobayashi, Shigetaka Matsumuro, Maldini Alifro, Yoichi Sato, Daisuke Saito, Hiroshi Sato, Kanako Hosoya, and Gregory N. Nishihara	No. 2024-30 A Study on Island Ecotourism Development Models Based on System Dynamics: A Case Study of Amami-Oshima Island Yining Wang and Aiko Endo
14.45 - 15.00	**Break**	
15.00 - 16.30	Session 3: Innovations and Technologies for Net Zero Chair: Professor Dr. Hideki Nakayama Co-chair: Associate Professor Dr. Sukanya Sereenonchai Room: **Arnoma Grand Ballroom 2-3**	Session 2: Mitigation, Adaptation, Policy and Governance Research Chair: Associate Professor Dr. Thamarat Phutthai Co-chair: Assistant Professor Dr. Wanwisa Pansak Room: **Arnoma Grand Ballroom 1**
15.00 - 15.15	No. 2024-03 Stability Investigation of Extracted Lignins from Bagasse, Coconut Husk, Rice Straw, and Corn Stover: Kinetic and Thermodynamic Aspects Tirapote Rattana-amron, Navadol Laosiripojana and Wiyong Kangwansupamonkon	No. 2024-67 Exploring Extended Producer Responsibility in Thailand: Progress and Opportunities for Alternative Waste Management Policy Napazz Asawachet and Phatra Samerwong
15.15 - 15.30	No. 2024-04 Toward Net-Zero: Green Industry Prospects and Carbon Neutrality in Southeast Asia Xiaoyue Shi	No. 2024-45 Thai Universities Performance in Global Sustainability Rankings for Educational Institutions Sawatdirak Saingam and Kitikorn Charmondusit
15.30 - 15.45	No. 2024-09 Optimizing Wastewater Treatment for a Carbon-Neutral Future: A Data-Driven Approach Praifa Jaturus and Praewa Wongburi	No. 2024-47 The Precautionary Behavior Against $PM_{2.5}$ Exposure Pailin Suntigul

Time	Event	
15.45 - 16.00	No. 2024-13 Stakeholder Engagements in Maintaining Marine Ecosystems in the Bali Sea, Indonesia Ratna Azis Prasetyo, Bagong Suyanto, Rahma Sugihartati, Nur Syamsiyah and Karnaji Karnaji	No. 2024-50 Strategies for Achieving Net Zero Emissions in the Beverage Industry: A Case Study from Thailand's Carbon Footprint Analysis Phanuwat Prasertpong, Parichat Limpaiboon and Sarut Prapatpong
16.00 - 16.15	No. 2024-18 Social Capital and Waste Management Practices in Jembrana and Banyuwangi, Indonesia Nur Syamsiyah, Sudarso, Ana Voronkova, Kayleigh Wyles, Lesley Henderson, Eddy Setiadi Soedjono, and Susan Jobling	
16.15 - 16.30	No. 2024-32 The Potential of Biomethane Recovery from Hemp Biomass Residue (*Cannabis sativa L.*) Sasithorn Saipa, Yanika Boonyuang, Todsapol Promwong, Supot Boonraeng, Surasak Noommeesri, Chan Yodle and Chayanon Sawatdeenarunat	
18.00 - 21.00	**Welcome Reception (Gala Dinner with Special Event: Loi Krathong Festival)** Room: Swimming pool 4th FL.	
18.00 - 18.30	Arrivals	
18.30 - 19.30	Gala Dinner	
19.30 - 19.40	Opening Speech by Associate Professor Dr. Kitikorn Charmondusit Dean of the Faculty of Environment and Resource Studies, Mahidol University	
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Day 2: 15 November, 2024

Time	Event	
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09.00 - 10.00	Session 1: Impact of Climate Change and Pollution Chair: Professor Dr. Sangam Shrestha Co-chair: Assistant Professor Dr. Allan Sriratana Tabucanon Room: **Arnoma Grand Ballroom 2-3**	Session 2: Mitigation, Adaptation, Policy and Governance Research Chair: Associate Professor Dr. TIAN Xu Co-chair: Associate Professor Dr. Noppol Arunrat Room: **Arnoma Grand Ballroom 1**
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09.15 - 09.30	No. 2024-44 Investigation of the Nutrient and Organic Matter Removal in Surface Water by Aquatic Plants: A Laboratory Scale Study Ngo Anh Dao Ho and Nguyen Thi Minh Trang	No. 2024-33 Environmental Governance for Sustainable Natural Resource Management in Indonesia Darmanto and Heri Wahyudi
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09.45 - 10.00	No. 2024-70 Boosting Tourism Resilience Through Enhanced Disaster Mitigation: A Case Study of Batu City Andini Risfandini, Ayu Fitriatul ‘Ulya, Annisaa Hamidah Imaduddina, and Irwan Yulianto	No. 2024-61 Exploring Greenwashing Awareness Among Thai Retail Investors Towards Sustainable Investment Trends Kotchanipha Vich Owen and Tawalhathai Suphasomboon

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10.00 - 10.15	No. 2024-14 Enhancing Thermal Performance of Cotton Facemasks through the Integration of Phase Change Materials: A Simulation Study Poptham Chaviengpop and Pimporn Ponpesh
10.15 - 10.30	**Break**
10.15 - 12.00	Session 3: Innovations and Technologies for Net Zero Chair: Assistant Professor Dr.Anish Ghimire Co-chair: Associate Professor Dr. Noppol Arunrat Room: **Arnoma Grand Ballroom 2-3**
10.30 - 10.45	No. 2024-26 Taurine Production in Engineered *Halomonas elongata* Hideki Nakayama, Thu Ya Kyi Zin, and Pulla Kaothien-Nakayama
10.45 - 11.00	No. 2024-36 Unlocking the Potential for Carbon Dioxide Removal (CDR) by *Ulva prolifera*: How Does the Addition of CO_2 Enhance Growth and Photosynthesis Rates? Kaho Yamaha, Eri Inomata, Hikari Nagoe, Yoichi Sato, and Gregory N. Nishihara
11.00 - 11.15	No. 2024-52 Advanced Analytical Approaches to Dissolved Organic Matter for a Sustainable Future: Innovations for a Net Zero Future Liza Saharani Hamzah and Jongkwan Park
11.15 - 11.30	No. 2024-69 Generating Low Lipid and Protein Food Waste Hydrolysate by a Dilute Sulfuric Acid Thermohydrolysis for Biorefinery Applications Julkipli Julkipli and Sandhya Babe
11.30 - 11.45	No. 2024-64 Effect of MOF-derived Cu/CeO_2 Catalysts Depending on Calcination Temperature in Water-Gas Shift Reaction Su-Bin Min, Hak-Min Kim, and Dae-Woon Jeong

Time	Event
11.45 - 12.00	No. 2024-71 Modulating the Co-CoO_x Interface in Co-Nb-CeO_2 Catalysts through Controlling Titration Rate for Enhanced Performance in Water-Gas Shift Reaction J.S Bang, H.M. Kim, and D.W Jeong
12.00 - 12.30	**Closing Ceremony** Conferenceꞌs Audio-Visual Presentation Conference Overall Conclusions Reported by Associate Professor Dr. Noppol Arunrat, Conference Chair Occasion - Presentation of Certificate to Chair and Co-chair Session - Outstanding Conference Papers Award Closing Speech by Associate Professor Dr. Kitikorn Charmondusit Dean of the Faculty of Environment and Resource Studies, Mahidol University
12.30 - 13.30	**Lunch**
13.30 - 16.00	Special Trip in Bangkok

Table of Content

Full Paper
Oral Presentation

Stability Investigation of Extracted Lignins from Bagasse, Coconut Husk, Rice Straw, and Corn Stover: Kinetic and Thermodynamic Aspects

Tirapote Rattana-Amron[1,2,*], Navadol Laosiripojana[1,3], and Wiyong Kangwansupamonkon[2,3]

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ABSTRACT

The influence of different biomasses on lignin extraction impacts the thermal stability of lignin. Four extracted lignins from the soda pulping process were prepared from agricultural wastes, including bagasse, coconut husk, rice straw and corn stover. Kinetic and thermodynamic analyses were utilized to compare and investigate the thermal-oxidative stability behavior of all lignins. Experiments were conducted using the non-isothermal method for four heating rates with a thermogravimetric analyzer. The Friedman, FWO, KAS and Starink kinetic methods were used to investigate the oxidative kinetics of lignins. Thermodynamic parameters involving enthalpy (ΔH), Gibbs free energy (ΔG) and entropy (ΔS) were considered for observing thermal characteristics. Thermal degradation of lignin consists of three consecutive regimes: moisture content, lignin degradation and decomposition of residues. All kinetic models showed average activation energies between 132.89 and 144.52 kJ/mol, 109.75 and 121.72 kJ/mol, 156.62 and 167.98 kJ/mol and 160.11 and 171.64 kJ/mol for BG, CH, RS and CS, respectively. The coefficient of determination revealed that all models are promising kinetic methods for calculating kinetic parameters. The fluctuation of kinetic and thermodynamic parameters showed that the thermal oxidative degradation of lignin was a complicated mechanism. The conversion process corresponds to a non-spontaneous endothermic reaction. The results provide valuable information to deeply understand the thermochemical conversion for characterizing the thermal stability of lignins.

Keyword: Soda lignin extraction/ Agricultural wastes/ Thermal oxidative degradation/ Kinetic and thermodynamic

1. INTRODUCTION

The production of agricultural waste increases as a result of the growing worldwide population and rising demand for agricultural products [1]. Agriculture is the most important sector to drive the Thai economy with high domestic and overseas demands for rice, sugar, coconut and corn [2]. The production of these agricultural wastes is created by the harvesting operations and the food processing industries. Currently, burning is an efficient method for removing excessive residues due to its inexpensive, rapid and uncomplicated approach [3]. The combustion process releases particulate matter, black carbon and greenhouse gases (GHGs) into the atmosphere, affecting air pollution, climate change and human health. Therefore, managing agricultural residues illustrates the greatest challenge for waste management in agricultural countries. Converting agricultural waste into high value products, including polysaccharides (cellulose and hemicelluloses) and lignin as aromatic polymers, remains economical, sustainable and advantageous for humans and the environment [4].

Lignin demonstrates excellent antioxidant properties; it has been promisingly utilized in many applications, such as film fabrication, thermo-oxidation stabilizers, and polymer additives [5]. Thermal stability and decomposition profiles are normally evaluated via thermal gravimetric analysis (TGA). But the results of TGA thermograms cannot disclose the reaction mechanisms during thermal degradation.

Kinetic and thermodynamic analyses provide beneficial information through kinetic and thermodynamic parameters for revealing the mechanisms and thermal degradation behavior. Kinetic analysis focuses on the determination of kinetic parameters such as activation energy (E) and pre-exponential factor (A). The obtained kinetic parameters are calculated from different kinetic models.

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Model-free methods are generally used for predicting kinetic parameters. Model-free techniques have isoconversional bases. This method works well for uncovering intricate chemical reaction processes that involve multiple elementary steps in their mechanisms. The rate of reaction is related to temperature and the kinetic parameters are assessed at a constant conversion degree [6]. Model-free approaches can be categorized into two main categories: differential and integral kinetic methods. The differential kinetic methods such as Friedman produce the most precise kinetic findings, but they have a defect in that noise from data amplification through numerical differentiation may influence accuracy [7]. The methods of studying material stability that have gained widespread acceptance include the integral isoconversional kinetics of Flynn-Wall-Ozawa (FWO), Kissinger-Akahira-Sunose (KAS), and Starink. However, because of the Arrhenius integral's oversimplified estimation and the activation energy constant assumption used in their derivation, these kinetic techniques would lead to systematic calculation errors [8]. Thermodynamic analysis is used to forecast the possibility of a chemical or physical reaction, which includes occurring on its own initiative, based on the distribution of energy contained in reactants and products. Thermodynamic parameters involving enthalpy (ΔH), Gibbs free energy (ΔG) and entropy (ΔS) are utilized to describe spontaneous reactions, absorbed or released energy, stability determination as well as the degree of disorder [9]. The study of oxidative degradation kinetics in lignin in terms of characteristics, kinetic mechanism, thermodynamic analysis and comparison between different kinetic methods is limited and not well understood.

Determining the thermal oxidative stability of lignins derived from bagasse, coconut husk, rice straw, and maize stover was the primary objective of this study. Kissinger-Akahira-Sunose (KAS), Flynn-Wall-Ozawa (FWO), Friedman, and Starink models' kinetic parameters were predicted using the TGA and DTG results of soda lignin degradation, which were based on the kinetic analysis. Activation energy data were used to determine thermodynamic parameters such as entropy (ΔS), Gibbs free energy (ΔG), and enthalpy (ΔH). The results of thermodynamic and kinetic assessments included comparisons of various kinetic techniques, kinetic mechanisms, and features of thermal degradation. The variance of lignin compounds in these various biomasses was also seen by analyzing a number of other factors, including chemical composition, molecular structure, and glass transition temperature.

2. METHODOLOGY

2.1 Materials and methods

Four agricultural residues were used to extract the soda lignin. Coconut husk (CH), rice straw (RS) and corn stover (CS) were collected from local fields in Thailand and bagasse (BG) was obtained from the sugar factory in the central region. Dry samples were carried out in an oven at 50 ºC for 4 days to remove the moisture content and crushed with a laboratory grinder mixture. The particle size of lignin samples was controlled to less than 3 mm with a sieve and stored at room temperature in zip lock plastic bag.

2.2 Lignin dissolution and precipitation

Soda lignin was prepared by the soda pulping process utilizing an alkaline hydrolysis based on sodium hydroxide (NaOH). Four samples were mixed with 3% (w/v) of NaOH solution at a ratio of solid to liquid of 1:12 (w/v). The reaction temperature was adopted at 121 ºC for 1 h for reaction time and the pressure was kept at 15 psi. Next, fibers and excess pulp residues were separated by vacuum filtration several times. Black liquor had a high alkali content, showing a pH of approximately 11. The precipitation of lignin was carried out by adding 20% (v/v) of sulfuric acid to black liquor under magnetic stirring. The amount of sulfuric acid in black liquor was controlled by reaching pH 2 and samples were set for 1 day at 25 ºC. Subsequently, precipitated lignin was filtrated to remove excess water with a centrifugation speed of 4,000 rpm and a time of 15 minutes. The washing process with hot water at 60 °C was adopted many times to neutralize the pH of lignin. Finally, all soda lignins were dried for 5 days in an oven at 55 ºC to reduce moisture and then milled to powder. Extraction processes are expressed in Figure 1.

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2.3 Thermogravimetric analysis (TGA)

The thermal oxidative degradation characteristics and kinetic analysis of soda lignins were tested by a thermogravimetric analyzer (TGA/DSC Mettler-Toledo). The weight loss profile was a function of mass change under increasing temperatures. Approximately 10 mg of lignin was allowed to stabilize at 25 ºC in an alumina crucible. Thermal oxidative degradation behavior was achieved at temperatures from 25 to 800 ºC under heating rates of 5, 10, 20 and 30 ºC/min. TGA results are not only used to describe data on weight loss but also to determine kinetic parameters. To ensure reproducibility, a minimum of three replications were conducted.

2.4 Kinetics analysis

Evaluating the reaction mechanism of lignin degradation becomes more difficult because of the complicated chemical composition. The model-free isoconversional methods, including Friedman, Flynn-Wall-Ozawa (FWO), Kissinger-Akahira-Sunose (KAS) and Starink were employed for approximating the activation energy and pre-exponential factor. Generally, when biomass is thermally degraded, a number of parallel and simultaneous processes take place and the reaction is described in Eq. (1).

$$\text{Biomass } (s) \rightarrow \text{Volatile } (g) + \text{Residue } (s) \tag{1}$$

The reaction rate is dominated by the conversion function $f(\alpha)$ and can be defined by the following equation:

$$\frac{d\alpha}{dt} = Ae^{\left(\frac{E}{RT}\right)}f(\alpha) \tag{2}$$

The terms of E, A, R, T and t represent the activation energy of reaction, pre-exponential/frequency factor, gas constant, absolute temperature and reaction time, respectively. The instantaneous conversion ratio (α) of biomass can be expressed as:

$$\alpha = \frac{m_i - m_t}{m_i - m_f} \tag{3}$$

Where m_t is the mass at a considered time, m_i and m_f designate initial mass and final mass. A constant heating rate $(\beta = dT/dt)$ for non-isothermal condition is added to Eq. (2), the new function can be generated as follows:

$$\frac{d\alpha}{dT} = \frac{E}{\beta}e^{\left(\frac{E}{RT}\right)}f(\alpha) \tag{4}$$

Based on Eq. (4), rearranging and integrating can be expresses as:

$$g(\alpha) = \int_0^{\alpha} \frac{\mathrm{d}\alpha}{f(\alpha)} = \frac{A}{\beta}\int_{T_0}^{T} e^{\left(\frac{E}{RT}\right)}dT = \frac{AE}{\beta R}\int_x^{\alpha} \frac{e^{-x}}{x^2}dx = \frac{AE}{\beta R}\ p(x) \tag{5}$$

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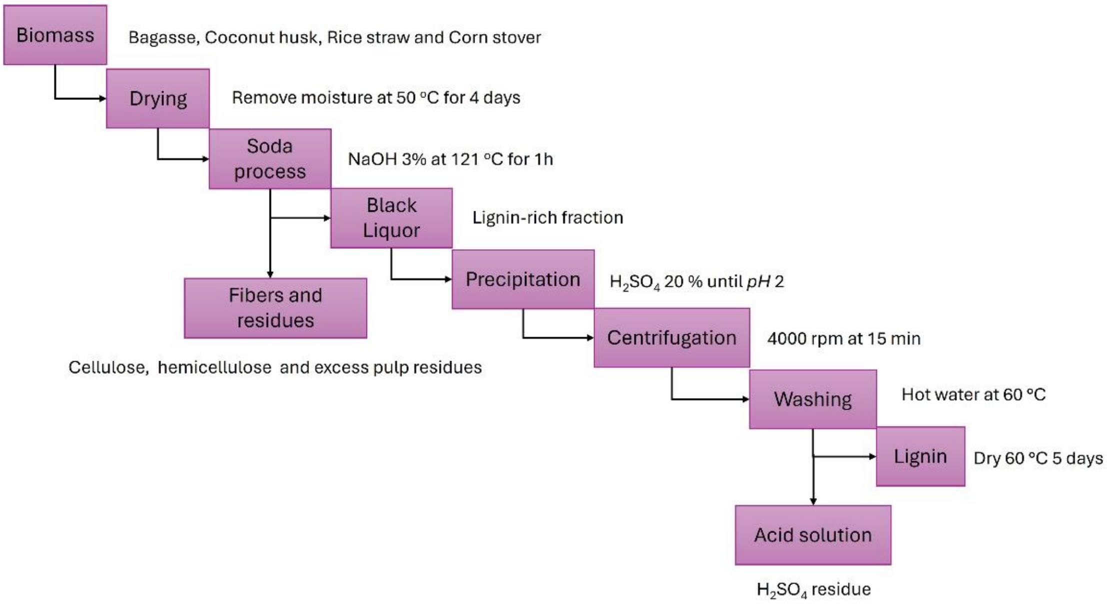

Figure 1. Schematic diagram of lignin extraction from agricultural residues.

The term $g(\alpha)$ is the reaction model function of integral form and $p(x)$ represents the Arrhenius integral/temperature integral function. It has no analytical solution except utilizing different approximation approaches for determination [10].

2.4.1. Friedman method

The assumption of Friedman method proposes the conversion function $f(\alpha)$ will be constant. This indicates that thermal degradation depends on the mass loss rate but is not influenced by temperature [11]. By taking natural logarithm of Eq. (4), Friedman differential isoconversional method can be obtained [12]:

$$ln\left(\frac{d\alpha}{dt}\right) = ln\left[\beta\left(\frac{d\alpha}{dt}\right)\right] = ln\,A + ln\left(f(\alpha)\right) - \frac{E}{RT} \quad (6)$$

Plotting $ln(d\alpha/dt)$ against $1/T$ for a specified conversion value provides the slope and $-E/R$ can be evaluated from a slope.

2.4.2. Flynn-wall-ozawa (FWO) method

FWO applied Doyle's approximation at $\ln p(x) \cong -5.3305 - 1.051x$. Based on the method developed by FWO, it can be expressed as follows [13,14]:

$$ln(\beta) = ln\left(\frac{AE}{g(\alpha)R}\right) - 5.3305 - 1.0516\left(\frac{E}{RT}\right) \quad (7)$$

Since $ln(AE/g(\alpha)R)$ keeps constant, the relationship of $\ln(\beta)$ relates to $1/T$ to offer a linear function. The E can be determined by the slope of this line $-1.0516\ (E/RT)$.

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2.4.3. Kissinger -Akahira -Sunose (KAS) method

This integral isoconversional method is commonly used in the comparative kinetic study of several materials. The assumption of KAS method fixed the value of the conversion and applied Doyle approximation for substituting the temperature integral function [15]. The general equation of KAS is presented in Eq. (8) [16,17].

$$ln\left(\frac{\beta}{T^2}\right) = ln\left(\frac{AR}{Eg(\alpha)}\right) - \frac{E}{RT} \quad (8)$$

Similar as FWO method, the plot of $ln(\beta/T^2)$ versus $1/T$ provides a linear function. The slope of this line equals to $-E/RT$.

2.4.4. Starink method

Starink considered both FWO and KAS kinetic approaches and proposed a more accurate kinetic method by combining both FWO and KAS with correct approximation [18,19]. Starink method cab be express as follow [20]:

$$A = \ln\left(\frac{\beta}{T^{1.92}}\right) = \ln\left(\frac{AR^{0.92}}{g(\alpha)E^{0.92}}\right) - 1.0008\left(\frac{E}{RT}\right) - 0.312 \quad (9)$$

The slope of $ln(\beta/T^{1.92})$ versus $1/T$ give a linear function and E can be achieved from the slope of $-1.0008(E/RT)$.

2.5 Thermodynamic analysis

Kinetic information from Friedman, FWO, KAS and Starink kinetic models is utilized to estimate the parameters of thermodynamic in various extracted lignins. The frequency factor can be obtained from Eq. (10). Thermodynamic determinations, involving the changes of enthalpy (ΔH), Gibbs free energy (ΔG) and entropy (ΔS) are presented in Eq. (11) to (12) [21]:

$$A = \left[\beta E exp\left(\frac{E}{RT_p}\right)\right]\frac{1}{RT_p{}^2} \quad (10)$$

$$\Delta H = E - RT \quad (11)$$

$$\Delta G = E - RT_p ln\left(\frac{KT_p}{hA}\right) \quad (12)$$

$$\Delta S = \frac{(\Delta H - \Delta G)}{T_p} \quad (13)$$

Where K represents the Boltzmann constant of 1.381 × 10^{-23} (J/K), h corresponds to the Plank constant of 6.626 × 10^{-34} (J·s) and T_p denotes the temperature (K) of the DTG peak.

3. RESULTS AND DISCUSSION

3.1 Yields of lignin extraction

Four different biomasses of bagasse (BG), coconut husk (CH), rice straw (RS) and corn stover (CS) were selected to extract lignin through soda pulping. The percentage yield of lignin from different sources was determined by the gravimetric method and the results are presented in Table 1. CH yielded the highest lignin level of 38.51%, followed by BG, RS and CS with yields of 31.34%, 19.37% and 15.85%, respectively. Regarding the separation of fiber in black liquor, rapid clogging was found in rice straw and corn stover using filtration. However, this problem could not be observed in bagasse and coconut husk.

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3.2 Thermogravimetric analysis

The thermogravimetry (TG) and derivative thermogravimetry (DTG) representing mass loss and degradation rate with respect to temperature under the air are shown in Figure 2. The first regime under 100 ºC could be attributed to moisture evaporation, which was relatively small (4-5%). The second regime described the major degradation stage of lignin. It was observed predominantly in the range of 180–400 ºC. This can be assigned to the degradation of lignin showing dehydrogenation of the hydroxyl group of benzyl and the fragmentation of α-O-4 and β-O-4 ether bonds at inter-unit linkages [22]. The third regime of lignin degradation occurred at a temperature above 400 ºC. This segment occurred slowly to form char and various volatiles (H_2, CO_2, CH_4 and hydrocarbons) were produced and finalized with char combustion in the presence of oxygen [23-25]. The ash residue could be observed at the final stage of thermal oxidative degradation. The amount of ash from RS and CS samples was higher than that from BG and CH around 1–2%. The formation of these inorganic salts and mineral components influences

The amount of lignin ash and its thermochemical properties [26]. According to this study, low ash formation was observed for all four lignin samples. This indicated that the washing process in this study was effective enough to remove contaminants. The thermal degradation of lignin is obviously controlled by variations in heating rates. As shown in Table 2, shifting to a higher temperature was evident with increasing heating rates from 5 to 40 ºC/min. The shifting temperature is attributed to the effect of heat transfer limitations. At high heating rates, samples cannot maintain a homogeneity of temperature between core and surface. It extends the temperature gradients and results in faster devolatilization [27-29]. The effect of different heating rates is also significant on the yield of residue (ash or char) at the end of thermal degradation. Results showed that the residue after thermal degradation using heating rates of 5, 10 and 20 ºC/min yielded ash, while increasing the heating rate up to 40 ºC/min only char was observed at the end of the degradation process. Thermal oxidative degradation of lignin requires a period to complete the degradation step for converting char to ash. At the highest heating rate of 40 ºC/min cannot provide sufficient time to complete the combustion process [30].

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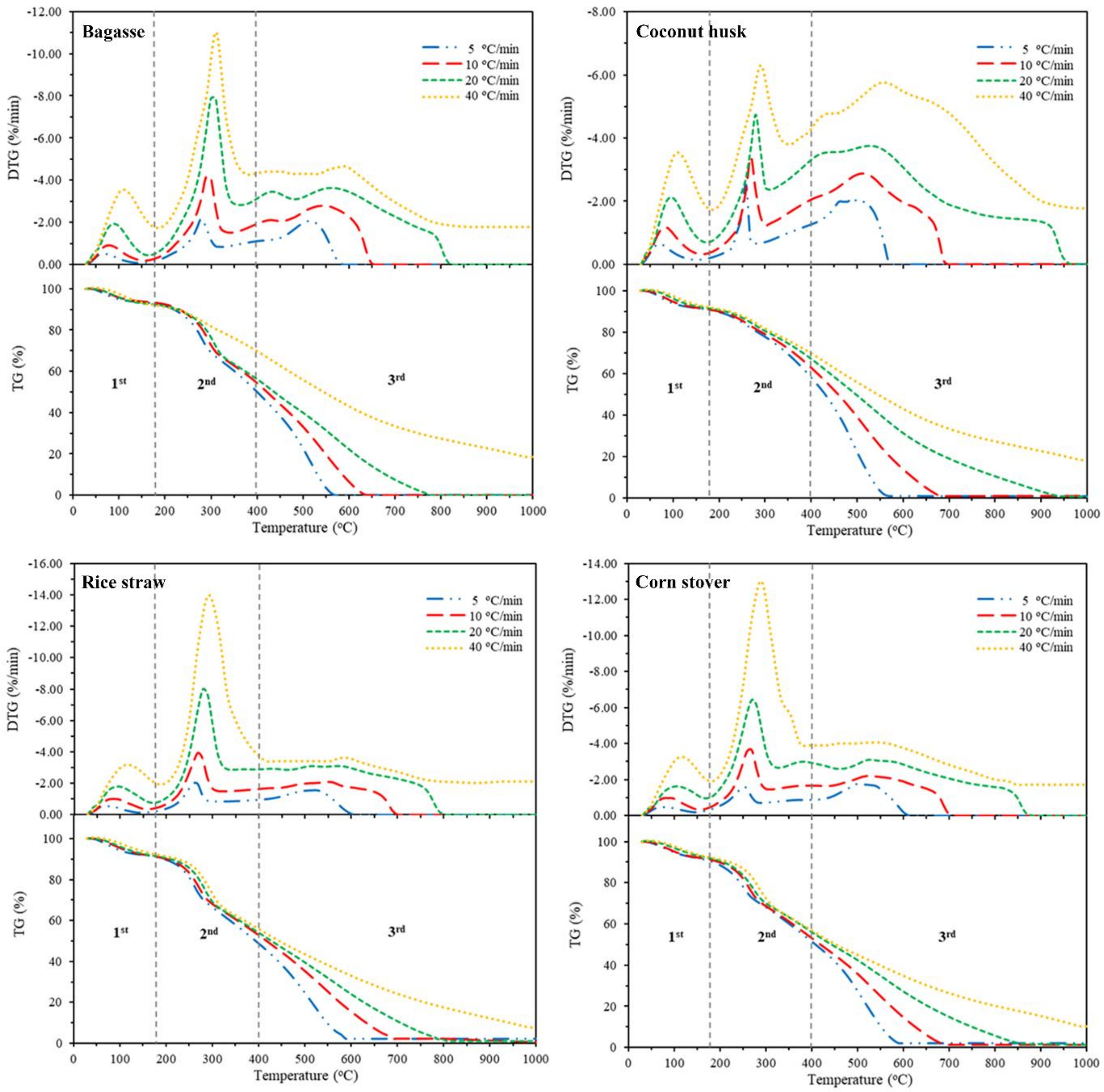

Figure 2. TG and DTG profiles of four different lignins.

3.3 Kinetic analysis

The linear regression plots of four model-free methods for all lignins are shown in Figure 3. The average activation energy (*E*) values are summarized in Figure 4. The linear correlation coefficient (R^2) is typically used to compare several kinetic models with respect to the acceptable accuracy of the results. High R^2 signifies the optimal kinetic model with experimental data. Moreover, the causes of poor fits may be due to the high heterogeneous secondary formation of char and ash residues [8,31]. The results of thermal degradation in BG, CH, RS and CS lignins in this study show in Table 3 that high R^2 values were apparent using the Friedman, FWO, KAS and Starink methods. Therefore, all kinetic models were considered promising methods to apply for determining the stability of lignin from different biomasses at a high level of acceptable accuracy.

The combination of Friedman, FWO, KAS and Starink kinetic models to determine the average *E* values is shown in Figure 4. By comparing the individual biomasses, the horizontal lines represented the means of the *E* throughout the whole degradation process. These lines indicated that extracted lignin from CS (164.05 kJ/mol) and RS (159.96 kJ/mol) had higher activation energies than BG (136.24 kJ/mol) and

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CH (114.01 kJ/mol). With an increase in conversion, the degradation behavior of all lignin samples could be observed to indicate that high energy requirements occurred in the beginning and decreased continuously until the end of the degradation process. The thermal degradation profiles of combination kinetic models also confirmed that the thermal oxidative degradation of soda lignin was the result of multiple reaction systems.

The statistical analysis for comparing the variances of four kinetic models showed that at the p = 0.05 level of significance, the critical F-distribution was adapted with a 95% confidence interval and correlated with the right tail area. The error degree of freedom connected with the number of observations was 64, whereas the treatment degree of freedom related to the number of kinetic models was 3. The critical F-distribution ($F_{(p=0.05,3,64)}$) was 2.7481 and the F-test results of BG (0.1188), CH (0.1634), RS (0.0717) and CS (0.0575) were lower than the critical value, accepting them for analysis of statistical data. It can be stated that there is no difference in the average of these four kinetic methods within the test population. The A results of soda lignins from four different biomasses are exhibited in Table 1. The A value of CH lignin degradation at α = 0.2 was 10^{18} s^{-1}, while BG, RS and CS lignins were degraded at different α of 0.35 and showed A values between 10^{24} and 10^{32} s^{-1}. The value of A is less than 10^9 s^{-1}, indicating a surface-control reaction but the A value is higher than 10^9 s^{-1}, meaning that the reaction is independent of surface area [30,32].

3.4 Thermodynamic analysis

According to thermodynamic analysis, kinetic parameters (E and A) of lignin degradation derived from four model-free methods were applied for thermodynamic parameter determination (Table 1). The ΔH corresponds to a specific amount of heat energy that is necessary for degradation to break the heterometric linkages in the lignocellulosic biomass structure. The order of the average ΔH from lower to higher is as follows: lignin CS > RS > BG > CH. A small ΔH value is connected with the formation of the transition state at a lower energy barrier [33]. This means that CH lignin requires the lowest energy demand to degrade when compared with the others. The positive ΔH were found during lignin degradation. This suggests that the energy required for the lignin thermal decomposition is a naturally endothermic process.

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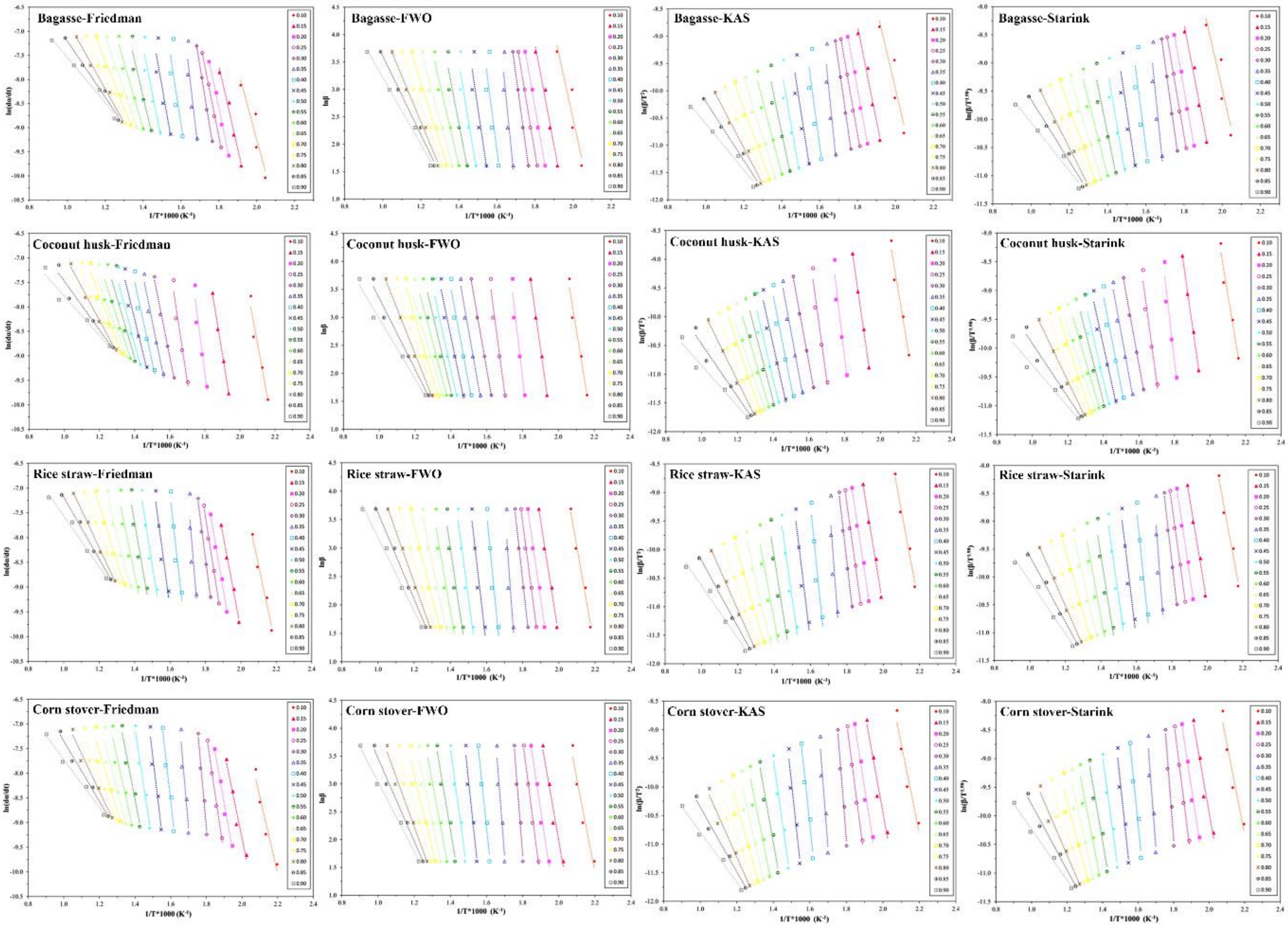

Figure 3. Linear regression plots of the Friedman, FWO, KAS and Starink models.

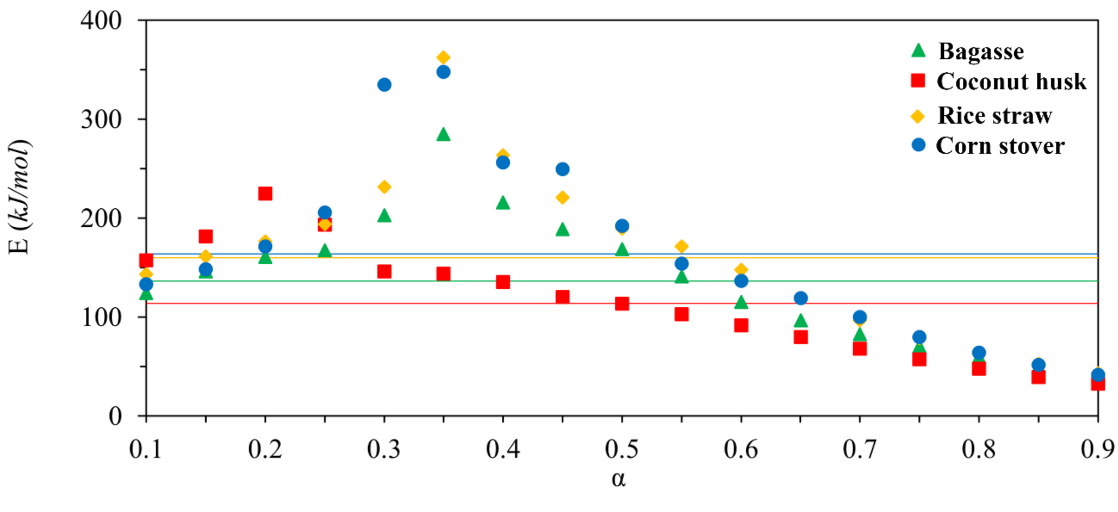

Figure 4. The average activation energies of Friedman, FWO, KAS and Starink models.

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Table 1. Thermodynamic parameters of extracted lignins according to four model-fre e methods

α	A (s^{-1})				$ΔH$ (kJ/mol)				$ΔG$ (kJ/mol)				$ΔS$ (J/mol)			
	Friedman	FWO	KAS	Starink	Friedman	FWO	KAS	Starink	Friedman	FWO	KAS	Starink	Friedman	FWO	KAS	Starink
BG																
0.10	1.5E+09	1.4E+10	2.2E+09	2.4E+09	116.00	126.24	117.82	118.16	163.53	163.14	163.46	163.44	-82.96	-64.41	-79.65	-79.04
0.15	1.8E+11	1.6E+12	2.3E+11	2.5E+11	138.10	148.14	139.19	139.55	162.73	162.40	162.69	162.68	-42.97	-24.90	-41.02	-40.37
0.20	4.6E+12	4.0E+13	5.4E+12	5.8E+12	153.01	162.98	153.74	154.11	162.26	161.96	162.23	162.22	-16.14	1.77	-14.83	-14.16
0.25	2.1E+13	1.8E+14	2.3E+13	2.5E+13	159.98	169.92	160.48	160.86	162.05	161.77	162.03	162.02	-3.61	14.22	-2.71	-2.03
0.30	4.5E+16	3.8E+17	4.8E+16	5.2E+16	195.67	205.59	195.95	196.33	161.12	160.89	161.11	161.10	60.30	78.01	60.80	61.49
0.35	2.0E+24	1.6E+25	1.9E+24	2.1E+24	277.87	287.79	277.78	278.18	159.48	159.31	159.48	159.47	206.63	224.21	206.45	207.16
0.40	7.8E+17	6.6E+18	6.9E+17	7.5E+17	208.93	218.88	208.34	208.76	160.81	160.59	160.82	160.81	83.99	101.72	82.93	83.68
0.45	2.3E+15	2.0E+16	1.8E+15	2.0E+15	181.81	191.83	180.80	181.24	161.46	161.21	163.22	161.47	35.52	53.44	30.69	34.51
0.50	3.3E+13	2.9E+14	2.4E+13	2.7E+13	162.10	172.21	160.72	161.18	161.99	161.71	162.03	162.01	0.20	18.32	-2.28	-1.45
0.55	9.1E+10	8.3E+11	6.2E+10	6.9E+10	134.88	145.09	133.15	133.62	162.84	162.50	162.90	162.88	-48.78	-30.38	-51.92	-51.06
0.60	3.2E+08	3.0E+09	2.0E+08	2.2E+08	108.88	119.23	106.78	107.28	163.82	163.40	163.91	163.89	-95.87	-77.10	-99.70	-98.80
0.65	5.3E+06	5.3E+07	3.1E+06	3.5E+06	90.28	100.77	87.84	88.35	164.67	164.17	164.79	164.77	-129.82	-110.65	-134.31	-133.36
0.70	2.4E+05	2.6E+06	1.3E+05	1.5E+05	76.35	86.98	73.60	74.14	165.42	164.84	165.59	165.56	-155.45	-135.88	-160.53	-159.54
0.75	1.6E+04	1.8E+05	8.3E+03	9.4E+03	64.26	75.04	61.22	61.77	166.19	165.50	166.41	166.37	-177.90	-157.88	-183.57	-182.54
0.80	1.5E+03	1.8E+04	7.2E+02	8.2E+02	53.75	64.69	50.42	50.99	166.98	166.16	167.26	167.21	-197.61	-177.09	-203.91	-202.83
0.85	1.5E+02	2.0E+03	6.6E+01	7.6E+01	43.69	54.83	40.03	40.62	167.88	166.89	168.25	168.19	-216.73	-195.58	-223.78	-222.64
0.90	1.8E+01	2.5E+02	6.7E+00	7.7E+00	34.35	45.74	30.28	30.90	168.90	167.68	169.42	169.34	-234.82	-212.81	-242.83	-241.60
Avg.	-	-	-	-	129.41	139.76	128.13	128.59	163.65	163.18	163.86	163.73	-	-	-	-
CH																
0.10	4.0E+12	4.8E+12	9.1E+11	9.7E+11	155.69	156.56	148.68	149.00	177.62	177.60	177.85	177.84	-38.27	-36.70	-50.91	-50.34
0.15	5.0E+14	1.0E+15	1.6E+14	1.8E+14	178.56	182.01	173.21	173.57	176.93	176.84	177.09	177.08	2.84	9.03	-6.76	-6.13
0.20	4.1E+18	1.0E+19	1.4E+18	1.5E+18	221.34	225.60	216.25	216.62	175.85	175.75	175.97	175.96	79.40	87.00	70.30	70.97
0.25	7.4E+15	1.3E+16	1.6E+15	1.8E+15	191.29	194.08	184.08	184.48	166.59	162.51	164.10	176.77	43.11	55.10	34.88	13.46
0.30	3.7E+11	6.3E+11	6.7E+10	7.3E+10	144.43	146.98	136.38	136.81	160.54	158.36	158.32	160.27	-28.12	-19.87	-38.28	-40.95
0.35	1.8E+11	4.9E+11	4.7E+10	5.2E+10	141.07	145.77	134.76	135.20	158.12	147.95	148.35	158.33	-29.76	-3.80	-23.71	-40.36
0.40	2.5E+10	9.5E+10	8.4E+09	9.2E+09	131.85	138.03	126.62	127.08	157.35	158.33	148.66	157.64	-44.50	-35.43	-38.45	-53.33
0.45	9.5E+08	3.9E+09	3.2E+08	3.5E+08	116.43	123.10	111.28	111.75	156.08	159.88	161.48	155.28	-69.21	-64.20	-87.61	-75.96
0.50	1.7E+08	9.9E+08	7.3E+07	8.1E+07	108.37	116.62	104.47	104.96	155.47	159.41	152.32	154.59	-82.20	-74.68	-83.51	-86.62
0.55	1.3E+07	1.2E+08	8.2E+06	9.2E+06	96.40	106.75	94.30	94.80	154.01	156.02	137.23	153.09	-100.54	-85.99	-74.92	-101.73
0.60	1.2E+06	1.1E+07	7.2E+05	8.1E+05	85.41	95.85	83.07	83.58	153.56	155.04	98.56	151.56	-118.94	-103.30	-27.04	-118.64
0.65	9.1E+04	9.0E+05	5.2E+04	5.8E+04	73.52	84.06	70.94	71.46	152.34	154.68	157.54	151.47	-137.56	-123.24	-151.14	-139.63
0.70	7.3E+03	7.6E+04	3.9E+03	4.4E+03	62.02	72.69	59.20	59.74	151.16	152.39	154.35	150.39	-155.56	-139.10	-166.05	-158.20
0.75	6.9E+02	7.5E+03	3.4E+02	3.9E+02	51.37	62.17	48.29	48.84	150.06	152.15	150.36	149.22	-172.24	-157.04	-178.14	-175.18
0.80	8.1E+01	9.5E+02	3.8E+01	4.3E+01	41.87	52.84	38.49	39.07	149.05	151.92	166.58	148.36	-187.05	-172.92	-223.53	-190.74
0.85	1.3E+01	1.6E+02	5.4E+00	6.2E+00	33.78	44.95	30.06	30.66	148.33	150.68	165.22	146.47	-199.92	-184.52	-235.88	-202.12
0.90	2.6E+00	3.7E+01	9.6E-01	1.1E+00	26.97	38.40	22.84	23.46	147.04	148.41	166.72	144.23	-209.55	-191.98	-251.10	-210.76
Avg.	-	-	-	-	109.43	116.85	104.88	105.36	158.24	158.70	156.51	158.15	-	-	-	-

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Table 1. Thermodynamic parameters of extracted lignins according to four model-fre e methods (cont.)

α	*A* (s^{-1})				*ΔH* (kJ/mol)				*ΔG* (kJ/mol)				*ΔS* (J/mol)			
	Friedman	FWO	KAS	Starink	Friedman	FWO	KAS	Starink	Friedman	FWO	KAS	Starink	Friedman	FWO	KAS	Starink
RS																
0.10	2.8E+11	3.1E+12	5.3E+11	5.7E+11	134.80	145.46	137.61	137.92	169.04	168.67	168.94	168.93	-59.75	-40.52	-54.67	-54.11
0.15	1.8E+13	1.7E+14	2.5E+13	2.7E+13	153.25	163.41	154.83	155.17	168.42	168.12	168.38	168.36	-26.49	-8.22	-23.64	-23.02
0.20	6.0E+14	5.7E+15	7.9E+14	8.5E+14	169.02	179.08	170.20	170.56	167.95	167.68	167.92	167.91	1.87	19.89	3.99	4.62
0.25	2.8E+16	2.6E+17	3.5E+16	3.8E+16	186.26	196.26	187.19	187.55	164.12	163.89	167.46	164.09	38.64	56.49	34.43	40.95
0.30	1.3E+20	1.1E+21	1.5E+20	1.6E+20	223.98	233.94	224.68	225.05	161.70	161.60	166.58	161.73	108.69	126.25	101.38	110.50
0.35	5.2E+32	4.7E+33	5.6E+32	6.1E+32	355.31	365.23	355.62	356.01	164.36	164.23	167.36	164.35	333.24	350.79	333.80	334.48
0.40	3.2E+23	1.3E+24	1.4E+23	1.5E+23	259.31	265.75	255.60	256.00	165.89	165.77	165.96	165.95	163.03	174.49	156.44	157.16
0.45	2.3E+19	1.1E+20	1.1E+19	1.2E+19	216.43	223.53	212.86	213.29	163.06	163.00	166.84	163.21	93.15	105.64	80.31	87.40
0.50	1.9E+16	1.1E+17	8.7E+15	9.7E+15	184.54	192.16	180.98	181.43	164.29	164.22	164.51	164.50	35.34	48.77	28.75	29.55
0.55	3.0E+14	2.3E+15	1.7E+14	1.9E+14	165.86	175.01	163.36	163.83	168.05	167.79	168.12	168.10	-3.81	12.60	-8.30	-7.46
0.60	1.2E+12	1.2E+13	8.2E+11	9.1E+11	141.41	151.66	139.54	140.02	168.81	168.47	168.87	166.19	-47.82	-29.35	-51.19	-45.66
0.65	2.2E+09	2.3E+10	1.3E+09	1.5E+09	113.30	123.70	111.06	111.56	166.71	169.45	169.96	169.94	-93.22	-79.84	-102.79	-101.87
0.70	1.3E+07	1.4E+08	7.0E+06	7.8E+06	90.57	101.13	87.98	88.51	167.60	167.11	171.05	167.71	-134.43	-115.15	-144.98	-138.23
0.75	2.2E+05	2.5E+06	1.1E+05	1.2E+05	72.87	83.60	69.93	70.48	168.71	168.09	168.90	168.87	-167.26	-147.45	-172.73	-171.71
0.80	8.0E+03	1.0E+05	3.7E+03	4.2E+03	58.65	69.57	55.34	55.91	172.93	172.15	173.20	173.15	-199.45	-179.01	-205.68	-204.60
0.85	5.8E+02	8.0E+03	2.4E+02	2.8E+02	47.50	58.65	43.81	44.40	173.89	172.93	174.25	174.19	-220.58	-199.44	-227.65	-226.51
0.90	6.0E+01	9.2E+02	2.2E+01	2.6E+01	38.01	49.45	33.88	34.50	174.88	173.71	175.38	175.31	-238.87	-216.86	-246.96	-245.73
Avg.	-	-	-	-	153.59	163.39	152.03	152.48	167.67	167.46	169.04	167.79	-	-	-	-
CS																
0.10	2.7E+10	3.0E+11	5.3E+10	5.7E+10	124.44	135.17	127.39	127.70	166.31	165.93	166.20	166.19	-73.07	-53.68	-67.73	-67.17
0.15	1.0E+12	1.0E+13	1.5E+12	1.6E+12	140.49	150.72	142.28	142.62	165.75	165.41	165.69	165.67	-44.07	-25.65	-40.84	-40.23
0.20	1.7E+14	1.7E+15	2.3E+14	2.5E+14	163.49	173.57	164.81	165.16	165.03	164.75	164.99	164.98	-2.70	15.40	-0.32	0.31
0.25	4.1E+17	3.8E+18	5.1E+17	5.5E+17	198.23	208.25	199.25	199.61	169.49	167.24	176.78	167.45	50.17	71.58	39.22	56.12
0.30	1.7E+30	8.4E+30	1.1E+30	1.2E+30	329.45	336.62	327.27	327.64	169.60	166.39	178.29	172.58	278.97	297.09	260.00	270.62
0.35	9.1E+31	1.2E+32	1.4E+31	1.5E+31	347.42	348.75	338.84	339.24	161.45	161.43	161.57	161.56	324.55	326.91	309.38	310.08
0.40	2.0E+23	2.0E+23	1.9E+22	2.1E+22	257.13	257.14	246.66	247.08	162.89	162.89	161.08	163.08	164.48	164.50	145.85	146.60
0.45	2.6E+22	4.9E+22	4.3E+21	4.7E+21	248.01	250.86	239.88	240.32	168.76	166.61	179.30	168.83	138.30	147.04	105.73	124.76
0.50	8.4E+16	1.7E+17	1.3E+16	1.4E+16	191.16	194.21	182.68	183.14	168.53	167.34	167.63	168.61	39.49	46.90	26.27	25.35
0.55	1.4E+13	3.9E+13	2.6E+12	2.9E+12	152.31	156.80	144.71	145.20	165.37	165.23	165.61	168.10	-22.78	-14.71	-36.46	-39.98
0.60	1.7E+11	8.8E+11	5.2E+10	5.8E+10	132.53	139.88	127.33	127.84	166.02	165.77	166.21	165.59	-58.44	-45.18	-67.84	-65.89
0.65	2.7E+09	2.3E+10	1.2E+09	1.4E+09	114.19	123.68	110.74	111.25	169.86	166.34	166.86	166.84	-97.16	-74.45	-97.94	-97.00
0.70	2.9E+07	3.3E+08	1.6E+07	1.8E+07	94.29	104.91	91.56	92.10	170.92	170.40	167.74	171.03	-133.73	-114.30	-132.94	-137.75
0.75	2.8E+05	3.4E+06	1.4E+05	1.6E+05	74.05	84.83	71.00	71.56	171.93	171.29	172.12	172.09	-170.82	-150.90	-176.47	-175.45
0.80	7.7E+03	9.9E+04	3.5E+03	4.0E+03	58.52	69.49	55.12	55.70	169.78	169.00	170.05	170.00	-194.18	-173.67	-200.56	-199.48
0.85	4.2E+02	5.9E+03	1.7E+02	2.0E+02	46.19	57.40	42.41	43.01	170.83	169.87	171.21	171.15	-217.52	-196.28	-224.77	-223.62
0.90	3.7E+01	5.9E+02	1.3E+01	1.5E+01	36.05	47.55	31.81	32.44	171.91	170.71	172.45	172.36	-237.12	-214.94	-245.44	-244.20
Avg.	-	-	-	-	159.29	167.05	155.52	155.98	167.91	166.86	169.04	168.01	-	-	-	-

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The direction of the chemical process and the energy change throughout the formation of the activated complex are observed using the ΔG value [34]. The variation of ΔG at the conversion extent of 0.1-0.9 could be observed in Table 1. The average ΔG for BG, CH, RS and CS obtained from four kinetic models were 163.61, 157.90, 167.99 and 167.96 kJ/mol, respectively. The greater ΔG value of RS and CS pointed out that both lignins were more difficult to thermally convert than BG and CH. The positive magnitude of ΔG is apparent at the thermal conversion of all soda lignins. It is evident from the results that the thermal oxidative degradation of lignin correlates with a non-spontaneous reaction [35].

According to the higher ΔS degree, the substance is out of equilibrium with itself, resulting in an increasing degree of disorder in the system [36]. Results from Table 1 showed that thermal degradation soda lignin had a higher minus value of ΔS at the end of conversion. This implies that the disordered degree of lignin is decreased after thermal oxidative degradation. In addition, the co-occurrence of both positive and negative ΔS values can be observed during the process. This characteristic confirms that the specific thermal degradation processes of lignin have complex reactions [37].

4. CONCLUSIONS

Based on the obtained data and kinetic and thermodynamic analyses, the following conclusions were created as follows:

1. Thermogravimetric analysis showed that the thermal degradation of lignin could be separated into three regimes, representing the moisture content, lignin degradation and decomposition of residue.
2. Friedman, FWO, KAS and Starink kinetic models were reliable for predicting the thermal stability of lignin at an acceptable level of accuracy.
3. Rice straw and corn stover had the highest thermal stability compared to the others.
4. Thermodynamic parameters (ΔH, ΔG and ΔS) are obtained based on E values, revealing that thermal degradation of soda lignins is an endothermic reaction, which corresponds to a complex mechanism and degradation has never been spontaneous in nature.

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Application of Geographic Information System for PM2.5 Risk Assessment in Din Daeng District, Bangkok

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ABSTRACT

Air pollution from particulate matter smaller than 2.5 microns (PM2.5) is a global concern. In Din Daeng District, Bangkok, PM2.5 levels frequently exceed Thailand's air quality standards from January to April in every year due to traffic pollution and temperature inversions. Furthermore, climate change is expected to exacerbate the inversion phenomenon, significantly elevating risks to vulnerable populations, including children, the elderly, and individuals with respiratory and cardiovascular conditions. This study employs Geographic Information System (GIS) technology to create risk maps for PM2.5, aiding local governments in developing strategies to mitigate its impact. Data on PM2.5 concentrations, building footprints, and the distribution of vulnerable populations were collected and analysed for risks using Weighted Linear Combination (WLC) with assigned scores based on expert inputs. According to the assigned scores, people vulnerability is the most critical factor in assessing PM2.5 risk with a score of 45.00%, followed by PM2.5 concentration (33.33%) and population density (21.67%). Because of different patterns of population distribution in the area, the study also reveals that risk levels are higher during the day than at night, with 11.20% of the population at the highest risk during daytime, compared to 1.11% at night under worst case scenario. The study recommends different mitigation measures based on the time of day and suggests three actionable strategies: 1) distributing PM2.5 masks to all children monthly, 2) installing outdoor PM2.5 monitoring devices, and 3) constructing PM2.5 pollution control rooms for use when pollution levels exceed standards. The first two measures are short-term actions that local governments can implement immediately, while the third requires long-term investment and is particularly effective for protecting vulnerable groups.

Keyword: PM2.5/ Geographical Information System/ Risk assessment

1. INTRODUCTION

Air pollution, particularly Particulate Matter with a diameter of less than 2.5 microns (PM2.5), poses a significant threat to human health, especially for vulnerable groups in densely populated urban areas [1,2,3]. Exposure to high PM2.5 concentrations can severely impact respiratory and cardiovascular systems, increasing mortality risk [4,5]. Air pollution is closely linked to meteorological conditions; hence, climate change affects PM2.5 concentrations by altering patterns of precipitation, atmospheric circulation, temperature, radiation, and ventilation. These changes raise concerns about the intensity and frequency of PM2.5 events [6,7,8]. Consequently, assessing PM2.5 exposure has become a critical focus for governments and researchers [5,9]. Therefore, research on PM2.5 risk mapping is essential for helping national and local governments develop effective measures to mitigate its impact, particularly in urban areas.

Risk assessment is complex, relying on mathematical models to estimate the likelihood and intensity of specific events at particular locations [10]. Historically, spatial risk assessment was challenging due to the lack of advanced Geographic Information Systems (GIS), limited access to high-quality spatial data, and computational constraints that hindered accurate modeling of spatial distribution and risk intensity. However, advancements in GIS technology and improved access to high-quality spatial data, such as building footprints, have significantly enhanced the accuracy of urban

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population distribution analysis, which is crucial for risk assessment. The successful application of GIS in risk assessments has been demonstrated in numerous studies [11,12,13].

This study focuses on Din Daeng District, a densely populated urban area in the northern part of Bangkok, Thailand, to demonstrate the application of GIS for PM2.5 risk assessment. The district consistently experiences high PM2.5 concentrations between January and April each year [14,15]. In addition, this study proposes PM2.5 impact mitigation measures based on field surveys. The goal is to provide the local government of Din Daeng District with high-resolution PM2.5 risk maps to inform appropriate responses and actions to combat air pollution.

2. METHODOLOGY

2.1 Study area

Din Daeng District, located in the Bangkok Metropolitan Area, covers a total area of 8.35 km², comprising Din Daeng Subdistrict (3.73 km²) and Ratchadaphisek Subdistrict (4.62 km²), as shown in Figure 1. According to the Department of Provincial Administration, in 2023, the district had 109,802 registered residents and 64,834 households. Din Daeng is considered a key economic area in Bangkok due to its high concentration of department stores, condominiums, offices, government agencies, and schools, which attract people from nearby districts and provinces. The latent population is estimated to add an additional 75% to the registered population in the area [16]. Pollution Control Department reported that in 2021, there were 101 days, and in 2022, there were 91 days when the monitored PM2.5 concentrations exceeded Thailand's air quality standards [17].

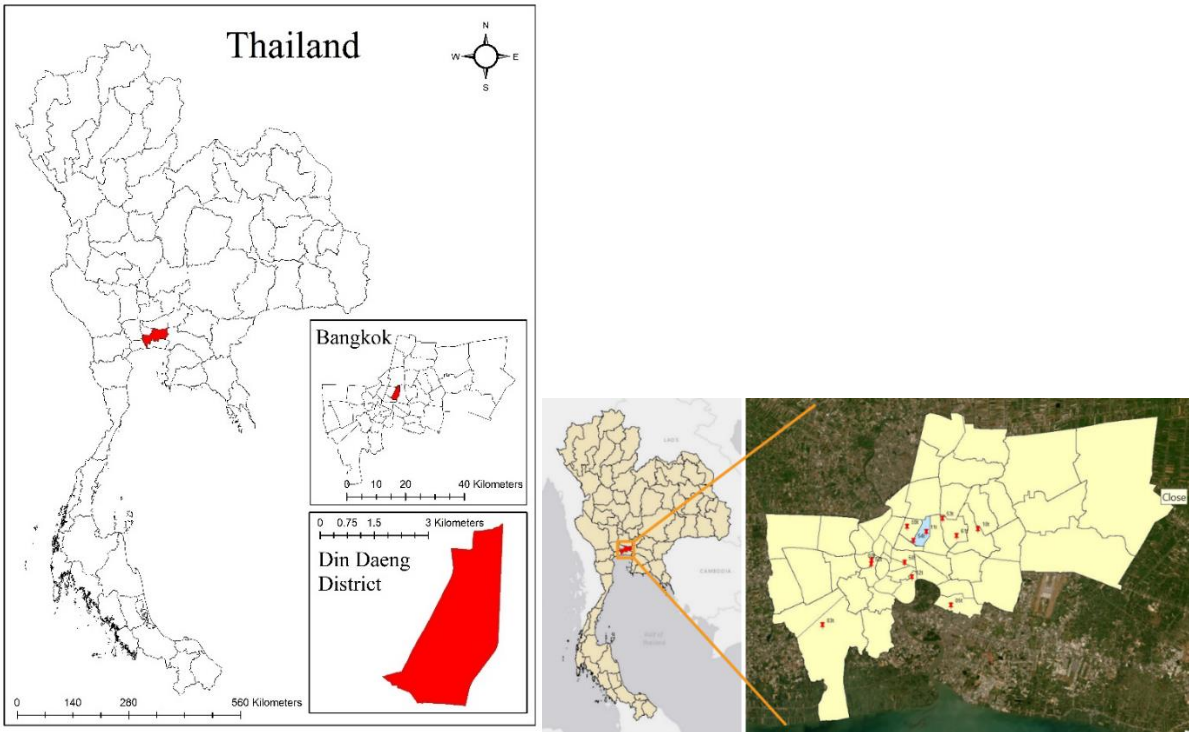

Figure 1. Location of Din Daeng District and 12 air quality monitoring stations in Bangkok

2.2 Development of PM2.5 risk map

The methodological flow is illustrated in Figure 2. PM2.5 risk is determined by three factors: PM2.5 concentration, population density, and vulnerability. All maps were generated using ArcGIS Version 10.8 (ESRI), grided into 20 m x 20 m.

The PM2.5 concentration map was created using the Inverse Distance Weighting (IDW) technique with data from 12 Pollution Control Department (PCD) air quality monitoring stations in Bangkok as shown in Figure 1 [18]. Daily PM2.5 concentration data from 1 January 2023 to 31 March

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2023, were used to produce spatial distribution maps at the 50th, 95th, and 99th percentiles. The population distribution maps were based on building footprints in the Din Daeng District in 2022, sourced from the Department of City Planning and Urban Development under the Bangkok Metropolitan Administration (BMA). The maps were divided into daytime and nighttime to reflect different settlement patterns: during the day, people are assumed to reside in non-residential buildings such as offices, schools, and government buildings, while at night, they reside in residential buildings including hotels. Daytime population density was calculated by summing the surveyed census data from 2020 with the commuter population [16], then dividing by the total non-residential building area. Nighttime population density was calculated by summing the surveyed census data from 2020 with the estimated non-registered population in the area [16], then dividing by the total residential building area. The gridded population for each building was determined by multiplying the population density by the floor area (number of floors multiplied by the building area), then dividing by 400 (as a grid size is 20 m x 20 m). The vulnerability map shows the locations of nurseries, schools, hospitals, and nursing homes, along with the number of occupants, as collected during field surveys.

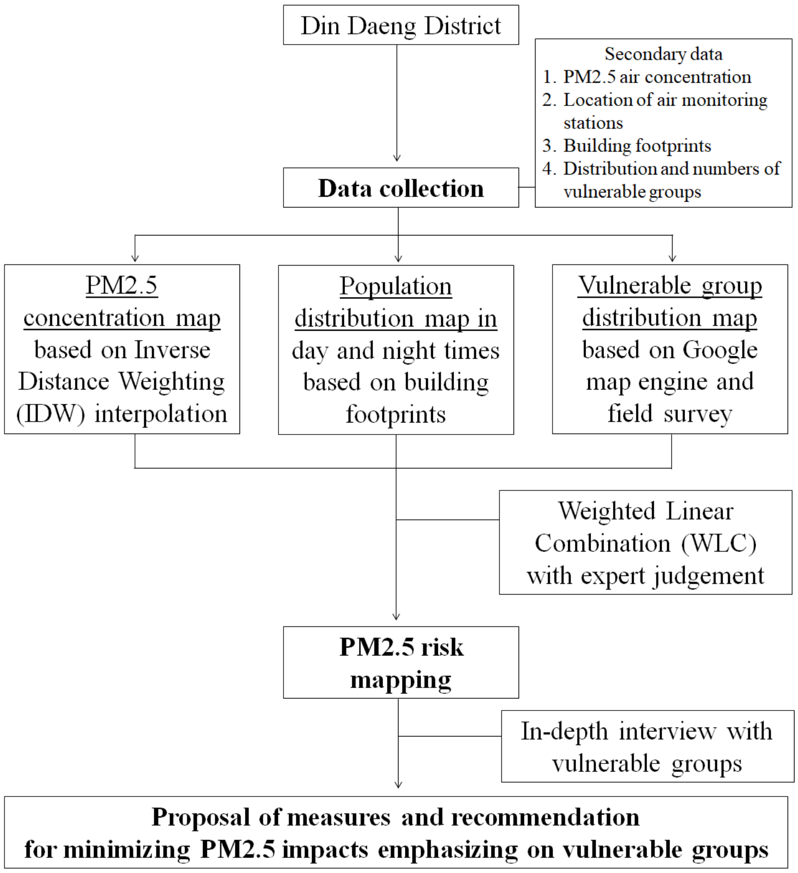

Figure 2. Methodological flow

A Weighted Linear Combination (WLC) method was applied to calculate PM2.5 risks, incorporating PM2.5 concentration, population distribution, and vulnerability factors. These factors were weighted to a total score of 100 by three academic experts in the fields of air pollution, population studies, and health. The selection criteria for experts include relevant academic backgrounds and extensive journal publications in the fields especially in Bangkok area. Similarly, spatial values across the three maps were converted to ordinal values based on expert judgment. All maps were then rasterized, and PM2.5 risks were calculated using the equation below:

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$$Aij = \frac{\sum_{i=1}^{n} WjXij}{\sum_{j=1}^{k} Wj\,Yj}$$

Where; A_j=risk score of grid I; W_j=weighting based on expert judgement for factor j; X_{ji}=ordinal value of factor j at grid i; Y_j=maximum ordinal value of factor j. The risk scores are categorized into "very low", "low", "medium", "high" and "very high" and the definitions are summarized in Table 1.

Table 1. Risk score categorization

Risk level	Risk score	Definition
Very low	0.00-0.20	Carrying out activities or operations does not necessarily require risk management or further control improvements.
Low	0.21-0.40	Carrying out activities or operations does not necessarily require additional risk management. However, activities or operations involving vulnerable groups should reduce outdoor activities, and risk management should be consistently maintained to ensure that adequate risk controls are still in place.
Medium	0.41-0.60	Carrying out activities or operations should reduce outdoor activities. For activities or operations involving vulnerable groups, wearing dust masks is recommended. At this level of risk, information on air pollution and self-protection methods should be communicated to the public.
High	0.61-0.80	Activities or operations during this period may be considered for cancellation as appropriate until the risk is reduced. If going outdoors is necessary, wearing a dust mask is recommended. At this level of risk, information about air pollution conditions and self-protection methods should be communicated to the public.
Very high	0.81-1.00	Activities currently underway cannot continue until the risk is reduced. If the risk cannot be mitigated, the activity must be halted or suspended. At this level of risk, information about air pollution conditions and self-protection methods should be communicated to the public.

2.3 Proposal of PM2.5 impact minimization measure

Field surveys were conducted in March 2024 for face-to-face interviews with vulnerable groups in Din Daeng District. Response to time with PM2.5 concentration exceeding the air quality standards and expected support from local governments were inquired. Costs of implementing the expected support is estimated following Thailand market prices as of 30 April 2024.

3. RESULTS AND DISCUSSION

3.1 PM2.5 risk map

Figure 3 shows PM2.5 concentration maps at the 50^{th}, 95^{th}, and 99^{th} percentiles. According to Thailand's air quality standards, ambient PM2.5 concentrations should not exceed 37.5 $\mu g/m^3$ over a 24-hour period or 15 $\mu g/m^3$ annually. The ranges of minimum and maximum concentrations at the 50^{th}, 95^{th}, and 99^{th} percentiles were 29.0-37.0 $\mu g/m^3$, 63.4-72.5 $\mu g/m^3$, and 77.11-91.33 $\mu g/m^3$, respectively. Figure 4 illustrates the population distribution maps for daytime and nighttime. During the day, people are assumed to be at their workplaces, leading to minimal population dispersion but high density in outer areas along the main roads. At night, people return to their residences, resulting in greater population dispersion across all residential zones. From these maps, considering different population patterns between daytime and nighttime can overcome shortcomings of remote sensing as described in the previous study [19]. As for the vulnerable group map shown in Figure 5, these groups tend to cluster on the west side, which accounts for 75% of all vulnerable buildings, while the Ratchadaphisek Subdistrict accounts for the remaining 25%.

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The weighting and criteria for ordinal conversion values determined by experts for PM2.5 concentration, population distribution, and vulnerability are presented in Table 2 and Table 3, respectively. The weighting scores show that vulnerable groups (45.00%) are the most significant factor influencing PM2.5 risk, followed by PM2.5 concentration (33.33%) and population distribution (21.67%). Older adults are positively and strongly associated with natural mortality due to short-term exposure to PM2.5 [20, 21]. Additionally, high population density significantly increases the risk of PM2.5 due to pollution centralization and congestion effects [22, 23].

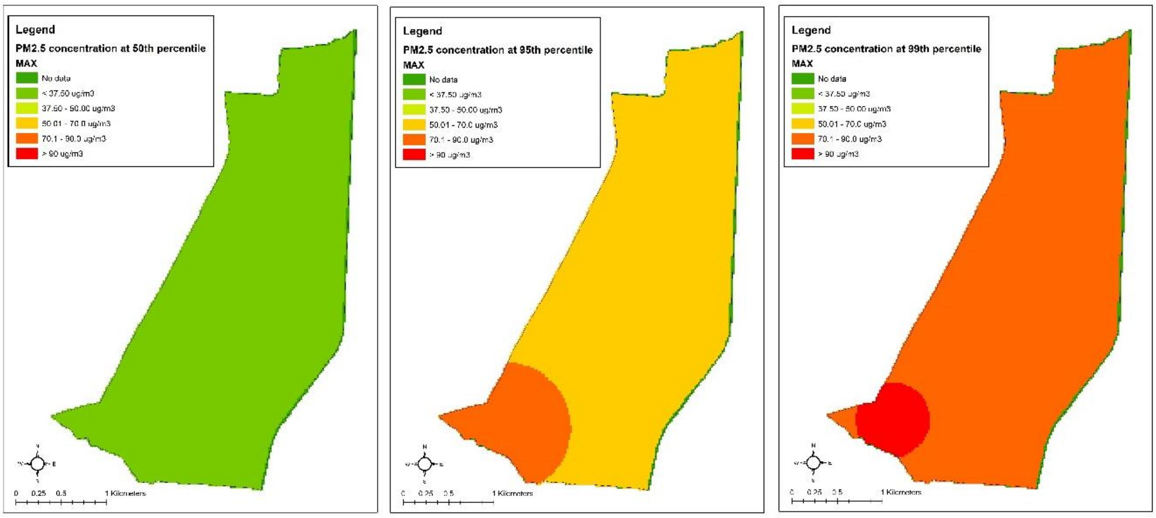

Figure 3. PM2.5 concentration maps at 50th percentile (left), 95th percentile (middle) and 99th percentile (right)

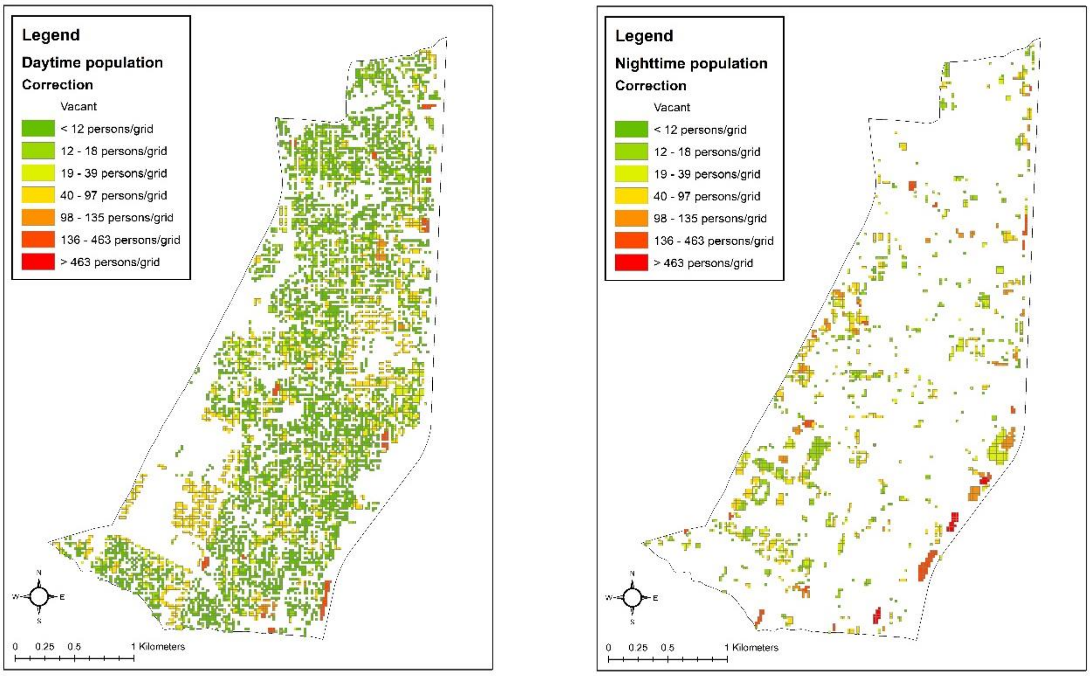

Figure 4. Population distribution in daytime (left) and night time (right)

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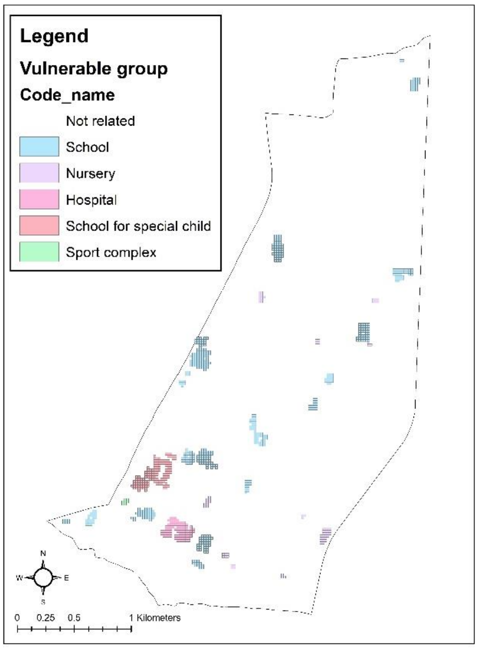

Figure 5. Location of vulnerable groups

Table 2. Weighting scores of PM2.5 risk factors by experts

PM2.5 Risk factor	Expert scoring			Average score
	Expert No.1	Expert No.2	Expert No.3	
PM2.5 concentration	40	30	40	33.33
Population density	30	10	25	21.67
Vulnerability	30	60	35	45
Total	100	100	100	100

Table 3. Criterion for ordinal conversion by experts

PM2.5 concentration		
PM2.5 concentration	Definition	Ordinal score
> 75.0 µg/m^3	Air quality affects health	5
37.6 – 75.0 µg/m^3	Air quality is likely to affect health	4
25.1 – 37.5 µg/m^3	Moderate air quality	3
15.0 – 25.0 µg/m^3	Good air quality	2
< 15 µg/m^3	Very good air quality	1
Population density		
Population Density	Definition	Ordinal score
> 50 person/m^2	Relatively high density	5
20.0 – 50.0 person/m^2	High density	4
10.0 – 20.0 person/m^2	Medium density	3
4.0 – 10.0 person/m^2	Low density	2
< 4 person/m^2	Very low density	1
Vulnerability		
Vulnerable group	Definition	Ordinal score
Young children (ages 0-5), elderly (60 years and above), and patients	High vulnerability	3
Primary school children (ages 6-12)	Medium vulnerability	2
Secondary school children (ages 13-18) and older	Low vulnerability	1

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PM2.5 risk maps are shown in Figure 6, and the affected population during daytime and nighttime is summarized in Table 4 and Table 5, respectively. The results indicate that, during the daytime, high-risk grids were predominantly located in areas with vulnerable groups, such as children, the elderly, and patients, who are at greater risk. Medium risk was the most common in scenarios with PM2.5 concentrations at the 50th percentile (85.38%) and 95th percentile (84.65%), while high risk was primarily observed in the 99th percentile scenario (82.56%). At nighttime, high-risk areas were identified in hotels and condominiums in the central part. Similarly, medium risk accounted for the majority in the 50th percentile (85.34%) and 95th percentile (95.78%) scenarios, while high risk was mainly observed in the 99th percentile scenario (72.93%). This detailed information can help local governments develop effective responses tailored to the different risk profiles of daytime and nighttime during periods of high PM2.5 concentration.

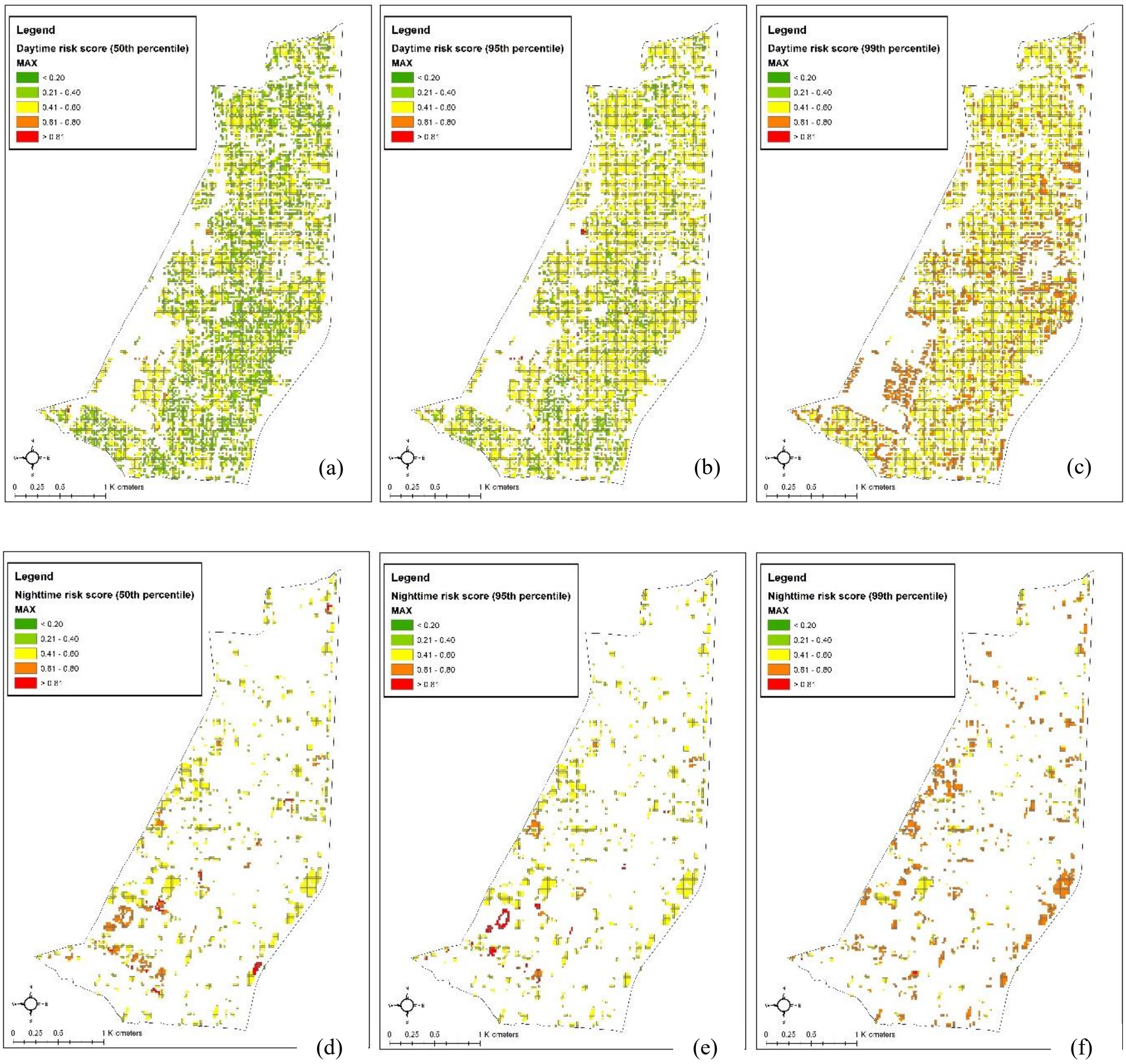

Figure 6. PM2.5 risk map: (a) Daytime at 50th percentile, (b) Daytime at 95th percentile, (c) Daytime at 99th percentile, (d) Night time at 50th percentile, (e) Night time at 95th percentile and (f) Night time at 99th percentile

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Table 4. Affected population in daytime

Risk score category	Affected population impacted by PM2.5 at different percentiles in daytime		
	50	95	99
Very low	50 (0.04%)	0 (0%)	0 (0%)
Low	511 (0.37%)	70 (0.05%)	50 (0.04%)
Medium	116,768 (85.38%)	115,775 (84.65%)	8,478 (6.20%)
High	11,615 (8.49%)	5,773 (4.22%)	112,915 (82.56%)
Very high	7,824 (5.72%)	15,151 (11.08%)	15,325 (11.20%)
Total	136,768 (100%)	136,768 (100%)	136,768 (100%)

Table 5. Affected population in nighttime

Risk score category	Affected population impacted by PM2.5 at different percentiles in nighttime		
	50	95	99
Very low	9 (0.01%)	9 (0.01%)	9 (0.01%)
Low	21,865 (13.42%)	4,770 (2.93%)	0 (0.00%)
Medium	138,972 (85.34%)	155,972 (95.78%)	42,263 (25.95%)
High	1,704 (1.05%)	355 (0.22%)	118,765 (72.93%)
Very high	290 (0.18%)	1,734 (1.06%)	1,803 (1.11%)
Total	162,840 (100%)	162,840 (100%)	162,840 (100%)

3.2 PM2.5 impact minimization measure

Based on the interviews, three measures supported by local governments were proposed by vulnerable groups in the study area: Measure (1) is the monthly distribution of PM2.5 masks to all children (43.75% of total respondents), Measure (2) is the construction of PM2.5 pollution control rooms to be used when pollution levels exceed standards (37.50% of total respondents), and Measure (3) is the installation of outdoor PM2.5 monitoring devices (18.75% of total respondents). Respirator face masks, as a personal-level intervention, can effectively reduce ambient particle concentrations by 68.1% [24]. However, caution should be exercised when using N95 masks, as they can increase the workload on the metabolic system, particularly for pregnant workers, potentially causing dizziness and hypoxia [25]. Furthermore, ventilation and air conditioning systems in buildings or rooms can effectively control indoor PM2.5 concentrations. For example, the China Academy of Building Research has developed the T/CECS 586-2019 standard, titled "Technical Specification for Pollution Control of Fine Particulate Matter (PM2.5) in Buildings," under the China Engineering Construction Standardization Association [26]. In Thailand, the adoption of PM2.5 pollution control rooms is still relatively limited and primarily implemented by the national government due to the high investment costs, which are not feasible for private uses. Regarding outdoor PM2.5 monitoring devices, several low-cost sensors have recently been introduced to the market. This suggests that, initially, the government can easily provide these devices to vulnerable groups to enhance awareness, encourage timely responses, and prompt action when PM2.5 concentrations are high. A successful example of a participatory urban sensing framework for PM2.5 monitoring can be observed in Taiwan [27]. Currently, the ground-based monitoring devices called DustBoy, initiated by the National Research Council of Thailand (NRCT), are widely used across several provinces in Thailand. However, their intelligent application in urban areas is still under investigation [28].

When considering their application for vulnerable groups, the estimated annual cost for Measure (1) is 67,126,055 Baht, for Measure (2) is 7,035,750 Baht, and for Measure (3) is 160,072 Baht, based on current Thailand market prices. However, integrating all three measures is recommended: Measure (1) offers a short-term solution, Measure (3) facilitates immediate action during peak pollution levels, and Measure (2) should be considered for medium-to-long-term implementation.

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4. CONCLUSIONS

This study demonstrates the successful application of GIS for PM2.5 risk assessment. The primary factors influencing PM2.5 risk are receptor vulnerability, PM2.5 concentration, and population density, with vulnerability being the most significant factor. Notably, there is a considerable difference in population distribution between daytime and nighttime, underscoring the need for tailored implementation strategies throughout the day. To ensure the proposed measures are practical and effective, it is recommended to conduct interviews with local governments. Short-term plans include providing N95 masks and installing additional PM2.5 monitoring devices to facilitate timely responses and actions. The construction of PM2.5 pollution control rooms is considered a long-term plan due to its high investment costs.

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An Empirical Study on Carbon Tracking for Thai Hotel Operation

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ABSTRACT

Thailand relies on the tourism industry as a major industry that can contribute to Thai business, jobs, and other tourism supply chains. Tourists' demand focuses on significant areas in the megacity of tourist destinations around Thailand. The study focuses on carbon emissions by tracking hotel operations in Thailand. Data analysis shows how much carbon emissions are in three major tourism destinations in Thailand namely, Bangkok, Chonburi, and Phuket. The areas are coastal or seaside vacations in the tourism industry and are classified as megacities. Additionally, behavior changes in the hotel business can be observed by using the number of hotel establishments. The increasing number of rooms registered throughout Thailand. The observation found that the number of hotels in study areas has continuously increased for years. The increasing figures showed from 2,958 hotels in 2016 to 3,857 hotels in 2024 (TAT intelligence center, 2024). Converting to the number of rooms will be calculated along with tracking carbon emission by using average data from the Hotel Sustainability Benchmarking Index from Cornell Hotel Sustainability Benchmarking study (CHSB), in 2023 (Ricaurte & Jagarajan, 2023). The study measures the relative content of the number of rooms and carbon emission per room night (occupied room). According to the CHSB report, the tracking of carbon emissions shows a significant result in increasing trends in the operation of the hotels. The means figures of a kilogram of carbon dioxide emission equivalent ($kgCO_2$) in 2023 showed that Bangkok is 123.7 kilograms per room night, Chonburi is 54.2 kilograms per room night and Phuket is 126.5 kilograms per room night. Furthermore, carbon dioxide emission tracking will be observed by rooms sold and occupancies in each area. The results in the study areas can be applied to all hotels in the whole country.

Keywords: Carbon tracking/ Tourism/ Sustainability hotel / Low carbon tourism

1. INTRODUCTION

An Empirical Study on Carbon Tracking for Thai Hotel Operations study is the primarily study for Thai Hotel and Carbon emission equivalence to total Green House Gases Emission. Three main tourist destinations in this study are; Bangkok; Thailand metropolitan, which can be identified as a megacity in the region. Pattaya is one of the most popular tourist destinations not far from Bangkok. The last destination which is taking place as a famous tourist destination located along the Andaman coastal line is Phuket.

1.1 Why three main destinations are selected?

The reason for selecting the 3 main tourist areas, Bangkok, Phuket, and Chonburi, is because these are the main areas that tourists will travel to. Bangkok is considered the initial area where tourists will enter the country. Phuket is the area where tourists intend to go to relax. Chonburi is the area closest to Bangkok. Therefore, there is a connection between the number of tourists, both Thai and foreigners. The reason why this study selected 3 areas for comparison and initially studied the amount of carbon dioxide equivalent produced by providing accommodation services in the 3 areas.

1.1.1 Bangkok

Bangkok is one of the world's top tourist destinations of 162 cities worldwide, Master Card ranked Bangkok as the top destination city by international visitor arrivals in its *Global Destination Cities Index 2018*, ahead of London, with just over 20 million overnight visitors in 2017.

This was a repeat of its 2017 ranking (for 2016). Euromonitor International ranked Bangkok fourth in its Top City Destinations Ranking for 2016. Bangkok was also named "World's Best City" by *Travel + Leisure* magazine's survey of its readers for four consecutive years, from 2010 to 2013.As the main gateway through which visitors arrive in Thailand, Bangkok is visited by the majority of international

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tourists to the country. Domestic tourism is also prominent. The Department of Tourism recorded 26,861,095 Thai and 11,361,808 foreign visitors to Bangkok in 2010. Lodgings were made by 15,031,244 guests, who occupied 49.9 percent of the city's 86,687 hotel rooms. Bangkok also topped the list as the world's most popular tourist destinations in 2017 rankings (wikipedia, 2024a).

1.1.2 Chonburi

Following the end of World War II, coastal towns particularly Ang Sila witnessed an influx of Teochew Chinese migrants.

The Vietnam War would also cause an influx of American G.I.S to arrive, particularly in Pattaya. This would go on to lead Chonburi province to become popular among foreign tourists (wikipedia, 2024b).

1.1.3 Phuket

The development of Phuket's tourism sector began in earnest in the 1980s, with the west coast beaches, notably Patong, Karon, and Kata, emerging as key tourist destinations. Following the 2004 tsunami, efforts were made to restore all affected buildings and attractions. The island has since undergone extensive development, evidenced by the construction of new hotels, apartments, and houses.

In a 2005 report by Fortune Magazine, Phuket was listed among the top five global retirement destinations. The island's appeal as a retirement location is attributed to various factors, including its climate, lifestyle, and amenities.

The year 2017 marked a significant influx of tourists to Phuket, with the island welcoming approximately 10 million visitors, predominantly from overseas. China was noted as the primary source of these foreign tourists. The tourism sector in Phuket played a crucial role in Thailand's economy, generating about 385 billion baht in revenue, which constituted nearly 14% of the nation's total earnings of 2.77 trillion baht in that year.

In the first half of 2019, Phuket experienced a decrease in tourist arrivals, which impacted the local hospitality industry. This trend was marked by reduced hotel occupancy rates and intensified price competition among accommodations. Consequently, there was a noted decrease in revenue per available room (RevPAR). Analysts attribute this downturn to the fewer tourists and an oversupply of hotel rooms. However, despite the decline in tourist numbers, the Tourism Authority of Thailand (TAT) reported a 3.1% increase in tourism revenues for the same period.

Estimates of the total number of hotel rooms in Phuket vary. According to Oxfam, Phuket has approximately 60,000 hotel rooms to cater to its 9.1 million annual visitors. Contrasting figures were presented in reports by the Bangkok Post in September 2019. One report indicated that Phuket has around 600 hotels comprising 40,000 rooms. A separate report from three weeks earlier estimated 93,941 available hotel rooms, excluding villas and hostels, with an expectation of an additional 15,000 rooms by 2024. These varying figures highlight the difficulty in accurately quantifying the total number of hotel accommodations in the region.(wikipedia, 2024c)

1.2 Hotel business

Hospitality includes a range of businesses, such as hotels, restaurants, bars, resorts, cruise ships, theme parks, and other service-oriented businesses that provide accommodations, food, and beverages. Hospitality is all about creating a welcoming and comfortable environment for guests and meeting their needs. (insider, 2024)

1.3 Climate change and tourism

The world has agreed to keep global warming at 1.5 to 2°C compared to pre-industrial levels, for which it will be necessary to reduce emissions of greenhouse gases to net zero by mid-century (Singh et al., 2018). As a result, there is a pressing need to identify strategies that can significantly reduce emissions throughout the world economy. Tourism has considerable relevance for achieving this goal, as it includes

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various vital emission subsectors such as aviation and is estimated to have been responsible for 8% of global CO_2-equivalent emissions in 2013 (Lenzen et al., 2018).Tourism is also a growth sector, further emphasizing the importance of mitigation, specifically since a COVID-19 rebound is evident and future high growth rates are expected (Citaristi, 2022). Carbon management, including CO_2 as well as other greenhouse gases, is thus a key management challenge for the sector (Stefan Gössling, 2023).

The impossibility of accommodating further growth and emission reductions aligned with scientific targets was already outlined in the(UNWTO & Change, 2008) report "Climate Change and Tourism – Responding to Global Challenges". Even in the most ambitious mitigation scenario, the sector's emissions were projected to fall by just 16% (2005-2035) if growth continued. National studies confirm this. For example, research for Norway has shown that under a continued tourism growth scenario, country-wide decarbonization rates would have to be 30 times higher than observed rates to approach net zero by 2050 (Sun et al., 2022) . Decarbonization challenges for tourism have now been repeatedly outlined (Scott & Gössling, 2021), with the central conclusion that tourism will not achieve carbon neutrality under continued growth scenarios.

1.4 Sustainability benchmarking for hotel business

Tourism places pressures on the environment through the services provided (accommodation, food, leisure activities, and transport), meanwhile it is particularly vulnerable to global warming as climate is a crucial component of destinations' attractiveness. As a result, research focusing on the impacts of tourism has increased significantly. Practitioners consult a plethora of frameworks and publications to environmentally assess tourism but none of the existing guidelines provides specific recommendations making it difficult to obtain reliable results that can be properly replicated and compared. This paper discusses the use of Footprint family indicators in tourism through a review of studies that measure the Water, Carbon, and Ecological Footprint of tourists (Miralles et al., 2023).

1.5 Carbon footprint for hotel business

The Carbon Footprint as a concept was born from the Ecological Footprint. Considering the definition by (Ewing et al., 2012) "the CF measures the total amount of GHG emissions that are directly and indirectly caused by an activity or are accumulated over the life stages of a product" and is expressed in mass units of CO_2 or mass units of CO_2 Equivalent if other GHG besides CO_2 have been accounted for. Several standards and methodologies tackle the CF issue of products and services.

- Energy in kilowatt-hours (kWh),
- Water in liters (L) and
- Waste generation (kg)

Greenhouse gas emissions (also termed carbon footprint) in kilograms of carbon dioxide equivalent ($kgCO_2e$), converting each energy source of GHG emissions into $kgCO_2e$ (using only carbon dioxide, methane, and nitrous oxide).

The data provided on the following pages in Exhibits 6, 7, and 8 show the average change in the following six measures from 2019 to 2022 and from 2021 to 2022: (1) GHG emissions per occupied room, (2) GHG emissions per square meter, (3) energy per occupied room, (4) energy per square meter, (5) water per occupied room, and (6) water per square meter.

2. METHODOLOGY

2.1 Tracking for hotel consumption profile

Hotels and resorts are required to conduct assessments or city measurements to assess their energy and resource consumption, which we call tracking for the Hotel consumption Profile.

The hotel's resource usage tracking will be used in this study are energy, water, and waste.

The factor that may have an impact on resource consumption or what will be used to calculate the hotel's carbon footprint is climate change at different times of the year.

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However, Bangkok and Pattaya are connected by being tourist cities for tourism throughout the year.

In Phuket province, there may be fluctuations depending on the tourist seasonal change, which includes both the high season and the location due to the southwest monsoon.

However, since these three areas are the main tourist areas of Thailand, there is a campaign to promote tourism throughout the year, which may have different customer groups using the services.

2.2 Carbon footprint and calculation

This study, specifically on carbon emission, will refer to the carbon calculation CHSB in 2023.

Carbon calculation of the number of rooms sold throughout the year in the study area is compared with the standard value obtained from the calculation per room sold of the reference value.

The preliminary calculations will be shown in the study results and study analysis.

3. RESULTS AND DISCUSSION

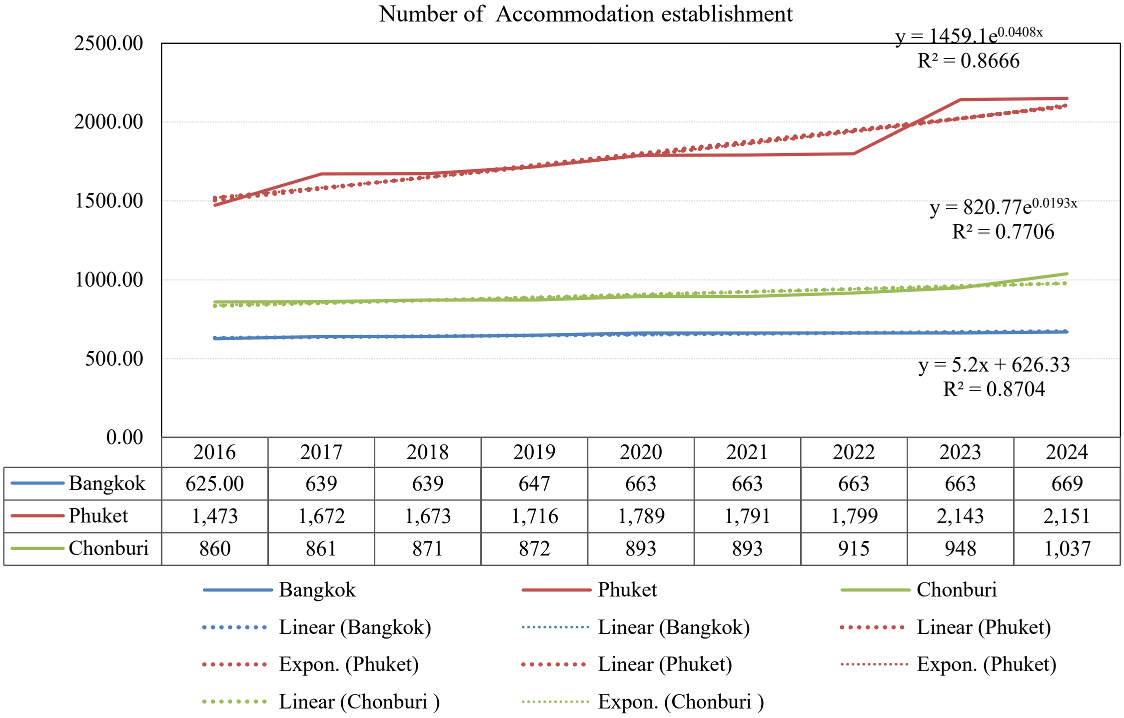
3.1 Comparison of CO_2 profile in the study area

From the graph on the number of hotels in the 3 study areas, namely Bangkok, Phuket, and Chonburi, the number of hotels registered in Phuket has increased each year with a relatively high trend followed by an increase in the number of hotels in Chonburi. In Bangkok, the number is quite stable.

That is, from 2016 onwards until the present at the time of the study, which is mid-2024, it was found that the number of hotels registered in Bangkok was 625 hotels in 2016, increasing to 669 hotels in 2024.

In the number of hotels in Phuket Province in 2016, there were 1,473, increasing to 2151 in 2024, which is a very high percentage increase of 86.41%.

Meanwhile, Chonburi Province has 860 registered hotels in 2016 and will increase to 1,037 in the middle of this year in 2024. (See Figure 1.)



	2016	2017	2018	2019	2020	2021	2022	2023	2024
Bangkok	625.00	639	639	647	663	663	663	663	669
Phuket	1,473	1,672	1,673	1,716	1,789	1,791	1,799	2,143	2,151
Chonburi	860	861	871	872	893	893	915	948	1,037

Figure 1. Number of accommodation establishment (Source: TAT Intelligence 2024, complied by Authors)

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If we consider the number of rooms registered in three areas, Phuket Province will certainly have the largest number of rooms, followed by Bangkok and Chonburi respectively (See Figure 2).

The conclusion of the study, if we consider the number of rooms sold since 2018, except during the COVID-19 crisis, it was found that the trend of room sales has increased and the amount of carbon dioxide emissions per room sold has also increased.

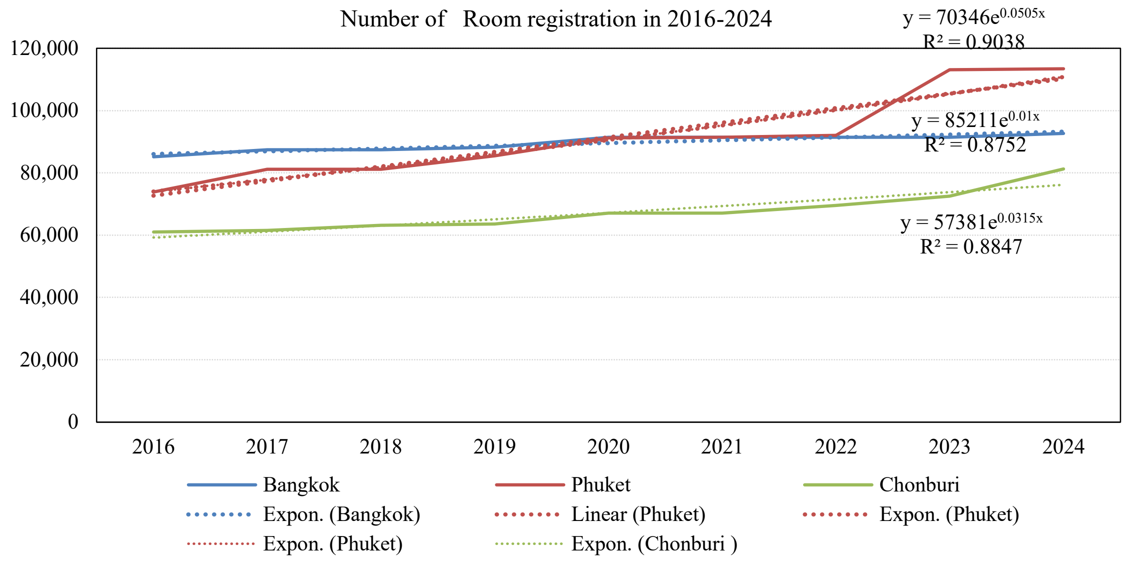

Figure 2. Number of room registration in 2016-2024 (Source: TAT Intelligence 2024, complied by Authors)

However, the highest number of occupancy or rooms sold each month of each year will be in the area with relatively consistent travel in Bangkok.

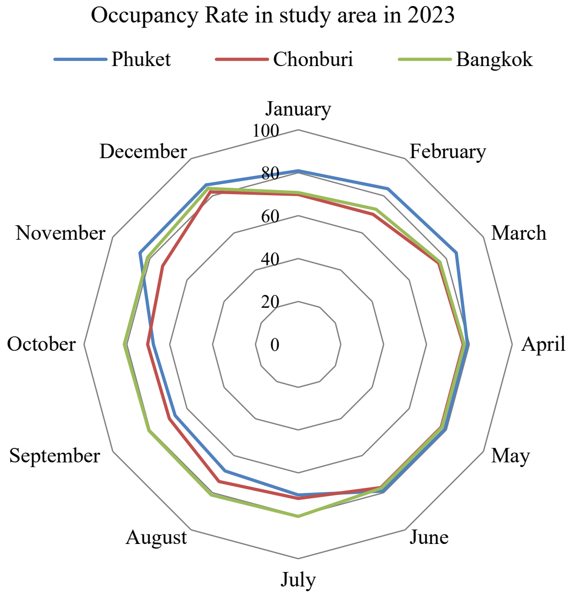

Figure 3. Room occupancy in 2016-2024 in three destinations (Source: TAT Intelligence 2024, complied by Authors)

From Table 1, when the Total Number of rooms in 2023 is multiplied by the average of the per room in each area, what will be the number of groups in each area. Phuket had approximately 32 million room-sold per year follow by Bangkok was around 26 million room-sold and 19.5 million room-sold in Chonburi.

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Table 1. Shows the total room-night in 2023

Area	Number of Room	Average occupancy rate	Room-Night	Total Room-night in 2023
Bangkok	91,421	78.44	71,711	26,174,381
Phuket	113,065	77.59	87,727	32,020,404
Chonburi	72,557	73.98	53,678	19,592,349

Source: TAT Intelligence 2024, complied by Authors

From the CHSB study, it was found that Chonburi has carbon dioxide emissions of 54.2 kilograms per room-night, which is the lowest in the three study areas, followed by Bangkok with carbon dioxide equivalent emissions of 123.7 kilograms per room-night, while Phuket has the highest with an average of 126.5 kilograms of carbon equivalent per room-night.

Table 2. Shows the total CO_2e in 2023

Area	Room-Night	Emission Per Room-night (kg·CO_2e)	Ton CO_2e/day	Total of CO_2e/year (ton)
Bangkok	71,711	123.7	8,870.61	3,237,770.91
Phuket	87,727	126.5	11,097.48	4,050,581.07
Chonburi	53,678	54.2	2,909.33	1,061,905.32

Source: TAT Intelligence 2024, complied by Authors

Table 2, the equivalent amount of carbon emission per day, found that Bangkok accounted carbon from selling rooms at about 324 tons, Phuket at about 405 tons, and Chonburi at about 106 tons. However, when taking the average number of days that rooms can be sold in each area, it will be found that Bangkok has a total of carbon emissions of 2023, Phuket has a total of 2023, and Chonburi has a total of 2023.

However, such quantity, even though the technology is introduced, or some issues are debated and used as indicators for management and sustainability management in the tourism and hotel industries, is still an issue that hotels must manage the release of carbon dioxide or greenhouse gases, especially the management of resources that are the cause of greenhouse gases that were studied this time.

3.2 Discussion

In summary, if there is a need to study further in the area and in-depth the consumption profile in each category that will be used to calculate carbon dioxide, at least 3 categories: energy, which is the main calculation of water, which is a necessary resource for hotels, and finally, waste production or resource use that will create waste for hotels, all 3 elements can be studied in depth in future research.

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Optimizing Wastewater Treatment for a Carbon-Neutral Future: A Data-Driven Approach

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ABSTRACT

The research explores the pivotal role of wastewater treatment plants (WWTPs) in addressing energy consumption and greenhouse gas (GHG) emissions to achieve carbon neutrality (CN) and the United Nations' Sustainable Development Goals (SDGs), notably promoting health, clean water, and sustainable energy while mitigating climate change impacts. In 2023, Thailand will have wastewater treatment plants capable of handling around 620 million cubic meters, or about 45% of wastewater produced, and data reveals that 3,621.574 thousand kg CO_2 eq/year is emitted from wastewater treatment, highlighting the need for sustainable practices to reduce emissions. The objective of this research is to develop a framework that integrates structured query language (SQL) with life cycle inventory (LCI) methodologies to create a comprehensive database for WWTPs. This includes goal and scope determination in assessment to identify inputs, outputs, and emissions throughout the WWTPs process lifecycle. This framework aims to analyze energy consumption and reduce GHG emissions by examining the correlations between WWTPs operational parameters and electricity consumption, thereby contributing to carbon neutrality, and supporting the United Nations' Sustainable Development Goals (SDGs). These findings emphasize the critical importance of understanding the relationship between WWTP operational efficiency and energy consumption to effectively mitigation for enhance and optimize efficiency in reducing energy consumption and GHG emissions in WWTPs. Ultimately, this framework aims to enhance and optimize the efficiency of reducing energy consumption and GHG emissions in WWTPs, thereby contributing to CN and the SDGs.

Keyword: Carbon neutrality / Greenhouse gas emissions / Wastewater treatment plants / Life cycle inventory / Database

1. INTRODUCTION

Wastewater treatment plants (WWTPs) play significant role in realizing the United Nations' Sustainable Development Goals (SDGs), contributing to clean water (SDG 6), clean energy (SDG 7), good health (SDG 3), sustainable cities (SDG 11), responsible consumption and production (SDG 12), and climate action (SDG 13) (Obaideen et al., 2022). Evaluating wastewater treatment infrastructure through the lens of SDGs is crucial for global water quality improvement, particularly in addressing issues like greenhouse gas emissions (Ho et al., 2021). The emphasis of SDG 6.3 on reducing untreated wastewater discharge necessitates a forward-looking strategy beyond the 2030 targets, addressing challenges such as greenhouse gas emissions for effective climate change (Adhikari & Halden, 2022). The importance of accurate greenhouse gas accounting, especially for N_2O and CH_4 emissions, underscores the significance of adopting a multi-criteria approach for sustainable wastewater management (Faragò et al., 2022). Monitoring and managing greenhouse gas emissions are crucial for countries addressing wastewater challenges, aligning with climate targets, and participating in the UNFCCC negotiations. Supporting partner countries, such as Thailand, in preparing Intended Nationally Determined Contributions (INDCs), is essential for collectively addressing climate-related challenges (GIZ, 2021). In 2023, Thailand's wastewater treatment capacity will cover 45% of treatable wastewater, and data reveals that 3.6 thousand kg CO_2 eq/year is emitted as greenhouse gasses from wastewater treatment (DSPOT, 2023). This underscores the need for sustainable practices in emissions reduction, aligning with the United Nations' Sustainable Development Goal by 2030.

The objective of this research is to identify and analyze the correlations between various operational parameters and electricity consumption in WWTPs. By understanding these correlations,

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the aim is to optimize energy efficiency and reduce greenhouse gas (GHG) emissions. This analysis provides insights into managing influent and effluent parameters and optimizing aeration processes to improve treatment efficiency and reduce energy consumption. The findings from this research are intended to contribute to the development of sustainable practices within wastewater management, ultimately supporting the achievement of carbon neutrality and the UN's SDGs.

2. LITERATURE REVIEW

2.1 Evaluating Wastewater Treatment Infrastructure Systems Based

Challenges for Wastewater Treatment Plants (WWTPs) play a vital role in addressing the United Nations' Sustainable Development Goals (SDGs), influencing various dimensions such as clean water, sanitation, clean energy, responsible consumption, climate action, and life below water (Obaideen et al., 2022). In 2015, the United Nations General Assembly established 17 interlinked goals as part of the SDGs. These goals cover a range of areas, including poverty reduction, good health, sustainable land use, zero hunger, gender equality, quality education, economic growth, clean water, reducing inequality, affordable energy, sustainable communities, life below water, responsible production and consumption, climate action, partnership for the goals, peace, industry, innovation, and infrastructure (Bebbington & Unerman, 2018). The SDGs are embedded in the United Nations Resolution known as the 2030 Agenda, with a target completion date of 2030. It mentions that while most SDG targets are set to be achieved between 2020 and 2030, some targets do not have a specific end date (Costanza et al., 2016). Monitoring progress toward these goals is essential, and various tools and techniques have been presented to track and evaluate progress. The latest data from the United Nations SDGs dashboard indicates that many countries still face significant challenges in achieving the SDG targets, with only two countries (Andorra and Monaco) doing well in SDG 6. However, the detailed data reveals that even these countries are not performing well in achieving SDG 6 targets, as illustrated in Figure 1.

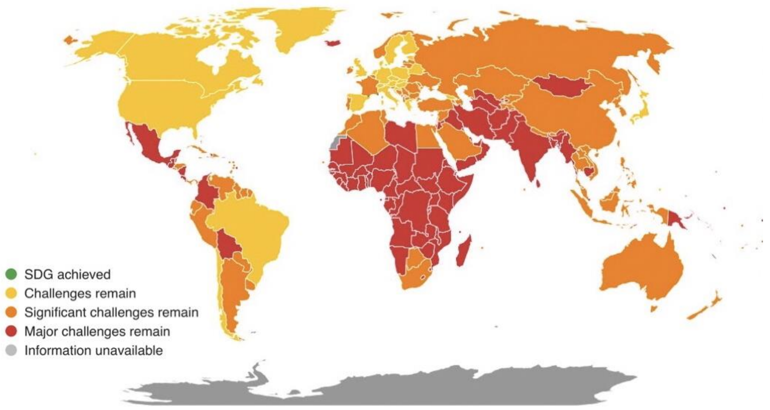

Figure 1. Status of SDG 6 (Clean Water and Sanitation) (Sustainable Development Report 2023, 2024)

According to the UN World Water Development Report 2023, global water use has increased by approximately 1% per year over the past 40 years, particularly in middle- and low-income countries, notably in emerging economies. Population growth, economic and social development, and changing consumption patterns all contribute to the increased demand for water, leading to water stress and ultimately contributing to water scarcity (United Nations, 2023). Achieving SDG 6 by 2030, as depicted in Figure 2, requires each country to commit to systematic monitoring and review of progress toward the SDGs and associated goals (Kanchanamala Delanka-Pedige et al., 2021).

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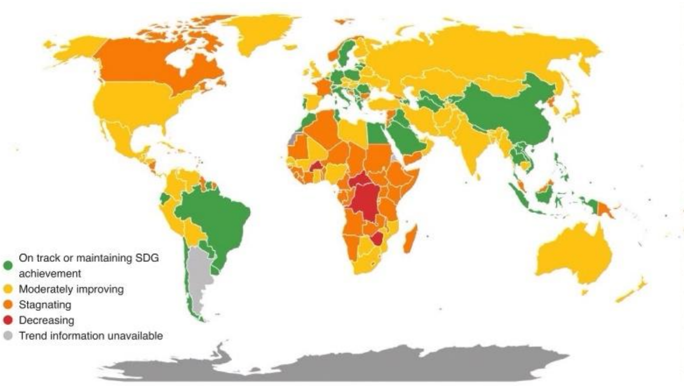

Figure 2. Trends indicate whether a country is on track to achieve the SDG 6 by 2030 (Sustainable Development Report 2023, 2024)

2.2.1 Sustainable development goals (SDGs)

Sustainable development is defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The challenges faced by societies globally, such as poverty, environmental degradation, climate change, and inequality, underscore the importance of SDGs as a blueprint for achieving sustainability and a better future (Obaideen et al., 2022). The broader aim of sustainable development includes mitigating poverty, protecting the planet, and ensuring prosperity and peace for individuals. It is highlighted as an approach that influences businesses and individuals to adopt behaviors that benefit societies and communities. Governments adopting a sustainable development approach are expected to bring benefits to the entire country, protecting society on all fronts. Achieving SDGs requires a commitment to social progress, economic growth, and environmental balance. Strategies to attain SDGs include promoting education, initiating fundraising campaigns, encouraging volunteering, empowering change-makers, and more (Malik et al., 2015). Wastewater infrastructure and the 17 Sustainable Development Goals can be linked by defining seven characteristics related to challenges and opportunities related to wastewater infrastructure: 1. effluent quality, 2. pathogen removal, 3. energy consumption, 4. gaseous emissions, 5. nutrient recovery, 6. footprint, and 7. reliability. The above opportunities and challenges are then mapped with appropriate SDGs and targets to achieve the following 30 sustainability indicators/measures in Table 1 (Kanchanamala Delanka-Pedige et al., 2021).

Table 1. Parameters to evaluate the sustainability of wastewater treatment technologies.

Attributes of wastewater infrastructure	Opportunities	Challenges	Linkages to SDG targets	Process parameters considered
Effluent quality	Potential for reuse high-quality effluent for potable and non-potable applications; combat water scarcity; improve resource use efficiency and conserve ecology	Poor quality effluent can contaminate surface waters, promote eutrophication, degrade soil quality; aggravate water scarcity; additional cost for effluent treatment, and ecological impact mitigation.	2.3, 2.4	Effluent BOD
			3.3, 3.9	Effluent NH_4–N
			6.1, 6.3, 6.4, 6.6	Effluent PO_4
			9.1, 9.4	Effluent COD
			11.3, 11.6, 11.9	Effluent TN
			12.4	Effluent TP
			14.1, 14.3	
			15.1, 15.3	
			17.7	

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Attributes of wastewater infrastructure	Opportunities	Challenges	Linkages to SDG targets	Process parameters considered
Pathogen control	Pathogen free effluents are safe for reuse; reduced disinfectant demand and lower possibilities of subsequent disinfection by-products (DBP) formation	Health and safety issues due to pathogen outbreak; higher disinfection demand and DBP formation; increased health risk in water reuse; transmission of antibiotic resistance.	3.3, 3.9	LRV of *E. coli*
			9.1	LRV of Fecal coliform
			11.5, 11.9	LRV of Somatic coliphages
			12.4	LRV of F-specific coliphages
				LRV of ARBs
Energy demand	Low energy consumption and energy-efficient treatment can conserve fossil- fuel reserves; reduction in operation and maintenance costs; reduction in indirect emission of greenhouse gases (GHGs); opportunities to recover energy from resulting biomass add revenue	High energy consumption contributes to depletion of limited fossil-fuel reserves; Increased emission of GHG during energy generation process degrades environmental sustainability.	7.3, 7.4, 7.5	Energy for WW treatment
			8.4	Energy for resource recovery
			9.2, 9.4	N reduction per unit energy
			11.3, 11.6, 11.9	P reduction per unit energy
			12.2, 12.9, 12.11	BOD reduction per unit energy
			13.2	Gross energy recovery
			17.7	
Emissions	Technologies with low harmful emissions promote better air quality, livable cities; prevent the greenhouse effect, and subsequent climate-change impacts.	Technologies with higher emission degrade air quality; contribute to greenhouse effects and climate-change scenarios.	3.3, 3.9	GHG- CO_2 emissions (direct)*
			9.1, 9.4	GHG – CO_2 emission (indirect)**
			11.3, 11.6, 11.9	GHG- N_2O emissions
			12.4	GHG- CH_4 emissions
			13.2	Odor- NH_3 emissions
			17.7	
Resources recovery	Ability to recover energy and nutrients embedded in wastewater as biogas, fertilizers add revenue; conserve natural resources; mitigate environmental impacts of energy and fertilizer production	If energy and nutrients embedded in wastewater are not recovered, they are dissipated into atmosphere, surface water bodies, and land causing a series of environmental impacts.	2.3, 2.4	N partitioning into gas phase
			3.3, 3.9	N partitioning into sludge/biomass
			9.1, 9.2, 9.4	P partitioning into sludge/biomass
			11.3, 11.6, 11.9 12.2,	Potential N recovery

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Attributes of wastewater infrastructure	Opportunities	Challenges	Linkages to SDG targets	Process parameters considered
			12.4, 12.5 12.9	
			17.7	Potential P recovery
Footprint	Lower space requirement of sewage treatment technologies best suited for dense urban areas with limited space; conserves natural ecosystems (e.g.: Forests)	Larger land requirement will be challenging for urban areas; can promote deforestation and loss of biodiversity; loss of visual appeal	8.4	Time for wastewater treatment
			9.2, 9.4	Area
			11.9	
			17.7	
Reliability/acceptability	Technologies with longer history imply greater reliability and acceptance.	Reluctance of industries to adopt innovative and novel technologies. Limited opportunities to introduce sustainable technologies	8.2	Years of operation
			9.1, 9.2, 9.3, 9.4; 9.5, 9.6, 9.7;	
			17.6, 17.7	

Remark: *CO_2 emission due to biogenic oxidation is excluded. **CO_2 emission during electricity generation. (Kanchanamala Delanka-Pedige et al., 2021)

2.2 Carbon Neutrality of Wastewater Treatment

Wastewater treatment plays a critical role in sanitation systems, contributing to nearly 5% of total global greenhouse gas (GHG) emissions, with projections indicating a potential 22% increase by 2030 (Li et al., 2024; Maktabifard et al., 2023). Within the wastewater treatment plants (WWTPs) sector, CH_4 and N_2O emissions collectively account for up to 7% and 10% of anthropogenic emissions, respectively (Maktabifard et al., 2023). WWTPs currently play a crucial role in reducing CO_2 emissions through various effective measures, such as sludge anaerobic digestion. These practices aim to promote environmental sustainability. Additionally, wastewater treatment employs various technologies, including energy recovery, resource recovery, and water reuse, all of which contribute to the pursuit of carbon-neutral wastewater treatment (Li et al., 2024). Hence, wastewater systems, concerning carbon credits, carbon neutrality, and achieving net-zero emissions through environmentally friendly measures, need to undergo systematic analysis of their scope and inventories of WWTP (Li et al., 2024).

2.2.1 Greenhouse gas emission from wastewater treatment plants

Climate change introduces uncertainties in water supply, exacerbating the existing water scarcity, which affects over 40 percent of the global population (Biru et al., 2017). World Water Day, recently observed, highlighted the crucial role of wastewater management in the circular economy. Proper wastewater management is recognized as a strategic investment benefiting both human and ecosystem health. Countries' nationally determined contributions (NDCs) include energy production, methane emissions reduction, and the expansion of wastewater treatment plants (ECA, 2020). Methane emissions from wastewater contribute around 9 percent of global anthropogenic methane sources (Biru et al., 2017). While water-related concerns are expressed in the adaptation sections of many countries' NDCs, the explicit mention of "wastewater" might be limited. Effective recycling and reuse of wastewater emerge as crucial strategies, especially in regions facing increased drought and water stress due to climate change (ECA, 2020).

Evaluating GHG emissions involves determining the scope of the assessment. The Thai Government Organization (TGO) has outlined a methodology for calculating an organization's carbon

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footprint, which involves categorizing activities that emit and absorb greenhouse gases into three scopes (TGO, 2022):

Scopes 1: Direct GHG emissions arise from sources within the organization's boundaries. These emissions originate from assets owned or controlled by the organization, including stationary sources like heaters and wastewater treatment plants (WWTPs), as well as mobile sources such as vehicles.

Scopes 2: Energy indirect GHG emissions result from fuel combustion associated with final energy production and various utilities like electricity and heat. This scope excludes emissions from the extraction of fuels to the power plant gate and greenhouse gas emissions related to building electric power plants. It also includes greenhouse gas emissions allocated from transportation and losses in power distribution systems.

Scopes 3: Other indirect emissions occur outside the organization's boundaries and predominantly stem from mobile sources, particularly emissions from fuel combustion in transportation equipment. This category encompasses a broad range of activities, including upstream greenhouse gas emissions generated during fuel manufacturing and transport/distribution processes.

2.3 Life Cycle Inventory in Wastewater Treatment

The Life Cycle Inventory (LCI) involves the goal and scope of conducting a comprehensive, integrated environmental impact assessment for wastewater treatment for use in data collection and inventory development (Straub et al., 2023). In general, LCI aims to identify the inputs, the outputs, and the respective amounts of emissions over the entire life cycle of the specific process (Rashid et al., 2023). LCI aims to identify inputs, outputs, and emissions throughout the life cycle of the process. It entails compiling primary data (foreground) from operational records and detailed designs covering the entire process from influent to effluent, as well as secondary data (background) from databases such as IPCC, Eco Invent, and ELCD (Gong et al., 2024; Li et al., 2024). In the LCI phase, identified inventories are collected for all processes along the boundary and calculated to the same functional unit (Rashid et al., 2023).

Table 2. Input and output flows of the wastewater treatment process

Input	Output
Wastewater influent	Biological oxygen demand (BOD)
Electricity	Chemical oxygen demand (COD)
Natural gas	Ammonium nitrogen
Fuel oil	Nitrate nitrogen
Precipitation chemicals	Nitrite nitrogen
	Phosphorus
	Greenhouse gas emissions
	Sewage sludge
	Screenings
	Grit chamber trappings

Source: (Straub et al., 2023)

The calculation of flows in the LCI of wastewater treatment processes is a critical step in understanding the environmental impact of such systems. This comprehensive methodology is developed using Python and exemplified through a case study to calculate and standardize these flows for subsequent LCI studies (Straub et al., 2023). The process begins with a clear representation of input and output flows, as illustrated in Table 5 for the wastewater treatment case study.

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3. METHODOLOGY

The research methodology involved collecting and analyzing operational data from Siriraj Hospital and Siriraj Piyamaharajkarun Hospital, over the past five years (2020-2024). Data collected included parameters such as effluent quality, dissolved oxygen (DO) levels in aeration tanks, dewatered sludge, electricity consumption, and other significant influent and effluent parameters. These parameters were measured monthly and included pH, biochemical oxygen demand (BOD), total Kjeldahl nitrogen (TKN), suspended solids (SS), settleable solids (Set S), sulfide, total dissolved solids (TDS), and fats, oils, and grease (FOG).

The operation steps are shown in Figure 3, which presents the framework for collecting and analyzing data from WWTPs. The steps are as follows: data collection, data cleaning, data analysis, and performance assessment and optimization.

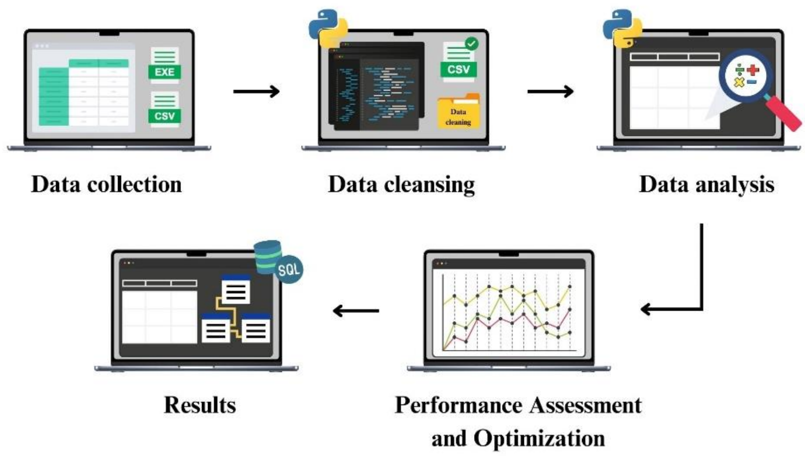

Figure 3. Framework for Collecting and Analyzing Data from WWTPs

The framework for collecting and analyzing data can be explained as follows:

3.1 Data Collection

Gathering data involves recording information from records and inputting it into a computer, including wastewater parameters, DO level in the aeration tank, and electrical consumption. Then, specify the plant ID for the WWTP data, which is imported into Python for analysis to summarize statistics for various parameters. The statistics dataset includes the maximum value (max) and minimum value (min) of the dataset. The mean (average), which represents the middle value of the dataset, is used as a representative for the entire dataset. The standard deviation measures how dispersed the data is, indicating how much or how little the data spreads from the mean. A small standard deviation suggests that each set of data is similar and accurate.

3.2 Data Cleansing

Data cleansing is a crucial step in the process of preparing data for analysis. It involves carefully examining the raw data or data that has been obtained, identifying any inconsistencies, errors, or missing values, and then interpolating statistical data from the raw dataset analyzed in Section 3.1 into the dataset to ensure completeness of the data.

3.3 Data Analysis

Data analysis focuses on understanding the correlation and GHG emissions calculations to mitigate the environmental impact of wastewater treatment, including optimizing energy usage and reducing GHG emissions.

The correlation between the involvement of various influent (INF) and effluent (EFF) water quality parameters, as well as aeration tank DO and electricity consumption for assessing the energy

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efficiency of WWTPs, as it results in indirect GHG emissions from energy use. Understanding this correlation helps optimize energy usage and reduce GHG emissions.

3.4 Performance Assessment and Optimization

Analyzing the correlations provides valuable insights into the environmental impact of wastewater treatment operations. Understanding these correlations is crucial for optimizing processes and developing guidelines to reduce GHG emissions. The core of the methodology involved correlation analysis using statistical measures to identify relationships between various operational parameters and electricity consumption. Correlation coefficients, ranging from -1.00 to +1.00, were calculated to determine the strength and direction of these relationships. Positive correlation coefficients indicate direct relationships, while negative coefficients signify inverse relationships.

These insights help in setting the scope for developing frameworks that integrate structured query language (SQL) with life cycle inventory (LCI) methodologies, aimed at optimizing performance and achieving carbon neutrality in WWTPs. By focusing on these correlations, it is possible to enhance operational efficiency, reduce energy consumption, and minimize GHG emissions, contributing to the broader goals of sustainability and the United Nations' Sustainable Development Goals (SDGs).

4. RESULTS AND DISCUSSIONS

4.1 Data collection

Statistical analysis was performed on the operational data collected from Plant 1 and Plant 2. The results include the maximum, minimum, mean, and standard deviation values for various wastewater parameters, as shown in Tables 3 and 4.

Table 3. Statistics for Data Plant 1

	count	mean	std	min	25%	50%	75%	max
INF_pH	35	7.549714	0.350516	7.01	7.33	7.46	7.72	8.8
INF_BOD	35	168.0129	61.15152	15.3	124.65	159.7	205.15	340
INF_SS	35	131.7714	56.47023	42	89	122	168	256
INF_Sulfide	35	0.280857	0.107056	0.1	0.2	0.27	0.355	0.6
INF_TDS	35	273.7054	71.27966	155.4	231.4	269.75	310.65	460.85
INF_Set S	35	4.114286	4.540675	0.2	1.4	2.5	5.25	23
INF_FOG	35	7.685714	3.570891	2	5	7	10.5	15
INF_TKN	35	34.848	23.28974	4.48	22.97	28.55	36.73	104.43
EFF_pH	35	6.966857	0.337611	6.31	6.74	6.92	7.17	7.71
EFF_BOD	35	3.878286	2.108422	1	2.63	3.5	3.98	9.2
SS_EFF	35	8.045714	6.004525	0.8	3.2	6.4	11.4	24
EFF_Sulfide	35	0.052857	0.023461	0.01	0.03	0.05	0.07	0.11
EFF_TDS	35	156.1697	65.81257	9.75	126.425	157.3	180.7	374
EFF_Set S	35	0.107143	0.029061	0.09	0.1	0.1	0.1	0.2
FOG_EFF	35	1.085714	1.358447	0	0	1	2	6
EFF_TKN	35	1.213429	1.197338	0	0.58	1.08	1.21	6.2
Dew Sludge	42	8.67881	3.260978	2.78	5.8675	8.775	11.0325	16.29
Effluent	42	115337.1	12324.78	89202.49	107541.6	116260.1	123225	143956.6
Aeration Tank 1_DO	47	2.335922	0.749809	0.612222	1.964847	2.439077	2.780122	4.473333
Aeration Tank 2_DO	47	0.79119	0.723602	0.152843	0.406058	0.651397	0.915339	4.663333
Electricity consumption	47	81924.21	8441.453	60099	77400	83100	87300	103500

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Table 4. Statistics for Data Plant 2

	count	mean	std	min	25%	50%	75%	max
INF_pH	35	7.215714	0.198676	6.84	7.05	7.2	7.385	7.6
INF_BOD	35	219.9857	116.4072	100.2	146.25	182	256.75	703
INF_SS	35	257.9429	295.0264	64	92	138	348	1650
INF_Sulfide	35	0.572	0.250961	0.2	0.395	0.6	0.7	1.25
INF_TDS	35	356.9529	68.11705	182	306.5	358.8	415.35	462.15
INF_Set S	35	13.36571	23.54053	0.1	1.2	3.5	18	130
INF_FOG	35	9.342857	6.457749	3	5	7	11.5	27
INF_TKN	35	41.63657	24.34984	10.64	27.735	33.9	48.58	122.59
EFF_pH	35	7.23	0.267087	6.7	7.015	7.28	7.48	7.67
EFF_BOD	35	7.114	3.794167	2.5	4.52	6.04	9.07	19.28
SS_EFF	35	6.468571	3.463403	0.8	4	6	8.8	15.2
EFF_Sulfide	35	0.049429	0.024488	0	0.03	0.05	0.07	0.09
EFF_TDS	35	243.65	55.62122	146.9	210.6	239.2	256.425	396
EFF_Set S	35	0.100571	0.018778	0.06	0.1	0.1	0.1	0.2
FOG_EFF	35	0.8	1.346018	0	0	0	1	5
EFF_TKN	35	8.209429	8.143892	0	2.805	5.3	11.76	28.62
Dew Sludge	43	21.48465	13.71544	0	13.615	21.39	26.31	49.36
Effluent	42	38006.05	6112.001	25214.51	33666.44	37236.44	43212.29	49786.64
Aeration Tank 1_DO	46	0.371145	0.364517	0.051429	0.166875	0.256389	0.431349	1.875
Aeration Tank 2_DO	47	0.40729	0.493343	0.048889	0.126429	0.217	0.431667	2.341667
Electricity consumption	47	38722.19	3051.896	29087	37683	39392	40162	47300

4.2 Data cleaning

The dataset from both plants had varying numbers of observations, ranging from 35 to 47 data points. To ensure consistency, data cleaning involved removing duplicates and addressing missing values where necessary. This step was essential for ensuring the accuracy and reliability of the statistical analysis. The cleaned data was then used to carry out further analyses, including correlations and performance assessments.

4.3 Data analysis

This research analyzed data from the wastewater treatment plants (WWTPs) at Siriraj Hospital and Siriraj Piyamaharajkarun Hospital, focusing on correlations between various operational parameters and electricity consumption. Understanding these correlations is essential for optimizing operational efficiency and reducing energy costs. The correlation coefficient is a statistical measure that ranges from -1.00 to +1.00, used to analyze the relationship between two or more variables. A positive correlation indicates a direct relationship, while a negative correlation signifies an inverse relationship.

In Figure 6, the correlation heatmap for Plant 1 highlights the relationships between various operational parameters and electricity consumption. Notably, electricity consumption is moderately positively correlated with dewatered sludge (0.23), indicating that as the volume of dewatered sludge increases, energy usage also tends to rise, likely due to the energy-intensive nature of sludge processing. Additionally, there is a slight positive correlation with effluent settleable solids (Set S) (0.16), suggesting that higher levels of settleable solids may necessitate more energy for treatment processes.

The observed negative correlations between influent FOG (-0.33), TKN (-0.33), TDS (-0.23), and electricity consumption suggest that lower levels of these parameters may require more energy-intensive treatment processes. For instance, reduced FOG levels may demand higher aeration efforts to maintain oxygen transfer efficiency, while lower concentrations of TKN and TDS could necessitate

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additional treatment stages, such as nitrification and denitrification, to meet effluent standards, thereby increasing electricity consumption.

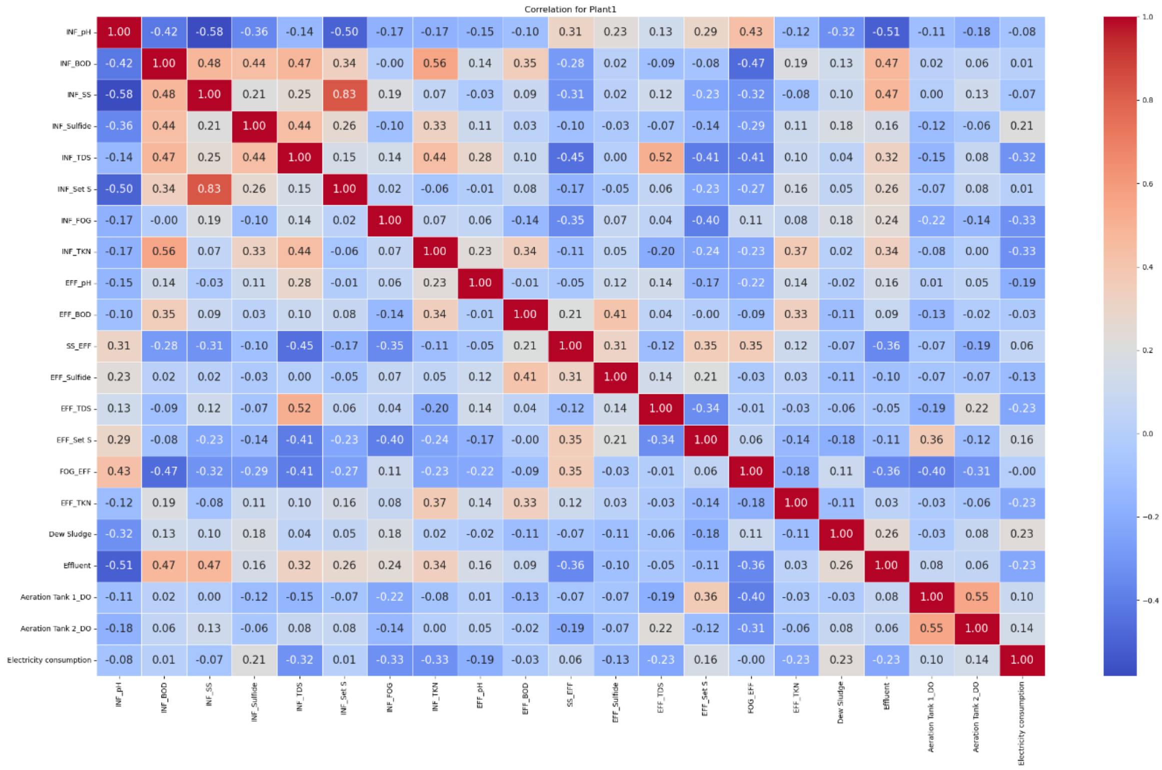

Figure 6. Correlation for Plant 1

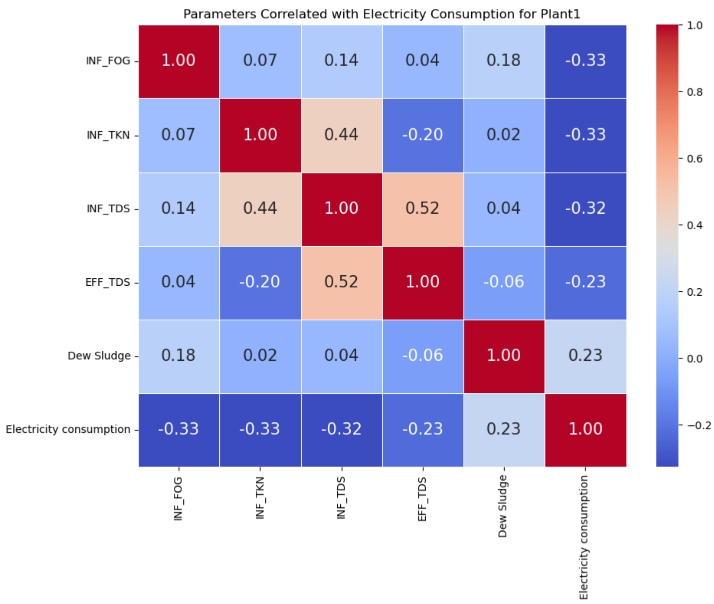

Figure 7. Parameters Correlated with Electricity Consumption for Plant 1

In Figure 7, this heatmap further delves into the specific parameters most closely related to electricity consumption in Plant 1. Similar to Figure 6, the analysis shows that electricity consumption is moderately positively correlated with dewatered sludge (0.23). On the other hand, negative correlations with influent FOG, TKN, and TDS (-0.33, -0.33, and -0.32 respectively) suggest that maintaining lower levels of these substances may demand additional energy-intensive treatments, highlighting the complexity of balancing influent composition with energy efficiency.

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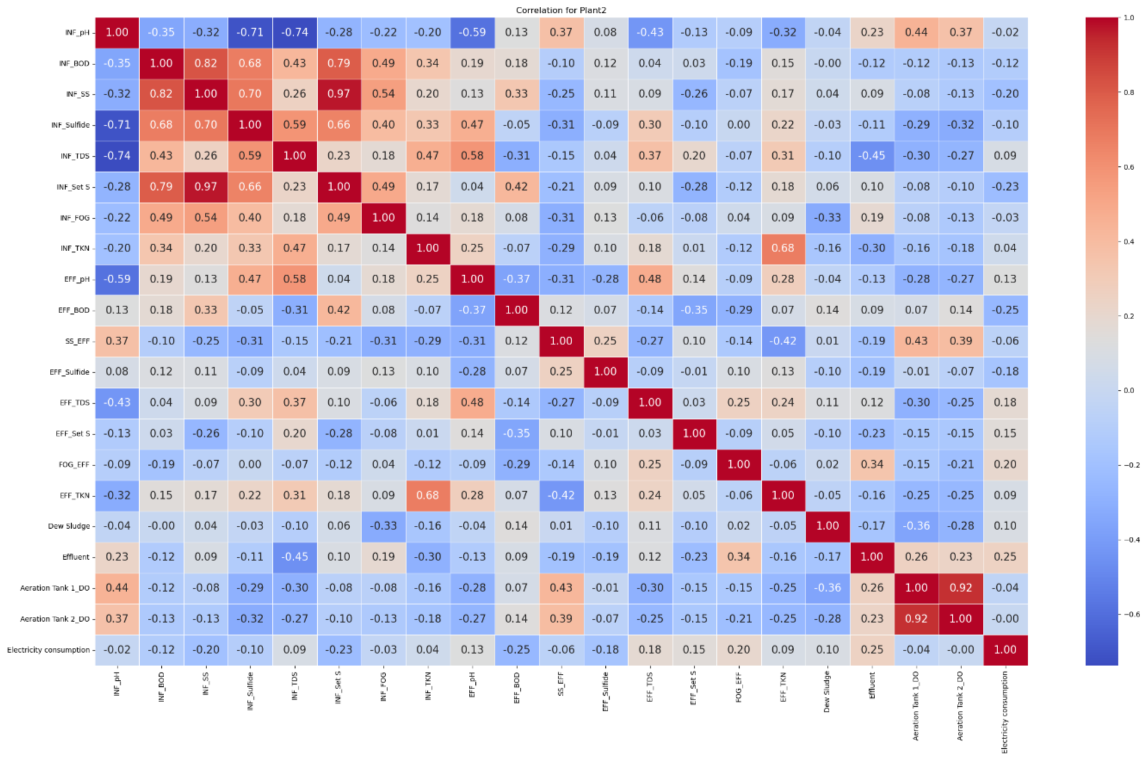

Figure 8. Correlation for Plant 2

Figure 8, the analysis of Plant 2 shows positive correlations such as effluent SS with aeration tanks 1 (0.43) and 2 (0.39), suggesting that adequate aeration promotes microbial activity and solid breakdown. Similarly, the positive correlation between influent pH and DO levels in aeration tanks 1 (0.44) and 2 (0.37) emphasizes the importance of oxygen in microbial processes and the breakdown of organic acids. Negative correlations, such as those between dewatered sludge and DO levels in aeration tanks 1 (-0.36) and 2 (-0.28), indicate that lower sludge accumulation might lead to increased aeration demands to maintain treatment efficiency.

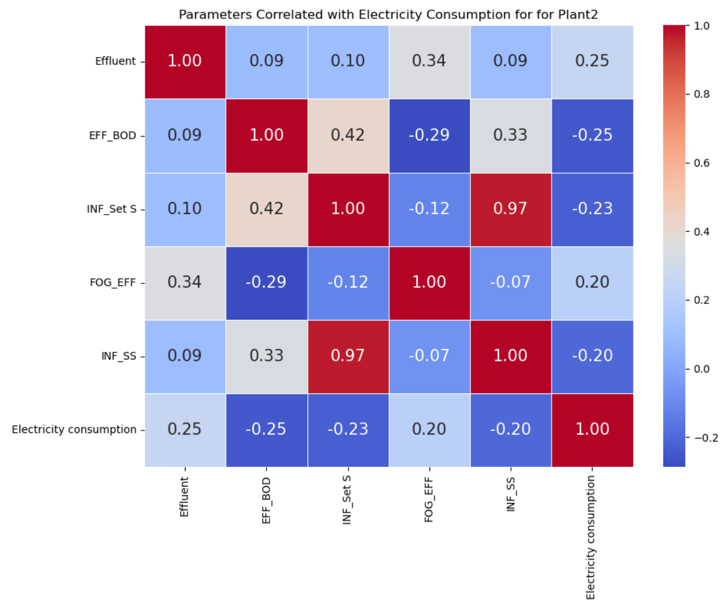

Figure 9. Parameters Correlated with Electricity Consumption for Plant 2

In the analysis of electricity consumption for Plant 2, both positive and negative correlations are observed in Figure 9. Positive correlations, such as those between effluent FOG (0.20) and electricity

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consumption, indicate that higher levels of FOG require more energy, likely due to the need for more intensive processes like pumping and aeration. Conversely, negative correlations with parameters like influent Settleable Solids (Set S) and SS (-0.23 and -0.20, respectively) suggest that lower levels of these parameters may lead to higher energy requirements, possibly due to the need for additional treatment steps to achieve the desired effluent quality.

The correlation analysis for both Plant 1 and Plant 2 reveals significant interdependencies between influent and effluent water quality parameters, aeration tank dissolved oxygen (DO) levels, and electricity consumption. In Plant 1, positive correlations, such as those between dewatered sludge and electricity consumption, suggest that higher sludge volumes increase energy usage, emphasizing the need for efficient sludge management. Conversely, negative correlations between influent FOG, TKN, and electricity consumption highlight that optimizing these influent parameters can reduce the energy demands of the treatment process. Similarly, in Plant 2, positive correlations, such as those between effluent FOG and electricity consumption, indicate that higher levels of FOG require more intensive energy usage. Negative correlations, like those between influent Settleable Solids (Set S) and electricity consumption, suggest that lower levels of certain influent parameters might increase energy requirements for adequate treatment. These findings underscore the importance of optimizing influent quality and aeration efficiency to improve overall treatment performance and minimize energy consumption.

4.4 Performance Assessment and Optimization

The schematic provided outlines the process flow and input-output data relevant to wastewater treatment plants (WWTPs). The performance assessment and optimization involve setting the scope for developing frameworks that enhance the efficiency of these plants while minimizing environmental impacts.

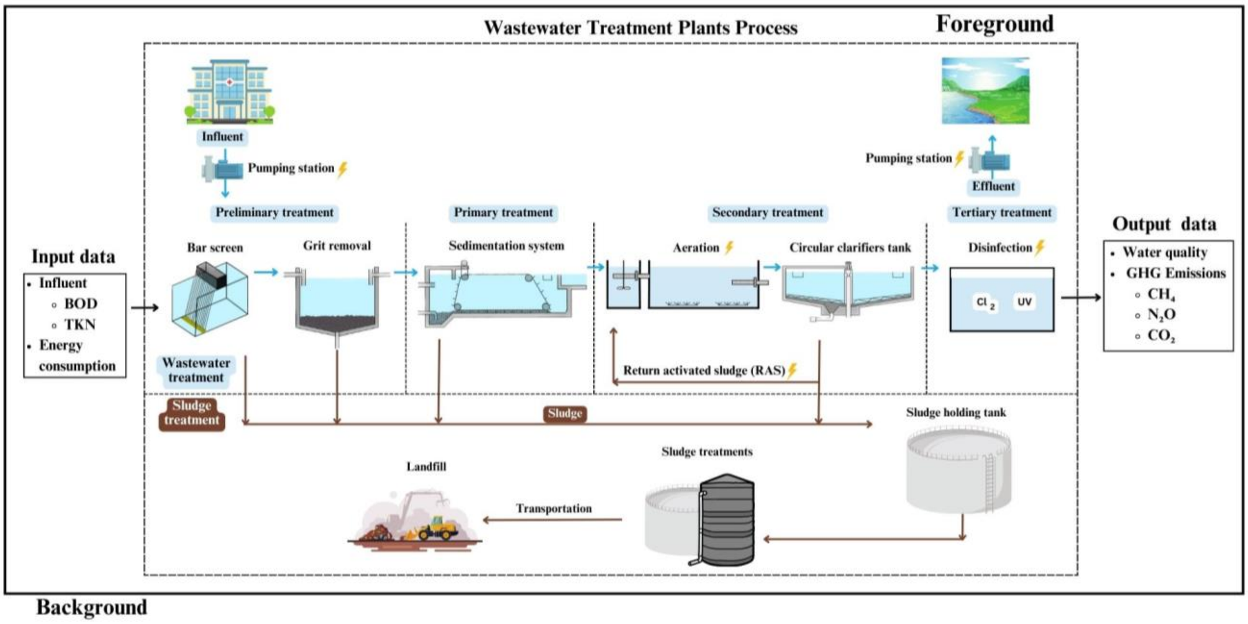

Figure 10. Framework of LCI for WWTP

Figure 10 is the Framework of LCI for WWTP, designed to systematically assess the inputs, processes, and outputs involved in the operation of a WWTP.

- Input Data: The framework integrates various influent parameters such as biochemical oxygen demand (BOD), total Kjeldahl nitrogen (TKN), and energy consumption. These parameters are crucial for assessing the operational efficiency and environmental performance of the WWTPs.

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- Treatment Processes: The diagram details the stages of wastewater treatment, including preliminary, primary, secondary, and tertiary treatments. Each stage is designed to progressively improve water quality and manage sludge generated during the treatment process.
- Sludge Management: Sludge treatment and its return as activated sludge (RAS) to the system, along with its transportation and disposal, are critical aspects of the performance assessment. Optimizing sludge management can significantly impact the plant's overall energy consumption and greenhouse gas (GHG) emissions.
- Output Data: The framework considers output data such as effluent water quality and GHG emissions (CH_4, N_2O, CO_2). These outputs are essential for evaluating the plant's environmental impact and for developing strategies to achieve carbon neutrality.

Figure 10 serves as a comprehensive framework that guides the life cycle inventory (LCI) analysis of WWTPs, providing a structured approach to assess and optimize the performance of wastewater treatment operations. By integrating input and output data with detailed process analysis, the framework helps in identifying opportunities to enhance efficiency, reduce energy consumption, and minimize environmental impacts, thereby contributing to the sustainability and resilience of WWTPs.

5. CONCLUSIONS

The correlation analysis provides valuable insights into the interdependencies between various parameters in both WWTPs, revealing significant interdependencies between influent and effluent water quality parameters, aeration tank DO levels, and electricity consumption. For Plant 1, positive correlations such as the correlation of 0.31 between effluent SS and influent pH indicate that optimizing pH can enhance solid removal. Effluent Set S correlates with aeration tank 1 at 0.36, suggesting that efficient aeration improves the settling process. Negative correlations, such as effluent FOG with aeration tanks 1 and 2 (-0.40 and -0.31, respectively), underscore the importance of FOG management to maintain adequate DO levels, thereby reducing energy consumption. Additionally, the positive correlation of 0.23 between electricity consumption and dewatered sludge highlights that higher sludge quantities increase energy use. Conversely, lower influent FOG, TKN, and TDS levels are associated with higher energy consumption, indicating the need for improved treatment processes.

For Plant 2, significant positive correlations include effluent SS with aeration tanks 1 (0.43) and 2 (0.39), indicating that adequate aeration promotes microbial activity and solid breakdown. Influent pH also shows strong positive correlations with aeration tanks, suggesting that optimal pH levels enhance oxygen availability and microbial activity. Negative correlations, such as dew sludge with aeration tanks 1 (-0.36) and 2 (-0.28), imply that less sludge accumulation may lead to higher aeration demands. Electricity consumption correlates positively with effluent FOG at 0.20 and effluent at 0.25, indicating higher energy requirements for processes like pumping and aeration when these parameters are elevated. Conversely, low influent Set S and SS correlate with higher energy consumption, highlighting the need for efficient solids removal to optimize energy use.

These findings emphasize the importance of managing influent and effluent parameters and optimizing aeration to improve treatment efficiency and reduce energy consumption in WWTPs. By implementing targeted parameter management and optimizing treatment processes, WWTPs can significantly enhance operational performance and sustainability. This approach not only contributes to achieving carbon neutrality but also aligns with the Sustainable Development Goals (SDGs), promoting environmental stewardship and resource efficiency in wastewater management.

The developed framework for Life Cycle Inventory (LCI) analysis further supports this by providing a structured approach to systematically assess and optimize the performance of WWTPs. By integrating detailed process analysis with input and output data, the framework helps in identifying

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opportunities to reduce energy consumption and minimize environmental impacts, thereby contributing to the overall sustainability and resilience of WWTP operations.

6. RECOMMENDATIONS

Future research should prioritize the development of a comprehensive database aimed at enhancing pollutant removal efficiency while simultaneously reducing energy consumption and greenhouse gas emissions. Recommendations for future research include:

Expanding data collection is a crucial step. This includes capturing data on direct, energy indirect, and other indirect GHG emissions, alongside critical parameters like chemical oxygen demand (COD), total nitrogen (TN), sludge management, and chemical usage. Utilizing automatic measurement equipment for continuous data recording will improve accuracy and minimize missing data, enhancing GHG emission assessments. Additionally, it is necessary to study the formula for calculating greenhouse gas emissions appropriate for the wastewater treatment system used in the study and to conduct regular monitoring and updating of Thailand's emission factor (EF) values, which may fluctuate over time. This practice would reduce discrepancies and enhance the reliability of research analyses.

Equally important is the creation of a comprehensive database, integrating structured query language (SQL) with life cycle inventory (LCI) methodologies. This database will serve as a foundation for evaluating the energy efficiency and carbon neutrality of WWTPs. It will guide the development of frameworks to optimize processes and reduce emissions, offer insights into achieving net-zero GHG emissions, and support sustainable development goals.

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Carbon Footprint of Rice Straw Paper Plate

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ABSTRACT

The objectives of this research to study the greenhouse gas emissions (GHG) of rice straw paper plates and to compare the environmental pollution from burning rice straw to make rice straw paper plates. In addition, it is suggested as a guideline for the use of rice straw. The study was based a Carbon Footprint of Products (CFP) on the concept estimation principle of the Thailand Greenhouse Gas Management Organization (TGO). Data was recorded from rice straw paper plate production by community enterprise Arak Group from Lat Bua Khao sub-district, Ban Pong district, Ratchaburi province, Thailand. The methodology was investigated from harvest material to production process until rice straw paper plate. The result was that 20 kg of rice straw emitted 7.93 kg CO_2e; on average, 1 plate emitted 0.0441 kg CO_2e. The results of the data analysis in each process were as follows: most GHGs averagely emitted 7.29 kg CO_2e; GHGs accounted for 91.96% of process production. The second highest from raw material usage emitted 0.64 kg CO_2e of GHGs, which accounted for 8.04% of the reduction in burning as follows: CO_2, CH_4, PM10, PM2.5, Black Carbon, CO, NH_3, NO_X, SO_2, NMVOC and Organic Carbon averagely emitted 351,765.39, 1,115.52, 3,631.93, 150.47, 15,357.88, 153.06, 767.89, 155.65, 2,062.42, and 907.98 tons, respectively, of the total amount of rice straw in Ratchaburi province, Thailand.

Keyword: Carbon footprint of product/ Greenhouse gas/ Life cycle assessment/ Air pollution/ Rice straw paper plate

1. INTRODUCTION

Global warming is an important environmental problem. It is mainly caused by human activity, primarily through emitting greenhouse gases from the burning of fossil fuels and deforestation. Carbon footprint has become an increasingly popular concept for labeling goods and services. The carbon footprint is the sum of all greenhouse gases released during the life cycle of a product, expressed as CO_2 equivalents as a common unit for all greenhouse gases. It is increasingly used by businesses, governments, and other stakeholders to quantify and subsequently reduce emissions.

Thailand is an agriculture area, it covered rice production area around 9.76 million hectares or 20 percent of the total rice planted area. It can produce 24 million-ton rice yield per year [4]. The rice straw waste is approximately 25.45 million tons per year. Furthermore, rice straw residue remains in the rice paddy area, about 16.9 million tons per year. In one rai was produced 329 kilograms of rice straw residue [5]. In general, farmers manage the rice straws by burning them because it is easy, time-consuming, and saves the budget for rice farming. The burned rice straw caused the air pollution in terms of PM 2.5, black carbon, and the other effected greenhouse emissions. The one rai emitted greenhouse gas emissions about carbon dioxide (CO_2) of 446.11 kg, methane (CH_4) of 1.41 kg. Furthermore, the air pollution from one rai of rice emitted PM10 of 4.61 kg, PM2.5 of 4.18 kg, black carbon of 0.19 kg, carbon monoxide (CO) of 19.48 kg, ammonia (NH_3) of 0.19 kg, nitrogen oxide (NO_X) of 0.97 kg, sulfur dioxide (SO_2) of 0.20 kg, NMVOC of 2.62 kg, and organic carbon (OC) of 1.15 kg [7]. The management of rice straw residue by applying them to rice straw paper plate production is one idea to reduce rice straw waste and get more value from waste. It can help farmers manage rice straw waste, reduced air pollution, and greenhouse gas emissions from biomass open burning. Accordingly, this study used the Life Cycle Assessment (LCA) concept and carbon footprint (CFP) framework to evaluate carbon footprint and compare air pollution and GHG emissions from conventional frameworks and reduce rice straw waste by producing rice straw paper plates. The

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objective of this study is to evaluate the carbon footprint of rice straw paper plate and compare it with the conventional plastic material in terms of environmental impact based on the LCA concept.

2. METHODOLOGY

2.1 Study site

The study site is located in Lat Bua Khao sub-district, Ban Pong district, Ratchaburi Province, West of Thailand. The evaluation of rice straw paper plates by community enterprise Arak Group from Lat Bua Khao sub-district, Ban Pong district, Ratchaburi province, Thailand. The community enterprise Arak Group activities promote the product from rice straw material.

2.2 Functional unit

The functional unit, which all inputs and outputs of analysis are related to in order to allow emissions estimation for rice straw paper plate size 20 × 20 cm. These was defined as kg CO_2e. The greenhouse gases under consideration are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Each gas is converted into a CO_2 equivalent value using global warming potential from the latest IPCC 100-year time horizon GWP equivalent factors (CO_2, CH_4, and N_2O having GWP of 1, 25, and 298, respectively) [6].

The CFP was estimated following the life cycle assessment concept and PAS 2050 methodology [1,7]. Therefore, the CFP presented in this study includes carbon emissions from raw material preparation and production up to the rice straw paper plate being stored in warehouses (consistent with the "cradle to gate" approach) [1]. Additionally, the scope of carbon footprint (CFP) is shown in Figure 1.

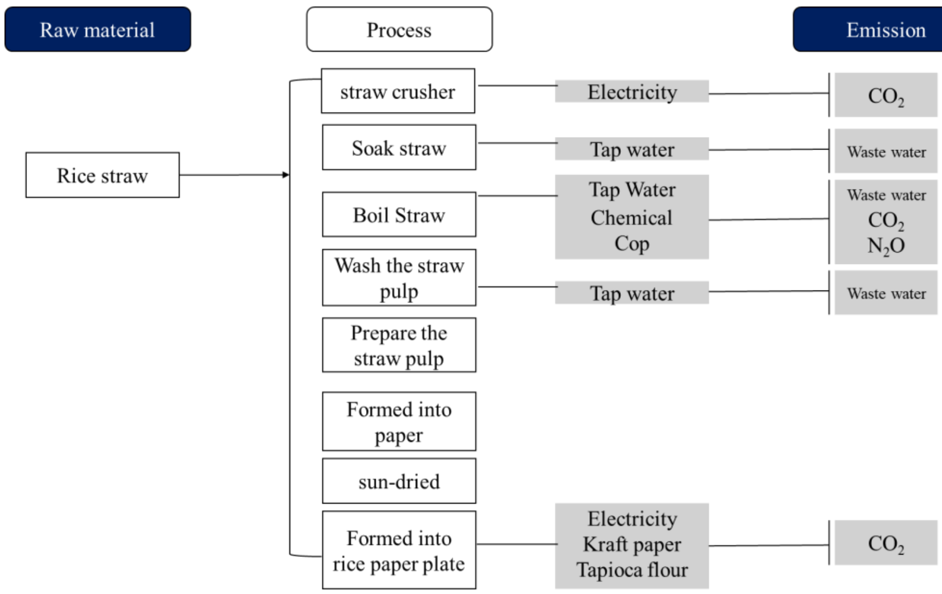

Figure 1. Scope of the study carbon footprint of rice straw paper plate

2.3 Data collection

The evaluations follow the life cycle assessment concept (cradle to gate), the IPCC 2006 guideline, and Thailand Greenhouse Gas Management Organization (TGO), (emission factor and methodology) [7]. The data used in this study were collected from interviews and relevant publications. Data were collected into two types these include;

Primary data were collected from community enterprise Arak Group about raw materials (electricity, water tap, chemicals, etc.) used for producing rice straw paper plates in 1 functional unit set up for this study. In addition, raw materials of rice straw quantity from farmer in the study area. The data shown in Table 1.

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Secondary data were recorded and reviewed from relevant publications about emission factors, air pollution from biomass open burning, global warming potentials (GWP100), and the other CFP of products from plastic and other materials. All documents used for evaluating greenhouse gas emissions and comparing the impact of open burning and greenhouse gas emissions between rice straw paper plates and the other material used for produced plates.

Table 1. Raw material for produced rice straw paper plate (Size 20 x 20 cm)

Inventory	Quantity	Unit
Raw material		
Rice straw	20	kg
Process		
Electricity	4.10	kWh
Tap water	46	L
Cob (biomass)	15	kg
Sodium hydroxide	3	kg
Tapioca flour	20	g
Kraft paper	0.90	kg

2.4 Impact assessment

The life cycle assessment concept was used for calculation. The conversion was calculated into equivalent carbon dioxide emission (CO_2e). Greenhouse gas inventories to estimate greenhouse gas emissions from these activities were used for the calculation**.** These show in equation 1.

$$CF = AD \times EF \qquad (1)$$

Where; CF is carbon footprint (CO_2e per unit product), AD is activity data (mass/volume/kWh/km), and EF is emission factor GHG (CO_2e per unit) is the default emission factor of a given GHG by type of resource use. In addition, the emission factor used is shown in Table 2.

Table 2. Emission factor used to evaluate greenhouse gases in scope of raw material and production process [7].

Name	Unit	Emission Factor ($kgCO_2e$)	References	Date update
Cob	kg	0.0319	IPCC Vol.2 Table 2.2, DEDE	UPDATE_1Apr22
Sodium hydroxide	kg	1.1148	Ecoinvent 2.2, IPCC 2007 GWP 100a	Update_24Sep12
Sodium hydroxide diaphram	kg	1.3711	Ecoinvent 2.2, IPCC 2007 GWP 100a	Update_24Sep12
Tapioca flour	kg	0.5410	Ecoinvent 2.2, IPCC 2007 GWP 100a	Update_24Sep12
Electricity, grid mix	kWh	0.5986	Thai National LCI Database, TIIS-MTEC-NSTDA (with TGO electricity 2016-2018)	Update Dec2019
Tap water	m^3	0.2843	Thai National LCI Database, TIIS-MTEC-NSTDA (with TGO electricity 2016-2018)	Update Dec2019
Kraft paper	kg	1.6324	Thai National LCI Database, TIIS-MTEC-NSTDA	

3. RESULTS AND DISCUSSION

3.1 Inventory assessment

The inventory and raw materials used for 1 paper plate size 20 × 20 cm as show in Table 3. These include raw materials; rice straw, in process product; electricity, tap warer, fire wood, sodium hydroxide, tapioca flour and kraft paper.

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Table 3. Raw material used for 1 rice straw paper plate size 20 × 20 cm [7].

Boundary	Inventory	Emission Factor	Unit
Raw material	Rice straw	0.0319	kg
Process	Electricity, grid mix (Electricity)	0.5986	kWh
	Tap water	0.2843	m^3
	Fire wood (biomass)	0.0000	kg
	Sodium hydroxide	1.1148	kg
	Tapioca flour	0.5410	kg
	Kraft paper	1.6324	kg

3.2 Carbon footprint of rice straw paper plate

The 20 kilograms of rice straw produce 180 rice straw paper plates size 20 × 20 cm. The greenhouse gas emissions from this product emitted 7.93 kg CO_2e. Based on the use and source of fuels (chemicals, tap water, tapioca flour), rice straw paper plates and raw materials are used. The greenhouse gas emissions from the raw material emitted about 0.64 kg CO_2e (8.04% of total emissions). In the part of rice straw paper plate product process is 7.29 kg CO_2e (91.96%) of total emissions. (Figure 2 and Table 4). Thus, the average emission from 1 rice straw paper plate is 0.044 kg CO_2e.

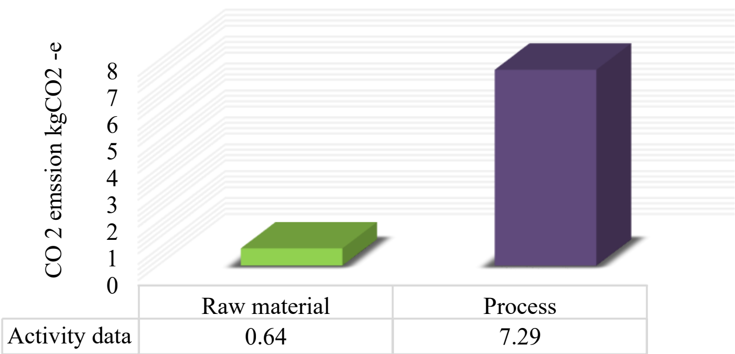

Figure 2. Greenhouse gas emission of 180 rice straw paper plates size 20 × 20 cm.

Table 4. The 1 rice straw paper plate size 20 × 20 cm.

Rice straw paper plate						
Product picture	Product name	Owner	Scope	Carbon footprint (kg CO_2e)		GHG emission (kg CO_2e)
				Raw material	Process	
	Rice straw paper plate size 20 × 20 cm.	Community enterprise Arak Group	Cradle to gate	0.0035	0.0405	0.0441

3.3 Comparison air pollution from open burning and product of rice straw paper plate

In 2021, Thailand can produce 31,329,655 tons of rice yield. The rice straw waste is approximately 37,282,289.45 tons per year. Ratchaburi Province produced 218,003 tons of rice. The rice straw waste is approximately 259,423.57 tons per year [4].

If all waste gets into open burning, these emit air pollution and greenhouse gas emissions: CO_2, CH_4, PM10, PM2.5, black carbon, CO, NH_3, NO_X, SO_2, NMVOC, and organic carbon. When thinking about reducing biomass burning, it could be reducing emissions, as shown in Table 5.

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Table 5. The quantity of air pollution from rice straw open burning in Ratchaburi province, Thailand**.**

Air pollution	Air pollution from rice straw open burning	
	Ratchaburi Province Air pollution (tons per year)	Whole area of Thailand Air pollution (million tons)
CO_2	351,765.39	50.55
CH_4	1,115.52	0.16
PM10	3,631.93	0.52
PM2.5	3,299.87	0.47
Black Carbon	150.47	0.02
CO	15,357.88	2.21
NH_3	153.06	0.02
NO_X	767.89	0.11
SO_2	155.65	0.02
NMVOC	2,062.42	0.03
Organic Carbon	907.98	0.13

Note: Carbon dioxide (CO_2), Methane (CH_4), Particulate matter 10 micrometers or less in diameter (PM10), Particulate matter 2.5 micrometers or less in diameter (PM2.5), Carbon monoxide (CO), Ammonia (NH_3), Nitrogen oxides (NOx), Sulfur dioxide (SO_2), Non methane volatile organic compounds (NMVOC)

3.3.1 Comparison of rice straw paper plate and rice straw open burning

Rice straw paper plate clouds help reduce emissions from rice straw open burning, as shown in Table 6.

Table 6. The ability of rice straw paper plate help to reduce air pollution and greenhouse gas emission

Air pollution	1 rice straw paper plate size 20 × 20 cm. Reduce air pollution (kg)	180 rice straw paper plates (rice straw 20 kg) Reduce air pollution (kg)
CO_2	0.1506	27.12
CH_4	0.0005	0.09
PM10	0.0016	0.28
PM2.5	0.0014	0.25
Black Carbon	0.0001	0.01
CO	0.0066	1.18
NH_3	0.0001	0.01
NO_x	0.0003	0.06
SO_2	0.0001	0.01
NMVOC	0.0009	0.16
Organic Carbon	0.0004	0.07

3.3.2 Comparison air pollution between rice straw paper plate and plastic PP plate

The previously study presented the rice straw paper plate cloud, which helps reduce emissions from plastic PP plates, as shown in Table 7.

Table 7. Comparison air pollution between rice straw paper plate and plastic PP plate [8]

Air pollution	Rice straw paper plate		Plastic PP plate	
	Rice straw 20 kg Emitted air pollution (kg)	Rice straw 0.11 kg (1 rice straw paper plate) Emitted air pollution (kg)	Plastic PP 20 kg Emitted air pollution (kg)	Plastic PP 0.11 kg (1 plate) Emitted air pollution (kg)
CO_2	27.12	0.1506	37	0.2035
CO	1.18	0.0066	0.0144	0.0001
SO_X	0.01	0.0001	0.2588	0.0014
NO_X	0.06	0.0003	0.1914	0.0011

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3.3.3 Comparison carbon footprint of rice straw paper plate and product certify by TGO

Comparison of greenhouse gas emissions of rice straw paper plates in Tables 8 with plastic plates that have been approved for the product's carbon footprint label by TGO in the same assessment scope, “Cradle to Gate or B2C”. It was found that the greenhouse gas emissions of one rice straw paper plate have the lowest greenhouse gas emission value, with a value of 0.0441 kg CO_2e. When considering each step, the step of obtaining raw materials will have lower greenhouse gas emissions than plastic plates. However, the production process has 2 types of plastic plates that emit slightly less greenhouse gases: a 16 oz. natural bowl with a natural color lid and a 13 oz. white cup with a white lid. The reason for this is because rice straw biomass is a plant with a strong fiber structure**.** In the production process, chemicals and energy are required to break down the fibers so that they are soft enough to be molded. This is different from plastics that are very soft and can be blown into shape faster than rice straw paper plates.

Table 8. Carbon footprint of product certify by TGO [**7**].

Product picture	Product name	Scope	Ratio of CFP (kg CO_2e)		GHG emission (kg CO_2e)
			Raw material	Process	
	16 oz. natural bowl with a natural color lid	Cradle to gate	0.0523	0.0376	0.0899
	16 oz. bowl white	Cradle to gate	0.0542	0.0426	0.0968
	with lid white	Cradle to gate	0.0497	0.0633	0.1130
	shrimp wonton cup 16 oz. white	Cradle to gate	0.0554	0.0576	0.1130
	with Lid	Cradle to gate	0.0963	0.0197	0.1160
	shrimp wonton cup 425 ml	Cradle to gate	0.0578	0.0602	0.1180
	black with lid	Cradle to gate	0.0773	0.0607	0.1380
	13 oz. white cup with a white lid.	Cradle to gate	0.0814	0.0566	0.1380
	15 oz. cup white	Cradle to gate	0.1920	0.0480	0.2400

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4. CONCLUSIONS

This study has tried to estimate the CFP from rice straw paper plate size 20 × 20 cm. in community enterprise Arak Group from Lat Bua Khao sub-district, Ban Pong district, Ratchaburi Province, Thailand. The data used were taken from surveys, interviews, and statistics, covering the majority of farmers and community enterprise Arak Group in the study area. Rice straw 20 kg cloud produced 180 rice straw paper plates and emitted greenhouse gases about 7.93 kgCO_2e. Thus, the estimated CFP was 0.0441 kgCO_2e per 1 rice straw paper plate size 20 × 20 cm. More than 91% of greenhouse gas emissions come from the production process in manufacture. We found that rice straw management cloud helps to reduce greenhouse gas emissions and air pollution from biomass open burning in rice planted areas.

Acknowledgement

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Stakeholder Engagements in Maintaining Marine Ecosystems in the Bali Sea, Indonesia

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ABSTRACT

The Bali Sea has an important role in supporting the fishing and tourism industries. However, as with many other seas, exploitation of natural resources through economic and tourism activities in the Bali Sea may endanger marine ecology, which has brought various advantages to coastal populations. Thus, this study aims to examine how stakeholders participate in preserving the environment of the Bali Sea and encounter challenges. This study used a qualitative method by conducting in-depth interviews with stakeholders in Sapeken Island, Bali Island, Lombok Island, and Sumbawa Island. The collected data were analyzed to evaluate the strengths and interests of each stakeholder. The study revealed that traditional and religious leaders and the local governments had high power and importance in protecting marine ecosystems. In contrast, fishermen, fishermen's groups, family welfare activists, and Non-Government Organizations, although highly interested, had less power. Meanwhile, Community-Based Organizations, like youth organizations, had low interest and power as many of them were already part of the fishermen's groups. A major challenge faced by stakeholders in maintaining the marine ecosystem in the Bali Sea was the presence of fishing purse seine vessels from outside their area that could damage the ecosystem and harm local fishermen. This study concludes that the involvement of stakeholders, especially local communities, greatly contributes to maintaining the Bali Sea's marine ecosystems. They recognize that the sustainability of their lives depends on the preservation of the Bali Sea's marine ecosystem.

Keywords: Stakeholders/ Marine ecosystem sustainable development goals/ Fishermen/ Local community

1. INTRODUCTION

Coastal ecosystems offer social welfare to coastal communities [1]. The Bali Marine Ecosystem has a strategic position as a tourist area and sea transportation route that connects between islands. The sea, located north of Bali Island, is surrounded by several islands including Sapeken, Bali, Lombok, and Sumbawa. The existence of these four islands makes the Bali Sea ecosystem a source of life for the people in the region. Communities in the four regions are coastal communities that have special interests from a social and economic perspective [2]. The abundant natural resources of the Bali Sea and its beautiful natural conditions for tourism purposes are important elements in the growth of the blue economy [3] and local people's welfare.

Many countries, including Indonesia, have adopted the blue economy as part of their national development goal [4]. For this reason, the Government of Indonesia through the Coordinating Ministry for Maritime Affairs and Investment has issued Law Number 32 of 2014 concerning Maritime Affairs. The law aims to regulate the central and local governments in managing marine affairs to bring prosperity to the people through the utilization of marine resources with blue economy principles. Although there are laws governing marine affairs, in practice, the government is still unable to implement, monitor, and enforce them [5]. There are still many legal loopholes, environmental pollution, and a lack of collaboration and coordination with local communities as users of marine ecosystems [6].

Several cases related to marine ecosystem damage still occur frequently. As reported in Detik.com [7] on Monday, May 29, 2023, there was a reclamation on Bali's Melasti Beach, which allegedly caused environmental damage and marine biota ecosystems. In the same year, Detik.com [8], on Thursday, December 14, 2023, also reported that pollution in the Bali Sea caused several beaches in

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Bali to face a pollution crisis due to plastic waste from other regions. This negatively affects the beach tourism sector, especially Kuta Beach and Badung Beach.

Subsequently, the significance of marine ecosystems to the economy, along with a growth in marine-related activities without an efficient sustainable management system, is beginning to significantly damage physical and ecological conditions [9]. Some studies on the damage to marine ecosystems have resulted in the destruction of coral reefs and marine biota [10], extinction of fishery resources [11] due to overexploitation of fish [12], and microplastics impacting the survival of marine fauna [13].

The Bali Sea is a dynamic ecosystem giving rise to many interests [14]. This makes the Bali Sea potentially subject to natural damage related to activities carried out by humans such as the search for ornamental fish and coral reefs, oil exploration, and garbage as it is a sea traffic route that connects the surrounding islands. It is not uncommon for different interests in the Bali Sea to cause conflicts, both vertical, namely the community with the government or companies, and horizontal conflicts, namely the community with the community, which usually occurs between fellow fishermen.

Vertical conflicts between communities and the government, for instance, are related to vessel licenses and firm stances on violations [15]. Whereas, community-company conflicts are usually triggered by company activities that are considered to interfere with fishing activities by fishermen. Meanwhile, horizontal conflicts often occur between local fishermen and those from other regions or traditional and modern fishermen due to territorial struggles and differences in fishing gear [16], [17].

Therefore, this study aims to contribute to marine ecosystem conservation efforts by identifying characteristics, mapping functions, and stakeholder involvement around the Bali Sea. With the identification of stakeholder involvement, it is expected that there will be social justice in the conservation of the Bali Sea. According to Bennet et al. [18], marine conservation must consider the perspectives and needs of local communities to have a positive impact. In addition, the government has limitations in management, monitoring, and law enforcement, so the involvement of local stakeholders in the process of making and implementing marine policies is very important [19].

2. METHODOLOGY

The study was focused on nearby Bali Sea locations, including Sapeken, Bali, Lombok, and Sumbawa Islands. This study used a qualitative analysis to map stakeholders. Researchers used the snowball sampling technique to reach hard-to-reach research subjects such as marine ecosystem stakeholders [20]. To reach all informants, the researchers set the local government as the key informant. The local government then helped the researchers to find other relevant stakeholders. Data were collected by conducting in-depth interviews with informants, including village/local government, community leaders, fishermen leaders, local NGOs, local entrepreneurs, collectors, boat owners, cooperative leaders, and souvenir trader associations spread across four islands namely Sapeken, Lombok, Sumbawa, and Bali. Table 1 portrays the research subjects as informants involved in this study.

The interviews with stakeholders aimed to understand the role and influence of key actors, forums for community discussions, community vulnerabilities, fisheries sector activities, and social perceptions in the village. Key questions focused on identifying influential community and religious leaders who represent local interests, including both popular and lesser-known actors who are respected. The interviews explored the actors' backing and support networks, their ability to mobilize supporters, and the extent of their engagement with social media. Additionally, the study examined the actors' stances on industrialization, their relationships with formal village leaders, and any cooperation or conflict among them.

The interviews also sought insights into the forums used by villagers to discuss their needs and interests, the role of social institutions, and the actors who facilitate these discussions. Understanding the regularity of these meetings and their typical attendance was also a focus. The study further investigated the vulnerabilities within the community, identifying groups at risk—such as single parents

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or those who lost assets—and examined the underlying causes of their vulnerability, including their susceptibility to exploitative practices.

Table 1. Informants and Number of Informants

Island	Category	Total
Sapeken	Village/local government	2
	Community leaders	1
	Fishermen leaders	1
	Local NGOs	1
	Local entrepreneurs	2
Lombok	Village/local government	2
	Community leaders	3
	Cooperative leaders	2
	Fishermen leaders	1
	Fishermen	1
	Collectors	1
Sumbawa	Village/local government	4
	Community leaders	2
	Fishermen leaders	1
	Capital owner	1
Bali	Village/local government	2
	Community leaders	5
	Lovina Beach Souvenir trader organization	1
Total		33

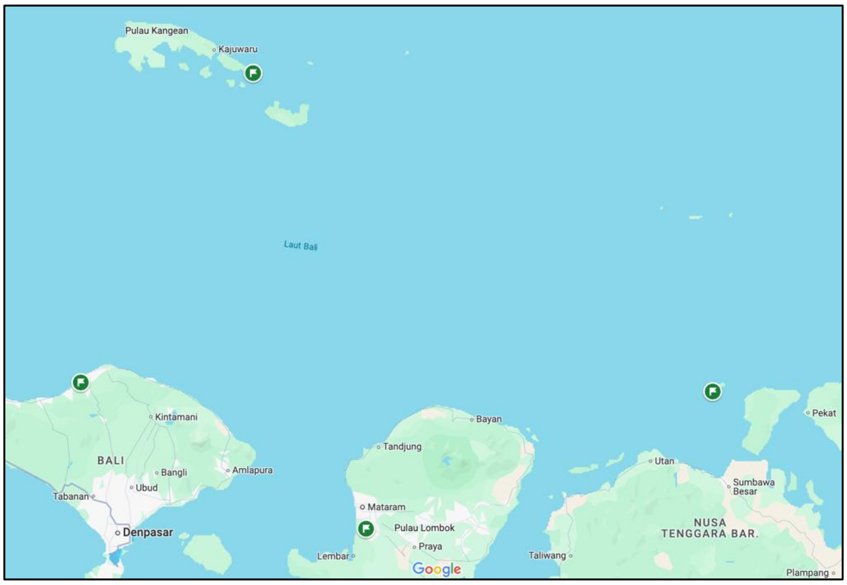

Figure 1. Map of Study Area (Source: https://www.google.com/maps)

In the fisheries sector, questions were aimed at identifying key fishing communities, understanding the market dynamics for their catch, and exploring the role of intermediaries (tengkulak). The study also gathered information on government and corporate social responsibility (CSR) programs that have been implemented for fisherfolk, as well as any challenges encountered in distributing these aids. Finally, the study explored the community's perceptions regarding the presence of oil and gas companies in the area, if any, and their impact on local life.

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In addition to the obtained interview data, researchers also collected secondary data from the internet and previous studies related to the role of NGOs and marine environmental issues to enrich the data. Data analysis included: first, stakeholder identification based on Crosby [21] which categorized stakeholders according to primary, supporting, and key stakeholders. Second, stakeholder mapping and functions were undertaken by referring to Bryson [22] which included stakeholder subjects, players, context setters, and crowd.

3. RESULTS AND DISCUSSION

3.1 Stakeholder identification

According to Crosby [21], stakeholder identification was based on three characteristics, namely primary, supporting, and key stakeholders. Primary stakeholders referred to those who are directly affected, both positively and negatively, by the sustainability of the marine ecosystem. Primary stakeholders included fishing communities, boat owners, and middlemen whose economic conditions depend on the condition of the Bali Sea ecosystem.

According to field observations, the condition of fishermen's catches near the Bali Sea was determined by erratic weather conditions, the equipment employed (e.g., small boats and traditional fishing gear), and price games played by collectors and middlemen. To deal with the price of fish, they formed social networks among fishermen in the four locations. The fishermen frequently shared information about the high price of fish in whatever place so they could reach the location even if it was too distant.

Key stakeholders were parties that had legal authority in making decisions related to marine ecosystem conservation. In this case, the Department of Fisheries and Marine Affairs became the key stakeholder that had the authority to make policies under the applicable laws. Meanwhile, supporting stakeholders were those who did not have a direct interest in the sustainability of the Balinese marine ecosystem but had concerns, including local, regional, and national NGOs.

3.2 Stakeholder mapping and function

In maintaining the Bali Sea ecosystem, the proactive and sustainable involvement of local stakeholders, assisted by community organizations and the government, was essential [23]. Community leaders representing the local community influenced the decision-making process when there were issues. There were community leaders who had formal legal and political legitimacy, such as government leaders, and those who did not have formal legal legitimacy but had social and cultural legitimacy. About maintaining the Bali Sea ecosystem, these stakeholders influenced the community on how to preserve the environment and take marine products with marine-ecosystem-friendly equipment. They also became the mediators of conflicts over the utilization of fisheries resources and decision-making concerning the exploration of natural resources in the Bali Sea.

According to Bryson [22], there were four stakeholder positions. First, the subjects were those who cared about an activity. They had great interest but little power, encompassing fishermen groups in Les Village, Kubutambahan, Sapeken, Bintaro, West Sekotong, Pokmaswas Baywatch, and souvenir traders on Lovina Beach. These stakeholders were directly affected by ecosystem damage and various marine issues.

From the results of interviews and field observations, fishermen in Bintaro admitted that they often returned home without bringing catches, or their catches were not as big as the capital obtained. This was influenced by the uncertain season and the condition of fishing equipment that was still conventional compared to boats from migrant fishermen. The Oncor Fishermen Group (KNO) in Sapeken also not only experienced a reduced catch of marine products but also had to face conflicts with companies such as PT. KEI, which conducted oil and gas exploration in the area. They also often came into conflict over fishing areas and differences in fishing gear [17]. Migrant fishermen in the Sapeken Island area, for example, used purse seines, which made it difficult for local fishermen to get fish.

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The fishermen on the four islands, although they got a small catch every day, still used traditional equipment. For coastal communities in remote island areas, the fisheries sector was the driver of economic development [12], while the economic development of coastal communities was a challenge between protecting biodiversity and maintaining access and sustainability to ecosystem benefits [3].

Second, concerning those acting as the player role category, village/local governments and community leaders (e.g., traditional and religious leaders) had great power because of the legitimacy of the local community. Moreover, the Department of Fisheries and Marine Affairs acted as a formal government institution. This institution had the authority to implement central policies, issue ship permits, and assist fishing groups in the form of training, equipment support, and capital. This institution also synergized with the village/local government because, in addition to being a government institution, it also had the same goal, namely to ensure the sustainability of the marine ecosystem and the welfare of fishermen. In addition, the capital owners/ship owners, local Sapeken entrepreneurs, and PT. Over Seas Seafood (OSS) Indonesia also had interests in marine catches, but they had a function among the fishing community. Investors usually partnered with small fishermen by providing capital and accommodating the catch. In Sapeken, PT. Over Seas Seafood (OSS) accommodated grouper catches from fishermen to be exported abroad. Meanwhile, local entrepreneurs who became members of the Sapeken Entrepreneurs Association (APS), in addition to accommodating the grouper, lobster, and ronggeng shrimp catches from fishermen to be exported abroad, also set aside some of the profits to help orphans and the poor in Sapeken. PT. OSS and local entrepreneurs had an interest in using the sea route in the Bali Sea to export the sea catch. These local entrepreneurs were also children of the islands who previously received scholarships from the local government in the “One Island One Graduate” program so that they could become the driving force of development in the islands.

Third, context setters were stakeholders who had small interests but conceived great power. Religious institutions such as Nahdlatul Ulama and Muhammadiyah had networks up to the national level. Their members were spread across various regions in Indonesia, including island regions such as Sapeken. These religious institutions did not have a direct interest in the Bali Sea but had a large role and influence in society. Both religious institutions had a role in maintaining social harmony in society based on religious values and preserving the culture of the local community. The figures in these religious institutions were influential, especially in resolving problems or social conflicts in society. Meanwhile, there was the BPD (Village Representative Body) that had the same role as other local governments but did not have a direct interest in the sustainability of the Bali Sea ecosystem.

NGOs such as the Indonesian Environmental Forum (WALHI), Greenpeace, the Indonesian Zero Waste Alliance (AZWI), ECOTON, ICEL, Gita Pertiwi, and the Environmental Rescue Front also helped to shape the setting. These non-governmental organizations (NGOs) had no interests but were deeply concerned about the preservation of the Bali Sea ecosystem. They supervised the development initiatives that had a direct influence on the marine ecosystem and occasionally carried out advocacy actions on cases of environmental damage both locally and nationally.

Fourth, Crowd was a stakeholder with limited authority and interests. It included Family Welfare Development (PKK), Karang Taruna, Community Empowerment Institution (LPM), and Bintaro Village Cooperative. These organizations played an important role in the local community. They aimed to empower local people, particularly women and youth, through a variety of activity programs, including health, integrated health posts, sports, arts, and small business development for fishers.

Table 2. Categories, Stakeholders, Functions and Responsibilities, and Levels

Category	Stakeholder	Fungctions, responsibilities, and obligations	Level
Player	Village/local government	Their functions, responsibilities, and obligations were: Carrying out village government and national government regulations, providing services to the community at the village level, improving community welfare at the village level, and resolving community problems at the village level.	Village/local

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Category	Stakeholder	Fungctions, responsibilities, and obligations	Level
Subject	Fishermen Group of Les and Kubutambahan Villages	Local fishing groups provided as a venue for fishermen's activities. Fishermen's groups served as social capital for fishermen in addressing various maritime environmental issues, boosting member welfare, and resolving conflicts among fishermen.	Village/local
Subject	Lovina Beach Souvenir Traders Organization	They became a souvenir merchant organization on Lovina Beach, one of Buleleng's dolphin-watching tourist attractions. This organization provided a platform for resolving difficulties encountered by souvenir merchants and attempting to improve the welfare of souvenir merchants at tourist destinations.	Village/local
Crowd	Family Welfare Development (PKK)	This was a small community organization with mostly female members. This group worked to improve the lives of local women through a variety of training and mentorship initiatives. Furthermore, it had a responsibility to empower women by raising awareness of various social issues in the community.	Village/local
Crowd	Youth organization	They were a youth group that provided a platform for local youth activities. This local group was also responsible for empowering youth through good activity programs such as collaborating with the village council to create villages, keeping the environment clean, and organizing positive youth activities and sports. Even in Les Village, this youth organization worked to expand the tourism and salt industries.	Village/local
Crowd	Community Empowerment Institution (LPM)	Formal institutions that had functions and responsibilities in empowering village communities. This institution seeked to improve the welfare of village communities.	Village/local
Player	Community Leaders in Kubutambahan Village and Les Village	In Kubutambahan and Les Villages, community leaders included both government officials and traditional leaders. Government officials were recognized by the community because they had political legitimacy, whereas traditional leaders were respected because they had socio-cultural legitimacy and, thus, were highly respected. The community in both places held both of them in high regard. Therefore, the village government and traditional leaders played an important role in decision-making.	Village/local
Player	Fisheries Service	A government institution that had a function in services in the field of water and marine, including shipping permit administration services to various assistance programs for fishermen.	Local/ regional
Context setter	Indonesian Environmental Forum (WALHI)	It was a national NGO that concerned on saving the environment. As the oldest environmental organization in Indonesia, it had considerable influence and a membership network throughout Indonesia including Bali. For its interest in saving the environment, it might be able to have positive relationships and provide a strong enough influence for fellow NGOs and the community.	National
Context setter	Greenpeace	Greenpeace was a fairly large international NGO and its membership network was also widespread, including in Indonesia. As an NGO concerning with the environment, it also often collaborated with WALHI in the mission of saving the environment. It Hhadas a good relationship with the community in saving the environment.	National/ International
Context setter	Alliance of Zero Waste Indonesia (AZWI)	AZWI was an alliance that actively campaigned for the correct implementation of the Zero Waste concept in order to mainstream various existing Zero Waste activities, programs, and initiatives to be implemented in various cities and regencies in Indonesia by considering the hierarchy of waste management, material life cycle, and circular economy. It also networked with WALHI and Greenpeace as well as other environmental NGOs and communities in Bali.	National
Context setter	ECOTON (ecological	Ecological Observation and Wetlands Conservation (ECOTON) was established in 1996 as a wetland's conservation study group	National

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Category	Stakeholder	Fungctions, responsibilities, and obligations	Level
	observation and wetlands conservation)	of Biology Study Program at UNAIR Surabaya and incorporated in 2000. ECOTON produced information related to the potential and threats of river ecosystems and water sources. This information was generated from studies, research, data exploration conducted by ECOTON with professional researchers. It also networked with WALHI and other environmental NGOs. It was active in checking river water quality with the Ekspedisi Sungai Nusantara (ESN) team and found microplastic contamination in the Bali river area.	
Context setter	ICEL	It fought for the realization of environmental justice based on the values of democracy, human rights, civilization, sustainability, rule of law, and good sustainable development governance. This organization also networked with other environmental NGOs.	National
Context setter	Gita Pertiwi	Yayasan Gita Pertiwi (GP) was a non-governmental organization (NGO) that focused on environmental conservation issues and fought for justice and gender equality. It also networked with other environmental NGOs.	National
Context setter	Pokmaswas Baywatch	The community was engaged in marine conservation, including monitoring the conservation beach of Gita Nada Sekotong Barat to Batu Putih Village (e.g., coral reef protection, monitoring fish bombing, actions that could potentially damage conservation waters, and making agency reports). This group had a good relationship with fishermen in maintaining the marine ecosystem.	Local/village
Subject	Oncor Fishermen's Group (KNO)	It was an association of fishermen using oncor boats in Sapeken. This fishermen group had a role in maintaining community harmony and preservation of marine ecosystems by catching fish using simple equipment. The oncor fishermen group also seeked to improve the welfare of fishermen and maintain the social life of the community from the impact of conflict over the presence of Purse seine vessels in the waters of the Bali Sea adjacent to Sapeken Island.	Local/village
Context setter	Nahdatul Ulama at Sapeken	It was an Islamic organization that had the function and responsibility of upholding the teachings of *Ahlusunnah wal Jama'ah* and preserving Islamic traditions that upheld tolerance. It organized pesantren-based education and had autonomous bodies that took part in every layer of society.	Local/ regional
Context setter	Muhammadiyah at Sapeken	It was an Islamic-based organizations that had the main function and task of upholding the pure teachings of Islam and eliminating misleading teachings. It conducted education including the study of social issues, formulating Islamic laws and *da'wah* widely, especially in Sapeken.	Local/ regional
Context setter	Environmental Rescue Front NGO	It engaged in the field of saving the coastal environment. The function of this NGO was to maintain the order of the village environment and coastal ecosystems by identifying and studying environmental problems in the Sapeken area and its coastal and water areas.	Local/village
Player	PT. Over Seas Seafood (OSS) Indonesia	It was a company that did business in the field of seafood around the world, especially Indonesia as a large source of all wild and exotic tropical species. It captured, handled, and processed marine catches, one of which came from Sapeken Village fishermen.	National/ international
Player	PT. KEI	It was an oil exploration company operating in Pagerungan Besar Village and adjacent to Sapeken Village. The company had a responsibility to conduct CSR programs for local communities in an effort to address the environmental, social, and economic impacts of the company’s operations.	National
Players	Sapeken Community Leaders	It was a respected group in Sapeken. Community leaders consisted of various elements such as religious leaders and heads	Local/village

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Category	Stakeholder	Fungctions, responsibilities, and obligations	Level
		of fishing groups. They had a role in preserving the traditions, environment, and social harmony of the Sapeken Island community.	
Players	Sapeken Local Entrepreneurs	Through the Sapeken Businessmen's Association, local entrepreneurs developed the shrimp and lobster business for maximum financial gain. Some of the profits earned were used to empower fishermen through the capture of their catches so as to help the local economy. They also did provision of social assistance through a number of social programs such as distribution of basic necessities and medical expenses.	Local/village
Subject	Cooperative and Fishermen Group “Samudera Biru” at Bintaro Village	The fishermen's cooperative had a function as a forum for fishermen to associate, do activities, transaction of fishing equipment, savings and loans, to discuss various issues related to fishermen. This fishermen group in Bintaro had an agenda of activities in the form of saving or compulsory contributions.	Local/village
Crowd	Bintaro Village Cooperative	This Cooperative drove the economy of the Bintaro Village community. It, together with fishermen's groups usually cooperated to advance MSMEs owned by the surrounding community.	Local/village
Player	Collectors	This group was a forum for collecting fish caught by fishermen. The fish caught by the fishermen were sold to various regions in Indonesia	Local/village
Subject	Fishermen Group at West Sekotong Village	This fishermen group had a function as a forum for fishermen to associate, did activities, and discussed various issues surrounding fishermen. The group had a routine gathering agenda once a month to discuss various problems and obstacles in the fishing process. It was a local actor that had a very strategic role, because in addition to being an organizational forum, the group also functioned as a forum for conflict resolution between fishermen both in the waters and at sea.	Local/village
Contex setter	BPD (Village Representative Body)	It was a government institution that had the function and responsibility of absorbing community aspirations based on their needs. It facilitated village and hamlet meetings with the aim of absorbing the aspirations of the community, which would later be reported to the village government.	Local/village
Player	Bugis Medang and Bajo Medang Community Leaders	They consisted of elements of village officials, religious leaders, fishermen financiers, chairman of the mosque committee, mosque imam, and traditional leaders. Community leaders in Bugis Medang and Bajo Medang villages had a function in maintaining socio-cultural values, maintaining traditions, preserving the environment, maintaining social respect in the community, and facilitating the resolution of various conflicts in the community.	Local/village
Player	Capital owner/ship owner	Capital owners or ship owners in the fisheries business chain were the capital providers of. They were commonly referred to as capital owners because economically they had large capital. Capital owners/ship owners often employed fishermen laborers or provided access to capital for small-scale fishermen, in return for this kindness, the fishermen usually sold their catches to the capital owners.	Local/village

Based on the levels, categories, functions, and responsibilities of stakeholders, the mapping of the strengths and interests of stakeholders for the sustainability of the Bali Sea ecosystem was drawn as follows:

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Table 3. Stakeholder mapping

High

Subject: - Les and Kubutambahan Village Fishermen Group - Lovina Beach Souvenir Traders Organization - Baywatch Community Group - Oncor Fishermen Group (KNO) - "Samudera Biru" Cooperative and Fishermen Group at Bintaro Village - Fishermen Group at West Sekotong Village	Player: - Village/local government - Community Leaders in Les and Kubutambahan Villages - Fisheries Office - PT. Over Seas Seafood (OSS) Indonesia - PT. KEI - Community Leaders of Sapeken - Collectors - Community Leaders of Bugis Medang and Bajo Medang - Capital Owners/Ship Owners - Local Entrepreneurs of Sapeken
Kerumunan: - Family Welfare Development (PKK) - Karang Taruna - Community Empowerment Institution (LPM) - PERSIS - Bintaro Village Cooperative	Cotext Setter: - Nahdatul Ulama at Sapeken - Muhammadiyah at Sapeken - BPD (Village Representative Body) - Environmental Forum (WALHI) - Greenpeace - Zero Waste Alliance Indonesia (AZWI) - ECOTON - ICEL - Gita Pertiwi - Environmental Rescue Front

Low → High

3.3. Important roles and strategies of stakeholders in maintaining marine ecosystems

In maintaining the marine ecosystem, cooperation between stakeholders was needed [24]. With the involvement and cooperation between stakeholders, especially local stakeholders, it could produce better support [25] [26] in efforts to preserve the Bali Sea ecosystem. Table 4 shows several problems faced in maintaining the Bali Sea ecosystem. Several strategies were developed in dealing with existing problems with cooperation between stakeholders.

Fishermen who belonged to the fishermen's group dedicated to preserving the Bali Sea ecosystem by collaborating with Pokmaswas Baywatch and the local authorities. To ward off purse seine vessels, Sapeken fishermen who belonged to the Oncor Fishermen's Group (KNO) collaborated with local companies. Local entrepreneurs also built grouper, lobster, and ronggeng shrimp hatcheries to house fishermen's catches so they might be exported. Exports increased fishermen's revenue, allowing them to catch only grouper, lobster, and ronggeng shrimp that were old enough to be sold.

Fishermen's groups in Bintaro collaborated with cooperatives to boost fishermen's incomes by teaching them in fish processing and marketing. In addition, to reduce contamination, fish processing waste was converted into other food ingredients. When at sea, fishermen typically resolved their own conflicts. If the situation remained unaddressed, it would be presented to community leaders for a solution. Conflicts arose due to the function of the environment, which could not be isolated from the human dimension. There were many competing interests, especially about access to the fisheries sector, business, government, and other ecosystem users [27]. With this cooperation between stakeholders, the Bali Sea ecosystem still survived and could be an economic foundation for the surrounding fishing communities.

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Table 4. Key Roles and Strategies for Stakeholders in Safeguarding Marine Ecosystems

Marine ecosystem issues	Indicators	Strategies
Ornamental Fish and Coral Reef Populations	Capture of ornamental fish for sale and fishing activities that had the potential to damage coral reefs	Ornamental fishing activities by diving and using simple equipment
Declining fish population	The existence of large vessels such as purse seines that could catch large amounts of fish	One of the fishermen groups, the Oncor Fishermen Group (KNO), prohibited the entry of purse seine vessels in their area.
Declining fish catches and potential conflicts between fishermen	a) Experiencing losses due to reduced fish catches b) Conflicts occurred between fishermen due to fighting over catchment areas	a. Using simple equipment to maintain the fish population b. Breeding grouper, lobster and ronggeng prawns c. Diversify businesses such as salt ponds
Fish processing waste in Bintaro	Used fish processing water can pollute the sea	Processing fish processing waste into food ingredients such as petis

4. CONCLUSIONS

Stakeholder cooperation is critical to the long-term viability of marine ecosystems. A well-maintained marine ecology can help promote social peace in coastal towns. One of the driving forces behind the preservation of the Bali Sea ecosystem is the role of local communities that continue to use traditional fishing methods and equipment. This surely requires support not only from the local government but also from other stakeholders, such as regional and national governments. There are various ideas for ensuring the sustainability of the Bali Sea ecosystem, including expanding the role and involvement of coastal people and local expertise in activities in the Bali Sea, such as the use of traditional equipment. Second, enhance local institutions and stakeholder networks in attempts to conserve the Bali Sea ecosystem. Third, there are strong bans and consequences for violations of legislation governing sustainable marine ecosystem management, such as the use of purse seine vessels or tiger trawls, which have the potential to harm marine ecosystems and generate conflict with local populations and fishermen. Further research should include mapping of social capital and stakeholder networks to evaluate the extent to which stakeholder social capital plays a role in attempts to maintain maritime ecosystems. This study also advises that future studies examine stakeholder perspectives of marine ecosystem preservation. This is crucial since it is related to how stakeholders act in using and conserving maritime habitats.

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Enhancing Thermal Performance of Cotton Facemasks through the Integration of Phase Change Materials: A Simulation Study

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ABSTRACT

In low temperature regions, people are often exposed to cold air which consumes bodily thermal energy during inhalation and exhalation, resulting in thermal loss from the body. Facemasks could reduce thermal loss. However, at low enough temperatures layering scarves or pieces of clothing on top of facemasks is required to provide adequate insulation against the cold, decreasing the comfort of the users through air pressure loss. Since the COVID-19 pandemic, there has been an increase in mask wearing. Therefore, an improvement of thermal loss reduction onto existing facemasks will grant the users both the benefit of thermal regulation and particulate protection all in one product. To achieve this, there have been suggestions of incorporating phase change materials (PCM) into facemasks to mitigate heat loss throughout the breathing cycle. Although there are some commercially available PCM incorporated facemasks, widespread adoption is limited due to the high cost of prototyping and testing in comparison to facemasks without PCM. Therefore, an investigation of PCM incorporated facemask through computational fluid dynamic (CFD) simulation would provide a low-cost and fast analysis of this technology's thermal performance, solving the problem. In this study, CFD modelling was used to create the model of the PCM incorporated cotton facemask and simulate the mask's thermal behavior under cold environments. The thermal data of inspiration and expiration through the facemask created by the simulation model was successfully validated against a valid numerical model from literature, with the deviation of less than 5.6% and 3.7% for the facemask model with and without PCM, respectively. Furthermore, the inhalation temperature through the PCM incorporated cotton facemask created in this study compared to cotton facemask without PCM is increased by 3.7°C and the exhalation temperature is decreased by 1.2°C, resulting in 2.5 times increase in thermal protection during inhalation and 1.50 times increase in facemask thermal retention during exhalation. The findings of this study will be used to provide manufacturers with an inexpensive and fast method to develop a simulation model of a PCM incorporated facemask that is accurate to reality, thereby reducing the cost of prototyping this technology.

Keyword: Phase change material/ Facemask/ CFD/ Heat transfer

1. INTRODUCTION

In the present, the world is facing severe climate change, causing temperature swings around the world. In areas near the equator and regions sharing the same climate, record low temperatures have been noted down in literature [1]. Exposure to cold environments causes adverse effects on human health. The severity corresponds to how low the body temperature gets. Hypertension, cold injuries, and in severe cases hypothermia can set in. Clothing with high thermal insulation can combat this problem by trapping skin heat radiation from being lost to the atmosphere [2,3]. In current literature, the majority of high thermal insulation clothing optimization is focused on the body, neglecting the respiratory system and the face which is equally important as a significant amount of body heat, 10%, is loss in the respiratory cycle [1,4].

Reported by Habchi et al., the traditional method to protect the respiratory system commonly used is by wrapping a winter scarf around the nostril and mouth. Though if not worn properly, folding cavities can form and enable cold air to directly enter the respiratory system [5]. In comparison, Carnivale et al. suggests that commercial facemasks are as effective as winter scarves in protecting the respiratory system with the advantage of being inexpensive, easier to wear and integrated into cultural norms, especially after the COVID-19 pandemic where facemask adoption is increased [6-8]. However,

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at lower temperatures, a single facemask will not be able to protect the user from cold air. Multiple facemasks or layering other types of clothing on top of the existing facemask will be required with the tradeoff of making breathing more difficult due to the increase in pressure drop through the fabric [9,10]. Alternatively, PCM can be added to the existing facemask to increase protection against cold air.

PCM in the context of industrial applications are materials that are easily able to change phase — with the majority being transitions between liquid and solid — and releases or absorbs a large amount of thermal energy during phase transition [11]. In textile applications, as cold air passes through the fabric, liquid PCM solidifies into solid phase. During the transition, thermal energy is released and heats up the cold air, resulting in comfort for the user [5]. In current literature, most PCMs are incorporated in bodily articles of clothing, especially cotton. However, the problem of this technology lies in the fact that PCM cannot be regenerated this way [5]. Skin heat radiation is not able to melt PCM at a rate fast enough compared to the solidification from the cold environment. Therefore, at steady-state, PCM incorporated clothing will not provide more protection than clothing without PCM [5,12].

In contrast, Habchi et al. and Ghali et al. reported that PCM incorporated within cotton facemasks can be regenerated. After cold air solidifies PCM during inhalation, the solidified PCM can be melted back to liquid during exhalation. The heat from exhalation provides enough heat in a short period of time to effectively melt PCM before the start of the next inhalation cycle, enabling PCM to continuously provide thermal protection [5,12]. Therefore, PCM incorporated facemasks is an interesting avenue for future research.

However, even with such advantages, the application of PCM in facemasks is still scarcely applied commercially. This is due to PCM incorporated fabrics, including facemasks, are significantly more expensive than traditional fabric [13]. Mondal et al. suggested that the increase in cost is due to research and development. Before PCM incorporated fabrics are released into the market, prototyping at different climate conditions needed to be done which uses up capital and time [10]. CFD simulations could be used to overcome this pain point since product modelling and prototyping at several conditions could be done at an extremely face pace and at a low cost. Therefore, the objective of this research is to prove that CFD simulation model of PCM incorporated cotton facemasks has the capability to accurately simulate the thermal behavior of real PCM incorporated cotton facemasks as a pathway for manufacturers to replace physical prototyping.

2. METHODOLOGY

2.1 Facemask Geometric Model

The drawn cotton facemask geometric model is in the style of plain weave and is created according to Pierce's geometric model. The mathematical equations which relate each geometric structure within the model is listed below [14]:

$$h_j + h_w = D_j + D_w \quad (Eq. 1)$$

$$\frac{h_j}{a_w} = \frac{4}{3}\sqrt{c_j}\ ;\ \frac{h_w}{a_j} = \frac{4}{3}\sqrt{c_w} \quad (Eq. 2\ \&\ 3)$$

$$a_w = \frac{1}{warp\ density} - D_j\ ;\ a_j = \frac{1}{weft\ density} - D_w \quad (Eq. 4\ \&\ 5)$$

$$\theta_j = 212\sqrt{c_j}\ ;\ \theta_w = 212\sqrt{c_w} \quad (Eq. 6\ \&\ 7)$$

$$c_j = \frac{I_j}{a_w} - 1\ ;\ c_w = \frac{I_w}{a_j} - 1 \quad (Eq. 8\ \&\ 9)$$

Where; h_j is the warp crimp wave height, h_w is the weft crimp wave height, D_j is the warp yarn diameter, D_w is the weft yarn diameter, a_j is the spacing between warp threads, a_w is the spacing between weft threads, c_j is the warp shrinkage, c_w is the weft shrinkage, θ_j is the warp cover contact

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angle, θ_w is the weft cover contact angle, I_j is the warp crimp wave length, and I_w is the weft crimp wave length.

The weft and warp density of the drawn cotton facemask model is 20 and 21 threads per centimeter respectively, resulting in a weft length of 0.5 mm and warp length of 0.4762 mm as shown in Figure 1. The fiber diameter used is 0.263 mm.

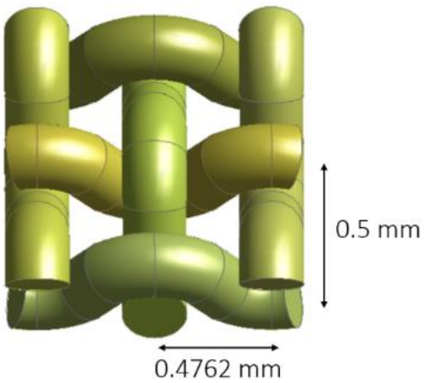

Figure 1. Facemask geometric model

2.2 PCM Incorporated Facemask Geometric Model

PCM is incorporated into the facemask using the random incorporation method, embedding PCM into the facemask randomly. To represent randomness within a volumetric model, the three-node model was used as recommended by Habchi et al. and Ghali et al. [5,12]. The three-node model is shown in Figure 2 [5]. According to the three-node model, PCM will be embedded within two concentric rings — an outer ring and an inner ring — within the cotton fiber.

Due to constrains from overlapping geometry, the PCM is drawn in the shape of a cylinder instead of multiple smaller spheres of the same diameter which is a more accurate representation of PCM embedded within the cotton fiber. There are 9 and 10 PCM cylinders in the outer ring of the warp and weft cotton fibers respectively. The mass fraction of PCM to cotton fiber is 20%, resulting in the calculated PCM cylinder diameter to be 0.04 millimeter. The drawn cross-sectional image of PCM inside a cotton fiber is shown in Figure 3. The side view display is shown in Figure 4. The same boundary conditions mentioned previously will be used to validate the PCM incorporated facemask.

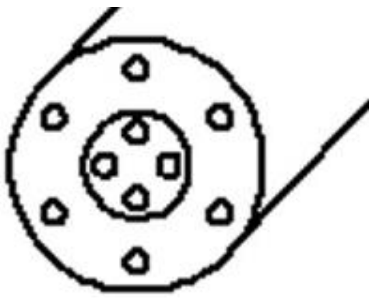

Figure 2. Three-node model diagram [5]

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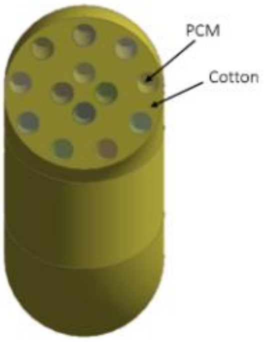

Figure 3. Cross-sectional image of PCM incorporated cotton fiber model

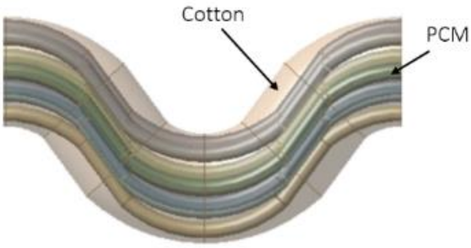

Figure 4. Side profile of PCM incorporation model cotton fiber model

2.3 Fluid Domains

The facemask model is placed within a laminar liquid domain with the same height and width as the facemask model. The domain can be separated into 3 distinct domains which is the interior fluid domain representing the mouth side of the fluid domain, facemask domain representing the volume of and near the facemask, and exterior fluid domain representing the volume outside of the facemask. According to Dbouk et al. [15], the average distance from the mouth to a facemask during usage is 4-14 mm. Therefore, both the interior fluid domain and exterior fluid domain are separated by 4 mm from the facemask domain. Furthermore, numerical verification tests have been done and the chosen minimum mesh resolution for the model is 4 million mesh. The simulation domain is shown in Figure 5.

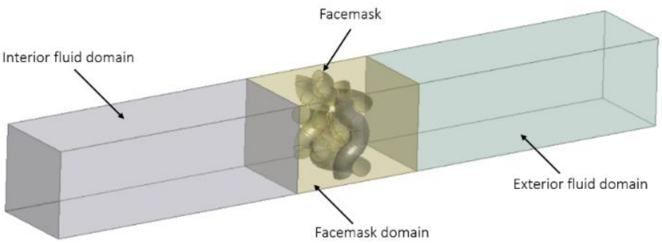

Figure 5. Simulation Domain

2.4 Governing Equations

The following governing equations are for laminar flow in a three-dimensional model without an accelerating reference frame. Conservation of mass, momentum, and energy is included in this study. Furthermore, governing equations relating to solidification/melting are also coupled within the simulation as well.

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The equation for the conservation of momentum can be written as:

$$\frac{d}{dt}(\rho\vec{v}) + \nabla \cdot (\rho\vec{v}\vec{v}) = -\nabla p + \nabla \cdot (\bar{\bar{\tau}}) + \rho\vec{g} + \vec{F} \qquad (Eq. 10)$$

Where; p is the static pressure, $\bar{\bar{\tau}}$ is the stress tensor, $\rho\vec{g}$ is the gravitational body force, $\vec{F}$ is the external body force. $\vec{F}$ arises from interaction with a second dispersed phase or with a porous media. Since the study does not include either of the mentioned models, $\vec{F}$ can be negligible.

The equation for energy conservation and transfer through conduction and convection of fluids (excluding buoyancy-driven flow and radiation) can be written as:

$$\frac{d}{dt}(\rho E) + \nabla \cdot \big(\vec{v}(\rho E + p)\big) = \nabla \cdot \left(k_{eff}\nabla T - \sum_j h_j\vec{J}_j + (\bar{\bar{\tau}}_{eff} \cdot \vec{v})\right) + S_h \qquad (Eq. 11)$$

$$E = h - \frac{p}{\rho} + \frac{v^2}{2} \qquad (Eq. 12)$$

$$k_{eff} = k + k_t \qquad (Eq. 13)$$

$$h = \sum_j Y_j\vec{J}_j + \frac{p}{\rho} \qquad (Eq. 14)$$

$$h_j = \int_{T_{ref}=298.15K}^{T} c_{p,j}\, dT \qquad (Eq. 15)$$

Where; h is the sensible enthalpy, v is the fluid velocity, k is the thermal conductivity, k_t is the turbulent thermal conductivity defined according to the laminar model, T is the temperature, Y_j is the mass fraction of species j, $\vec{J}_j$ is the diffusion flux of species j, $c_{p,j}$ is the specific heat of species j, and S_h is the defined volumetric heat source.

The energy transport equation in solid regions can be written as:

$$\frac{d}{dt}(\rho h) + \nabla \cdot (\vec{v}\rho h) = \nabla \cdot (k\nabla T) + S_h \qquad (Eq. 16)$$

The current model does not include translational or rotational movement of the solid within the simulation domain. Therefore, the second term of the left-hand side of the equation can be negated.

The energy equation for solidification and melting of the PCM is adapted from the energy transport equation in solid regions with an addition of an enthalpy term. The equation can be written as:

$$\frac{d}{dt}(\rho H) + \nabla \cdot (\vec{v}\rho h) = \nabla \cdot (k\nabla T) + S \qquad (Eq. 17)$$

$$H = h + \Delta H \qquad (Eq. 18)$$

$$\Delta H = \beta L \qquad (Eq. 19)$$

$$\beta = \frac{T - T_{solidus}}{T_{liquidus} - T_{solidus}}\ if\ T_{solidus} < T < T_{liquidus} \qquad (Eq. 20)$$
$$\beta = 0\ if\ T < T_{solidus}$$
$$\beta = 1\ if\ T > T_{liquidus}$$

Where; H is the enthalpy, ΔH is the latent heat, β is the liquid fraction of PCM, L is the total latent heat of the PCM material, and S is the source term.

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2.5 Boundary Conditions

Transient simulations were performed using Ansys Fluent 2022 R1 with the Laminar model. The boundary conditions used are specified from research done by Habchi et al. [5]. The boundary conditions are separated into inhalation and exhalation boundary conditions. During inspiration, the velocity inlet is set at the far-right end of the exterior fluid domain plane as shown in Figure 6 with the breathing velocity of 0.802 m/s. The inlet temperature is set at 12°C, representative of cold environmental air. The air will be uniform over the surface of the inlet and is directed through the facemask. The pressure outlet is set to the far-left end of the interior fluid domain. The pressure outlet is specified at atmospheric pressure and is representative of the user's mouth. Inhalation will last for 1.96 seconds after which exhalation will start.

During exhalation, the velocity inlet and pressure outlet will switch places. The velocity inlet will be located at the far-left end of the interior fluid domain and the pressure outlet will be located at the far-right end of the exterior fluid domain as shown in Figure 7. The breathing velocity will be set to 0.802 m/s and the inlet temperature will be set at 33°C, representative of hot exhaled air. Exhalation will last for 2.41 seconds after which the cycle will be completed. Adiabatic conditions and no slip conditions are set to the lateral boundaries of the model, ensuring zero-flux conditions.

Figure 6. Inhalation boundary condition

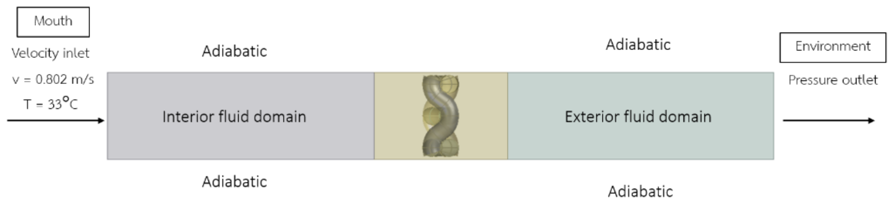

Figure 7. Exhalation boundary condition

3. RESULTS AND DISCUSSION

The data obtained from the CFD model created in this study is validated against the results provided by Habchi et al [5]. In the case of the cotton facemask model without PCM, the air temperature at the outlet during inhalation and exhalation against time is measured in the simulation and compared with data from Habchi et al. As for the cotton facemask model with PCM, both the outlet temperature and liquid fraction of PCM against time is used for validation.

The validation results of the cotton facemask model without PCM produced in this study shown in Figure 8 agree well with the data provided by Habchi et al. with a deviation of less than 5.6%. However, during the start of exhalation, the deviation rises to a peak of 17.9% before decreasing to 2% deviation after 1 second. The discrepancy of the results can be explained by how the transition from inhalation to exhalation is conducted in this study. As the velocity inlet and pressure outlet is swapped during the transition from inhalation to exhalation, the remaining air passing through the mask at the end of the inhalation phase cannot leave the interior liquid domain as the pressure outlet is switched to the side of the exterior liquid domain. The thermal energy from the leftover air at the end of inhalation is compounded with heat from air produced at the start of exhalation, resulting in the detected outlet

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temperature at the pressure outlet overpredicting the reference data. After the remaining air from inhalation has been expelled from the liquid domain, the outlet temperature will naturalize back to normal values. This is evident from the outlet temperature agreeing well with the reference data towards the later end of exhalation. Nevertheless, despite the overprediction, the outlet temperature produced in this simulation overall agrees well with data from Habchi et al. Therefore, the cotton facemask model without PCM is considered validated.

From Figure 8, it could be seen that the simulated facemask was able to increase the inhaled temperature to 13.5°C, a 1.5°C difference from the environmental temperature used in this study. The exhaled temperature out of the facemask was reduced from 33°C to 32.2°C. Both results are within 0.6% and 2% deviation from Habchi et al. From the results, it could be seen that wearing normal cotton facemasks provides a slight increase in thermal protection compared to direct breathing. However, normal cotton facemasks do not have a significant gain in reducing heat loss during exhalation.

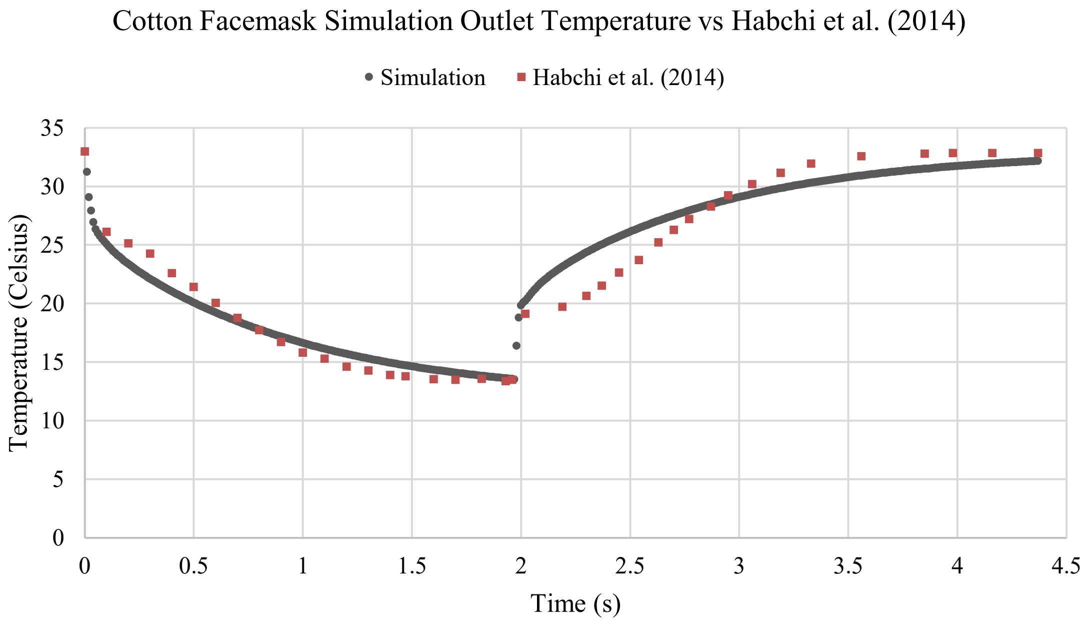

Figure 8. CFD outlet temperature data of cotton facemask compared to data provided by Habchi et al. [5]

The validation results of the cotton facemask model with PCM produced in this study are shown in Figure 9 and Figure 10, displaying the outlet temperature data and liquid fraction of PCM data respectively. From Figure 9, the outlet temperature data throughout both inhalation and exhalation agrees well with the outlet temperature data from Habchi et al. with a deviation of less than 3.7%. However, based on the data from the cotton facemask model without PCM presented in Figure 8, an overprediction in temperature should be present during the first second after exhalation but remarkably is missing in this model as the deviation from the referenced data is reduced in this region compared to that of the model without PCM. This lack of overprediction during the exhalation phase can be explained through the PCM absorbing the excess heat during its phase change. This statement is supported by the graph denoting the liquid fraction of PCM against time shown in Figure 10.

From the liquid fraction data shown in Figure 10, the simulated PCM seem to solidify more slowly than the data provided by Habchi et al. especially after the first second during inhalation. This can be explained by the PCM structure simplification used in this study. PCM structure in this study is a cylindrical shape instead of multiple spheres as used by Habchi et al. Due to the decrease in surface area of cylinders compared to multiple smaller spheres, the rate of solidification is slower. However, the liquid fraction data simulated in this study show an overprediction during most of the exhalation

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process. In other words, the PCM in this study melts faster. This can be explained by the excess heat from the outlet temperature during exhalation in this study as shown in Figure 9, which leads to an acceleration in melting of PCM. Nevertheless, the trend of both outlet temperature and liquid fraction behavior of PCM incorporated cotton facemask produced by this study matches closely with data provided by Habchi et al. Therefore, the validation of the cotton facemask model with PCM is also considered successful.

Based on the results simulated from both this study and Habchi et al. [5], it could be seen that adding PCM into cotton facemasks does increase the protection of the respiratory system against cold air. The inhaled temperature is increased to 17.3°C which nets an increase of 5.3°C compared to the environmental temperature and is 3.7°C higher than cotton facemask without PCM, a total of 2.5 times increase in thermal performance. Furthermore, more heat is retained from being lost to the environment as evident by the decrease in outlet temperature out of the facemask during exhalation by 2°C compared to 0.8°C of cotton facemask without PCM, a 1.5 times improvement. Therefore, it can be concluded that PCM does increase the thermal protection of cotton facemasks and retains more heat from exhalation.

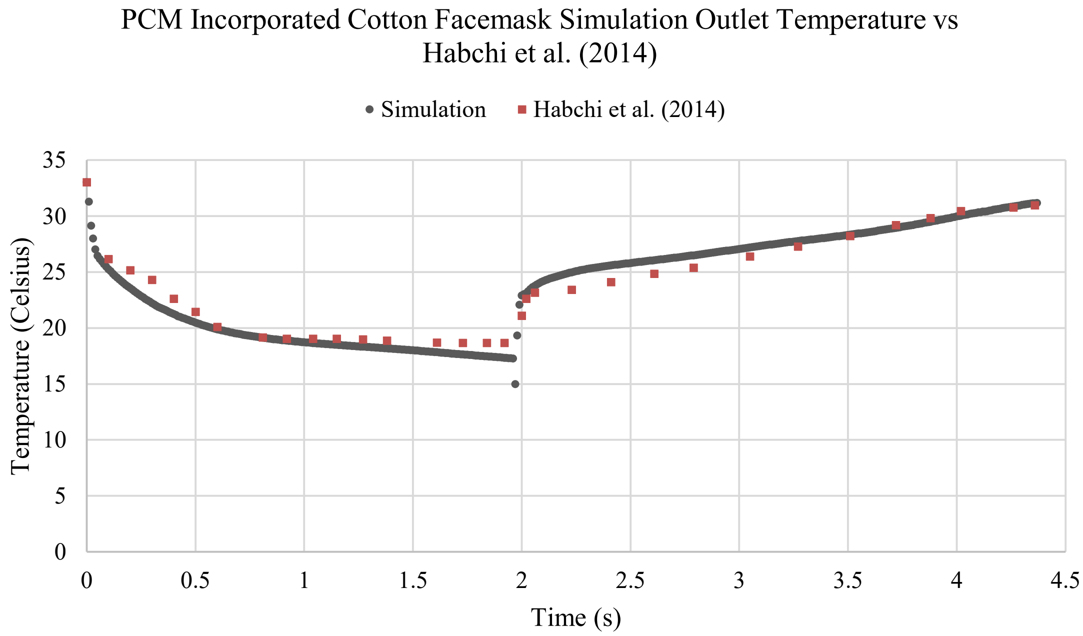

Figure 9. CFD outlet temperature data of PCM incorporated facemask compared to data provided by Habchi et al. [5]

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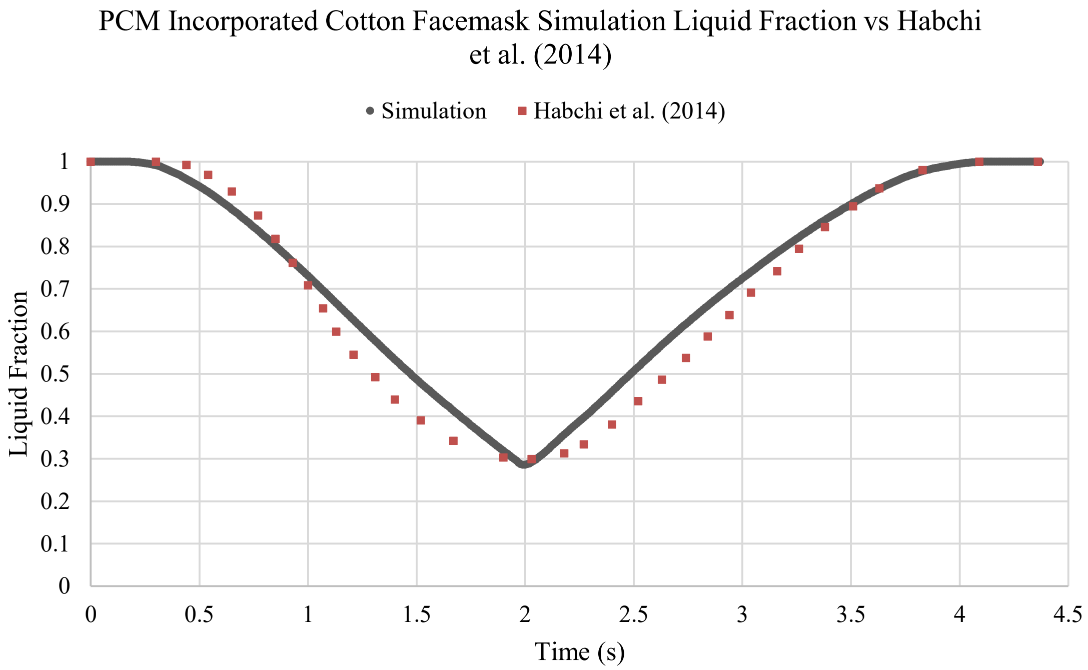

Figure 10. CFD PCM liquid fraction data of PCM incorporated facemask compared to data provided by Habchi et al. [5]

4. CONCLUSIONS

This study was aimed at creating a CFD model that could accurately simulate the thermal behavior of cotton facemasks with and without PCM for manufacturers. The model was validated through the values of outlet temperature and PCM liquid fraction during inhalation and exhalation provided by Habchi et al. The results confirm that CFD model employing Navier-stokes, energy transport, and solidification/melting equations within incompressible flows could predict the thermal behavior of cotton facemasks with the deviation of less than 5.6% and 3.7% for the model with and without PCM, respectively. Though there is an overprediction of the outlet temperature for the cotton facemask without PCM during exhalation and PCM liquid fraction for the cotton facemask with PCM, the simulation was still able to follow the trend closely and provide an accurate thermal data prediction compared to the reference data provided by Habchi et al. The study has confirmed along with the literature that cotton facemasks is able to increase the inhalation temperature by 1.5°C and reduce the exhalation temperature out of the facemask by 0.8°C. Meanwhile, PCM incorporated cotton facemasks can increase the protection of the users' respiratory system against cold air during inhalation and retain more heat within the facemask during exhalation compared to cotton facemasks without PCM. In this study, the inhalation temperature for cotton facemasks with PCM is increased by 5.3°C and exhalation temperature out of the facemask is decreased by 2°C which is 2.5 and 1.5 times improvement compared to cotton facemask without PCM, respectively. In conclusion, PCM incorporated cotton facemasks are a viable product and manufacturers of PCM incorporated facemasks could use CFD to prototype PCM incorporated cotton facemasks at different environmental conditions and windspeed without needing to create a physical model which would cost capital and time.

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Soil Cabon Sequstration Assessment in Major Cropping Patterns of the City of Batac, Philippines

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ABSTRACT

This study focused on assessing soil's capacity to sequester carbon under different rice-based cropping patterns that could result in formulation-specific soil and crop management for climate change mitigation in the agriculture sector. This study was conducted in the City of Batac with intensified and diversified cropping patterns centered around rice cultivation. A quantitative research design was employed to measure the different cropping patterns against the different soil characteristics. The hypotheses were tested focusing on the relationship among the variables through correlation and regression analysis. The cropping patterns observed in Batac City were dominantly rice followed by any of the following crops; corn, shallot, eggplant, rice, tomato, pepper, garlic, and tobacco. This cropping pattern is assumed to influence soil's pH, organic matter (OM), % carbon, phosphorus (P), potassium (K), bulk density, soil texture, moisture content, and soil carbon stock. Carbon stock was significantly influenced by soil organic matter content in various cropping patterns. Rice-tobacco exhibited the highest carbon stock (1.80%), while rice-garlic (0.63%) and rice-corn (0.60%) had the lowest carbon stocks. Due to their distinct organic matter compositions, different cropping patterns led to varying carbon stock levels. A regression model was constructed to predict the soil carbon stock variable using various predictors such as soil pH, soil texture, soil weight, phosphorus, potassium, Carbon, cropping pattern, and clay content. The regression model displayed a perfect fit with an R-squared value of 1.000, suggesting that the predictors collectively explain all the variability in the SC Stock variable. The model was statistically significant, as indicated by the low p-value and the significant F-test. Given the results, a further study should be done to have a thorough understanding of the physical, chemical, mineralogy, geology, and environmental conditions of a given area, which is necessary to fully interpret the significance of the above results. Importantly, this study can be used to design informed decision-making and advocacy for cropping patterns and management to be disseminated to farmers.

Keyword: Soil organic carbon/ Cropping pattern/ Climate change

1. INTRODUCTION

Soil carbon sequestration denotes transferring atmospheric CO_2 into the soil's carbon pool in the form of SOC, predominantly facilitated by plant photosynthesis [1]. The soil carbon pool dwarfs the atmospheric pool, approximately 3.1 times larger than the latter's 800 GT [2]. However, heightened temperatures can disrupt the carbon balance by limiting water availability and reducing photosynthesis rates [3]. Conversely, under conditions of water availability, elevated temperatures might bolster plant productivity and subsequently influence the carbon balance [4], accelerating SOM decomposition and yielding more CO_2, potentially engendering optimistic responses to climate change [5].

In cultivated lands, local influences on ecosystem processes, such as rainfall infiltration, soil erosion, sediment deposition, and varying soil temperatures due to landscape irregularities, can impact the carbon sequestration capacity of the soil. For instance, slope positioning affects soil moisture, nutrient levels, and plant root growth, all impacting soil carbon content [6]. The cumulative effects of carbon inputs and losses resulting from land use, management practices, and landscape dynamics lead to disparities in the capacity for carbon sequestration across landscapes. The critical threshold of soil organic carbon (SOC) in the root zone ranges from 1.5% to 2.0%, influenced by land use, soil

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management, and farming techniques. Over half of the total C pool at a 1-meter depth is concentrated between 0.3 and 1 meter [7]. Enhancing soil quality necessitates augmenting SOC concentration by implementing best management practices, such as conservation agriculture, which fosters a positive carbon budget [8].

The lowland areas of Ilocos Norte experience intensive cultivation, while upland and hilly areas remain less utilized. The province's agricultural production, centered in the City of Batac, is marked by rice-focused cropping patterns. Rice is typically cultivated during the wet season (June to October), and a diverse assortment of crops is grown during the dry season, including rice, corn, tobacco, garlic, eggplant, pepper, tomato, and onion. Given the escalating magnitude of typhoons and other natural calamities like drought impacting the province, it is imperative to evaluate the SOC content of the major rice-based cropping patterns in Batac City to estimate the extent of carbon sequestration by the soil.

The significance of this study lies in its potential to enhance soil fertility, structure, and crop yields, fostering favorable conditions for cultivation. Carbon is indispensable for sustaining life on Earth, underpinning biological activity, diversity, and ecosystem productivity. While humans and animals release CO_2, plants absorb it while emitting oxygen, ultimately returning carbon to the soil upon their demise. Moreover, crops exhibit greater resilience during droughts due to enhanced infiltration and water-holding capabilities. The proliferation of organic matter and associated soil biological populations stemming from diversified crop rotations augments soil health and vitality. It is, therefore, imperative to know the capacity of the soil to sequester carbon under different rice-based cropping patterns. Specifically, this study aimed to (1) identify the dominant rice-based cropping patterns in the city of Batac and select the major cropping patterns; (2) determine and compare the crop management practices; (3) determine and compare the soil characteristics under the major cropping patterns in the City of Batac; and (4) determine the relationship of physical properties, organic matter, and soil organic carbon under the major cropping patterns.

2. METHODOLOGY

2.1 Locale of the study

The City of Batac is situated in the province of Ilocos Norte's central-southwestern region, located approximately 17º17’ north and longitude 120º28’ east. It covers a total land area of 16,101 hectares; the terrain varies from gradually flat to rolling and hilly, with some areas being very steep. While the broader valleys are primarily located in the urban area, exhibiting a slope of 0-8%, the rural barangays, except those in the eastern section, have slopes ranging from 0-30%. The presence of different soil types with poor drainage characteristics is attributed to the heavy texture of the subsoil in most cases.

The City of Batac experiences a warm climate with two distinct seasons: the wet season spanning from the latter part of May to October, characterized by an annual average rainfall exceeding 2000 mm, and the dry season from November to April. It has a total cultivated land area of 2,063.65 ha, and the agricultural production system is characterized by intensified and diversified cropping patterns centered around rice cultivation. Figure 2 illustrates the sampling sites representing eight different cropping patterns.

2.2 Research design

The study utilized a quantitative research design due to the measurement of variables and testing hypotheses concerning the relationships among these variables through correlation and regression analyses. The sampling method employed was purposive random sampling, wherein barangays with the largest areas dedicated to major crops were chosen as the sampling sites.

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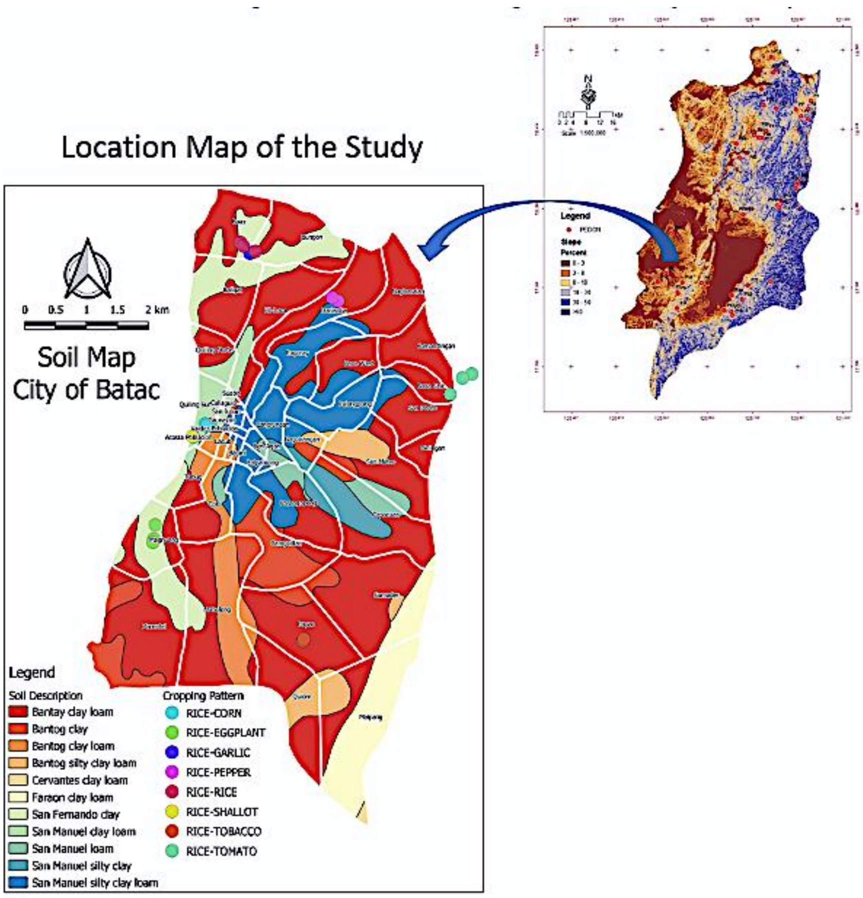

Figure 1. Sampling sites of the study area

The process of identifying the major crops planted and categorizing cropping patterns was executed by the City Agriculture Office, which provided classifications of major cropping patterns for each barangay. The top three crops with the most extensive planted areas were selected as the sampling sites among the barangays. A global positioning system (GPS) device was utilized to determine the geographical coordinates of these sampling sites.

Variables of the Study

INDEPENDENT VARIABLES		DEPENDENT VARIABLES
CROPPING PATTERNS • Rice-Corn • Rice-Shallot • Rice-Eggplant • Rice-Rice • Rice-Tomato • Rice-Pepper • Rice-Garlic • Rice-Tobacco	⇨	SOIL CHARACTERISTICS • Soil pH • Organic matter • % Carbon • Phosphorus (ppm) • Potassium (ppm) • Bulk density • Soil texture • Moisture content • Soil carbon stock/ha

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2.3 Population and sample

The study's participants consisted of the landowners from whom soil samples were acquired. A total of ten respondents were involved in the study. The research design employed was qualitative. The sampling approach combined purposive random sampling and composite sampling methods, selected based on the characteristics present within the study as a whole.

The rationale for opting for a quantitative research design was to examine the relationships between various variables. Purposive random sampling was chosen to ensure the sample was closely aligned with the study's objectives. Additionally, the composite sampling method was applied to amalgamate individual samples into a unified composite sample, enhancing the reliability of both data collection and outcomes.

2.4 Research instrument

Information about the management practices implemented by farmers was collected using a survey questionnaire.

2.5 Data gathering procedure

To accurately assess the physical and chemical attributes of the area, a composite sampling technique was utilized. A total of one kilogram of soil was collected from the composite samples, securely packed in plastic containers, and kept in an icebox. The geographical coordinates of the sampling sites were established using a GPS device.

After collection, the soil samples were transported to the laboratory and subjected to air-drying. Following the drying process, the samples were ground and sifted through a mesh with a 2 mm diameter. The finely ground samples were then carefully stored in labeled plastic bags.

The following parameters were gathered with their corresponding procedure:

1. Bulk density

It serves as an indicator of soil compaction. Bulk density is usually denoted in g/cm3 and is determined by dividing the dry weight of soil by its volume, as illustrated below:

$$\text{Bulk Density} = \frac{\text{Weight of ovendry soil (g)}}{\text{Volume of the sampler}}$$

To calculate the volume, measurements of the core sampler's height and diameter were taken, and the volume was determined using the following formula:

$$V = \pi r^2 h$$

When collecting soil samples, a level soil surface was identified either horizontally or vertically at the intended depth within the field. The core sampler was cautiously inserted into the soil using a hammer to prevent compression. Subsequently, the samples were subjected to drying in an oven set at a temperature range of 105°C to 110°C for a duration of three to four days, or until a consistent dry weight was achieved.

2. Soil pH

Soil pH measurement involved utilizing a pH meter to assess the level of acidity or alkalinity in the soil specimens. Before taking measurements from the samples, the pH meter was calibrated using buffer solutions with known pH values. A 20 g soil sample was placed into a 100 ml beaker, and 20 ml of distilled water was added. The mixture was stirred at 20-minute intervals over an hour. Before the pH reading was obtained, the sample was thoroughly mixed.

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3. Soil Organic Matter Content

Two approaches exist for assessing soil organic matter (SOM) content: the colorimetric method and the Walkley-black method. The selection between these methods depended on the pH of the soil samples. The colorimetric method was employed when the soil samples exhibited a neutral to alkaline pH, whereas the Walkley-black method was utilized for acidic soil samples. The estimation of organic carbon was derived from the measurements of organic matter in the soil samples.

4. Determination of Organic Carbon per Hectare

The determination of soil sample bulk density readings was essential for computing the soil weight and quantifying soil organic carbon stocks in tons per hectare. This computation was carried out using the formula outlined by the Agriculture and Food Division of the Department of Primary Industries and Regional Development in Australia (https://www.agric.wa.gov.au/soil-carbon/measuring-and-reporting-soil-organic-carbon).

$$\text{Soil Weight per Ha} = 10{,}000\,\frac{\text{m}^2}{\text{ha}} \times \text{Soil Depth} \times \text{Bulk Density}$$

$$\text{Soil Carbon Stock per Ha} = \text{Soil Carbon} \times \text{Soil Depth} \times \text{Weight of Soil per hectare}$$

5. Soil texture

Soil texture significantly affects soil structure, water dynamics, microbial communities, and organic matter stabilization – all of which play vital roles in soil carbon sequestration. Understanding the interactions between soil texture and these processes is essential for developing effective strategies to enhance carbon sequestration

6. Soil potassium

The soil's overall potassium content is typically abundant, except in sandy soils. The quantified amount of potassium, measured in milliequivalents per 100g of soil, extracted through neutral 1N ammonium acetate, is commonly used to indicate potassium availability in soils. Available potassium comprises the combined presence of exchangeable and water-soluble potassium ions. Exchangeable potassium is the portion that can freely replace cations within salt solutions added to soils. However, since the extent of potassium exchange depends on the properties of the replacing solution, the term "exchangeable K" is more precisely defined as the portion extractable with neutral 1N NH4OAc, subtracting the water-soluble potassium.

7. Soil phosphorous

The analysis of soil phosphorus utilized the Modified Truog method, which entails the extraction of adsorbed phosphate from the soil using a specific solution. Within an acidic environment, soluble orthophosphates interact with molybdates, resulting in the formation of heteropoly molybdophosphoric acid. The intensity of color developed through this reaction is directly proportional to the quantity of phosphates in the soil.

8. X-ray fluorescence (XRF) analysis

X-ray fluorescence analysis is a method that uses characteristic X-rays (fluorescent X-rays) generated when X-rays irradiate a substance. X-ray fluorescence analysis can be considered spectrochemical analysis within an X-ray region. It has the same characteristics as atomic absorption and optical emission spectrometry, except that the sample does not need to be dissolved in a solution to be analyzed.

This method allows you to theoretically derive the intensity of the fluorescent X-rays if the type and properties of all elements that compose a sample are known. The fluorescent X-ray intensities of each element extrapolated the composition of the unknown sample.

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9. X-ray diffraction (XRD) analysis

The sample was analyzed using Olympus BTX (Laue method) with Cu kα metal target and 2 theta from 0 to 55 degrees. Phase identification was carried out using match! computer program and using the principle of the Hanawalt method.

10. Determination of organic carbon per hectare

Determining soil sample bulk density readings was essential for computing the soil weight and quantifying soil organic carbon stocks in tons per hectare. This computation used the formula outlined by the Agriculture and Food Division of the Department of Primary Industries and Regional Development in Australia (https://www.agric.wa.gov.au/soil-carbon/measuring-and-reporting-soil-organic-carbon).

$$\text{Soil Weight per Ha} = 10{,}000\frac{\text{m}^2}{\text{ha}} \times \text{Soil Depth} \times \text{Bulk Density}$$

$$\text{Soil Carbon Stock}\frac{\text{kg}}{\text{ha}} = \text{Soil Carbon} \times \text{Soil Depth} \times \text{Weight of Soil per hectare}$$

2.6 Data analysis

The collected data was compiled and subjected to analysis of variance using STAR 2.0 v.1. Variations in means were assessed through the honest significant difference test at a significance level of 0.05 (HSD0.05). Additionally, correlation and regression analyses were conducted using SPSS to ascertain the connections and associations among the parameter.

3. RESULTS AND DISCUSSION

3.1 Major rice-based cropping patterns in the city of Batac

As per the records from the City Agriculture Office of Batac, approximately 2,053.65 hectares are utilized for rice cultivation during the wet season, while various vegetables and other high-value crops are grown in the dry season, involving a total of 5,193 farmers (as shown in Table 1). The city adheres to 13 distinct cropping patterns, among which the predominant ones include rice-corn (1,497.45 ha), rice-tobacco (374.74 ha), rice-rice (115.62 ha), rice-mungbean (53.91 ha), rice-garlic (41.10 ha), rice-eggplant (29.15 ha), and rice-shallot (14.68 ha). The rice-corn cropping pattern holds the largest area and engages the highest number of farmers, largely due to the support from the Department of Agriculture and the Cornick industry. Conversely, the study also encompasses the rice-tomato cropping pattern, which was once commonly cultivated until the closure of the National Foods Corporation (NFC), primarily known for tomato paste production.

3.2 Crop management practices

Table 2 assesses various crop management practices across different cropping patterns. The findings reveal that respondents following the rice-rice, rice-pepper, and rice-eggplant cropping patterns incorporated organic fertilizer before planting. Conversely, for rice-garlic and rice-tomato, they applied complete ammonium and sulfate. At the same time, respondents engaged in rice-corn, rice-tobacco, and rice-shallot patterns did not apply fertilizers before planting. Nearly all participants applied urea, complete, and sulfate fertilizers to their crops throughout the cropping period. Regarding pesticide usage, all the respondents applied insecticides and fungicides to control insect pests and diseases.

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Table 1. Cropping pattern and the number of farmers being engaged in 2020-2021.

CROPPING PATTERN	AREA PLANTED/HA	NUMBER OF GROWERS
Rice – Corn	1,497.45	3,637
Rice – Tobacco	274.74	593
Rice – Rice	115.62	316
Rice – Mungbean	53.91	288
Rice – Garlic	41.10	173
Rice – Eggplant	29.16	96
Rice – Shallot	14.68	62
Rice – Pepper	10.63	45
Rice – Squash	5.00	26
Rice – Stringbean	4.97	26
Rice – Ampalaya	3.63	23
Rice – Okra	1.24	5
Rice – Tomato	1.22	4
TOTAL	2,053.65	5,193

Source: City Agriculture Office, City of Batac

Table 2. Crop management practices of the different cropping patterns.

CROPPING PATTERNS	CROP MANAGEMENT PRACTICES				
	Code #	Rice-based	Fertilizer added before cropping	Fertilizer added during cropping	Pesticide used during cropping
Rice-Corn	1	/	None	Urea	Round up
	2	/	None	Urea	Round up
	3	/	None	Urea	Round up
Rice-Garlic	4	/	Complete, $NH_4^+$and SO4	None	Insecticide and Boulder
	5	/	Complete, $NH_4^+$and SO4	None	Insecticide and Boulder
	6	/	Complete, $NH_4^+$and SO4	None	Insecticide and Boulder
Rice-Rice	7	/	Organic Fertilizer	Urea and complete	Brodan and Magnum
	8	/	Organic Fertilizer	Urea and complete	Brodan and Magnum
	9	/	Organic Fertilizer	Urea and complete	Brodan and Magnum
Rice-Pepper	10	/	Organic Fertilizer	Urea, sulfate and complete	Brodan
	11	/	Organic Fertilizer	Urea, sulfate and complete	Brodan
	12	/	Organic Fertilizer	Urea, sulfate and complete	Brodan
Rice-Tobacco	13	/	None	Urea	Brodan
	14	/	None	Urea	Brodan
	15	/	None	Urea	Brodan
Rice-Tomato	16	/	Complete	Urea	Lanid
	17	/	Complete	Urea	Lanid
	18	/	Complete	Urea	Lanid
Rice-Eggplant	19	/	Organic Fertilizer	Complete	Magnum and Alika
	20	/	Organic Fertilizer	Urea and complete	Gold
	21	/	Organic Fertilizer	Urea and complete	Gold
Rice-Shallot	22	/	None	Urea and complete	Fungicide
	23	/	None	Urea and complete	Fungicide
	24	/	None	Urea and complete	Fungicide

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3.3 Soil characteristics of the cropping pattern

Soil physical properties are important in crop production due to their direct impact on root development, water accessibility, nutrient availability, and overall plant well-being. Furthermore, they shape nutrient cycling mechanisms within the soil, notably in the accumulation of organic matter. The physical attributes of soil also influence the availability, retention, and discharge of nutrients derived from organic matter. Soils that possess favorable structural characteristics contribute to effective nutrient cycling, ensuring that organic matter contributes to the nourishment essential for plant growth [9].

3.4 Soil physical properties under the different cropping patterns

Table 3 presents the soil physical properties of the selected cropping patterns investigated in this study. Soil texture was determined based on the relative proportions of three distinct soil particles: sand, silt, and clay. The analysis of variance results indicated significant variations (p=0.01) among the observed soil physical properties. The highest percentage of clay content was found in the rice-rice cropping pattern at 46.20%, followed by rice-garlic at 38.67%. Other cropping patterns showed similar clay contents ranging from 3.37% to 6.03%.

In terms of percent silt, the rice-eggplant cropping pattern exhibited the highest value at 32.53%, followed closely by rice-corn, rice-rice, and rice-garlic patterns with 29.07%, 28.60%, and 27.07% respectively. These values were comparable to the rice-pepper pattern at 23.33%. The rice-pepper pattern was similar to rice-shallot and rice-tobacco patterns, with silt contents of 20.40% and 20.27%, respectively.

Furthermore, the highest percentage of sand was found in the rice-tobacco and rice-shallot patterns at 74.77% and 74.24%, respectively, closely followed by the rice-tomato pattern at 72.47%. This value was also similar to the sand content in the rice-pepper pattern at 68.40%. Conversely, the rice-corn and rice-eggplant patterns exhibited the least sand content at 65.33% and 64.20%, respectively. Rice-garlic and rice-rice patterns had the lowest sand content, with 34.27% and 25.20% respectively.

According to [10], bulk density is influenced by various factors including clay content, land use, and management practices. Additionally, the impact of sand content on soil bulk density was found to be more significant than other soil properties [11]. Similar trends were observed in the bulk density values derived from different cropping patterns. Generally, cropping patterns with higher sand content exhibited greater soil bulk density. A study conducted also revealed a significant positive correlation between bulk density and sand content [12]. In the current study, the highest bulk density values were observed in cropping patterns such as rice-corn, rice-pepper, rice-tomato, rice-shallot, rice-eggplant, and rice-tobacco, all exhibiting comparable results. Conversely, the lowest bulk density values were found in the rice-garlic and rice-rice cropping patterns, characterized by clayey-textured soil, with 1.28 g cm^{-3} and 1.30 g cm^{-3}, respectively.

3.5 Soil chemical properties under the different cropping patterns

On the other hand, the impact of chemical soil properties can significantly influence the accumulation of organic matter in the soil. Sufficient nutrient availability is essential for the decomposition of organic matter. Microorganisms engaged in the breakdown of organic substances require vital nutrients like nitrogen (N), phosphorus (P), and potassium (K) to fuel their metabolic processes. The activity and efficiency of microbial decomposition and the subsequent accumulation of organic matter are influenced by soil pH [13].

Table 4 reveals notable disparities in the build-up of organic matter content among various cropping patterns. The rice-tobacco cropping pattern exhibited the highest organic matter content (3.11%), followed by rice-eggplant (2.46%). This can be attributed to the crops' characteristics, primarily broad leaves. Conversely, the rice-corn and rice-garlic cropping patterns displayed the lowest organic matter content, measuring 1.04% and 1.07%, respectively.

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Table 3. The soil's physical properties under the different cropping patterns.

CROPPING PATTERN	SOIL PHYSICAL PROPERTIES				
	% Clay	% Silt	% Sand	Soil Texture	Bulk Density
	**	**	**	**	**
Rice-Corn	5.60[c]	29.07[ab]	65.33[c]	sandy loam	1.43[a]
Rice-Garlic	38.67[b]	27.07[abc]	34.27[d]	clay loam	1.30[bc]
Rice-Rice	46.20[a]	28.60[abc]	25.20[e]	clay	1.28[c]
Rice-Pepper	6.03[c]	25.57[bcd]	68.40[bc]	sandy loam	1.41[a]
Rice-Tobacco	4.97[c]	20.27[d]	74.77[a]	sandy loam	1.36[ab]
Rice-Tomato	4.20[c]	23.33 [cd]	72.47[ab]	sandy loam	1.41[a]
Rice-Eggplant	3.37[c]	32.53[a]	64.10[c]	sandy loam	1.37[ab]
Rice-Shallot	5.37[c]	20.40[d]	74.24[a]	sandy loam	1.41[a]
CV (%)	14.23	7.59	3.00		2.14

*** –- Significant at 1% level; CV – coefficient of variation; Means with the same letter are significantly different at a 1% level of significance using the HSD Test.*

Bulk density, on the other hand, reflects the soil's capacity to serve as structural support, facilitate water and solute movement, and promote soil aeration. Bulk densities exceeding specific thresholds indicate compromised functionality (Table 1). Additionally, bulk density is utilized to convert between the weight and volume of soil. It expresses soil physical, chemical, and biological measurements based on volume for assessing soil quality and comparing different management systems. By using bulk density, errors stemming from variations in soil density at the time of sampling are eliminated, thus enhancing the validity of comparisons [14].

Table 4. The soil chemical properties under the different cropping patterns.

CROPPING PATTERN	SOIL CHEMICAL PROPERTIES				
	% OM	% OC	P, ppm	*K, ppm*	pH
	**	**	**	ns	**
Rice-Corn	1.04[e]	0.60[e]	161.77[b]	268.26	7.00[a]
Rice-Garlic	1.07[de]	0.63[de]	61.50[d]	210.79	7.00[a]
Rice-Rice	1.33[cde]	0.77[cd]	54.16[d]	223.47	7.00[a]
Rice-Pepper	1.33[cd]	0.77[cd]	122.54[c]	225.83	7.03[a]
Rice-Tobacco	3.11[a]	1.80[a]	72.11[d]	247.06	6.87[a]
Rice-Tomato	1.57[c]	0.91[c]	46.56[d]	257.62	6.80[ab]
Rice-Eggplant	2.46[b]	1.43[b]	126.62[bc]	222.95	6.57[b]
Rice-Shallot	1.34[cd]	0.78[cd]	293.30[a]	265.82	6.80[ab]
CV (%)	5.96	5.90	11.11	8.68	1.25

*** – Significant at 1% level; ns – not significant; CV – coefficient of variation*
Means with the same letter are significantly different at a 1% level of significance using the HSD Test.

The organic carbon estimation was conducted based on the assumption that soil organic matter comprises 58% carbon, which applies to certain soils or specific components of soil organic matter [15]. The results demonstrate a direct proportionality between organic carbon (OC) and organic matter (OM). As a result, the rice-tobacco cropping pattern exhibited the highest OC content at 1.80%, followed by rice eggplant at 1.43%. Conversely, rice-corn displayed the lowest OC content, accompanied by rice-garlic at 0.60% and 0.63%, respectively. Significant variation was observed in the phosphorus content among the different cropping patterns. The rice-shallot pattern exhibited the highest phosphorus content at 293.30 ppm, trailed by rice-corn (161.77 ppm) and rice-eggplant (126.62 ppm). However, the potassium content of soils across the various cropping systems did not exhibit significant differences.

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The soil pH of the distinct cropping patterns also displayed significant divergence. The results indicated that rice-corn, rice-garlic, rice-rice, and rice-pepper patterns possessed a neutral pH, while the remaining cropping patterns featured slightly acidic soils. It is worth noting that soil pH has a bearing on microbial activity and the composition of microbial communities. Different microbial groups exhibit preferences for specific pH levels. Soil chemical attributes influencing pH levels can impact the abundance and activity of microorganisms in decomposing organic matter. An optimal pH range, particularly a neutral pH, can stimulate microbial activity and enhance the breakdown of organic matter. Research has underscored that soil organic matter (SOM) associated with the sand-size fraction is more susceptible to decomposition, leading to higher turnover compared to the silt- or clay-size fractions [16].

3.5 X-ray fluorescence (XRF) analysis

As can be observed from the X-ray flourescence data (Figure 2), soil samples are Si-rich with significant amount of iron and aluminum with at least 60% light elements. Other inorganic ions such as magnesium, calcium, titanium and manganese were observed. It can be noted that the soil samples for Rice-Onion cropping pattern have trace amounts of phosphorous.

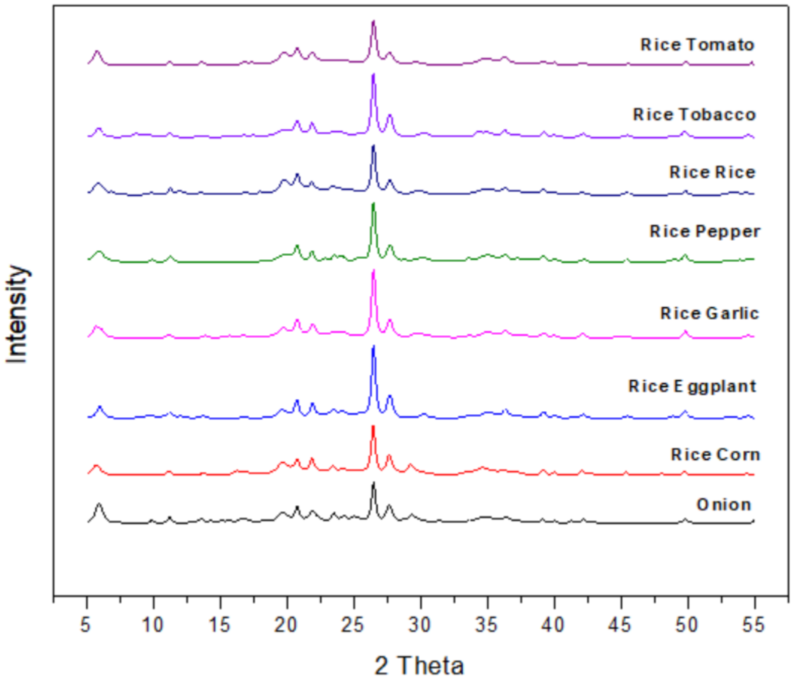

Figure 2. X-ray Fluorescence Analysis of soils under different cropping patterns in the City of Batac

It is also very evident that the ratio of silicon to aluminum is consistent for all the samples and is about 3.0 (Table 9). For environmental considerations, a high Si/Al ratio in soil or minerals can affect environmental factors like soil erosion and water retention. Minerals with higher Si/Al ratios may contribute to better soil stability and water-holding capacity. Similarly, a consistent ratio of iron to aluminum can also be observed and is equal to 1.0. This suggests that soils with a 1:1 Fe to Al ratio may contain significant amounts of these Fe-Al smectite minerals. Smectite minerals have a high cation exchange capacity (CEC), meaning they can hold onto and exchange various cations (positively charged ions) like calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na). This can affect nutrient availability in the soil. Smectite-rich soils have good water retention capabilities due to their expandable lattice structure, which can swell and hold water. This can be beneficial for plants in retaining moisture during dry periods [17].

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Table 5. The Chemical Composition of Soil based on the ratio of its components

CROPPING PATTERN	Si/Al Ratio, ppm	Fe/Al Ratio, ppm
Rice – Shallot	3.45	1.14
Rice – Eggplant	3.21	1.22
Rice – Tomato	3.12	1.13
Rice – Tobacco	3.28	1.09
Rice – Sweet Pepper/Chili	3.13	1.07
Rice – Rice	2.95	1.0
Rice – Corn	3.27	1.09
Rice – Garlic	3.24	0.99

3.6 Soil weight and soil carbon stock of the different cropping patterns

Soil weight was assessed at a depth of 30 cm, and the determination of carbon stock in the soil for each cropping pattern was based on bulk density. Findings indicated that soils characterized by higher bulk density tended to exhibit greater weight, ranging from 4,090 kg ha^{-1} (rice-tobacco) to 4,280 kg ha^{-1} (rice-corn), as detailed in Table 9. These soil types were identified as sandy loam and loamy sand.

In contrast, soils with a clay composition demonstrated notably lower weight, registering at 3,830 kg ha^{-1} (rice-rice) and 3,900 kg ha^{-1} (rice-garlic). The carbon cycle encompasses alterations in carbon stocks due to both ongoing processes and distinct occurrences. Continuous processes exert an impact on carbon stocks across all areas annually, while discrete events result in emissions and the redistribution of ecosystem carbon. The data underscores that carbon stock is significantly influenced by the presence of soil organic matter within various cropping patterns. The rice-tobacco pattern exhibited the highest carbon stock at 2,215.32 kg ha^{-1}, which was statistically distinct from the rice-eggplant pattern (1,757.16 kg ha-1) and rice-tomato pattern (1,155.10 kg ha^{-1}). Conversely, the lowest carbon stocks were observed in the rice-garlic (725.27 kg ha^{-1}), rice-corn (776.33 kg ha^{-1}), and rice-rice (883.19 kg ha^{-1}) patterns.

Table 6. Soil weight and soil carbon stock of the different cropping patterns.

CROPPING PATTERN	CARBON WEIGHT, kg/ha	CARBON STOCK, kg/ha
Rice – Shallot	4,220^{a}	980.40^{cd}
Rice – Eggplant	4,100^{ab}	1,757.16^{b}
Rice – Tomato	4,230^{a}	1,155.10^{c}
Rice – Tobacco	4,090^{ab}	2,215.32^{a}
Rice – Sweet Pepper	4,220^{a}	978.65^{cd}
Rice – Rice	3,830^{c}	883.19^{d}
Rice – Corn	4,160^{a}	779.25^{e}
Rice – Garlic	3,780^{d}	751.36^{e}

*** –- Significant at 1% level; CV – coefficient of variation*
Means with the same letter are significantly different at a 1% level of significance using the HSD Test.

3.7 Relationship of physical properties, organic matter, and organic carbon of the soil under the major cropping patterns

In Table 6, the clay content (Clay) displays a robust negative correlation with organic matter (OM) and sand content (Sand). At the same time, it exhibits a positive correlation with carbon (Carbon) and silt content (Silt). Sand content demonstrates a pronounced negative correlation with clay and a positive correlation with organic matter and silt content. Organic matter exhibits positive correlations with clay, sand, and silt content, indicating its association with higher proportions of these soil

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components. Bulk density (BD) exhibits a marked negative correlation with clay and silt content, implying that increased clay and silt content leads to reduced bulk density. Phosphorus (P) demonstrates positive correlations with clay, sand, and silt content, indicating its affiliation with higher proportions of these components. pH shows a robust negative correlation with clay, organic matter, and carbon content, suggesting that greater proportions of these components lead to lower soil pH. These correlations provide valuable insights into the interrelationships among various soil properties, enhancing our comprehension of soil composition and fertility.

Soil organic carbon constitutes a vital fraction of soil organic matter. Notably, organic matter consists primarily of carbon, constituting 58% [18]. As a result, the content of organic carbon is directly proportional to that of organic matter. Consequently, the rice-tobacco cropping pattern boasts the highest organic carbon content at 1.80%, followed by rice-eggplant at 1.43%. Conversely, rice-corn exhibits the lowest organic carbon content, accompanied by rice-garlic at 0.60% and 0.63%, respectively.

3.8 Regression

Table 7 offers a concise overview of the performance of a regression model in predicting the dependent variable "SC Stock" through the utilization of various predictors. The table presents measures of the model's fitness and its statistical significance.

The regression model demonstrates an impeccable match with an R-squared value of 1.000, implying that the collective effect of all predictors elucidates 100% of the variance in the SC Stock variable. The adjusted R-squared value of 1.000 further corroborates the robustness of the fit, underscoring that the model comprehensively encapsulates all available information. The standard error of the estimate is 8.55625, representing the average discrepancy between projected and actual values of the SC Stock variable. A smaller value suggests enhanced predictive precision.

The "Change Statistics" segment delineates the influence of adding predictors to the model. The R-squared change stands at 1.000, signifying that the incorporation of predictors accounts for the entire augmentation in the explained variance. The F-change statistic, computed at 8,951.352 with 9 degrees of freedom in the numerator and 14 degrees of freedom in the denominator, assesses the overall significance of the model. The exceedingly low p-value (<.001) indicates the statistical significance of the model, affirming its reliability in forecasting the SC Stock variable.

The predictors encompassed by the model encompass pH, REP, Silt, WS, P, K, Carbon, CP, and Clay. Additionally, the model incorporates a constant term as a predictor. These predictors hold substantial relevance in forecasting the SC Stock variable.

The regression model appears remarkably efficacious in predicting the SC Stock variable, evidenced by the impeccable fit, significant F-test, and inclusion of pertinent predictors. The ANOVA table elucidates the sources of variance within the regression model and appraises the significance of the overall model fit. Within the "Regression" segment, the sum of squares stands at 5,897,912.039, signifying the total variability elucidated by the regression model. The degrees of freedom (df) for the regression model amount to 9, corresponding to the number of predictors utilized. The mean square, calculated as 655,323.560 by dividing the sum of squares by the degrees of freedom, represents the average sum of squares. The computed F-statistic is 8,951.352, which is determined by dividing the regression mean square by the residual mean square (stated in the "Residual" section). The F-statistic evaluates the overall significance of the regression model. The exceedingly low p-value (<.001) attests to the model's statistical significance, substantiating that the predictors collectively substantially influence the dependent variable, SC Stock.

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Table 7. Sources of variation in the regression model and evaluates the significance of the model's overall fit.

ANOVA[a]						
Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	5897912.039	9	655323.560	8951.352	<.001[b]
	Residual	1024.932	14	73.209		
	Total	5898936.972	23			

a=Dependent Variable SC Stock; b=Predictors: (Constant), pH, REP, Silt, WS, P, K, Carbon, CP, Clay

Consequently, the ANOVA table (Table 8) reaffirms the high significance of the regression model, underscored by the substantial F-statistic and the remarkably low p-value. The model expounds on a substantial portion of the variability within the SC Stock variable, leaving only a relatively minor unexplained variability (Table 9).

Table 8. Coefficients of Regression

COEFFICIENTS[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	-804.079	186.153		-4.319	<.001
	CP	1.710	1.488	.008	1.150	.270
	Clay	-.190	.323	-.006	-.590	.564
	Silt	-.136	.552	-.001	-.247	.809
	Carbon	1217.354	7.749	.991	157.091	<.001
	WS	.200	.028	.068	7.161	<.001
	P	-.050	.032	-.008	-1.562	.141
	K	.031	.090	.002	.346	.735
	pH	-.545	19.400	.000	-.028	.978

a=Dependent Variable SC Stock

Table 9. Excluded Variables of Regression

EXCLUDED VARIABLES[a]						
Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Sand	-9.619[b]	-.231	.821	-.064	7.653E-9
	OM	.[b]	.	.	.	.000
	BD	.[b]	.	.	.	.000

a=Dependent Variable SC Stock; b=Predictors in the Model: (Constant), pH, REP, Silt, WS, P, K, Carbon, CP, Clay

Table 10. Residual Statistics of Regression.

RESIDUALS STATISTICS[A]					
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	637.044	2246.402	1183.926	506.390	24
Residual	-14.659	15.750	0.000	6.675	24
Std. Predicted Value	-1.080	2.098	0.000	1.000	24
Std. Residual	-1.713	1.841	0.000	0.780	24

Dependent Variable: SCStock

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The regression model demonstrates an impeccable alignment, evidenced by an R-squared value of 1.000, signifying that the collective impact of all predictors fully accounts for 100% of the variability in the SC Stock variable. Additionally, the adjusted R-squared value of 1.000 underscores the model's exceptional fit, indicating that the model effectively accommodates all accessible data.

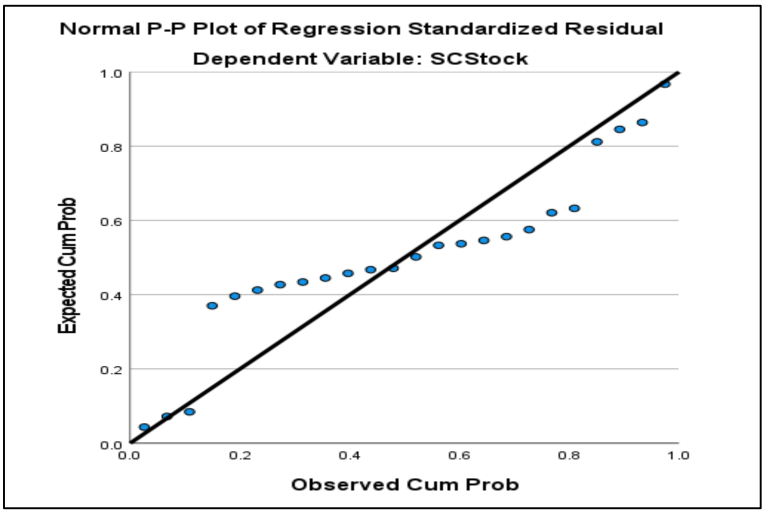

Figure 3. Regression Fit

4. CONCLUSIONS

Based on the comprehensive analysis of the study's findings, several noteworthy conclusions can be drawn, shedding light on the intricate relationships between soil properties, cropping patterns, and carbon sequestration:

1. Rice-corn cropping pattern is the most dominant followed by Rice-Tobacco in the City of Batac of which the latter obtained the higher Carbon stock
2. The traditional cropping management of the farmers includes the use and application of fertilizer and pesticides in their crops.
3. Cropping patterns significantly influence the clay, silt, and sand particles of the soil. Cropping patterns with higher proportions of clay tended to exhibit lower bulk density and soil weight. Conversely, those dominated by sand showed higher bulk density and soil weight.
4. Phosphorus content of the soil was significantly different among cropping patterns while potassium did not differ significantly. The soil organic content of the soil was highest in rice-tobacco cropping pattern as attributed to the biomass (broadleaves) of the crop. The rice-tobacco pattern demonstrated the potential to foster greater organic carbon accumulation in the soil.
5. The highest carbon stock was associated with the rice-tobacco pattern, while other patterns displayed varying levels. These findings highlight the potential for strategic cropping choices to enhance carbon sequestration, thus contributing to climate change mitigation efforts.
6. The model's high goodness of fit and significant predictors suggest that factors such as pH, soil texture, WS, P, K, Carbon, CP, and Clay can effectively predict carbon storage potential. This model can serve as a valuable tool for informed decision-making in land management.

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Appendix 1

Questionnaire for Farmers

"ASSESSMENT OF SOIL CARBON SEQUESTRATION CAPACITY IN MAJOR CROPPING PATTERNS IN SELECTED BARANGAYSOF THE CITY OF BATAC, ILOCOS NORTE"

Name (Optional): ……………………………………………………Contact Number: ………………………..
Address: ……………………………………………………………………………………………………….

1. Crop Management Practices

1. Is the soil or land where you are planting rice-based? …………………………………………………….
2. Is there anything you add to the soil before you plant a certain crop? …………………………………….
   If there's any, what is it or what are those?
   ………
3. What fertilizer are you adding and how many kilograms of fertilizer you are adding in every cropping?
   ………
4. Do you use pesticides in your crops?
   ………
   If yes, what kind of pesticides are you using?
   ………

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Women and the Risks of Using Polluted River Water: A Pioneering Study on the Marginalization of Women from an Ecofeminist Perspective, a Unique Contribution to the Field of Ecofeminism

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ABSTRACT

Various studies have shown that gender-based inequality in water governance and urban development is a significant challenge for women. This is especially true because most of their tasks are related to water collection and management, yet their opinions are often ignored in water management decisions. As a result, women experience economic disadvantages due to difficulties accessing clean water and sanitation services. This survey study aims to identify the use of river water for daily needs by housewives living in three cities (Surabaya, Sidoarjo, and Kediri) located on the banks of the Brantas River, East Java, Indonesia. An ecofeminist perspective is used in this study to determine whether women can address the problem of water pollution in their environment or, conversely, whether they experience marginalization due to their low ecological knowledge. This study found that: (1) housewives living on the banks of the Brantas River do not yet have sufficient awareness and knowledge regarding the quality of polluted Brantas River water; (2) they also experience vulnerability, especially to their own health and that of their families, where this vulnerability arises due to the habits and lifestyles they lead in interacting with river water, coupled with low levels of knowledge about the dangers of polluted river water, as well as the low economic conditions and social status of communities along the Brantas River Basin; (3) these women also experience structural marginalization, where external parties who work to provide knowledge and awareness to the community do not carry out their functions and women are not encouraged to participate in improving their fate.

Keywords: Women/ Polluter River Water/ Marginalization/ Ecofeminist Perspective/ Brantas River

1. INTRODUCTION

Various studies show that river water along the East Java Province is no longer suitable for consumption. Its quality has decreased with alert status because it has been polluted continuously [1]. Previous studies found that the level of water pollution of the Brantas River, which passes through several areas of East Java Province, is mild to moderate [2]. Another study along the Brantas watershed in East Java Province also showed that river water quality is increasingly concerning due to pollution caused by household and industrial waste. In contrast, Brantas River water is the raw material for clean water managed by the Regional Drinking Water Company (PDAM) in East Java Province [3].

Polluted river water can be detrimental to the community because it not only results in a decrease in health quality [4],[5] but also in the carrying capacity of the environment [6]. Previous studies found various diseases can arise due to environmental pollution [7],[8]. On the other hand, efforts to maintain river water quality are constrained by low public awareness of maintaining ecological cleanliness along the watershed [9],[10], as well as due to weak supervision and law enforcement against people who pollute river water [11]. Women are an element of society that contributes to saving the environment. Studies conducted by Bakti et al. [12] show that women can be involved in efforts to save the environment along the Ciliwung watershed, where women who are members of local organizations, such as Majelis Ta'lim, Arisan and PKK groups, and women members of farmer group associations (Gapoktan) can be an entry point for flood prevention programs along the watershed and waste management that can pollute river water. A study conducted by Mailisa et al. [13] found that most women living around the Sani watershed, Pati Regency, Central Java, know the functions and benefits

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of the river and are willing to be involved in its management. However, their participation still needs to be increased.

Considering the declining river water quality in East Java Province and the potential of the community, especially women who are more empathetic towards environmental preservation, the objectives of this study are as follows: (1) mapping women's knowledge of Brantas River water quality and health related to the utilization of Brantas River water in the East Java Province area; (2) identifying forms of women's awareness to improve the quality of health and environmental preservation along the Brantas River watershed in the East Java Province area; (3) Analyzing women's participation in managing and preserving the environment along the Brantas River watershed in East Java Province.

Approach and State-of-the-Art

Past studies have shown that gender-based inequalities in water governance and urban development are challenging as women are primarily tasked with water collection and management. Yet, their opinions are sidelined and rarely heard in water governance. Ultimately, women suffer economic losses due to difficulties accessing water and sanitation services. Lafuente analyzed the gender gap in environmental awareness and political knowledge, where it turns out that women's preferences in industrialized countries are related to their activeness in protecting the environment for domestic purposes and their low political participation in water management. Studies have also shown that women are the most affected by health due to river water pollution and waste disposal [14]. Studies conducted in India show that women are an integral part of the movement to save the environment [15].

The perspective of ecofeminism explains how women who experience social and economic marginalization due to the destruction of nature and the environment can rise and fight to overcome the inequality they experience. Ecofeminism explains how women, in particular, have an attachment to the environment due to their traditional role as caregivers and nurturers [16]. Vandana Shiva [17] explains that women daily interact with the environment. In their subsistence economic activities, women partner with nature and become experts in holistic ecological knowledge and understanding of natural processes.

Women's awareness to save their environment certainly does not appear instantly. Women make various efforts by mobilizing existing resources, such as through grassroots organizations managed by women [18] and non-governmental organizations that simultaneously foster public awareness, including women, to preserve the environment [19]. The form or level of women's participation in protecting the environment can also be studied from the participation theory proposed by Arnstein [20],[21]. Arnstein's ladder of participation theory can be used to measure the extent to which women can participate in managing and preserving their environment. The ladder of participation introduced by Arnstein shows that if citizens have been able to participate up to the ladder of partnership to citizen control, then the community has reached the highest level of participation, called citizen power. The power of citizens, in this case women, to control their environment will also impact their ability to improve their quality of life.

The novelty of this study is in the effort to map the forms of women's awareness and their level of participation in managing and preserving the environment related to the water resources of the Brantas River in the East Java Province. By understanding women's awareness of river water pollution and mapping their participation level in preserving the environment, women can be part of the early warning system in managing and saving river water from more severe pollution. Suppose women can participate fully in environmental management. In that case, it can also improve women's bargaining position to be equal to men in preventing various things that harm women in health, economic, and social aspects.

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Figure 1. Residential Settlement in the Brantas River Basin in the Sidoarjo Region

2. METHODOLOGY

This study was conducted in three cities in East Java, namely Surabaya, Sidoarjo, and Kediri, where the Brantas River, a large river in East Java, crosses the three towns (see Figure 2). The Brantas River is the second longest river in Java, Indonesia, after the Bengawan Solo River. The Brantas River has a vital role for the people of East Java because around 46.7% of the population of East Java lives along the Brantas River basin. This river also plays a vital role in supporting East Java's status as a national food barn [22].

Since this study aims to map women's knowledge about the quality of Brantas River water and their health related to the use of Brantas River water in East Java Province, this study was conducted using a survey method, where the respondents in this study were women, especially those who were married and lived in three cities along the Brantas River Basin. The total number of respondents was 300 housewives, and 100 housewives were taken in each town as research samples. Sampling was conducted using the quota sampling technique, where homemakers were taken as samples and were met based on their residential areas along the river. This quota sampling technique was used considering that families or households living along the Brantas River Basin are not evenly distributed but are clustered in certain areas along the river.

Data collection was conducted through interviews using a questionnaire as a research instrument. Interviews were conducted by several interviewers trained to conduct interviews using standards and procedures that the ethics team of the Faculty of Social and Political Sciences, Airlangga University, had set. The interviewers approached the homemakers selected as research respondents one by one. Before conducting the interview, the interviewers explained the purpose of the interview to the homemakers. The respondents were also free to participate or not in the research. If the respondents were willing to participate in the study, they were asked to sign a statement of willingness provided during the research. However, if the respondents were unwilling to be interviewed, the interviewer did not continue the interview process.

The data that had been collected was then processed using the SPSS data processing application. The categorical data is presented as frequency tables and analyzed descriptively based on the data category. The data in the form of an attitude scale is calculated on average and analyzed based on the attitude tendencies of each variable and research indicator.

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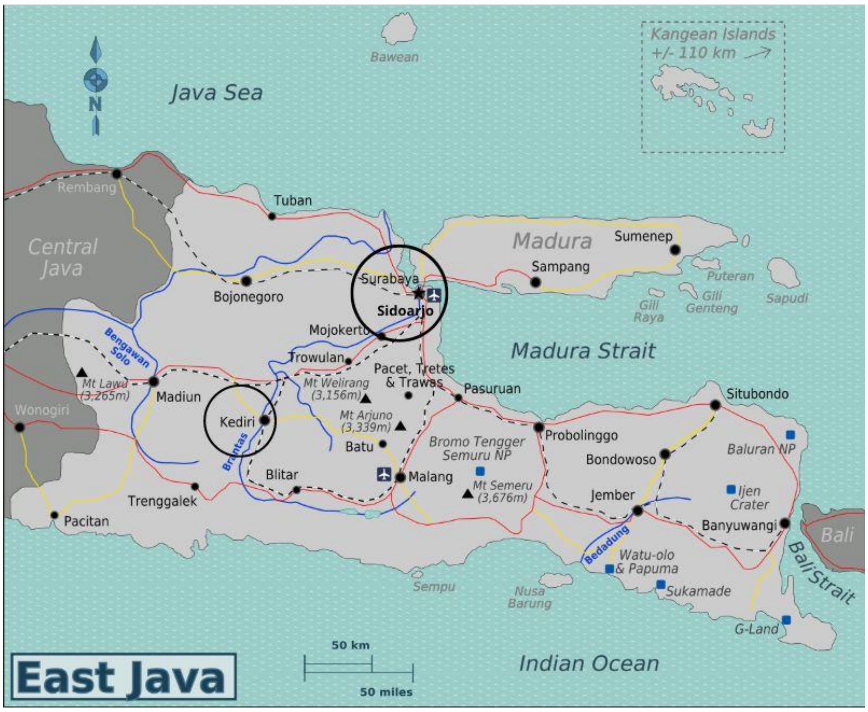

Figure 2. Map of East Java with Brantas River Flow (Source: https://id.wikipedia.org/wiki/Daftar_sungai_di_Jawa_Timur)

3. RESULTS AND DISCUSSION

The research results presented in this section consist of (1) a description of respondent characteristics; (2) housewives' habits in water use; (3) a mapping of homemakers' knowledge about the quality of Brantas River water; (4) identifying women's awareness in maintaining health and preserving the environment, and (5) analyzing women's participation in managing and preserving the environment along the river basin.

3.1 Description of respondent characteristics

The characteristics of respondents in this study include age, education level, daily occupation of respondents, average family income, status, and length of residence in the riverbank area. The following table contains the average figures for each indicator of respondent characteristics.

Table 1. Characteristics of Respondents

Respondent Characteristics Indicators	Average Value		
	Surabaya	Sidoarjo	Kediri
Age	44 years	37 years	44 tahun
Education Level	Junior High School	Junior High School	Senior High School
Daily Occupation	Informal Sector	Housewife	Informal Sector
Average family Income per Month	Rp. 2,400,000	Rp. 1,750,000	Rp. 1,670,000
Status of Occupied House	Contract/Rent	One's own	One's own
Length of Residence in the Riverbank Area	16 years	18 years	17 years

Source: processed from primary research data

Based on the respondents' characteristic indicators, it can be said that, in terms of age, the housewives who were respondents in this study were, on average, 37 to 44 years old. This means that the average Housewife found in the research area was mature. In terms of education, it appears that they have not yet reached higher education because, on average, they only completed their education up to junior high and high school levels, and even quite a few respondents had elementary school education or had not graduated from elementary school. The jobs of respondents in the cities of Surabaya and Kediri were, on average, in the informal sector, such as working as small traders selling around or

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having a small industry that was carried out at home. Meanwhile, respondents in Sidoarjo were, on average, only housewives. The level of welfare of the respondents' families, when viewed from the average monthly family income and their residential status, was categorized as families with a low level of welfare, where their average income was low, below the average regional minimum wage in East Java, especially from the areas in Sidoarjo and Kediri Regencies. Meanwhile, respondents from Surabaya City can be categorized as lower-middle-income families. Meanwhile, the population status of respondents, seen from their residence status and length of stay, appears that respondents from Surabaya City are primarily immigrants, not native residents of the city because, on average, their residences are rented or contracted/non-permanent houses. In contrast, most of the respondents from Sidoarjo Regency and Kediri City are native residents in their areas.

3.2 Housewives' habits in water use

Since the respondents live along the Brantas River, it is possible that they also use river water for daily needs. The habit of using water for daily life can be distinguished for (1) bathing and brushing teeth and (2) other household needs, such as drinking, cooking, and washing. This knowledge is needed to find out the water usage habits of the respondents, most of whom have been living in the highlands of the Brantas River Basin for quite a long time. The following table contains information on water usage for both of these things.

Table 2. Water Sources Used for Bathing and Other Household Needs

Water Source	Used for Bathing			Used for Other Household Needs		
	Surabaya (%)	Sidoarjo (%)	Kediri (%)	Surabaya (%)	Sidoarjo (%)	Kediri (%)
Filtered river water	1.0	2.0	0	0	18.0	3.0
Direct river water	0	0	0	0	0	0
Well water	16.0	98.0	82.0	4.0	63.0	66.0
Subscribe to water treated by a government-owned drinking water company (PDAM)	83.0	0	17.0	54.0	0	15.0
Buying clean water from water vendors	0	0	1,0	42.0	19.0	16.0
Total	100.0	100.0	100.0	100.0	100.0	100.0

Source: processed from primary research data

Table 2 shows an interesting phenomenon, where respondents in each region have different habits of getting water sources. For bathing and brushing their teeth, respondents from Surabaya City mostly use PDAM water (83%), while in the other two regions, most respondents use well water (Sidoarjo 98% and Kediri 82%). However, the water sources vary for drinking, cooking, and washing. In Surabaya, half of the respondents use PDAM water (54%), but quite a lot also buy clean water from traveling water sellers (42%). While in Sidoarjo Regency, most use well water (63%) and buy clean water (19%), and in Kediri City, most use well water (66%), then some use PDAM water (15%) and buy from clean water traders (16%).

A pretty exciting phenomenon is in respondents who use river water, even though the river water used has been filtered. In Surabaya, 1% of respondents use river water for bathing and brushing their teeth, while in Sidoarjo, 2% use river water for bathing and brushing their teeth, and 18% for drinking, cooking, and washing. In Kediri, 3% of respondents use river water for drinking, cooking, and washing.

Let's look at the habits of respondents in using water for daily needs. It appears that respondents from Surabaya City take into account safety and health aspects more in choosing the use of water for bathing, brushing their teeth, drinking, cooking, and household cleaning needs because they prefer to use PDAM water, well water, and buy clean water from street vendors even though they have to pay for it. Likewise, for respondents from Kediri City, the use of well water is more dominant, in addition to using PDAM water and buying from street vendors. Meanwhile, respondents from Sidoarjo Regency,

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because of their characteristics as rural communities, use water for daily needs, relying more on well water and buying from street vendors and river water.

3.3 Mapping of housewives' knowledge about the quality of Brantas River water

In addition to being known for using water for daily needs, mapping respondents' knowledge about Brantas River water can also be measured from other indicators. In this study, there are 10 indicators to determine the level of health of respondents related to the use of river water; where these indicators are measured through perception in recognizing and interpreting sensory information related to river water along the Brantas Watershed to provide an overview and understanding of the environment around them.

Measuring respondents' perceptions of river water quality or pollution levels, this study uses a Likert scale of 1 to 5, where a score of 1 indicates that respondents strongly agree with the quality of river water that can be used for daily needs. In contrast, a score of 5 indicates that respondents strongly disagree with using river water for daily needs. Thus, if most respondents provide answers to each statement indicating that the quality of river water is very poor, then the average value will tend to be high, which means that respondents perceive Brantas river water as unsuitable for human life. Suppose most respondents agree that river water can be used for human needs; the average value will tend to be low, which means that respondents perceive Brantas River water still benefits their lives.

The ten indicators used to map housewives' knowledge of river water quality include perceptions about (1) the level of river water quality along the respondent's residence, (2) the suitability of using river water for bathing and brushing the teeth, (3) the suitability of using river water for drinking and cooking; (4) the suitability of river water for washing, cleaning the house and other household needs; (5) the suitability of river water for drinking for livestock and watering plants; (6) the suitability of consuming fish from river water; (7) the level of river water quality compared to well water; (8) the level of river water quality compared to PDAM water; (9) the level of river water pollution by waste; (10) the level of river water pollution for fish along the Brantas River.

Table 3. Mapping of Women's Knowledge about Brantas River Water Quality for the Lives of the Surrounding Community

Women's Perception/Knowledge Variables on Brantas River Water Quality		Mean		
		Surabaya	Sidoarjo	Kediri
Average Knowledge of River Water Quality and Its Utilization (combination of 10 indicators)		3.25	3.12	2.77
Respondents' perceptions with a range: 1 (strongly agree); 2 (agree); 3 (less agree); 4 (disagree); 5 (strongly disagree)				
(1)	The quality of river water where I live is clean/good.	3.36	3.59	2.72
(2)	The river water along my residence suits bathing and brushing my teeth.	3.57	4.06	3.44
(3)	The river water along where I live is suitable for drinking and cooking	3.90	4.24	3.62
(4)	The river water along my residence is suitable for washing clothes, household items, mopping floors, and other household needs.	3.53	3.55	3.10
(5)	The river water along my residence suits livestock and watering plants.	2.75	2.26	2.32
(6)	The fish caught from the river where I live are suitable for cooking or consuming for the family.	2.80	2.40	2.42
(7)	The river water quality along my residence is as good as the well water at my house.	2.12	4.30	3.57
(8)	The river water quality along my residence is as good as my area's PDAM/tap/piped water.	3.98	4.00	3.47
(9)	The river along my residence has been polluted by household and factory waste/garbage.	3.43	3.85	3.06
(10)	The fish in the river where I live have been polluted by household and factory waste and are unfit for consumption.	3.10	3.56	2.68

Source: processed from primary research data

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Based on Table 3, if we look at the average score for the 10 indicators, it can be seen that the range of scores in the three regions is at an average value of 3.25 to 2.77. This means that the respondents' perception or knowledge of the quality of the Brantas River water shows a tendency or assumption that the Brantas River water is beneficial for their lives, even though they know that the quality of the Brantas River water is no longer good/clean (Surabaya, average 3.36; Sidoarjo average 3.59; Kediri average 2.77). Specifically, two indicators show a tendency that river water has benefits; in this case, it is helpful for (1) drinking livestock and watering plants (Surabaya, average 2.75; Sidoarjo, average 2.26; Kediri average 2.32); and (2) the fish are taken and are suitable for cooking and consumption as their daily food menu (Surabaya, average 2.80; Sidoarjo, average 2.40; Kediri, average 2.42).

The indicators that further strengthen that the Brantas River water is still considered good and can be used in their lives are: (1) the quality of the Brantas River water is comparable to well water (for respondents from Surabaya City, with an average of 2.12); (2) the water quality is still clean or good (for respondents from Kediri City, with an average of 2.72); (3) the fish in the Brantas River have not been or are not polluted by waste (for respondents from Kediri City with an average of 2.68).

Based on the community's habit of using clean water for daily life, it can be concluded that respondents from Surabaya City never use Brantas River water to meet their basic needs (bathing, drinking, cooking, and so on). Meanwhile, for respondents from Kediri City, the use of well water is more dominant, in addition to using PDAM water and buying from traveling water vendors. For respondents from Sidoarjo Regency, because their characteristics are rural communities, water use for daily needs relies more on well water, buying from traveling water vendors, and river water.

Interestingly, a few housewives still use river water to meet their basic needs, such as processing food, drinking, bathing, brushing their teeth, etc. Those still using river water for daily needs also know that Brantas river water is no longer good/clean. However, from the perspective of their perception or knowledge about the quality of Brantas river water, respondents tend to agree that Brantas river water can still be used for daily life, especially for giving livestock water, watering plants, and taking fish to be cooked and consumed, as a daily food menu for their families.

3.4 Identifying women's awareness in maintaining health and preserving the environment

This section presents the research results that map women's awareness of maintaining their family's health. In addition, the results of this study also highlight the ecological awareness of housewives in maintaining cleanliness and sustainability of environmental preservation along the Brantas River Basin.

3.4.1 Women's Awareness in Maintaining Family Health

This sub-chapter attempts to present data on the level of awareness of women in the Brantas River Basin area in maintaining their family's health, along with various health risks due to river water pollution from various industrial and household waste. To assess the extent of women's awareness of health concerning river water, it is measured from seven indicators which include the level of understanding of (1) diarrhea experienced in the last 12 months; (2) stagnant water which causes dengue fever cases; (3) typhoid due to lack of food and environmental hygiene; (4) level of understanding of the condition and nature of river water which can cause skin diseases/itching; (5) level of understanding of pollutants in river water on fetal growth in the womb; (6) dental health to the use of polluted water; and (7) oral health to the use of polluted water.

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Table 4. Women's Awareness in the Brantas River Basin Regarding Family Health

Variable of health awareness	Mean		
	Surabaya	Sidoarjo	Kediri
Average score of Respondents' Awareness level regarding various diseases in relation to Brantas River Water Respondent awareness range: 1 (strongly agree); 2 (agree); 3 (less agree); 4 (disagree); 5 (strongly disagree)	3.00	3.23	2.92
Contaminated drinking water cannot cause diarrhea	4.42	4.46	4.32
Stagnant water does not cause dengue fever	3.25	4.02	3.57
River water contaminated with hazardous waste does not cause typhoid fever	3.20	3.70	2.96
River water does not cause skin pain/itching	2.95	3.62	3.44
Pollutants in river water do not affect fetal growth.	3.07	3.44	3.03
Dental health is not caused by polluted water	2.37	2.70	2.41
Oral health is not caused by contaminated water	2.30	2.69	2.36

Source: processed from primary research data

Based on Table 4, if we look at the average score for the 7 indicators, it can be seen that the range of scores in the three regions is at an average value of 2.92 to 3.23. This means that, in general, respondents are unaware of the various diseases that can be caused by polluted river water. The relatively low awareness of respondents about the various diseases that can be caused by polluted river water also seems to be due to the lack of exposure to information provided by health educators or parties who are competent in this matter. The following data shows the low exposure to health information from health educators.

Table 5. Intensity of Health Workers Providing Counseling to the Community

The intensity of health workers in providing counseling	Percentage (%)		
	Surabaya	Sidoarjo	Kediri
Never	57.0	82.0	86.0
Rarely	17.0	17.0	6.0
Sometimes	9.0	1.0	5.0
Often	13.0	0	2.0
Always	4.0	0	1.0
Total	100.0	100.0	100.0

Source: processed from primary research data

The data in Table 5 proves that it is true that health workers or counselors never or rarely provide health counseling to mothers along the banks of the Brantas River Basin. In Surabaya, more than half of the respondents admitted that health workers or counselors had never visited them (57%), as well as in the other two areas, the majority admitted that they had never received information about health from health counselors (Sidoarjo, 82%; Kediri, 86%).

3.4.2 Ecological awareness of women in maintaining cleanliness and sustainability of Brantas Watershed

Ecological or environmental awareness is also important for the community, especially those who live on riverbanks. Dirty or polluted rivers can be caused by the community's neglect in protecting river water from all waste. The community's habit of throwing away garbage or the slum environment along the Brantas River Basin is also an indicator of the low ecological awareness of the community towards preserving the river basin. The following are indicators used to measure the level of ecological awareness of respondents in maintaining the cleanliness and sustainability of the Brantas River Basin. These indicators measure awareness of (1) the dangers of household waste in the form of plastic waste

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that can pollute the river; (2) the dangers of factory waste containing chemicals and dangerous metal particles that are dumped into the river; (3) river water is not suitable for use for household purposes; (4) preferring to buy mineral water/PDAM for drinking rather than using sedimented river water; (5) fish in the river have been polluted and are dangerous to health so they are not suitable for consumption; (6) not throwing household waste into the river because it can pollute the environment.

Figure 3. Garbage on the Edge of the Brantas River Basin in Surabaya

Figure 4. Garbage on the Edge of the Brantas River Basin in Kediri

The two figures above show that residents in the research area still ignore environmental cleanliness and health. It has been proven that they still throw garbage in the wrong place and do not manage it properly, so garbage is seen piling up on the riverbank.

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Table 6. Women's Ecological Awareness in Maintaining the Cleanliness and Sustainability of the Brantas Watershed

Respondents' Ecological Awareness Level Variable	Mean		
	Surabaya	Sidoarjo	Kediri
Average score of respondents' ecological awareness level in the Brantas watershed area	3.82	3.94	3.79
Respondent awareness range: 1 (strongly disagree); 2 (disagree); 3 (less agree); 4 (agree); 5 (strongly agree)			
(1) Household plastic waste thrown into rivers is difficult to decompose and causes pollution that is dangerous to health.	4.13	4.11	4.17
(2) Factory waste in rivers contains chemicals and metal particles that are dangerous to health.	3.53	3.67	3.56
(3) Although river water can be filtered, it cannot be used for household purposes.	3.34	3.97	3.43
(4) I prefer to buy mineral water/well water/PDAM water for drinking, cooking, and washing rather than using sedimented river water.	4.44	4.37	4.41
(5) Fish along the river are not suitable for consumption because they have been contaminated with waste/materials that are hazardous to health.	3.11	3.18	2.89
(6) Household waste should not be thrown into rivers because it can pollute river water.	4.41	4.38	4.29

Source: processed from primary research data

The data in Table 6 shows that the respondents' overall ecological awareness score is 3.79 to 3.82. This means that the respondents do not yet have good enough environmental awareness. This is because not all indicators have an average score of 4 or more (which means they agree that the Brantas River water has been polluted and is hazardous to health).

Several indicators that show respondents' relatively low ecological awareness regarding pollution and environmental preservation of the Brantas River Basin are found in the indicator regarding the quality of fish along the river that has been polluted by waste/materials hazardous to health. On average, respondents in the three research areas disagreed with this statement (score range between 2.89 to 3.11). This data is consistent with the respondents' knowledge about river water quality in Table 3, where the average respondent considered it suitable to consume fish from the Brantas River water.

Another indicator that shows respondents' relatively low level of ecological awareness is seen from the statement related to the unsuitability of river water for household purposes. The average respondent from the three research areas disagreed with the statement (scores ranging from 3.34 to 3.97). The third indicator that shows respondents' low ecological awareness is that "factory waste in the river contains chemicals and metal particles that are harmful to health". The average score ranges from 3.53 to 3.67, meaning respondents disagree with the statement.

The factors causing respondents' relatively low ecological awareness regarding pollution and conservation in the Brantas Watershed environment can be seen from the absence of parties competent to provide counseling or socialization about the environment.

Table 7. Parties Who Have Provided Environmental Counseling to Residents

Parties who have provided counseling	Surabaya (%)	Sidoarjo (%)	Kediri (%)
Never given counseling about the environment	42.0	89.0	72.0
Family Welfare Empowerment (PKK)	18.0	6.0	8.0
Mothers' relegious study groups	7.0	2.0	2.0
Community of mothers who care about the environment	1.0	0	0
Neighborhood Association/Citizens Association (RT/RW)	2.0	0	2.0
village government	16.0	2.0	7.0
sub-district government	1.0	0	0
Environmental Service	6.0	0	4.0
Non-Governmental Organization	7.0	1.0	5.0
Total	100.0	100.0	100.0

Source: processed from primary research data

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The data in Table 7 shows quite concerning empirical facts, because most respondents, especially in Sidoarjo Regency (89 percent) and Kediri City (72 percent), have never received counseling on river water pollution and environmental preservation along the Brantas Watershed. According to respondents' confessions, the parties who have provided counseling on river water pollution and environmental preservation are PKK or religious study groups, village or sub-district officials, environmental services, and non-governmental organizations. The data in Table 7 is consistent with the data presented in Table 4 regarding the low awareness of the emergence of various diseases caused by polluted river water. The relatively low awareness of respondents about the various diseases that can be caused by polluted river water is caused by the limited exposure to information provided by health counselors or competent parties in this matter to the community. Likewise, with the respondents' awareness of river water pollution and environmental preservation along the Brantas Watershed, on average, they do not have sufficient ecological awareness. The absence of competent parties in the environmental field in the lives of communities along the Brantas River Basin can also cause respondents to have relatively low ecological awareness. This can be shown by the confession of most respondents who have not or have never been visited by environmental extension officers.

3.5 Analyzing women's participation in managing and preserving the environment along the river basin.

The final discussion on the findings of this research data is about the participation of women who live along the Brantas River Basin in maintaining the environment and family health. Participation is a form of community awareness to participate in activities that can improve their welfare. Participation is important in realizing a just and prosperous society [23]. Through participation, programs to improve the quality of life and community welfare can be carried out more efficiently and effectively and encourage the community to have a shared responsibility in realizing the welfare of the community or their community. The following is data on women's participation in three areas along the Brantas River Basin.

Table 8. Women's Participation in Brantas Watershed in Protecting the Environment and Health

Women's Participation Variable	Mean		
	Surabaya	Sidoarjo	Kediri
Average score of Women's Participation rate	1.44	1.17	1.22
Respondent participation range: 1 (never); 2 (rarely); 3 (sometimes); 4 (often); 5 (always)			
(1) Mothers' involvement in village deliberation activities to address river water and environmental pollution issues	1.46	1.21	1.11
(2) Mothers' involvement in village deliberation activities to address community health problems	1.76	1.25	1.32
(3) Mothers' involvement in decision-making at village meetings to address river and environmental pollution issues	1.42	1.17	1.04
(4) Involvement in decision-making at village meetings to address community health issues	1.68	1.08	1.10
(5) Involvement of mothers in community groups/citizens/organizations to address water pollution and environmental damage problems	1.31	1.07	1.16
(6) Involvement in monitoring water pollution and environmental damage	1.24	1.07	1.08
(7) Involvement of mothers in organizations/community groups that play a role in handling community health/integrated service posts	1.57	1.45	1.82
(8) Involvement of mothers in monitoring community health	1.10	1.03	1.15

Source: processed from primary research data

Information obtained from Table 8 shows that respondents in Surabaya, Sidoarjo, and Kediri almost always or rarely participate in various activities related to efforts to maintain environmental sustainability and health at the village deliberation level or other community organizations. This can

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be proven by the average score from the three regions being 1.17 to 1.44. The low participation of women in village forums that men or fathers structurally dominate shows that women are considered to have no role in managing their environment. Therefore, their voices are not heard, or their opportunity to express their opinions is not given space at the macro level (village deliberation). Although almost all women in this study were not or rarely involved in village deliberation activities related to environmental and health conservation issues, at a more micro level, some respondents were involved or were part of efforts to improve the community's welfare in their area. Their participation includes being members or cadres of PKK and integrated service for children under five years old (*Posyandu Balita*), becoming mosquito larvae monitors (*Jumantik*), participating in waste management socialization activities in their area, and participating in community service activities to clean up their residential environment. The following data relates to respondents' participation at the micro level in their efforts to maintain environmental sustainability and residents' health.

Table 9. Respondents' Participation at the Micro Level in Protecting the Environment and Health of Residents

Respondent Participation at the Micro Level	Surabaya (%)	Sidoarjo (%)	Kediri (%)
Not participating	66.0	90.0	88.0
Member/Cadre of PKK and Posyandu for Toddlers & Elderly	17.0	2.0	8.0
Mosquito Larvae Monitoring Officer (*Jumantik*)	3.0	1.0	0
Participate in managing waste and monitoring river pollution	6.0	1.0	0
Participate in community service to clean the environment	8.0	6.0	4.0
Total	100.0	100.0	100.0

Source: processed from primary research data

Based on the data in Table 9, it can be seen that most respondents were not involved or participated in environmental conservation and health maintenance activities at the micro level. This can be seen in the three research areas, where as many as 66 percent of mothers in Surabaya City did not participate, 88 percent of mothers from Kediri did not participate, and most mothers from Sidoarjo (90 percent) were not involved in environmental conservation and health maintenance activities in their environment.

Meanwhile, the number of respondents who participated in environmental conservation and health maintenance activities in their homes was relatively small: in Surabaya, 34 percent; in Sidoarjo, 10 percent; and in Kediri, 12 percent. The experience of mothers in Surabaya City who participated in environmental conservation and health maintenance activities at the micro level was handling matters related to toddler nutrition and stunting, managing waste and establishing waste banks anticipating river water pollution due to waste, making herbal medicine (from medicinal plants planted along the river basin), counseling on family toilets so that residents do not defecate in the river, participating in clean green competitions organized by the Surabaya City Government.

Meanwhile, the experience of mothers in Sidoarjo Regency who participated in environmental conservation and health maintenance activities at the micro level was to handle matters related to toddler nutrition and stunting, counseling on family toilets so that residents do not defecate in rivers, counseling on preventing diseases such as Dengue Fever (DBD), Diabetes, and Hypertension, as well as skin diseases. Mothers in Kediri City who participated in environmental conservation and health maintenance activities at the micro level were to handle matters related to toddler nutrition, counseling on preventing hypertension and diabetes, and distributing social assistance funds.

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3.6 Discussion: Analysis of data findings

The data presented above shows an interesting and worrying phenomenon. Based on the awareness and knowledge of housewives regarding the quality of Brantas River water in Surabaya City, Sidoarjo Regency, and Kediri City shows that they know and realize that the river water has been polluted and is not suitable for consumption. Most respondents in the three regions also know that the cause of river water pollution is household and factory waste. However, ironically, although most respondents know about Brantas River water pollution, there are still some housewives in Surabaya City, Sidoarjo Regency, and Kediri City who still use Brantas River water to meet their daily needs, such as for bathing, drinking, cooking, washing clothes, and washing household items, even taking fish from the Brantas River to be used as side dishes for their daily meals.

Several factors can cause the irony experienced by residents along the banks or Brantas Watershed. Research conducted by Suryadi et al [24] shows that the factors that influence people's behavior in using river water for daily needs are caused by community habits that have been carried out for generations. In addition, it is also caused by the community's low social and economic status. The findings are also in line with the results of this study, where the majority of respondents have a lower to middle socioeconomic status, and their length of residence in the Brantas Watershed area is also quite long; some even live on the banks of the Brantas Watershed for more than 20 years.

People living on riverbanks generally perceive river water as a source of life, so they try to use it for their daily needs. Research conducted by Rismawati, et al. [25] on several respondents along the Martapura River showed that most respondents in their study had a bad perception of river water pollution. However, they still use it for their daily needs. Rismawati's findings are in line with this study. Although most of the respondents' housewives knew that the Brantas River water was polluted, some still used it for their daily needs.

Research conducted by Husain [26] on community perceptions of using river water along the Jagir River in Surabaya City showed that although it was perceived as unclear, they thought it could still be used. Husain identified four patterns of river water use by the community, namely: (1) to flush and flush dirt from human activities; (2) to purify or perform ablution in the context of Islam; (3) to clean, for example, bathing and washing; (4) and as a place of recreation and to earn a living. With a cognitive map based on the knowledge and habits of the community identified by Husain, this condition is relevant to the results of this study, where respondents who live along the Brantas River Basin do not feel guilty and are "okay" if they use river water for their daily needs.

The behavior of housewives utilizing Brantas River water daily apparently impacts their neglect of health. It seems that many respondents do not know that several diseases can be caused by their interaction with the use of river water. Diarrhea, skin diseases, and DHF are some diseases that can be caused by river water pollution. Research conducted by Firmansyah, et al. [27] stated that the cause of diseases suffered by people living on riverbanks is suspected to be due to basic sanitation that does not meet the requirements and individual characteristics that still use low-quality river water as a water source. Purwaningsih [28], in her research on the correlation between the incidence of skin diseases and the use of polluted river water, showed a significant relationship between the use of polluted water and the incidence of skin diseases. Furthermore, Purwaningsih also found that personal hygiene also affects the emergence of skin diseases. If a person's level of personal hygiene is relatively low, coupled with the use of water for personal hygiene that does not meet quality standards or exceeds the pollution threshold, then more and more people will suffer from skin diseases. Other research related to river water pollution and its impact on public health has also been conducted by Ritiau [29]. The results of his research show that river water or well water has been contaminated by household and factory waste; the disease often found is diarrhea. This is because water that has been polluted and consumed by humans contains many microbes and has a bad impact on human digestion.

Considering the interaction and behavior of female housewives towards using Brantas river water in this study, it can be said that women have a weak bargaining position in obtaining resources, in this case, good quality, clean, and suitable water for their lives. In addition, women in this study also

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experienced structural marginalization, where external parties responsible for raising public awareness of river water pollution, health, and environmental preservation were not present in front of the community. Women, including polluted river water, are vulnerable in their interactions with the environment. A study conducted by Situmeang & Aflaha [30] showed that women and children are the most vulnerable to poor environmental ecology, including water and air pollution, which can also be linked to climate change. In their daily lives, women are the ones who have to directly struggle to maintain the survival and needs of their households. The limitations or vulnerabilities of women, especially those from low-income communities, mean that they do not receive adequate protection and rights to obtain clean water and health services from the government and stakeholders, most of whom come from the dominant class of society. In such situations and conditions, women can rally defenses for environmental sustainability and a better ecosystem for human life. Still, they must be supported and given adequate space and facilities to voice their interests. In such situations and conditions, women can rally defenses for environmental sustainability and a better ecosystem for human life. Still, they must be supported and given adequate space and facilities to voice their interests.

The study conducted by Situmeang & Aflaha shows that the bargaining position of women who are vulnerable and marginalized due to pollution and climate and ecological change can be weakened or strengthened when women can mobilize their capital and social networks. From an ecofeminist perspective, women's abilities are needed and must continue to be developed. Women can overcome ecological injustice when they have sufficient capital (human, financial, natural, social, and physical). The study conducted by Situmeang & Aflaha seems to align with this study's results, where women do not have sufficient capital, support, and knowledge to be the driving force in maintaining and preserving the environment along the Brantas River Basin.

4. CONCLUSIONS

Considering the data description and discussion above, the conclusion that can be drawn is that women do not have sufficient awareness and knowledge regarding the quality of polluted Brantas River water. This is a matter of concern and is detrimental to them because they are part of the ecosystem and ecology of the environment along the Brantas River Basin. Women also experience vulnerability, especially to their health and that of their families, where this vulnerability arises because of the lifestyle habits they lead in their interaction with river water. The habit of using unhygienic river water, coupled with low knowledge about the dangers of polluted river water, as well as the low economic conditions and social status of the community along the Brantas River Basin, can be factors causing the weak position of women in obtaining clean and adequate water services. This condition then impacts the health status of women and their families. The vulnerability of women living along the Brantas River Basin is also exacerbated by structural marginalization, where external parties who work to provide knowledge and awareness to the community along the Brantas River Basin do not carry out their functions, and women are not given the opportunity and encouragement to participate in village deliberation institutions to improve their fate. Women's participation in protecting and preserving the environment is social capital that can be developed and relied on to achieve a quality life even though they live along the Brantas River basin.

Suggestions and Recommendations

The results of this study have implications that women do not yet have strong enough bargaining power to save themselves and their families from various dangers of pollution and changes in the environmental ecosystem, in this case, polluted river water. This bargaining power can continue to be developed, institutionalized, and strengthened through social capital owned by housewives who know the importance of saving the Brantas River water from all forms of pollution. Therefore, this study also recommends that related parties routinely and intensively provide awareness to the community to change their lifestyle and habits that depend on river water for their needs. In addition, support for women as a group vulnerable to water pollution must continue to be improved, both through

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socialization, education, advocacy, and collaboration from various stakeholders to synergistically and simultaneously equip women with various skills and knowledge that can strengthen their bargaining position as citizens who are vulnerable to the impacts of damaged river water ecology.

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Taurine Production in Engineered *Halomonas elongata*

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ABSTRACT

Taurine (Tau) is a conditionally essential amino acid in fish diet. Dietary supplementation of Tau in fish feed improved their survival rate, growth rate, protein and energy retention, metabolism, antioxidation response, stress response, disease resistance, muscle texture, and reproductive performance. Therefore, Tau is added to plant-protein-based fish feed due to the absence of Tau in plant protein. *Halomonas elongata* OUT30018 is a moderately halophilic bacterium with the ability to utilize a wide range of sugars and amino acids, including the putrefactive non-volatile amines such as histamine and tyramine derived from biomass waste as carbon (C) and nitrogen (N) sources for cell growth. The work presented here aims to generate a Tau-producing *H. elongata* cell factory to be used as a single-cell aquaculture feed additive. In bacteria, Tau is synthesized via two pathways: the L-cysteine (L-Cys) sulfinic acid pathway, mediated by the L-Cys dioxygenase (CDO) and the Cys sulfinic acid decarboxylase (CSAD) enzymes and the L-Cys sulfonic acid pathway, mediated by the L-Cysteate synthase (CS) and the CSAD enzymes. To compare the efficiency of these pathways, the expression cassettes encoding the codon-optimized artificial genes encoding these enzymes were introduced into the genome of *H. elongata* OUT30018 to generate *H. elongata* CSAD-CDO, CSAD-CS, and CSAD-CDO-CS strains. Subsequently, the amount of Tau accumulated in the three recombinant strains cultured in the M63 minimal media containing 4% glucose, 3% w/v NaCl, and 5 mM Cys were compared by HPLC analysis. Our result shows that *H. elongata* CSAD-CDO, expressing the enzymes of L-Cys sulfinic acid pathway, was the only strain that successfully accumulated Tau in the cells. Currently, we are conducting tests to determine if the *H. elongata* CSAD-CDO can grow and produce Tau when cultivated in a medium made from Cys-rich biomass waste, such as wool and chicken feathers. The use of *H. elongata* CSAD-CDO cells grown in Cys-rich biomass waste medium as a single-cell Tau-rich feed additive could decrease costs and improve the sustainability of the aquaculture feed industry.

Keyword: Taurine/ Feed additives/ Essential amino acids/ Cysteine/ *Halomonas elongata*

1. INTRODUCTION

A moderately halophilic *Halomonas elongata* is a gram-negative eubacterium well adapted to high-salinity environments by producing and accumulating ectoine as a compatible solute [1]. *H. elongata* OUT30018, isolated from a high-salinity agricultural field in Khon Kaen, Thailand [2], is unique among the members of the *Halomonas* genus in its ability to utilize biomass-waste derived sugars [3] and amino acids, including histamine and tyramine, which are the major putrefactive non-volatile amines derived from biomass waste and composted fertilizer as carbon (C) and nitrogen (N) sources for growth [4, 5, 6]. Therefore, we have selected *H. elongata* OUT30018 as a host strain to develop cell factories to produce amino-acid-derived chemicals, including ectoine (Ect), L-proline (Pro), and γ-aminobutyric acid (GABA) using media derived from nitrogen-rich waste biomass [3, 7, 8, 9, 10, 11].

A sulfur-containing amino acid, Taurine (Tau), is a conditionally essential amino acid in the fish diet [12, 13]. Dietary supplementation of Tau has been shown to improve survival, growth, feed utilization, protein and energy retention, intermediate metabolism, antioxidation, stress reduction, disease resistance, muscle texture, and reproductive performance in fish [13, 14, 15, 16]. As a result, Tau supplementation is recommended in plant-protein-based fish feeds due to the absence of Tau in plant proteins [13, 16]. Here, we report the generation of *H. elongata* strain that biosynthesizes and accumulates Tau instead of Ect. The prospect of using medium derived from nitrogen and sulfur-rich

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waste biomass for the cultivation of this strain to be used as a Tau-rich feed additive for the sustainable aquaculture industry is discussed.

2. METHODOLOGY

2.1 Bacterial strains and plasmids

Bacterial strains used in this study are listed in Table 1. The *Escherichia coli* DH5α strain was used as a cloning host, while *E. coli* HB101 strain, which harbored a pRK2013 plasmid was used as a helper strain in the triparental conjugative transformation of *H. elongata*. Plasmids used in this study are listed in Tables 2.

Table 1. List of Bacterial strains

Strains	Genotypes and Phenotypes	References
Escherichia coli		
DH5α	F⁻ ΦH5α*lacZDM15*Δ*(lacZYA-argF)U169 recA1 hsdR17(*r_K^- m_K^+*) supE44* Δ⁻*thi-1 gyrA relA1* Used as cloning host and donor host for triparental mating.	[17]
HB101	F⁻, *hsd S*20(rB-, mB-), *recA*13, *ara*-14, *proA*2, *lacY*1, *galK*2, *rpsL*20 (str), *xyl*-5, *mtl*-1, *supE*44, *leuB*6, *thi*-1, Δ(*mcrC-mrr*), Used as a host for pRK2013 plasmid.	[18]
Halomonas elongata		
OUT30018	Wild type strain (Osaka University Type Culture, formerly designated as KS3). Salt-tolerant phenotype (0.3 to 21% w/v NaCl) due to ability to produce and accumulate ectoine as a major osmolyte.	[2]
KA1	Δ*ectABC* Ectoine-deficient salt-sensitive mutant of *H. elongata* OUT30018 with genomic deletion of *ectABC* gene cluster.	[8]
CSAD-CDO	Δ*ectABC*::*mCherry-CSAD-CDO* Engineered strain, in which the *ectABC* gene cluster on the genome of *H. elongata* OUT30018 was replaced with the salt-inducible Tau-synthetic *mCherry-CSAD-CDO* operon. Produce and accumulated Tau in the cell.	This study
CSAD-CS	Δ*ectABC*::*mCherry-CSAD-CS* Engineered strain, in which the *ectABC* gene cluster on the genome of *H. elongata* OUT30018 was replaced with the salt-inducible Tau-synthetic *mCherry-CSAD-CS* operon.	This study
CSAD-CDO-CS	Δ*ectABC*::*mCherry-CSAD-CDO-CS* Engineered strain, in which the *ectABC* gene cluster on the genome of *H. elongata* OUT30018 was replaced with the salt-inducible Tau-synthetic *mCherry-CSAD-CDO-CS* operon.	This study

Table 2. List of Plasmids

Plasmids	Descriptions	References
pK18N*mobsacB*-U_{ectA}-*mCherry-CSAD-CDO*-D_{ectC}	pK18N*mobsacB* containing an artificial Tau biosynthetic *mCherry-CSAD-CDO* gene cluster, which was put under the control of the salt-inducible *ectA* promoter (U_{ectA}) and *ectC* terminator (D_{ectC}); Kan^r.	This study
pK18N*mobsacB*-U_{ectA}-*mCherry-CSAD-CS*-D_{ectC}	pK18N*mobsacB* containing an artificial Tau biosynthetic *mCherry-CSAD-CS* gene cluster, which was put under the control of the salt-inducible *ectA* promoter (U_{ectA}) and *ectC* terminator (D_{ectC}); Kan^r	This study
pK18N*mobsacB*-U_{ectA}-*mCherry-CSAD-CDO-CS*-D_{ectC}	pK18N*mobsacB* containing an artificial Tau biosynthetic *mCherry-CSAD-CDO-CS* gene cluster, which was put under the control of the salt-inducible *ectA* promoter (U_{ectA}) and *ectC* terminator (D_{ectC}); Kan^r.	This study

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2.2 Generation of recombinant H. elongata strains

To generate Tau-producing *H. elongata* strains, pK18N*mobsacB*-based plasmids harboring different artificial Tau biosynthesis operons (Table 2) were introduced into *H. elongata* OUT30018 strain by *E. coli* HB101/pRK2013-mediated triparental mating method followed by the integration of the introduced Tau biosynthesis operons into the genome of *H. elongata* OUT30018 by homologous recombination [8, 19]. Briefly, three bacterial strains: the donor *E. coli* DH5α strains harboring the plasmid, the helper *E. coli* HB101 harboring pRK2013 conjugative plasmid, and the recipient *H. elongata* OUT30018 were co-cultured for triparental conjugation on Omnipore™ membrane (Merck Millipore, Darmstadt, Germany), which was placed on a solid Luria-Bertani (LB) medium containing 2% w/v NaCl. After triparental conjugation, cells were cultured on a solid LB medium containing 6% NaCl and 100 mg/L Kanamycin (Kan) to select the first crossover strains, which were transferred to an LB solid medium supplemented with 6% NaCl and 15% sucrose for selection of the second crossover strains with sucrose-tolerant phenotype.

2.3 Media and growth conditions

LB medium, consisting of 5 g/L yeast extract, 10 g/L tryptone, and 10 g/L NaCl, was used for routine culture of *E. coli* strains. A high-salinity LB medium containing 6% NaCl was used for the routine culture of *H. elongata* strains. LB media were sterilized by autoclave at 121 °C for 15 minutes. Antibiotics were added to the culture medium to select transformant *E. coli* and *H. elongata* harboring plasmids with antibiotic-resistant genes. The concentration of Ampicillin in the medium was 100 µg/mL for *E. coli*, and the concentration of Kan in the medium was 50 µg/mL for *E. coli* and 100 µg/mL for *H. elongata*. For solid medium, 15 g/L agar was added. To select a counter-selectable marker gene (*sacB*) used in *H. elongata* transformation, 150 g/L sucrose was added to the M63 minimal media [20]. For Tau production analysis, *H. elongata* strains were cultured in 5 mL of M63 minimal media, which contained 100 mM KH_2PO_4, 15 mM $(NH_4)_2SO_4$, 1 mM $MgSO_4$, 3.9 µM $FeSO_4$, 4% glucose, 3% NaCl, and 5 mM cysteine (Cys). The pH of M63 media was adjusted to 7.2 with KOH solution, and the media were filter-sterilized using a bottle top filter with 0.22 µm pore-size polyethersulfone (PES) membrane (Sartorius, Germany). For routine culture of *E. coli* and *H. elongata* strains, the cultures were incubated at 37°C in a water bath shaker with an agitation rate of 120 rpm.

2.4 Extraction of major osmolytes from H. elongata cells

Intracellular free amino acids of *H. elongata* cells were extracted by a hypo-osmotic extraction method [1, 8, 21]. Briefly, *H. elongata* cells were harvested from the culture medium by centrifugation at 10,000 *g* for 3 min, and the weight of the cell pellet was recorded as cell fresh weight (CFW). The cell pellets were then suspended in pure water (20 µL per 1 mg CFW). After centrifugation at 10,000 *g* for 3 min, the supernatant containing free amino acids was collected as a major osmolyte sample.

2.5 High-Performance Liquid Chromatography (HPLC) analysis of dabsyl amino acids

Dabsylation of amino acids was performed based on a previously described method [22] with a slight modification [8, 10]. The dabsyl amino acids solution of each sample was collected and filtered through a filter vial with 0.2 µm pore-size Polytetrafluoroethylene (PTFE) membrane (SEPARA® Syringeless filter, GVS Japan K.K., Tokyo, Japan) before being used as an HPLC sample. The quantification of dabsyl amino acids was carried out using an HPLC system (Shimadzu, Kyoto, Japan) equipped with a UV/VIS detector (SPD-10 A VP), an autosampler (SIL-10 AD VP), two pumps (LC-10 AD VP), degasser (DGU-14A), system controller (SCL-10A Vp), and column oven (CTO-10AC VP). The LabSolutions LC software (Shimadzu, Kyoto, Japan) was used to control the system and collect data. Dabsyl amino acids were separated through an analytical C18 column (Poroshell 120, 2.7 µm, EC-C18, 4.6 × 75 mm, Agilent Technologies Inc.) equipped with C18 guard column (Poroshell 120, 2.7 µm Fast Guard, EC-C18, 4.6 × 5 mm, Agilent Technologies Inc.) using a mobile phase gradient system consisting of 15% acetonitrile in 20 mM sodium acetate (pH 6.0) (mobile phase A) and 100%

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acetonitrile (mobile phase B). Dabsyl amino acids were detected by the UV/VIS detector at 468 nm. The injection volume was 10 µL, the flow rate was 0.5 mL/min, and the column temperature was maintained at 25°C. The eluent gradient was set as previously described [8].

3. RESULTS AND DISCUSSION

3.1 Metabolic pathway engineering for Tau biosynthesis in H. elongata

In this study, two metabolic pathways for Tau biosynthesis, the L-cysteine sulfinic acid pathway mediated by the L-cysteine dioxygenase (CDO) and the L-cysteine sulfinic acid decarboxylase (CSAD) enzymes and the L-cysteine sulfonic acid pathway mediated by the L-cysteine sulfonic acid synthase (CS) and the CSAD enzymes (Figure 1), were engineered in *H. elongata*.

To produce Tau in *H. elongata*, we designed *H. elongata*'s codon-optimized genes encoding the combinations of CSAD, CDO, and CS, and then assembled them with a *mCherry* reporter gene encoding a red fluorescent protein to generate three types of artificial Tau biosynthesis operons (Figure 2). Each artificial Tau biosynthesis operon is introduced into the genome of *H. elongata* OUT30018 at the *ectABC* locus by homologous recombination using 1.0 kb 5'-flanking region of the *ectA* gene (U_{ectA}) and 1.0 kb 3'-flanking region of the *ectC* gene (D_{ectC}). The expression of mCherry red-florescent reporter protein allowed us to quickly select recombinant *H. elongata* cells directly on the selection medium (Figure 3A). The correct integrations of the transgenes into the genome of the recombinant *H. elongata* strains were also confirmed by colony PCR using specific primers to amplify the Tau biosynthesis operons (Figure 3B).

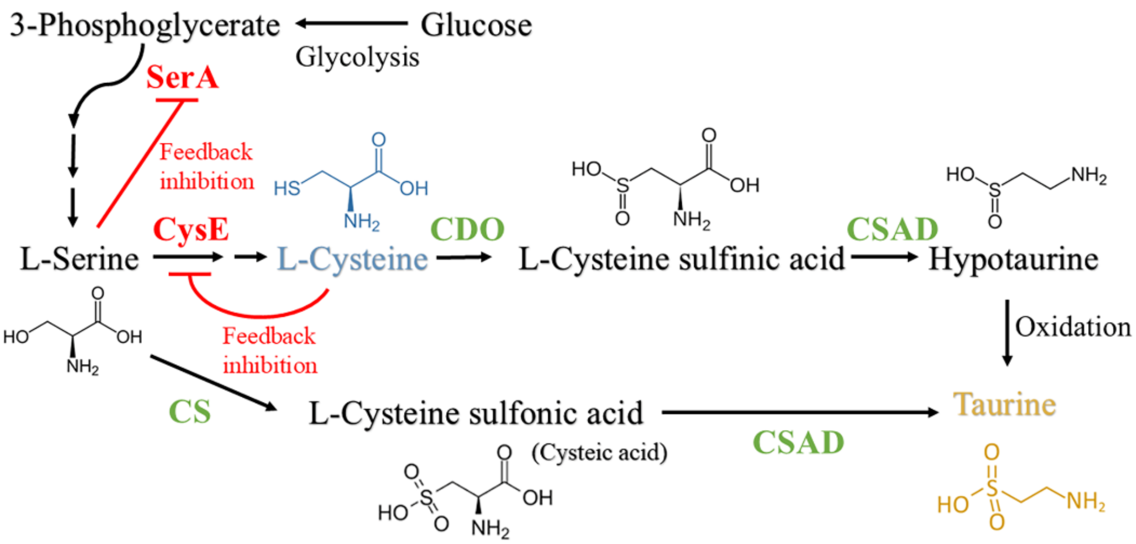

Figure 1. The two biosynthesis pathways of taurine: 1. the L-cysteine sulfinic acid pathway mediated by the L-cysteine dioxygenase (CDO) and the L-cysteine sulfinic acid decarboxylase (CSAD) enzymes and 2. the L-cysteine sulfonic acid pathway mediated by the L-cysteine sulfonic acid synthase (CS) and the CSAD enzymes. In these pathways, 3-Phosphoglycerate dehydrogenase (SerA) is feedback-regulated by L-Serine, and Serine-O-acetyltransferase (CysE) is feedback-regulated by L-Cysteine.

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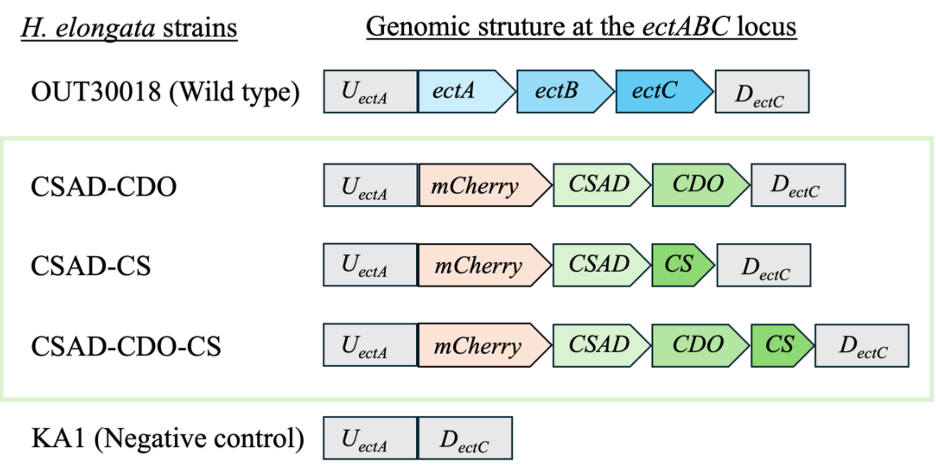

Figure 2. Schematic diagram showing genomic structure at the *ectABC* locus of the wild-type and recombinant *H. elongata*.
U_{ectA}: a 1.2-kb 5'-upstream region of the *ectA* gene. Contains a salt-inducible *ectA* promoter region for homologous recombination at the *ectABC* locus.
D_{ectC}, a 1.2-kb 3'-downstream region of the *ectC* gene. Contains the *ectC* terminator region for homologous recombination at the *ectABC* locus.
ectA: a gene that encodes an L-2,4-diaminobutyric acid (DABA) acetyltransferase (DAA).
ectB: a gene that encodes a DABA transaminase (DAT).
ectC: a gene that encodes an ectoine synthase (ES).
mCherry: a gene that encodes a red fluorescent mCherry protein used as a visual aid to facilitate the selection of transformed *H. elongata*. Correct expression of the mCherry protein also indirectly verifies correct transgenes' expression.
CSAD: a gene that encodes L-cysteine sulfinic acid decarboxylase (CSAD).
CDO: a gene that encodes L-cysteine dioxygenase (CDO).
CS: a gene that encodes L-cysteine sulfonic acid synthase (CS).

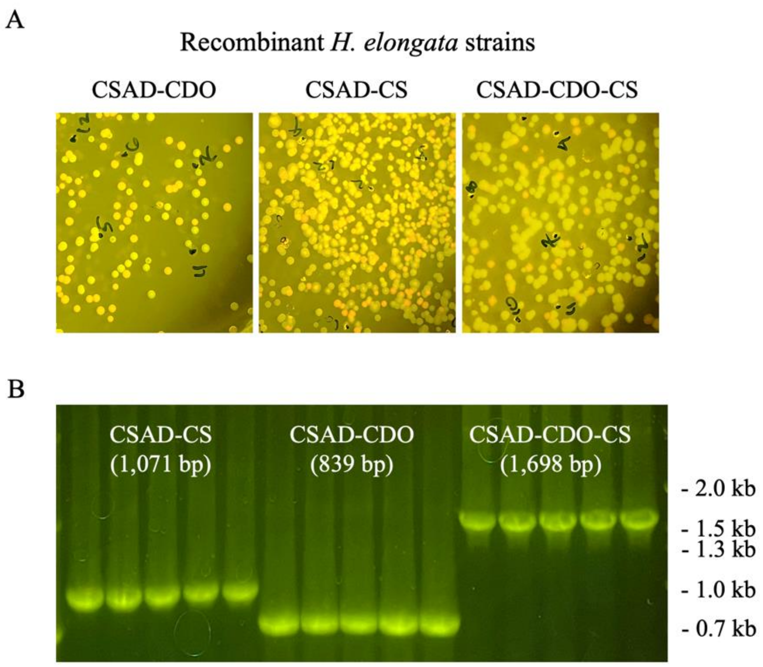

Figure 3. Verification of recombinant *H. elongata* CSAD-CDO, CDAD-CS, and CDAD-CDO-CS strains. A. Pink colonies of transformed *H. elongata*, as a result of the expression of the red fluorescent mCheery, facilitate the selection of the positive clones on the selection medium. B. Genomic PCR using specific primers to amplify the artificial Tau biosynthesis operons that were integrated into the genome of the positive clones. DNA size marker is shown on the right of the PCR products photo. bp, base pair; kb, kilobase.

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3.2 Verification of Tau production in the engineered H. elongata strains

To check the ability of the three engineered strains to produce and accumulate Tau, each strain was cultured in liquid M63 minimal medium containing 4% Glucose, 3% NaCl, and 5 mM Cys, and intracellular free-amino acids were extracted from their cells and analyzed by HPLC. As shown in Figure 4, the *H. elongata* CSAD-CDO was the only one that could efficiently produce Tau via the L-cysteine sulfinic acid pathway (Figure 4). Interestingly, Tau was not detected in the extracts from the *H. elongata* CSAD-CS and CSAD-CDO-CS (Figure 4).

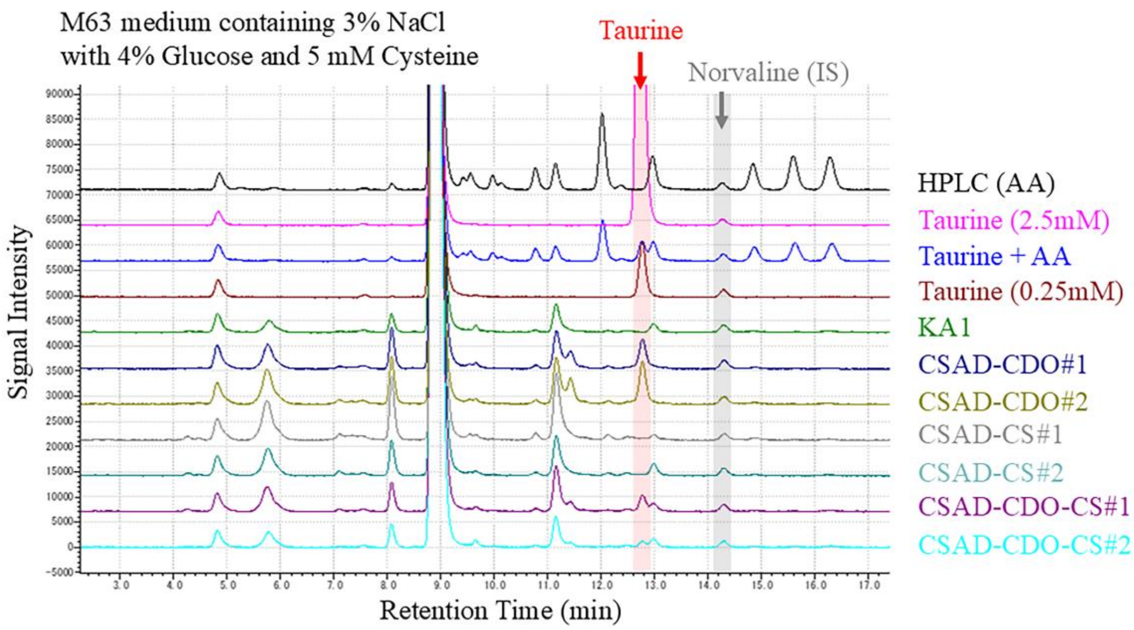

Figure 4. HPLC Chromatograms showing major osmolyte profiles of engineered *H. elongata* strains. *H. elongata* KA1 (negative control), CSAD-CDO, CSAD-CS, and CSAD-CDO-CS strains were cultured in M63 medium containing 3% NaCl, 4% glucose, and 5 mM Cys until the optical density at 600 nm (OD_{600}) reached more than 0.8, and major osmolytes inside the cells were extracted and analyzed by HPLC. AA, amino acid standards; IS, Internal standard Norvaline. Red and gray arrows indicate the peaks of Tau and Norvaline. #1 and #2 indicate independent recombinant clones.

4. CONCLUSIONS and PROSPECTS

In this study, we successfully engineered a Tau-producing *H. elongata* CSAD-CDO, which expresses the enzymes CSAD and CDO of the L-cysteine sulfinic acid pathway. As Cys is important as a precursor for Tau biosynthesis, we are developing a method to prepare a medium based on Cys-rich biomass waste, such as animal wool, human hair, and chicken feathers, to be used in the cultivation of *H. elongata* CSAD-CDO. The L-cysteine sulfinic acid pathway is constrained by feedback-inhibition control on SerA and CysE, which function upstream from the CDO and CSAD enzymes (Figure 1). Therefore, replacing these enzymes with their feedback-inhibition insensitive mutants could be next step to further enhance the ability of *H. elongata* CSAD-CDO to produce and accumulate Tau.

Acknowledgement

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Project Efficiency Assessment for Eco-Industrial Area

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ABSTRACT

This study evaluates efficiency of the developed eco-industrial area project by applying a principle of costs and benefits. The objective is to compare costs and benefits between establishment of eco-industrial area and typical industrial one. Therefore, this study investigates the project costs from construction, maintenance, and operation in both fixed and variable costs. Furthermore, valuation of direct returns from income and indirect benefits from the development of eco-industrial area project were also conducted, based on the technique of experimental behavior or Choice Experiment to estimate the willingness to pay of factories in the projects. Finally, the results were compared with costs and all benefits to calculate the efficiency of the developed eco-industrial area project to support investment decision. The results of this research are intended to incentivize developers to choose to invest in an eco-industrial area project. A method was developed to analyze indirect benefits through questionnaires, such as a willingness to pay to maintain environmental quality. The value of the indirect benefits of developing the eco-industrial area per year equals 148,965,380.64 baht when combined with the direct returns of the eco-industrial area project and comparing costs-benefits. Cost analysis found that the Eco-Industrial Area Project has a net profit equal to 25,948,470,863.00 baht and has a payback period of 2.82 years, which shows that it is a fast payback period, which is very attractive for investment because the payback period of an industrial park/zone is approximately 3.27 years. Which is derived from comparing the development costs of the project with the direct benefits calculated as profit. However, suppose the development is in the form of eco-industrial areas. In that case, there will be additional indirect benefits that can be assessed from the willingness of factory operators to pay for the value of investments in environmentally-friendly industrial areas. This results in a faster return on investment and may meet the demand from many factory operators in the current era who have a positive attitude towards maintaining environmental quality, coexisting peacefully with communities, reducing pollution and impacts that could lead to conflicts, and potentially enhancing economic competitiveness..

Keyword: Eco-Industrial/ Willingness to Pay/ Environment

1. INTRODUCTION

Industry is a business sector that is developing globally, including in Thailand. Economic prosperity contributes to the advancement of countries, leading them towards developed status. Therefore, many developing nations emphasize industrial development to foster economic growth, which can impact society and the environment.

Thailand has set development directions to ensure sustainable and prosperous development in line with national aspirations based on the principles and concepts of the 4 principles, namely: Sufficiency Economy Philosophy, Building Resilience, Sustainable Development Goals of the United Nations, which aim not to leave anyone behind, and the concept of bioeconomy development, circular economy, and green economy as outlined in the National Economic and Social Development Plan (13th Edition, B.E. 2566-2570). The Ministry of Industry and the Industrial Estate Authority of Thailand have collaborated to promote the establishment of eco-industrial estates or eco-industrial towns to achieve sustainable, balanced development in the economy, society, and environment

Currently, some developers are implementing eco-industrial developments. However, there are still many developers who are in the process of considering decisions to develop their projects in an environmentally friendly direction. Researchers identify cost issues in developing eco-industries, which may require investment in advanced waste treatment systems to prevent pollution.

Reducing pollution to preserve environmental quality, such as water and air quality, will benefit developers and factory operators by reducing costs associated with health care, health insurance funds, or compensation for workers and surrounding communities.

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Moreover, they enhance community satisfaction by addressing environmental quality concerns, potentially meeting requirements set by the Industrial Estate Authority of Thailand for eco-industrial development, which mandates the establishment of waste management centers to recycle industrial waste within industrial estates. This approach reduces pollution and waste disposal costs. Developing projects under environmentally friendly conditions can also create satisfaction among local residents and global markets, potentially increasing land value or the value of eco-friendly products and services from developers and factory operators alike.

Researchers recognize the importance of developing environmentally sustainable industries and are committed to conducting this research. The goal is to demonstrate to project developers the significant returns and the willingness of businesses to invest in maintaining a good environment. This will show developers the value communities place on investments made for industrial development in an environmentally friendly direction. This is part of sustainable industrial sector development based on economic, social, and environmental balance, aligning with Thailand's journey towards Thailand 4.0.

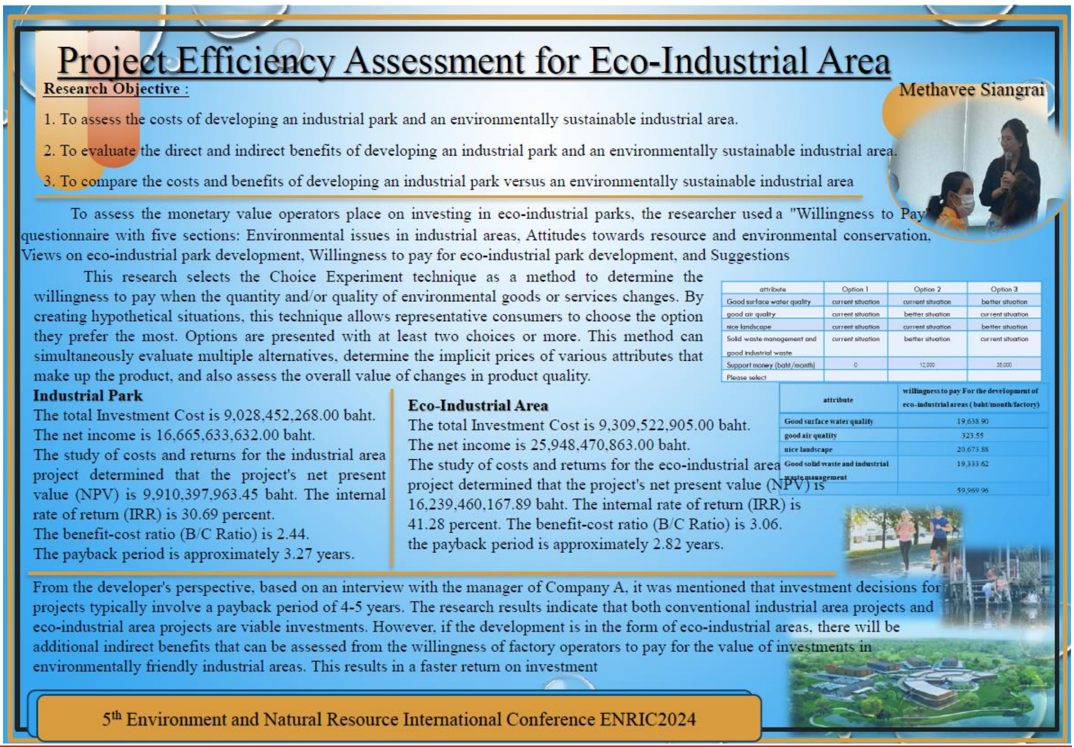

Figure 1. Poster of ENRIC conference

2. METHODOLOGY

2.1 Research tools

To assess the monetary value operators place on investing in eco-industrial parks, the researcher used a "Willingness to Pay" questionnaire with five sections: Environmental issues in industrial areas, Attitudes towards resource and environmental conservation, Views on eco-industrial park development, Willingness to pay for eco-industrial park development, and Suggestions

This research selects the Choice Experiment technique as a method to determine the willingness to pay when the quantity and/or quality of environmental goods or services changes. By creating hypothetical situations, this technique allows representative consumers to choose the option they prefer the most. Options are presented with at least two choices or more. This method can simultaneously evaluate multiple alternatives, determine the implicit prices of various attributes that make up the product, and also assess the overall value of changes in product quality.

The Choice Experiment technique is used to determine willingness to pay or willingness to accept compensation when the quantity and/or quality of environmental goods or services changes. By creating hypothetical situations, this technique allows representative consumers to choose the option they prefer

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the most, with at least two options presented. This method can evaluate multiple alternatives simultaneously, determine the implicit prices of various attributes that make up the product, and assess the overall value of changes in product quality.

2.2 Data preparation

Study the basic information of industrial park projects, industrial estate projects, and industrial zone projects from Company A, a leading company in developing industrial areas. This involves examining the costs of designing infrastructure for these projects by interviewing project managers of industrial park projects, industrial estate projects, and industrial zone projects to determine the cost of expenses involved in developing different types of projects.

Study secondary data, including the regulations of the Industrial Estate Authority of Thailand (IEAT) concerning the standards for infrastructure systems, facilities, and services for eco-industrial estates as outlined in the 2014 regulations and the framework for developing eco-industrial cities provided by IEAT and the Department of Industrial Works. Review relevant research both in Thailand and internationally to establish criteria for designing eco-industrial park projects. Additionally, investigate the central cost pricing by conducting focus group interviews with operators in an industrial park in Ayutthaya province, finding that acceptable central cost prices are 6,000 / 12,000 / 35,000 / 200,000 THB per month. The acceptable central cost prices are derived from the amounts previously paid by factory operators for managing common areas or paid to developers for general management of the common areas in the project.

Study the target industrial groups in Ayutthaya Province and conduct simple random sampling by drawing lots to select factories in an industrial park project as representatives of the industrial sector for the questionnaire. The Industrial Park in Ayutthaya was chosen because it comprises a diverse range of factories that have been operating for an extended period. These factories have extensive experience in operating within industrial parks, industrial estates, and industrial zones, making them suitable representatives for this study.

Study the characteristics of eco-industrial cities by reviewing the literature on eco-industrial cities both domestically and internationally. Compare the similarities and differences among various research works to identify characteristics other researchers agree upon as indicative of an eco-industrial city. The researcher then compared the summarized characteristics of eco-industrial cities with the development framework for eco-industrial city in Thailand. This comparison was made against the basic design data from Company A to identify which investments align with the characteristics of an eco-industrial city. It was found that there are four characteristics for which Company A has made investments in their eco-industrial park projects. The researcher chose these four characteristics to evaluate indirect returns by assessing the willingness to pay. This approach aims to obtain a total of the ecological returns and compare it with the ecological investments made by Company A. Finally, and this comparison will be used to assess the cost-effectiveness of developing eco-industrial park projects and determine whether the investment is worthwhile and attractive.

The characteristics selected for evaluating the willingness to pay for the development of eco-industrial areas by factory operators include:

1. Quality of Surface Water Sources
2. Air Quality
3. Landscape or Green Spaces
4. Management of Waste and Industrial By-products

These four characteristics are those for which costs are controlled and allocated in the operation of Company A's industrial area projects.

2.3 Data collection

Design the questionnaire

Based on the experience of developing an eco-industrial park project, the characteristics indicative of the development of eco-industrial areas were identified as a total of four key characteristics. The researcher then established two levels of change for these characteristics environmental quality to assess willingness to receive compensation.

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Attribute	Level
Surface water quality	current situation better situation
Air quality	current situation better situation
Landscape features	current situation better situation
Solid waste and industrial waste management	current situation better situation
Common fee (baht/month)	0/ 6,000 / 12,000/ 35,000 / 200,000

Therefore, according to Full Factorial Design, there would be a total of 2*2*2*2*5 = 80 options. This method results in a large number of options. In this study, the Orthogonal Design command in IBM SPSS Statistics 26 will be used to select independent possibilities and to ensure a manageable number of choices. Similar to the study by Udomsak Silpachavanich (2013) [1], which found a total of 16 options, this approach simplifies the questionnaire for interviewees. Thus, the set of options will be divided into 4 equal groups, resulting in 4 different questionnaire formats.

Card List							Group
	Card ID	Water	Air	Landscape	Waste	Price	
1	1	current	better	Current	better	12,000	1
2	2	better	Current	better	Current	200,000	
3	3	current	better	better	Current	12,000	
4	4	current	better	Current	better	200,000	
5	5	current	better	better	Current	6,000	2
6	6	better	better	better	better	0	
7	7	current	Current	Current	Current	6,000	
8	8	better	Current	better	Current	12,000	
9	9	better	better	Current	Current	35,000	3
10	10	better	Current	Current	better	6,000	
11	11	current	Current	Current	Current	0	
12	12	better	better	Current	Current	0	
13	13	better	better	better	better	6,000	4
14	14	current	Current	better	better	0	
15	15	current	Current	better	better	35,000	
16	16	better	Current	Current	better	12,000	

Next, the choice sets for each questionnaire format will be created using the Cyclical Design method. In this approach:

- Option 1 will be set at the current level.

Option 2 and Option 3 will reflect improvements in the situation.

- Option 2 will be derived from Row 1 of Table 3.3.1-3.
- Option 3 will build on Option 2 by increasing the level of each characteristic. When the highest level is reached, the sequence will restart from the lowest level.

This methodology is similar to that used by Areeyapat Petchrat (2016) in the academic work on willingness to pay for biodiversity benefits and ecosystem services, with a case study in Bang Krajao, Phra Pradaeng District, Samut Prakan Province. [2]

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Attribute	Option 1	Option 2	Option 3
Good surface water quality	current situation	current situation	better situation
good air quality	current situation	better situation	current situation
nice landscape	current situation	current situation	better situation
Solid waste management and good industrial waste	current situation	better situation	current situation
Support money (baht/month)	0	12,000	35,000
Please select			

To evaluate the validity of the developed questionnaire, it will be reviewed by 5 experts (Item Objective Congruence (IOC))

Next, to determine the sample size, using the Yamane formula (1970), it was found that this research requires a total of 137 samples from a population of 207 factories. The sample of 137 factories will be selected using simple random sampling by drawing lots. This will ensure that each factory has an equal chance of being selected and that the sample is representative of the population.

2.4 Data analysis

2.4.1 Cost analysis

Study the costs of developing an industrial eco-park by Company A, including fixed and variable costs. These costs comprise land costs, construction of infrastructure systems, operational costs, and maintenance costs. The costs have been collected from market prices and estimates from the developer and converted into the required quantities of work. By summing up the costs for each construction item and development, you can estimate the total cost of developing the industrial area and eco-industrial park.

The work volume used in this cost calculation is based on the area where companies or respondents have established their factories, specifically in the industrial area of Company A located in Uthai, Phra Nakhon Si Ayutthaya. Calculate the total cost by summing the unit price multiplied by the quantity for fixed costs (TFC) and variable costs (TVC), yielding the overall total cost (TC). This represents the cost of developing an industrial area as either an industrial park or an industrial estate.

For this research, the goal is to compare the costs and benefits of developing an eco-industrial area to provide developers with motivation to choose eco-industrial development. Therefore, the costs associated with the four identified attributes are separated: water quality, air quality, landscaping, and waste management. These are the attributes defined for developing an eco-industrial area in this study. The costs are then calculated and added to the total cost and benefits of developing the eco-industrial area.

2.4.2 Return analysis

Direct return: Analysis involves calculating revenue from the direct sale of industrial land developed by the project. The analysis includes; Total Revenue (TR): The total amount of money received from sales., Net Return (NR): The difference between total revenue and total variable costs., and Net Profit (NP): The difference between total revenue and total costs. Net profit indicates the company's profitability.

Indirect return: Indirect Return Analysis evaluates the indirect benefits or value through a willingness-to-pay approach. This involves direct questioning of individuals regarding the value they place on environmental preservation to maintain ecosystem services. The Choice Experiment (CE) technique is used, where individuals select the option they prefer most from various scenarios to assess their willingness to pay. The willingness-to-pay questionnaire in this study consists of five sections but is analyzed in two groups: general data not related to willingness to pay and data specifically related to willingness to pay. General data are analyzed using IBM SPSS Statistics 26 to calculate means and percentages. For the willingness-to-pay data, multinomial logistic regression is applied using IBM SPSS Statistics 26.

To assist developers in investment decisions, it's essential to assess the value of the investment by comparing the returns against the costs, known as Cost-Benefit Analysis. This involves evaluating the following: Net Present Value (NPV), Internal Rate of Return (IRR), Benefit-Cost Ratio (B/C Ratio), and Payback Period.

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3. RESULTS AND DISCUSSION

3.1 Development of industrial area projects

Total Area: Approximately 11,120.50 acres were developed, with approximately 8,400 rai available for sale. Infrastructure Development: The project included major public utility systems: 84,000 cubic meters per day for water supply, and 67,200 cubic meters per day for wastewater treatment. The total investment cost is 9,028,452,268.00 baht.

- Investment Phases: The investment was phased over three years:
  - Year 0: Initial investment in land purchase and land improvement, and development of 60% of the total infrastructure cost.
  - Year 1: Additional investment in infrastructure development covering 30% of the total cost.
  - Year 2: Additional investment covering the remaining 10% of the infrastructure cost.
- Operating Expenses: After the industrial area is operational:
  - Central maintenance costs 500 Baht.
  - Water production costs 17.50 Baht per cubic meter.
  - Wastewater treatment costs 4.50 Baht per cubic meter.
- Annual Costs: Vary each year, particularly higher during the first two years due to ongoing development activities until completion in Year 3. From Year 3 to Year 7, costs mainly involve operational expenses.
- The development costs for the industrial area project over the specified years:
  - Year 0: 8,110,114,616.00 Baht
  - Year 1: 723,619,538.00 Baht
  - Year 2: 334,183,313.00 Baht
  - Year 3: 209,197,888.00 Baht
  - Year 4: 348,663,000.00 Baht
  - Year 5: 488,128,200.00 Baht
  - Year 6: 662,459,700.00 Baht
  - Year 7: 697,326,000.00 Baht

The return on investment from industrial area development includes income from land sales, central service fees, revenue from industrial water sales, and revenue from industrial wastewater treatment by entrepreneurs. The total income is 28,239,325,800.00 baht, which will increase according to the number of units sold each year. Income will begin in year 1 after the industrial area is developed and ready for sale.

The revenues generated from the industrial area development project over the specified years:

- Year 1: 1,301,634,600.00 Baht
- Year 2: 2,644,903,800.00 Baht
- Year 3: 4,029,807,600.00 Baht
- Year 4: 5,456,346,000.00 Baht
- Year 5: 5,622,884,400.00 Baht
- Year 6: 7,091,057,400.00 Baht
- Year 7: 2,092,692,000.00 Baht

After deducting all the total costs incurred, the net income is 16,665,633,632.00 Baht. This represents the profit generated from the project after subtracting all expenses from the total revenue over the specified years

3.2 Development of eco-industrial area projects

The development of the eco-industrial project area covers approximately 11,120.5 acres, following the concept of Eco-Industrial development. The design incorporates green spaces and eco-belts surrounding the project area. Treated wastewater is recycled within the project to improve quality, reducing wastewater discharge outside the project area by 15%. This investment aims to preserve environmental quality, particularly surface water sources.

In addition to investing in quality surface water sources, the costs of developing this eco-industrial area include continuous air quality monitoring and establishing systems to collect data on air pollutants. Investments are also made in landscaping to enhance aesthetics and green spaces. Proper management of industrial waste, including setting up an industrial waste exchange center within the

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project to facilitate exchanges among factories, is another aspect of the investment. Overall, the total cost of developing the project amounts to 9,309,522,905.00 baht.

The project's investment is divided over three years as follows:

Year 0: It begins with purchasing and improving all the land and initiating 60% of the total public infrastructure development cost.

Year 1: Invests an additional 30% in public infrastructure development.

Year 2: Contributes the remaining 10% to complete the public infrastructure development.

After the industrial area opens for operation, ongoing operational costs include:

- Central maintenance fee: 1,000 baht/factory
- Production cost of tap water: 17.50 baht per cubic meter
- Production cost of RO water: 20 baht per cubic meter
- Wastewater treatment cost: 5.50 baht per cubic meter

Thus, initial operational expenses start in Year 1, continue through Year 2, and continue until Year 7, following the completion of the public infrastructure construction. After Year 7, only operational expenses will continue, resulting in fluctuating annual investment costs.

The development costs for the eco-industrial area project over the specified years:

- Year 0: 8,278,756,998.97 baht
- Year 1: 811,073,930.00 baht
- Year 2: 416,429,049.00 baht
- Year 3: 295,105,608.00 baht
- Year 4: 447,103,608.00 baht
- Year 5: 621,471,144.00 baht
- Year 6: 833,838,180.00 baht
- Year 7: 871,837,680.00 baht

The return on investment from developing eco-industrial areas includes income from land sales, central service fees, revenue from industrial water sales, and revenue from industrial wastewater treatment by entrepreneurs. In addition, there are environmental compensation payments and hidden price increases from additional investments in environmental aspects, totaling 11,733.97 baht per rai (for Total Projects Area approximately 11,120.50 rai: 19,638.90 baht/month/factory for good surface water quality, 323.55 baht/month/factory for good air quality, 20,673.88 baht/month/factory for nice landscape, 19,333.62 baht/month/factory for good solid waste and industrial waste management), resulting in a total income of 38,524,087.06 baht. Income will increase with the number of units sold increasing annually, starting with income in year 1 after the development of eco-industrial areas is completed and ready for sale.

The annual revenues for the first 7 years are as follows:

- Year 1: 1,731,578,100.00 baht
- Year 2: 3,570,658,140.00 baht
- Year 3: 5,433,354,360.00 baht
- Year 4: 7,319,666,760.00 baht
- Year 5: 7,553,941,080.00 baht
- Year 6: 9,519,793,500.00 baht
- Year 7: 2,851,371,600.00 baht

After deducting total costs, the net income amounts to 25,948,470,863.00 baht.

This phased approach and detailed cost breakdown allow developers to effectively manage and forecast expenses associated with eco-industrial park development.

3.3 Cost and return on investment comparison of projects

One of the objectives of this research is to illustrate the project's performance evaluation by comparing costs and benefits. The researcher interviewed the manager of Company A regarding their project development plans. It was found that Company A plans to develop the project by dividing the investment and setting a 7-year sales plan. This approach results in varying annual costs, operational expenses, and returns.

The study of costs and returns for the industrial area project determined that the project's net present value (NPV) is 9,910,397,963.45 baht. The internal rate of return (IRR) is 30.69 percent. The benefit-cost ratio (B/C Ratio) is 2.44. the payback period is approximately 3.27 years.

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The study of costs and returns for the eco-industrial area project determined that the project's net present value (NPV) is 16,239,460,167.89 baht. The internal rate of return (IRR) is 41.28 percent. The benefit-cost ratio (B/C Ratio) is 3.06. the payback period is approximately 2.82 years.

4. CONCLUSIONS

This research aims to evaluate the effectiveness of developing an eco-industrial park project. This involves assessing the development costs of industrial land and the eco-industrial areas of Company A, which has over 35 years of experience in developing industrial land. The researchers conducted research within an eco-land development scope covering approximately 11,120.50 rai. The researchers designed a research tool to assess the willingness to pay of factory operators in industrial areas in Ayutthaya province who have been operating their factories since the development of the industrial park from a conventional industrial park to an eco-industrial park format to determine the willingness to pay for the development of eco-industrial areas by the factory operators.

Then, compare the returns from industrial areas and eco-industrial areas with the amount of investment from developers in each format. Developers will be able to see the value of developing eco-industrial areas from the perspective of factory operators. Developers can use this information to make decisions about whether investing in eco-industrial projects is worthwhile. It was found that with good management by the developer, the development of industrial areas in the form of industrial parks can achieve a return on investment within a timeframe considered worthwhile by the developer, which is within 4-5 years. However, if the development is in the form of eco-industrial areas, there will be additional indirect benefits that can be assessed from the willingness of factory operators to pay for the value of investments in environmentally-friendly industrial areas. This results in a faster return on investment and may meet the demand from many factory operators in the current era who have a positive attitude towards maintaining environmental quality, coexisting peacefully with communities, reducing pollution and impacts that could lead to conflicts, and potentially enhancing economic competitiveness.

From the research, it is evident that respondents are largely interested in environmental issues because they understand the pollution caused by factories and the importance of maintaining environmental quality for surrounding communities. Therefore, developers should opt for the development of eco-industrial areas and invest in pollution treatment systems resulting from the project. For instance, investments might include wastewater treatment systems to maintain surface water quality, air pollution control systems for factories emitting airborne pollutants to ensure air quality, and increasing green areas with gardens or wider buffer zones to create a better landscape and serve as a barrier against air and noise pollution for nearby communities. Investments in waste collection and transportation systems, and establishing industrial waste exchange centers to address solid waste and industrial waste issues, are also recommended.

Alternatively, developers may invest further to enhance the area as an eco-industrial zone by considering attributes beyond those summarized in this research, such as installing solar panels on rooftops or in retention ponds to reduce energy consumption and combat global warming.

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The Potential of Biomethane Recovery from Hemp Biomass Residue (*Cannabis sativa* L.)

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ABSTRACT

Hemp (*Cannabis sativa* L.) is a plant with significant potential for use in the textile industry, medical applications, food and health benefits, environmental conservation, and as biomass fuel for renewable energy production. The initial raw material for hemp processing must undergo an oil extraction process to obtain hemp oil, resulting in residual material known as hemp biomass residue (HBR). Researchers are interested in utilizing this residue to produce biofuel energy through biogas technology using the biochemical methane potential test in 120 mL serum bottles. The temperature-controlled was at 35 ± 2 °C, and the experiment was conducted for 45 days. The study found that TCOD, TS, and VS removals were 57.32 ± 2.61%, 42.59 ± 4.18%, and 47.21 ± 3.52%, respectively. Cumulative biogas and methane yield were 109.61 ± 5.02 and 48.89 ± 2.69 N mL/g VS_{added}. In addition, the maximum methane concentration was 71.64 ± 0.33%. Because of the above statement, future studies could focus on scaling up and studying technical and economic feasibilities. In addition, other anaerobic digestion strategies such as co-digestion, different inoculum sources, and different SIR to increase biomethane production potential should also be evaluated.

Keywords: Hemp biomass residue/ Biochemical methane potential/ Biofuel/ Biogas/ Anaerobic digestion

1. INTRODUCTION

The study of biochemical methane potential (BMP) from hemp biomass residue explores a promising avenue for sustainable energy production. Hemp, a versatile plant traditionally cultivated for fibers, seeds, and oil, has recently gained attention for its potential in bioenergy applications [1]. The efficient conversion of agricultural residues, such as those from hemp, into biogas through anaerobic digestion is an environmentally friendly approach that contributes to the circular economy [2]. This process helps manage waste and generates renewable energy through biomethane [2, 3]. Hemp biomass, characterized by its high cellulose content and rapid growth rate, presents a valuable feedstock for biogas production [3]. As the global energy demand continues to rise, there is an increasing need to explore alternative energy sources that are both renewable and sustainable. This study aims to evaluate the BMP of hemp biomass residues, providing insights into their potential as a feedstock for biomethane production [4].

The research investigates key parameters influencing the anaerobic digestion process, such as substrate composition, inoculum type, and process conditions. By understanding these factors, the study seeks to optimize the methane yield from hemp residues by enhancing biogas production's efficiency and viability. The findings of this research could contribute to the development of more sustainable energy systems and support the broader adoption of hemp as a bioenergy resource [4].

This study is significant for its potential contributions to renewable energy and its implications in sustainable agriculture and waste management. This research underscores the importance of integrating energy production with agricultural practices to achieve a more sustainable future by valorizing hemp residues.

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2. METHODOLOGY

2.1 Sample collection and preparation

The substrate used in this study was hemp biomass residue (HBR) or *Cannabis sativa* L. from the Faculty of Agricultural Technology, Chiang Mai Rajabhat University (Mae Rim campus) Chiang Mai, Thailand. The biomass was collected after extracting the hemp oil, as shown in Figure 1. After collection, the biomass was dried at 45 ± 2 ºC in a hot air oven (120BOF, Ponpe Instrument, Thailand) to decrease its moisture content to less than 10% [5]. The dried biomass was then ground using a commercial grinder. Finally, the prepared HBR was stored in a vacuum plastic bag and kept at room temperature to prevent decay. TS and VS were analyzed using APHA (2005) [6], the C/N ratio was set based on Walkley and Black [7], and the Kjeldahl method [8], and fiber composition was analyzed using the Detergent method [9]. The results are presented in Table 1.

The inoculum used in this study was collected from anaerobically digested pig manure at the Faculty of Animal Science and Technology, Maejo University, Chiang Mai, Thailand, shown in Figure 1. The inoculum was stored at 4 ± 2 ºC and reactivated at 35 ± 2 ºC for several days before being transferred to the serum bottles [10]. The characteristics of the inoculum used in this study are presented in Table 1.

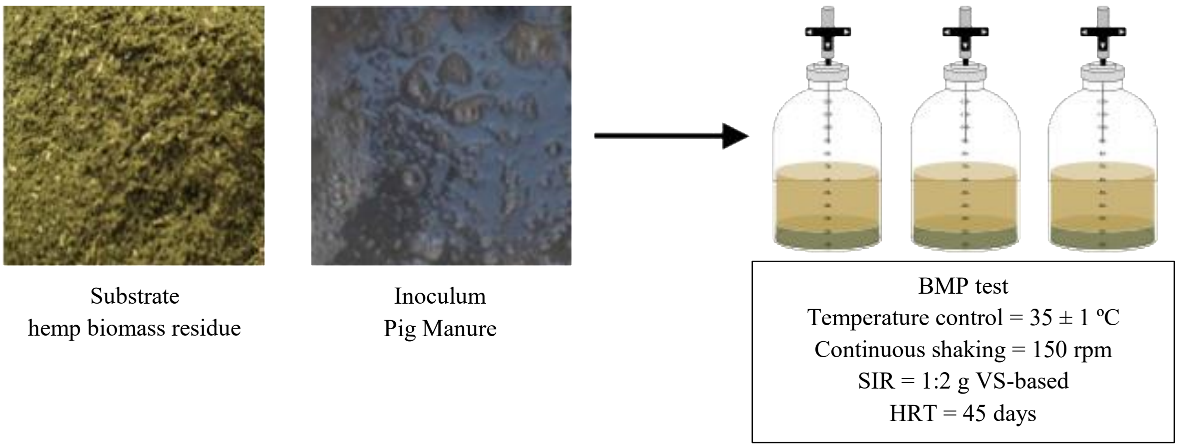

Figure 1. Diagram for biochemical methane potential test of hemp biomass residue

2.2 Experimental setup

The methane yield was evaluated in a series of serum bottle tests by digesting the substrate in a controlled environment. The biochemical methane potential (BMP) test was conducted in 120 mL serum bottles with a 60 mL working volume. The substrate-to-inoculum ratio (SIR) was set according to Moset et al. (2006) [11]. The BMP assays were carried out in triplicate. Stock nutrient solution 1% (v/v) and 50 g/L $NaHCO_3$ buffer solution 10% (v/v) were added to each serum bottle to ensure sufficient nutrition and acid buffer capacity during digestion. Stock nutrient solution at 5 times concentration contained NH_4Cl 1.4 g/L, K_2HPO_4 1.25 g/L, $MgSO_4 \cdot H_2O$ 0.5 g/L, $CaCl_2 \cdot 2H_2O$ 0.05 g/L, yeast extract 0.5 g/L, and trace element solution 5 mL/L. The trace element solution contained $FeCl_2 \cdot 4H_2O$ 2,000 mg/L, H_3BO_3 50 mg/L, $ZnCl_2$ 50 m/L, $CuCl_2.2H_2O$ 38 mg/L, $MnCl_2.4H_2O$ 500 m/L, $(NH_4)6Mo_7O_{24} \cdot 4H_2O$ 50 mg/L, $AlCl_3 \cdot 6H_2O$ 90 mg/L, and $CoCl_2 \cdot 6H_2O$ 2,000 mg/L [12]. A small amount of 0.1 M NaOH or HCl was used to adjust the pH to 7.00 ± 0.01, and then deionized water was added to make up a final volume of 60 mL. The headspace of the serum bottles was purged with nitrogen gas for 1 min and sealed immediately to ensure anaerobic condition. All bottles were placed in an incubator shaker (WiseCube WIS10RL, DAIHAN Scientific Co., Ltd., Gangwon-do, Korea) at 35 ± 1 ºC with a continuous shaking of 150 rpm. The volume of the biogas produced and methane concentration were analyzed regularly. The BMP test was terminated when the daily methane production was below 1% of the cumulative methane production, which took 45 days. All parameters were analyzed in triplicate except biogas production.

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2.3 Analytical methods

The operating parameters (i.e., pH, TCOD, TS, VS, VFA, and Alkalinity) were determined following the Standard Methods APHA (2005) [6]. pH of the leachate was analyzed using a benchtop pH meter (Mettler Toledo [S220], Columbus, OH, USA). Daily biogas production was measured by a micromanometer (MP 112; KIMO Instrument, France). The biogas compositions were analyzed using the Gas Chromatography model 7820A with Agilent TU-AMPKS6FHQ Packed column and thermal conductivity detector (TCD). Methane production was calculated by multiplying methane content and biogas production, where helium was used as carrier gas. The standard calibration curve was made with gas mixtures containing CH_4 at 3 levels covering the range of 20-99.999%, and verified with a standard gas mixture of 5% N_2, 60% CH_4, and 35% CO_2. Methane potential was calculated as N mL/g VS $_{added}$ (at 0°C and 1 atm). All parameters were analyzed in triplicate except biogas production.

2.4 Kinetic study

The data of cumulative methane yield from the experiments was fit by the modified Gompertz equation, as presented in Eq. 1 [13].

$$Y = M\exp\left\{-\exp\left[\frac{Rme}{M}(\lambda - t) + 1\right]\right\} \qquad \text{Equation 1}$$

Where;
- Y is the accumulated methane volume (mL/g VS $_{added}$)
- T is the experimental time (d)
- M is the methane production potential (mL/g VS $_{added}$)
- Rm is the maximum methane production rate (mL/g VS $_{added}$-d)
- λ is lag phase period (d)
- E is an Euler's number (2.718).

The variables were calculated using Microsoft Office Excel with the solver function.

2.5 Statistical data analysis

The experimental data were analyzed using analysis of variance (ANOVA) with a significance level (α) of 0.05; and a post hoc Tukey's test was conducted by using the Statistical Package for the Social Sciences (SPSS) version 22, IBM, USA.

3. RESULTS AND DISCUSSION

3.1 Characteristics of substrate and inoculum

The characteristics of HBR and inoculum are shown in Table 1. The HBR contained high VS, representing organic matter of 84.63 ± 4.88% of the total weight. Further, the VS/TS ratios of HBR and inoculum, indicators for evaluating biodigestibility, were high at 0.91±0.01 and 0.69±0.01, respectively. A substrate with a VS/TS ratio of over 0.80 isconsidered as a potential anaerobic digestion feedstock [14]. The C/N ratio, which indicates a proper amount of macronutrients to facilitate microbial growth, is one of the critical operating parameters for anaerobic digestion. Table 1 shows that the C/N ratios of HBR and inoculum were 18 ± 1 and 8 ± 1, respectively, which falls in the recommended range of 9 – 35 for the anaerobic digestion process [15]. In the fiber composition of HBR, cellulose was the main constituent, and the cellulose content of HBR was identical to Matassa et al., (2020) [4] the promising lignocellulosic substrate for anaerobic digestion process.

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Table 1. The Characteristics of substrate and inoculum before anaerobic digestion.

Characteristics	Substrate	Inoculum
TS	929653 ± 2516 mg/kg	128750 ± 1568 mg/L
VS	846274 ± 4884 mg/kg	88295 ± 1464 mg/L
VS/TS ratio	0.91 ± 0.01	0.69 ± 0.01
pH	NA	7.35 ± 0.02
VFA	NA	390 ± 20 mg/L as CH_3COOH
Alkalinity	NA	2033 ± 15 mg/L as $CaCO_3$
VFA/Alkalinity ratio	NA	0.19 ± 0.01
TCOD	NA	30667 ± 8269
C/N ratio	18 ± 1	8 ± 1
Cellulose	17.29 ± 0.86 % dry wt.	NA
Hemicellulose	21.45 ± 0.49 % dry wt.	NA
Lignin	33.78 ± 0.95 % dry wt.	NA
Ash	27.48 ± 0.78 % dry wt.	NA

Note: NA = Not Applicable

3.2 Removal efficiency of anaerobic digestion

Removal efficiencies for anaerobic digestion of HBR are shown in Table 2. The pH of the bottle content was maintained around neutral, which is in the optimization range for anaerobic digestion (6.8-7.2) [5, 10]. VFA concentrations before and after were 555 ± 64 and 445 ± 49 mg/L as CH_3COOH, and Alkalinity concentrations before and after were 3250 ± 141 and 3515 ± 213 mg/L as $CaCO_3$, respectively. Generally, VFA concentration in anaerobic digestion should not exceed 500 mg/L as CH_3COOH, but the maximum concentration could be as high as 2,000 mg/L as CH_3COOH. The system was kept in an anaerobic condition to decrease the excess VFA for a week until the produced biogas was undetected. The optimum alkalinity should be 1,000-5,000 mg/L as $CaCO_3$ for anaerobic digestion [5].

The VFA/Alkalinity ratios could be an indicator to determine the performance of the anaerobic digestion process. This study of before and after were 0.17 ± 0.08 and 0.13 ± 0.11, which is lower than the recommended value for anaerobic digestion, less than 0.4 [14] that could ensure system stability. Based on the characteristics of the bottle contents presented in Table 2, this study might not suffer from organic acid accumulation, which is one of the essential phenomena causing system failure during anaerobic digestion [10].

TCOD, TS, and VS removal strongly correlate with methane yield during anaerobic digestion. In this study, TCOD, TS, and VS removals of HBR were 57.32 ± 2.61%, 42.59 ± 4.18%, and 47.21 ± 3.52%, respectively is similar to that reported by Matassa et al. (2020) i.e., approximately 50% using hemp residue as the substrate.

Table 2. The characteristics of parameters analysis before and after anaerobic digestion.

Characteristic	Unit	Before	After	Efficiency
pH	–	7.00 ± 0.01	7.24 ± 0.01	NA
VFA	mg/L	555 ± 64	445 ± 49	NA
Alkalinity	mg/L	3250 ± 141	3515 ± 213	NA
VFA/Alkalinity ratio	mg/L	0.17 ± 0.08	0.13 ± 0.11	NA
TCOD	mg/L	90323 ± 1825	38550 ± 2828	57.32 ± 2.61
TS	mg/L	18455 ± 2496	10595 ± 1633	42.59 ± 4.18
VS	mg/L	11165 ± 1690	5895 ± 1294	47.21 ± 3.52
VS/TS ratio	–	0.61 ± 0.60	0.54 ± 0.48	NA

Note: NA is Not Applicable

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3.3 Biogas and methane yield

Maximum biogas and methane yield shown in Figure 2 were 39.59 ± 2.05 (day 9) and 18.04 ± 1.27 (day 9) N mL/g VS $_{added}$. Cumulative biogas and methane yield from the experimental shown in Figure 3 were 365.38 ± 16.72 and 162.97 ± 8.96 N mL/g VS $_{added}$, respectively. Average and maximum methane concentrations shown in Figure 4 were 51.69 ± 1.50% and 71.64% ± 0.33% (day 28). According to research by Matassa et al., (2020) [4], the different biomass residues (HBRs) were stalks, the unretted hurds, the retted hurds, the fibers, the inflorescences and the mix of leaves and inflorescences were evaluated as a potential feedstock for biomethane production. The specific cumulative biomethane production were 422 ± 20, 26 ± 5, 275 ± 7, 239 ± 10, 242 ± 13, and 118 ± 8 N mL/g VS $_{added}$, respectively. Moreover, according to Heiermann et al. (2009), the ensiling process might negatively influence biomethane formation due to the fermentation of plant sugars to lactic acid and other volatile fatty acids, thus obtaining a lower biomethane yield (259 N mL/g VS $_{added}$) under the same operating conditions. However, a general estimate of biogas production from lignocellulosic materials such as hemp typically consists of a methane concentration was 50-70% [16].

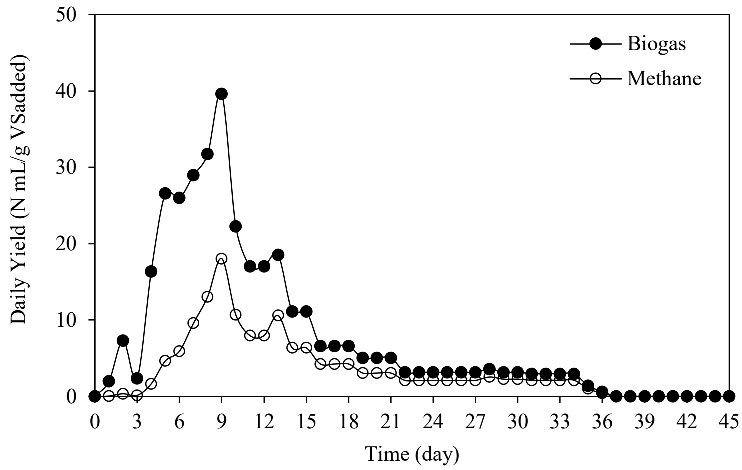

Figure 2. Daily biogas and methane yield

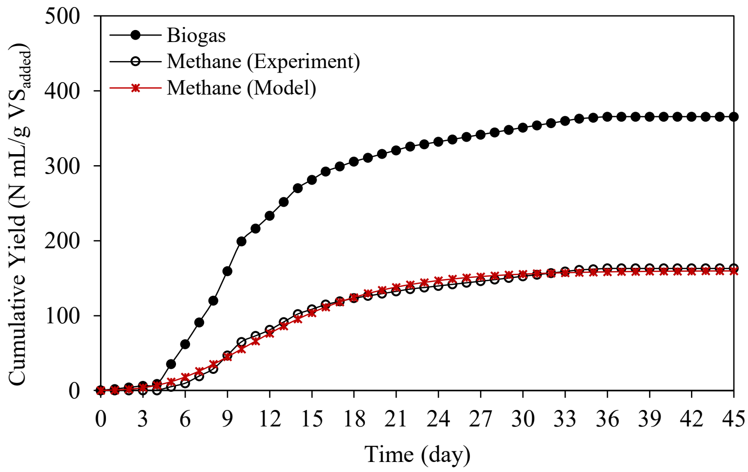

Figure 3. Cumulative biogas and methane yield

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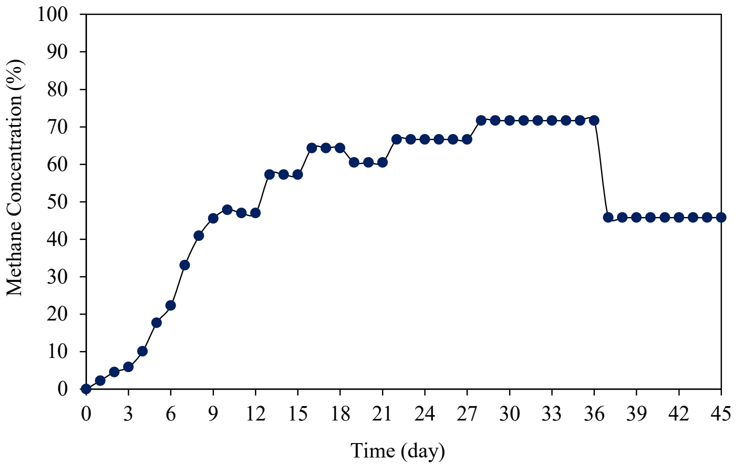

Figure 4. Methane concentration

3.4 Kinetic study

The information obtained from the kinetic study could be used to analyze and explain the cumulative methane yield (Model) from the anaerobic process shown in Figure 3 using the modified Gompertz model. Several models could be applied to fit the experimental data, including but not limited to first-order, logistic, and Gaussian equations [17, 18]. However, the modified Gompertz model was adopted to examine the kinetic parameters in this study. The modified Gompertz model has been widely used to fit the experimental data from the batch study of anaerobic digestion [18]. The lag phase during the acclimatization of microorganisms in the inoculum was included in this model; thus, it could effectively describe the anaerobic digestion process [4]. The kinetic parameters for anaerobic digestion of HBR are presented in Table 3.

Table 3. The kinetic parameters for biochemical methane potential

Substrate	M (N mL/g VS $_{added}$)	Rm (N mL/g VS $_{added}$-d)	λ (d)	R^2	Reference
Hemp biomass residue (mix of leaves and inflorescences)	160.0	10.59	4.75	0.9930	This study
Hemp Hurds (Narlısaray)	114.6	8.4	1.57	0.961	Arıç et al., (2014) [19]
Hemp Hurds (Futura)	108.0	8.1	1.49	0.963	Arıç et al., (2014) [19]
Oil palm empty fruit bunches	183.2	54.81	5.71	0.985	Wadchasit et al. (2020) [20]
Garden waste (Guinea grass (*Panicum maximum*), lawn grass (*Zoysia japonica*) and broadleaf carpet grass (*Axonopus compressus*))	267.0	33.6	0.1	0.996	Edwiges et al. (2019) [21]

The modified Gompertz model fitted well with the experimental data of all inoculum with a high R^2 of 0.9930. From Table 3, it is clear that HBRs presented the highest methane production potential of 160.00 N mL/g VS $_{added}$. The maximum methane production rates also showed the same trend with methane production potential. Typically, the lag phase of AD of the carbohydrate-rich substrate could be from VFA inhibition during the early stage of the anaerobic digestion process [22]. The short lag phase during the start-up period of the anaerobic digester could enhance the benefit of AD systems and the efficiency of biogas production [22]. HBR showed quite a short lag phase of 4.75 days.

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4. CONCLUSIONS

The study of biochemical methane potential test from hemp biomass residue (*Cannabis sativa* L.) obtained from the initial raw material for hemp processing must undergo an oil extraction process to obtain hemp oil, resulting in residual material known as hemp biomass residue was carried out in 120-mL serum bottles. The controlled at 35 ± 1 °C, and the experiment was carried out for 45 days. The study found that TCOD, TS, and VS removals were 57.32 ± 2.61%, 42.59 ± 4.18%, and 47.21 ± 3.52%, respectively. Cumulative biogas and methane yield were 365.38 ± 16.72 and 162.97 ± 8.96 N mL/g VS_{added}. In addition, the maximum methane concentration was 71.64 ± 0.33%. Because of the above statement, future studies on HBRs could scaled up and study technically and economical both technical and economical feasibilities. In addition, other anaerobic digestion strategies such as co-digestion, different inoculum sources, and different SIR to increase biomethane production potential should also be evaluated.

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Environmental Governance for Sustainable Natural Resource Management in Indonesia

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ABSTRACT

This research explores environmental governance and natural resource management in Indonesia, emphasizing its sustainability impacts. We identify key environmental issues, including deforestation, land degradation, and biodiversity loss, and assess government strategies and policies aimed at addressing these challenges effectively. Using public policy analysis, literature review, and stakeholder interviews, this study evaluates the current policy landscape and its implementation in the field of environmental and natural resource management. Despite efforts to improve environmental governance, challenges remain in the implementation of policies and oversight mechanisms. The results of this study highlight the need for further steps to strengthen environmental governance, support sustainability initiatives, and preserve Indonesia's valuable natural assets. The recommendations include active engagement with various stakeholders, refinement of regulations, and enhancement of the capacities of relevant institutions, all aimed at achieving the goal of sustainable environmental preservation in Indonesia.

Keyword: Environmental governance/ Sustainability impact/ Policy analysis/ Stakeholder engagement

1. INTRODUCTION

As a country with abundant natural resources, Indonesia faces various critical environmental issues, including deforestation, pollution, and a decline in biodiversity [1]. The expansion of agricultural land and industrial activities, largely responsible for deforestation, has emerged as a major challenge to maintaining environmental sustainability in Indonesia. In the past two decades, concerns about the harmful effects of severe climate change on the environment have grown among policymakers, regulators, environmentalists, governments, supranational organizations, and civil society [2]. Natural resources are fundamental to human well-being. They provide clean air, food, water, shelter, and energy, all of which are critical for human survival and quality of life. Natural resources are essential for human well-being, as we depend on clean air, food, water, shelter, and energy for survival and quality of life [3].

Indonesia's geographical and demographic conditions present various significant challenges that must be managed comprehensively, including the development of maritime infrastructure such as ports, regional development and increased economic activities, the sustainable management of marine biodiversity such as fisheries, and the utilization of oil, gas, minerals, currents, and waves for future energy and mineral needs [4]. In addition, sustainable management of natural resources requires a holistic approach that involves all stakeholders, including the government, local communities, and the private sector. Sustainable development must be a prerequisite in all policies related to the exploitation of natural resources. Strict regulations and consistent law enforcement are necessary to minimize destructive practices like illegal logging and mining. Indonesia's current laws tend to prioritize the principles of the Unitary State of the Republic of Indonesia (NKRI) and legal certainty over democracy, sustainability, and social justice. They also put the state's institutional strength ahead of community access to natural resources, which leads to sectoralism and corruption. To make the regulatory process more effective and coherent, it is important to continue harmonizing regulations at both the national and local levels, involving state institutions in both the executive and legislative branches [5].

The government also needs to invest in forest rehabilitation programs and community development that empower local communities to become forest guardians. Involving the community in

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the management of natural resources can reduce deforestation, preserve biodiversity, and support the community's economic well-being. All parties' involvement and a deep understanding of the importance of environmental sustainability can be the keys to facing existing challenges and realizing a greener and more sustainable Indonesia. In addition, environmental governance is increasingly adopting the expanded role of private actors and market mechanisms, reflecting neo-liberal trends characterized by the privatization of environmental resources, the implementation of programs such as payments for ecosystem services, and the establishment of carbon markets. This shift highlights the growing importance of private sector rulemaking, such as certification processes, which have now become integral to the management of many environmental resources. Public regulations rooted in legal and economic instruments have historically shaped environmental policy; however, emerging trends indicate a significant shift towards more private regulation, thereby altering the institutional landscape of environmental management [6].

To enhance the effectiveness of this policy, a community-based approach is essential. Local communities are often the best guardians of their environment, and their knowledge of managing natural resources is invaluable. Therefore, involving the community in the planning and implementation of policies can create a greater sense of ownership and responsibility towards natural resources. The integration and synergy between policies, as well as the strengthening of community roles, will contribute to the success of efforts to protect the environment and ensure the sustainability of natural resources in Indonesia. Participation influences governance outcomes through three dimensions: the extent of stakeholder involvement, the nature and intensity of communication among participants, and the level of decision-making authority granted to participants [7].

As environmental issues evolve, it is important to update and refine existing regulations. The government needs to carry out bureaucratic reform to be more responsive to environmental challenges and capable of adapting to constantly changing conditions. Formulating more inclusive and data-driven policies can enable all stakeholders to participate in decision-making. Success in achieving effective environmental governance relies not only on policies and regulations but also on the awareness and active participation of the community. Therefore, strengthening environmental education and outreach becomes crucial.

Conducting this study is crucial in addressing these challenges, as it aims to offer profound understanding of the dynamics of natural resource and environmental management, while also formulating practical and relevant suggestions to improve the efficiency of environmental governance and sustainable conservation efforts of natural resources.

2. METHODOLOGY

This study adopts a literature review methodology. Literature research aims to assess, criticize and synthesize literature related to research topics regarding environmental governance and sustainable natural resource management in Indonesia, so that it can generate new, constructive perspectives. We carry out the review process through several phases: 1) planning, 2) analysis, and 3) compiling and writing the review. In the first phase: planning, the focus of the review is to understand why this review is needed and how it contributes to the development of environmental governance in Indonesia. At this stage, we develop a practical plan for selecting articles, elucidate the search process, and choose sources for documentation. We will also establish criteria for evaluating the relevance and quality of the selected literature. In the second phase: analysis, we will analyze various types of information in accordance with the research objectives, including the type of information needed to carry out specific analyzes related to the sustainability of natural resource management. We will also engage in discussions about how to report and discuss the information within the framework of environmental governance's challenges and opportunities.

In the third phase, focused on drafting and discussing, we will prioritize reporting standards to ensure clarity in presenting information on environmental governance and related policies. We hope that the research results will offer tangible suggestions to enhance the efficiency of environmental

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governance and sustainable natural resource conservation initiatives in Indonesia. In this research, literature sources covering public policy, environmental policy analysis, and case studies related to natural resource management in Indonesia will be systematically searched from library sources available online and offline. This data will be used to provide deeper insight into the dynamics of natural resource management in Indonesia and the challenges faced in achieving harmony between economic development and environmental protection.

3. RESULTS AND DISCUSSION

3.1 Environmental challenges and natural resource degradation

The accelerated pace of global environmental change, particularly evident through climate change and rapid biodiversity loss, has ushered in the Anthropocene—a new era characterized by significant human impacts on biogeochemical cycles and ecosystems. This situation underscores the necessity for focused governance discussions regarding resource scarcity, ecosystem service degradation, and shifts in land use, while highlighting the importance of adaptive and collaborative approaches to effectively address these complex challenges [8]. Indonesia, an archipelagic country rich in natural resources, faces very serious environmental challenges. Unsustainable management of natural resources has led to environmental degradation that has profound impacts on economic, social, and ecosystem aspects. The implementation of sustainability policies has contributed to the failure to halt the overall decline in environmental quality [9].

Issues such as deforestation, pollution, and the decline of biodiversity are major concerns that require attention from various parties, including the government, society, and the private sector. The latest report shows that the deforestation rate in Indonesia reaches 3.5 million hectares per year. This figure clearly reflects a concerning situation, where many lands experiencing degradation could negatively impact the well-being of communities and the overall stability of ecosystems. Possibly nothing is more important today for business and society than the management of local and global environmental changes that are degrading every dimension of life—a trend that risks worsening for future generations [10].

The impact of this environmental degradation is not only limited to the immediately visible economic losses but also includes broader long-term consequences, such as the loss of biodiversity that is critical for the survival of ecosystems. Many species of flora and fauna are losing their habitats due to irresponsible human activities, which in turn can disrupt the food chain and the balance of ecosystems. In addition, the loss of forests also contributes to the increase in greenhouse gas emissions, which could potentially worsen global climate change. To improve this situation, the implementation of more sustainable natural resource management policies is crucial. A country has undergone significant economic transformation through mass production, often at the expense of environmental concerns, resulting in serious issues such as poor air, water, and soil quality, along with negative health effects on its population [11]. The collaborative governance approach underscores that environmental protection is a shared responsibility, requiring the involvement of all relevant stakeholders [12].

This includes the development of reforestation programs that involve local communities, the enhancement of sustainable agricultural practices, as well as strengthening law enforcement against activities that harm the environment. One of the biggest challenges for this vision of adaptive governance is to develop formal legal frameworks—legal principles, laws, and regulatory mechanisms—that support such adaptation without stifling stakeholders' inherent self-organizing potential or the emergent properties of adaptation itself. Through cross-sector collaboration and active community participation, Indonesia can develop a more comprehensive approach to preserving the environment while also supporting sustainable economic development for future generations. The goal of sustainable development was to justify economic expansion while preserving the environment [13].

The Sustainable Development Goals (SDGs) are greatly aided by commercial enterprises that prioritize environmental sustainability through eco-friendly practices, efficient resource management, and strong stakeholder communication. This is especially true in nations with rapid economic growth

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where the adoption of Environmental, Social, and Governance (ESG) practices is more common [14]. Deforestation in Indonesia is largely caused by the expansion of agricultural land and aggressive industrial activities. This process not only eliminates the natural habitat for various species, but also impacts the global climate. The urgency of addressing global environmental issues such as climate change and biodiversity loss raises important questions about whether democratic practices can effectively drive sustainability transformation, and if so, how these practices should be reformed to ensure a livable planet, while raising concerns about the future of the earth [15].

Indonesia's tropical forests play a significant role in carbon balance worldwide, and the loss of these forests will contribute to increased carbon emissions, which could exacerbate the problem of global climate change. The impact of deforestation also has significant social implications. Deforestation increasingly marginalizes local communities that depend on forests for their livelihoods, including hunting, gardening, and raw material gathering. The loss of these resources can trigger conflicts among communities, especially when there is increasing resource pressure due to industrial and agricultural development. In addition, the migration of people from degraded areas to cities can create housing issues and broader social dissatisfaction. In governance, all images of the resource can potentially change as a consequence of the ongoing co-evolution of actors, institutions, and discourses [16].

Therefore, it is important to develop forest management policies that not only consider economic and environmental aspects but also allow for the participation of local communities. Community-based initiatives, such as community forest management, can provide effective solutions by involving local residents in efforts to preserve and sustainably utilize forest resources. In this way, not only is the environment protected, but also the culture and way of life of the community can be preserved, strengthening resilience against ongoing environmental and social changes. The link between natural resources as a bestowed condition, regional infrastructure resources serving as the formal umbrella and framework for managing those natural resources, and most importantly, human resources as the key factor for the successful implementation of natural resource and infrastructure management, is essential and a prerequisite for the success of sustainable natural resource management programs [17]

In the context of addressing this challenge, effective and sustainable government policies are essential. However, the implementation of policies often faces various obstacles, including a lack of coordination among government agencies, weak oversight, and minimal community participation. Although several regulations have been put in place, their effectiveness in the field often falls short of expectations. The need to address persistent environmental problems more effectively arises from evolving institutional and policy frameworks, highlighting a shift from traditional hierarchical interventions to new cooperative governance approaches that, while offering opportunities to fill gaps in current policies, may also weaken state authority and democratic legitimacy [18].

Institutions are described as both formal regulations (such as laws and constitutions) and informal rules (such as social norms and cultural settings) that influence human interactions and direct managerial actions. The word "structures" include both official organizations (such as boards of directors) and unofficial networks that exhibit the ability to exercise governance. The formulation of institutional mandates, negotiation, dispute resolution, and policy making are all examples of governance processes. These procedures, which can take many different forms, including bottom-up strategies led by local communities, shared authority through co-management agreements, or top-down governance by governments or commercial players, are essential for decision-making and implementation. From local to global, institutional, structural, and procedural factors interact and have a substantial impact on the effectiveness, capability, and results of environmental governance.

Aside from the aforementioned aspects, it also provides an environmental governance framework that can be used in a variety of settings with varying issues and at different scales. Our goal is to make it both practical and all-encompassing. For instance, we could modify and use it to assess or examine the management of a locally managed community forest, a transboundary fishery, a national system of

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marine protected areas, or initiatives to preserve biodiversity and ecosystem services on a regional or global level.

The four key aspects of the framework for environmental governance include responsive, adaptive, robust, and polycentric governance. First, responsive environmental governance ensures that systems can adapt to changing environmental and social conditions through collective learning, communication, and reflection. Second, adaptive governance entails institutional spaces for dialogue and innovation, taking into account local contexts for policy adjustments. Third, robust governance showcases interconnected and nested legitimate institutions, underpinned by robust networks and positive social relations. Lastly, polycentric governance makes it easier to make decisions at many levels. It does this by letting semi-autonomous decision-making centers work together toward a common goal. This keeps institutions strong and running even during crises and pressures [19]. Figure 1 summarizes the explanation.

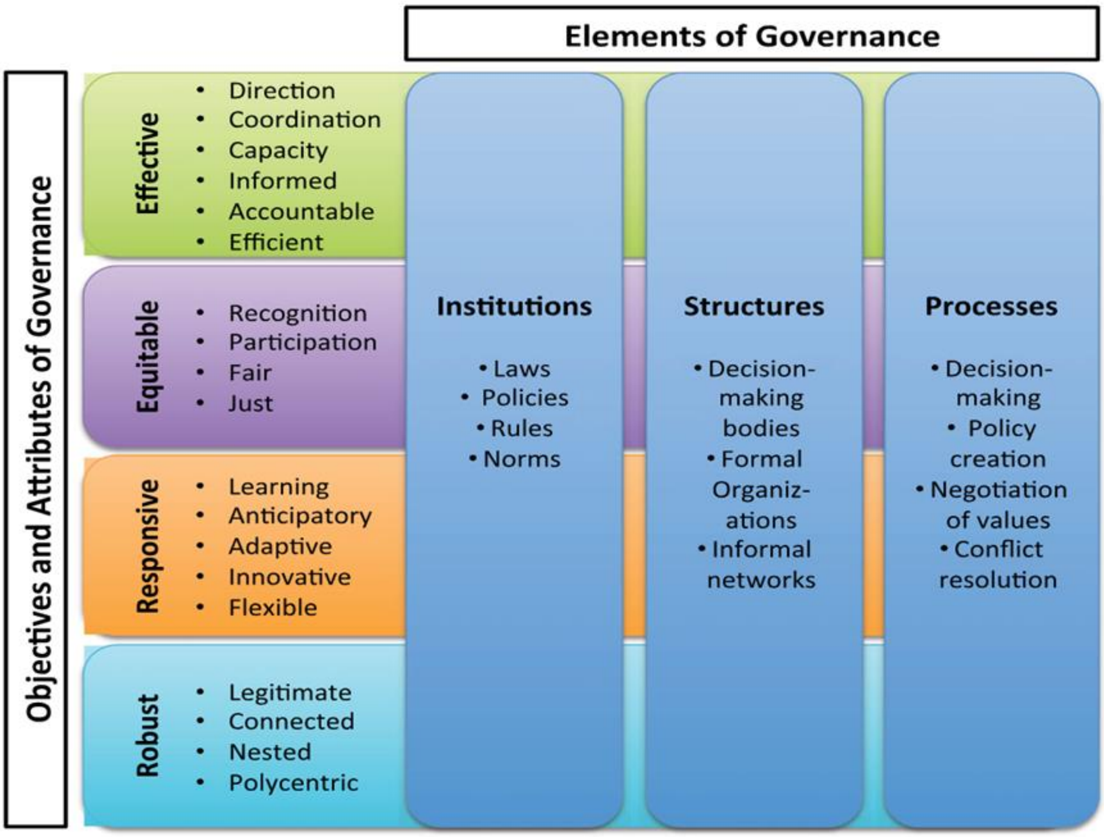

Figure 1. A practical framework for understanding the objectives, attributes, and elements of environmental governance (Source: Bennett & Satterfield, 2018)

3.2 Environmental governance policy

Various governance modes implement environmental policies to encourage desired behaviors among a range of actors, involving stakeholder inputs and collaboration between governments, the private sector, and civil society, while also integrating environmental goals into broader policy areas [20].

Policies and environmental governance implementation in Indonesia are an integral part of efforts to maintain the sustainability of abundant natural resources. An overview of Indonesia's environment, the DPSIR (Driving Forces, Pressure, State, Impact, and Response) framework based on ecoregions, and thematic environmental issues were used to do the analysis. Then, the most important concerns from past environmental issues were used to put together a list of national environmental issues. The

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analysis revealed that waste management, water resources, land use, and air quality emerged as the primary environmental issues in Indonesia.

Consequently, this necessitates formulating policy implications that effectively address these critical environmental challenges [21]. With increasingly complex environmental challenges, such as deforestation, pollution, and the decline of biodiversity, effective policies and consistent implementation are essential. Also, the fact that discourse approaches are used a lot in environmental policy analysis supports the idea that some discourse approaches and discursive policymaking can help us understand how policies are made [22]. Environmental policy in Indonesia has undergone significant development in recent decades. Both national and local levels have implemented various regulations to address pressing environmental issues. One of the important milestones is Environmental Law No. 32 of 2009, which emphasizes the importance of sustainability principles as well as the protection of natural resources and ecosystems.

Environmental policy encompasses governmental actions aimed at influencing environmental quality and the use of natural resources, reflecting society's collective choice to achieve specific environmental goals through various tools. Additionally, environmental policy involves both the proactive measures governments take to safeguard the environment and the conscious decisions not to act, which allow external forces to dictate environmental outcomes [23]. When private, public, and civil society actors work together to create, adopt, and implement voluntary sustainability standards, they create a complex policy ecosystem. This ecosystem challenges the idea that these standards work without government oversight, showing that these interactions often have positive effects [24].

Various factors, such as a lack of trained human resources, weak coordination among agencies, and minimal public participation in the decision-making process, have prevented the full implementation of many regulations in the field. Limited supervision and law enforcement often result in non-compliance with existing regulations. Therefore, to ensure correct implementation of these policies, it is crucial to strengthen the capacity of institutions responsible for environmental governance, which includes training and education for government employees and the development of more effective monitoring systems. Furthermore, encouraging active participation from civil society in the oversight, reporting, and implementation of sustainability projects can create a culture of greater accountability. By optimally utilizing natural resources and preserving environmental sustainability for the benefit of current and future generations, we can achieve the development of sustainable tourism areas [25].

These collective efforts will reinforce the framework of environmental governance in Indonesia, ensuring that not only existing regulations but also concrete actions on the ground can drive the achievement of improved sustainability goals for national welfare and environmental preservation. There is a greater body of research that examines place-based stewardship as an essential element and possibly a developing force in environmental governance and practice [26].

F. van der Molen provides a structured description of the elements of governance capacity involved: epistemic, normative, and social. The concept of coproduction in environmental governance has two meanings: the first refers to an interactive process where various actors, like experts and stakeholders, collaboratively create knowledge, while the second, which this paper focuses on, emphasizes the interconnection between knowledge and social order, suggesting that our understanding and representation of the world are inherently linked to the ways we choose to live in it. Recent scholarship has analyzed the interplay between knowledge and power dynamics in governance arrangements, viewing knowledge as a product of social interactions and vital for social functioning. This makes the case for thinking of governance as a process of coproduction that brings together material, cognitive, social, and normative abilities. It acknowledges that knowledge is an important part of governance while also questioning the common analytical gaps that exist between knowledge, values, and social aspects. The proposed framework highlights the interrelations among epistemic, normative, and social elements within governance capacities—such as regulatory, adaptive, and integrative capacities—acknowledging that these elements are interrelated and can overlap, thereby enhancing

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analytical sensitivity to the complexities of governance practices. Table 1 summarizes the social, moral, and epistemic components of the three governing skills. These components relate to one another, imply one another, and occasionally overlap; therefore, they are not as well divided as this table would imply [27].

Table 1. Conceptual Framework of Governance Capacity Elements

		Elements of governance capacities		
		Epistemic	Normative	Social
Governance capacities	Regulatory	• Knowledge creation and mobilization as enablers or constituents of regulation	• Goals • Visions • Limits	• Rules • Power • Modes of governance
	Adaptive	• Monitoring and understanding environmental change • Learning	• Willingness and opportunity to adapt or revise decisions	• Adaptive decision-making • Flexible arrangements • Iterative processes
	Integrative	• Incorporation of a variety of knowledge forms • Incorporation of diverging knowledge systems	• Incorporation of diverging values and normative frames	• Joint knowledge creation processes • Organized reflection on normative frames and epistemological beliefs

Source: van der Molen, 2018

Weak oversight also poses a significant challenge. Despite the establishment of numerous regulations aimed at ensuring sustainability and environmental protection, their implementation frequently lacks adequate oversight. As a result, various violations, such as illegal land clearing and destructive agricultural practices, are further worsening environmental conditions. Without strict oversight, the established policies do not yield the expected positive impact and become less meaningful. In addition, the lack of community participation in the decision-making process contributes to this challenge. Many environmental policies do not involve local communities, making them feel alienated and disconnected from those policies. When communities do not feel ownership or involvement, support for the policies becomes low, even though they possess valuable local knowledge.

We need to take several strategic steps to enhance the effectiveness of environmental policies and governance in facing these challenges. Strengthening coordination among government agencies has become very important. In addition to those steps, optimizing education and raising public awareness about environmental issues is also crucial. Integrated environmental education programs within school curricula and communities can help build an understanding of the importance of sustainability and practical ways to protect the environment.

The regulatory harmonization process should create greater opportunities for public involvement in the formulation and critique of regulations, thereby strengthening community positions and ensuring that future regulations empower them to manage local natural resources instead of merely reinforcing state institutions [5]. Thus, the community not only becomes a recipient of policies but also an active participant in the environmental management process. Additionally, the private sector's support through investments in sustainable projects and technological innovations is crucial. We hope that these collective steps will enhance the effectiveness, sustainability, and tangible benefits of environmental governance in Indonesia for both society and the environment. The enhancement of cooperation between the government, society, and the private sector is key to achieving sustainability goals and protecting Indonesia's natural resources for future generations. Only with the right policies and

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consistent implementation can Indonesia address the environmental challenges it faces and secure a sustainable future.

To measure the impact of the implemented programs and hold all parties accountable for the results, it is crucial to develop clear success indicators. By documenting and reporting on the progress and challenges faced in the implementation of sustainability policies, the parties involved can learn from experiences and make necessary adjustments in real time.

3.3 Environmental governance policy

Stakeholder engagement and collaboration are critical for achieving sustainability goals and effective environmental preservation in Indonesia. We believe that building trust is about fostering bonds and can serve as an alternative approach to encourage inter-institutional cooperation, which will foster inner incentives to increase inter-agency cooperation [28].

Recognizing the complexity of the environmental challenges we face, ranging from deforestation and pollution to the decline of biodiversity, collaboration among various parties is essential. The central government, local authorities, NGOs, and academics mainly serve as regulators, facilitators, and incubators in ecotourism, while the private sector enhances CSR efforts, and the general public supports infrastructure through environmental contributions [29]. This collaborative approach must integrate the traditional knowledge held by local communities, innovations from the business sector, as well as advocacy and support from non-governmental organizations (NGO). The Nebrodi case in Italy exemplifies the need for Environmental Governance (EG) to be adaptable and capable of comprehending and utilizing available environmental datasets. This is crucial for planning sustainable prospects, identifying interdependencies among sectors, assessing various aspects of sustainability, and generating alternative scenarios and implementation strategies. Strategic Planning (SP) serves as an instrument for strategic decision-making, facilitating the achievement of a new form of EG on a local scale, with all environmental aspects considered central to local development [30].

One way to implement this collaboration is by forming multifaceted partnerships that focus on specific projects, such as forest rehabilitation, waste reduction programs, or the conservation of endangered species. This partnership must empower local communities to become active agents of change, involving them in all stages of project development, from planning to evaluation. In this context, communities possess traditional knowledge that not only relates to sustainable resource management practices, but also to cultural values and local wisdom that require preservation. Environmental governance recognizes reflexivity as a core virtue, with ecological reflexivity emphasizing the capacity of social-ecological systems to adapt and reorganize through performance reflections [31]. Their experiences and insights about the local ecosystem enable them to contribute to formulating more relevant policies, leading to more sustainable solutions. On the other hand, the business sector has the potential to contribute through technological innovation and environmentally friendly practices that can enhance efficiency and reduce negative impacts on the environment. As more companies recognize the importance of sustainability, collaboration with the business sector can create better management system models.

NGOs, as representatives of community interests and advocates, play a crucial role in championing the needs of society and the environment at the policy level. They can serve as a bridge between the community, government, and the private sector, facilitating dialogue and creating platforms for sharing information as well as engaging community participation. Through educational and outreach programs, NGOs have the ability to raise public awareness about environmental issues, thereby strengthening the collective commitment to conservation. We must comprehend the collaborative network structures that shape the outcomes of environmental governance. Currently, knowledge about how various collaborative network structures interact with institutions and leadership is limited. We need to conduct further research to explore the adaptation of cooperative governance arrangements to diverse ecosystem characteristics and its impact on governance outcomes. Specifically, the relationship between adaptation to the ecological environment and specific collective action problems remains

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unclear. In addition, many environmental problems consist of multiple, interconnected collective action challenges. We must investigate whether we can effectively build and maintain collaborative networks with complementary ideal structural features to tackle these issues. These networks must strike a balance between various "ideal" but often conflicting structural properties to ensure that they are socially and ecologically suitable to address current environmental problems. A shift toward innovative public and private leadership models that focus on "networking" and facilitation rather than traditional command and control is critical to developing effective collaborative governance strategies [32]. Table 2 illustrates the management challenges in collaborative environmental governance.

Table 2. Management challenges in collaborative environmental governance

• How to create and maintain collaborative networks that are able to address tough problems involving deep-rooted conflicts of interests while simultaneously being conducive to the efficient coordination of relatively simple tasks?
• How to facilitate social tie formation processes in the local context in such ways that the evolving collaborative network develops desirable global structural properties, including a good fit to the biophysical context?
• How to best engage actors in collaborative networks even though some of them are not interested, or are interested for the 'wrong' reasons, or use the collaborative venue only as a way of obstructing any changes to status quo?
• How to create and maintain collaborative networks that are flexible and adaptable to changes, yet stable enough to facilitate the development of mutual trust and shared commitment?

Source: Bodin, 2017.

In this context, it is important to create effective communication mechanisms so that all stakeholders can share information and perspectives with one another. Various methods such as discussion forums, workshops, and regular meetings can guarantee the inclusion of everyone's voice. In addition, by improving access to information and education about environmental issues, the community will be better prepared to engage in discussions and decisions related to their environment. The use of technology to facilitate dialogue, such as online platforms and mobile applications, can also broaden the community's reach and participation. Thus, it will not only enhance the legitimacy of policies but also produce more innovative and adaptive solutions to increasingly complex environmental challenges, strengthening the sustainability and resilience of ecosystems for the future.

By taking these steps, Indonesia can address the environmental challenges it faces and achieve the desired sustainability goals.

Management that involves all stakeholders can not only create more effective and sustainable solutions, but also strengthen social bonds and the community's sense of ownership over their environment. Thus, a collaborative approach becomes a crucial strategy to carry out comprehensive environmental conservation efforts in Indonesia, sustain them over time, and pass them on to future generations. Furthermore, to ensure the sustainability of this collaborative approach, there needs to be a strong commitment from all parties to continue working together despite changes in political, social, and economic conditions. Cooperation agreements that delineate the roles and responsibilities of each stakeholder, along with a system for regular monitoring and evaluation to gauge the performance and impact of implemented policies, can actualize this long-term commitment. In addition, it is also important to identify sustainable funding sources, whether from the government, the private sector, or external donations, to support sustainability and environmental preservation programs. Adequate financial support will provide incentives for communities and businesses to actively participate in environmental initiatives. The awareness that sustainability is not only the responsibility of the government but also a shared responsibility of all elements of society will further strengthen and enrich efforts to protect the environment. Indonesia will be better prepared to face future environmental

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challenges and secure a healthy and sustainable ecological legacy for future generations by creating a strong and sustainable collaborative ecosystem.

4. CONCLUSIONS

Here are three concise conclusions based on the discussed aspects of environmental governance and sustainable natural resource management in Indonesia:

a) Environmental Challenges and Governance: Indonesia faces critical environmental challenges, such as deforestation, pollution, and biodiversity loss, requiring immediate action from various stakeholders. Effective governance must evolve from traditional hierarchical approaches to collaborative models that genuinely engage local communities, incorporate traditional knowledge, and align with the country's environmental sustainability goals.

b) Policy Implementation and Stakeholder Engagement: Weak implementation, a lack of trained personnel, and insufficient community involvement often hinder the effectiveness of environmental policies in Indonesia. To enhance governance outcomes, it is essential to strengthen inter-agency coordination, encourage public participation, and develop robust monitoring mechanisms to ensure accountability and transparency in natural resource management.

c) Collaborative Framework for Sustainability: Creating a comprehensive and adaptive environmental governance framework, centered on multi-stakeholder collaboration, is critical to achieving sustainable natural resource management in Indonesia. Collaboration between the government, private sector, civil society, and local communities can create innovative, equitable solutions that not only address immediate environmental concerns but also preserve ecological and cultural heritage for future generations.

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Unlocking the Potential for Carbon Dioxide Removal (CDR) by *Ulva prolifera*: How Does the Addition of CO_2 Enhance Growth and Photosynthesis Rates?

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ABSTRACT

In Japan, climate change has led to decreasing yields of *Ulva prolifera* from aquaculture farms, and therefore land-based aquaculture techniques were developed for this species. We investigated how temperature and CO_2 concentration affected relative growth rates (RGR) and net photosynthesis rates (NPR), with the intent to optimize the *U. prolifera* production in land-based aquaculture tanks. RGR and NPR of *U. prolifera* were measured at three temperature levels (10, 20, and 30°C) and a range of CO_2 concentrations (0 to 200 mg L^{-1}). To assess RGR, the samples were cultured for 6 days in flasks and the wet weight was recorded. To assess NPR, the increase in dissolved oxygen concentrations in 100 mL bottles was measured over time. A generalized additive model was fit to the data to elucidate the CO_2 concentration that leads to maximum RGR and NPR.

RGR and NPR increased with increasing CO_2 concentrations and declined after reaching a peak. Our analysis suggests that the maximum RGR occurred at CO_2 concentrations of 4.8, 14.0, and 22.2 mg L^{-1} at 10, 20, and 30°C, respectively. Whereas the maximum NPR occurred at CO_2 concentrations of 2.0, 13.8, and 3.5 mg L^{-1} at 10, 20, and 30°C, respectively. These results reveal that the addition of CO_2 enhances growth and photosynthesis rates and provides us with valuable information regarding carbon dioxide removal (CDR) potential of *U. prolifera* aquaculture. Additional experiments are being done to verify these results, and to provide more insight regarding why a reduction in the CO_2 concentration maximized NPR at 30°C.

Keyword: Carbon dioxide/ Carbon dioxide removal/ Land-based aquaculture/ Macroalga/ Net photosynthetic rate/ Relative growth rate

1. INTRODUCTION

Ulva prolifera O.F. Müller is a species of filamentous green alga that can often be observed in brackish environments, such as estuaries. This intertidal species is well adapted to fluctuating environmental conditions, therefore it is resistant to environmental changes. The growth rate of Ulva prolifera is reported to be maximized at 20°C and salinity 32. However, the algal thalli have been shown to grow at 5°C, suggesting a wide tolerance for temperature and salinity fluctuations [1].

U. prolifera is consumed as food in Japan and is coveted for its distinctive aroma. One of the major production areas of this species was the Shimanto River in Kochi Prefecture, where the thriving season is divided into two periods, from December to January and late April. *U. prolifera* was also intensively cultivated in the Yoshino River estuary in Tokushima Prefecture since 1983 [2] However, more recently, its quality and yield have been unstable, which can be attributed to the effects of climate change on water temperature and weather conditions [3,4].

To stabilize quality and yield, land-based aquaculture techniques have been developed (i.e., the Germling cluster method [5]. Pevious studies have reported that CO_2 aeration promoted the growth of this species [6,7]. However, our pilot research indicated that the growth rate decreased at CO_2 concentrations higher than 250 mg L^{-1}. Therefore, we hypothesize that the growth rate of *U. prolifera* has a maximal value when the concentration of CO_2 supplied to the *U. prolifera* clusters is below 250 mg L^{-1} and that maximal growth rates occur at different CO_2 concentrations under different cultivation

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temperatures (10, 20 and 30°C). Our group has investigated the response to CO_2 concentration on the relative growth rate and net photosynthesis rate of *U. proliferate.*

Currently, there is growing interest in the carbon dioxide removal (CDR) potential of various seaweed species, with ongoing research in this area. This study aims to enhance the efficiency of *U. prolifera* production in land-based aquaculture systems, which could contribute to increased CO_2 absorption. Such advancements may also provide opportunities for the application of gases emitted from sources such as thermal power plants [8,9].

2. METHODOLOGY

2.1 Growth experiments

The impact of CO_2 concentrations on the relative growth rate (RGR) of *Ulva prolifera*, were examined. The seawater used for the experiments were prepared using sterilized natural seawater. First the sterilized seawater was aerated with CO_2 gas using an air tube and an air stone. This high CO_2 concentration seawater was then dilated with sterilized seawater to create 8 to 9 different CO2 concentrations of seawater. All growth conditions used the same seawater supply which was pumped from a distance of 160 m from the shoreline. Salinity was periodically measured and ranged from 28 to 34 psu. Samples were incubated in 1L flasks containing 1.1 medium at 10, 20 and 30°C (CN-40A, MITSUBISHI) under conditions of 150 μmol m^{-2} s^{-1} (12 h photoperiod) with stirring. CO_2 concentration was modified using a portable carbon dioxide concentration meter (CGP-31, DKK-TOA) and the light source was 3LH-64 (NK system). The relative growth rate was determined with equation (1). Briefly, the wet weight of the sample measured on day 0 and day *t* was recorded. The difference of the natural logarithm transformed wet weights were calculated and divided by the duration of the growth experiment [10].

$$\mathrm{RGR} = \frac{(W_t)-(W_0)}{\mathrm{days}} \quad (1)$$

Where; W_t represents the wet weight at day t and W_0 represents the wet weight of day 0.

2.2 Photosynthesis rates

To assess the impact of CO_2 concentration on photosynthesis rates, the net photosynthetic rate (NPR) was examined using samples pre-cultured for 1-4 days under conditions of 18 μmol m^{-2} s^{-1} (24 h photoperiod), and 20°C. The NPRs were measured in a 100 mL BOD bottle containing a single cluster and medium that was prepared similarly to the RGR experiments. The CO_2 concentrations were adjusted to 7 to 9 levels. Samples were secured within the bottles using a net to prevent movement. The medium was poured into the bottle and a BOD sensor (Xylem) connected to ProSolo (Xylem) was carefully inserted into the bottle to prevent the trapping of bubbles. Bottles were placed in a glass water bath and provided light. The temperature of the water bath was controlled with a chiller and heater as needed. Three water temperatures were selected for this experiment and were 10°C, 20°C, and 30°C. The light intensity of 200 μmol m^{-2} s^{-1} was maintained. Dissolved oxygen (DO) was measured every 5 minutes for 1 hour; the water in the BOD bottles were continuously stirred with a stirrer attached to the BOD sensor. The NPR was determined from the slope of the linear regression model fitted to the DO concentration time series. pH was measured with D-52S (HORIBA). To account for the influence of photosynthesis on CO_2 concentration, the adjusted mean CO_2 concentration was calculated and used as the representative value.

2.3 Statistical analysis

All statistical analyses were done using R version 4.4.1 [R core team 2024]. The linear regression was fit using a least-squares approach, with time as the explanatory variable and DO concentration as the response variable. The response of RGR and NPR to various temperature and CO_2 concentrations were examined using a generalized additive model (GAM), using a P spline with 5 basis functions for

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the mean response and 7 basis functions for each temperature treatment. The response variable was either RGR or NPR and the explanatory variable was the natural logarithm of the CO_2 concentration. For the both models, a gamma distribution was assumed for the error distribution and the link-function was the natural logarithm. A Bayesian approach was used to fit the GAM and the priors for the model were defined with a gamma distribution (location 0 and shape of 2) for the model error. Model fit was assessed visually by inspecting the residuals and posterior distributions.

3. RESULTS AND DISCUSSION

In the relative growth experiment the RGR appeared to increase with increased CO_2 concentration, then decreased at higher concentrations; the responses were different with respect to temperature (Figure 1). Under the experimental conditions of 10°C, the maximum RGR (day^{-1}) reached 0.404 at the CO_2 concentration of 2.9 mg L^{-1}. Under the experimental conditions of 20°C, the maximum RGR reached 0.818 at the CO_2 concentration of 16.4 mg L^{-1}. Under the experimental conditions of 30°C, the maximum RGR reached 0.703 at the CO_2 concentration of 16.7 mg L^{-1}. In each experiment, the RGR was observed to have gradual reductions in areas with higher concentration of CO_2. However, the model predicted that the peak RGR would likely occur at 4.8 mg L^{-1} at 10°C, 14.0 mg L^{-1} at 20°C, and 22.2 mg L^{-1} at 30°C.

As in the RGR experiment, the NPR responded to changing CO_2 concentrations and temperature similarly (Figure 2). Under the experimental conditions of 10°C, the maximum NPR (μg O_2 g_{ww}^{-1} min^{-1}) reached 48.9 at the CO_2 concentration of 5.77 mg L^{-1}. Under the experimental conditions of 20°C, the maximum NPR reached 160 at the CO_2 concentration of 6.69 mg L^{-1}. Under the experimental conditions of 30°C, the maximum NPR reached 143 at the CO_2 concentration of 7.41 mg L^{-1}. However, the model prediction predicts that the peak NPR will likely occur at 1.95 mg L^{-1} at 10°C, 13.8 mg L^{-1} at 20°C, and 2.52 mg L^{-1} at 30°C.

The photosynthesis and growth of macroalgae requires an adequate supply of CO_2 and optimal temperature conditions. When CO_2 concentrations are too low or too high, photosynthesis rates and growth rates of macroalgae should be suboptimal. Additionally, when temperatures are the extremes of the tolerable temperature range of a species, suboptimal photosynthesis and growth can occur. The dome-shaped response of RGR and NPR observed in *U. prolifera* suggests that there is a combination of CO_2 concentration and water temperature that leads to maximal rates. In our study, RGR and NPR generally peaked at CO_2 concentrations between 2.0 to 22.2 mg L^{-1} (Fig. 1 and 2) and that the occurrence of these peaks were different with respect to temperature.

While optimal temperatures for plant growth are well-established [6], seaweeds also exhibit species-specific optimal temperature ranges that often reflect their natural habitats. For instance, *Undaria pinnatifida* and gametophytes of *Saccharina japonica* have reported maximum photosynthetic rates at 22.2°C and 23.3°C, respectively [11,12]. Xiao et al. observed high specific growth rates in *U. prolifera* between 14°C and 32°C, indicating its adaptability to a wide temperature range [1]. Our results align with these findings, as we observed no significant differences in relative growth rates between 20°C and 30°C.

Several studies have examined the effects of elevated CO_2 on seaweed growth, revealing species-specific responses. Similar to our findings, *Gracilaria* sp. and *G. chilensis* exhibited enhanced growth under elevated CO_2 conditions [13]. *Porphyra yezoensis* also demonstrated larger thalli in higher CO_2 concentrations [14]. Additionally, Wang et al. reported increased nitrate transporter activity in *U. prolifera* under elevated CO_2 conditions. *Hizikia fusiformis* not only showed accelerated growth but also increased average nitrate uptake rates and nitrate reductase activity, indicating enhanced nitrogen assimilation [15].

Studies investigating the combined effects of elevated CO_2 and temperature have yielded varied results. For instance, *Chlorella vulgaris* exhibited increased growth rates at 30°C under elevated CO_2 conditions [16]. In contrast, *Synechococcus* showed increased phycobilin and chlorophyll a content but no difference in growth rate [17]. *Kappaphycus alvarezii* cultured in vitro with CO_2 supplementation

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exhibited cellular changes such as cell wall thickening, starch granule formation, and the appearance of organelles associated with intense cellular activity, suggesting improved stress tolerance and productivity when transported to offshore aquaculture farms [18].

While previous studies examined a wider range of temperatures, they generally showed a trend of increasing RGR in *U. prolifera* at temperatures around 10, 20, and 30°C, respectively [1,19]. Our results are consistent with this general pattern. We hypothesize that at low temperature, respiration and enzymatic reactions are down regulated, while at high temperatures, enzyme denaturation and respiration increased respiration rate reduce photosynthesis efficiency. The dome-shaped response of the growth to temperature is well-documented in various microalgae studies and can also be expected in *U. prolifera* [20,7]. As a result, CO2 demand decreases compared to 20°C. In other words, temperature is likely a more significant limiting factor for the growth compared to CO_2 concentration.

A slight increase in CO_2 supply is expected to enhance the RGR of *U. prolifera.* Several factors may contribute to this, the primary one being energy conservation. Short-term low pH conditions can reduce the energy required for proton transport across membranes, potentially leading to increased energy available for growth. Additionally, restrictions on the carbon concentrating mechanisms (CCMs) may also lead to energy conservation that can be allocated to growth. CCMs widely found in seaweeds convert HCO_3^- to CO_2, enhancing the CO_2 environment to RUBISCO (Ribulose-1,5-bisphosphate carboxylase/oxygenase), the central photosynthetic enzyme [21]. CCM requires more substance transport and energy consumption than general photosynthesis. Therefore, the suppression of CCM might have promoted growth. In addition, a previous study reported that the NRT gene expression increased significantly under elevated CO_2 [22]. As a result, nutrient uptake was promoted and the growth rate increased.

The net photosynthesis rates in our study exhibited significant variability. One possible explanation for this is the displacement of the sample from the light during the experiment. Additionally, when comparing samples with the same CO_2 concentration, we observed a positive correlation between NPR and sample weight. It is possible that larger samples experienced oxygen saturation.

In aquaculture systems where production must be carried out within limited land areas, technologies to improve productivity are indispensable. Our study found that the growth of *U. prolifera* is promoted when supplied with 10-30 mg L^{-1} of CO_2 at 20°C. Therefore, we can expect that productivity will improve if similar land-based aquaculture tanks are placed in similar environments. Furthermore, since the optimal temperature and CO_2 concentration vary depending on the species being cultured, it is important to establish the optimal culture environment for each species. Improving the production efficiency of *U. prolifera* in land-based aquaculture systems could further enhance CDR. However, when cultivated in open-air tanks, an excessive supply of CO_2 not only fails to increase production but also results in the release of excess CO_2 back into the atmosphere. Therefore, when utilizing this species as a carbon sink, it is crucial to maintain an optimal CO_2 concentration to ensure efficient carbon absorption.

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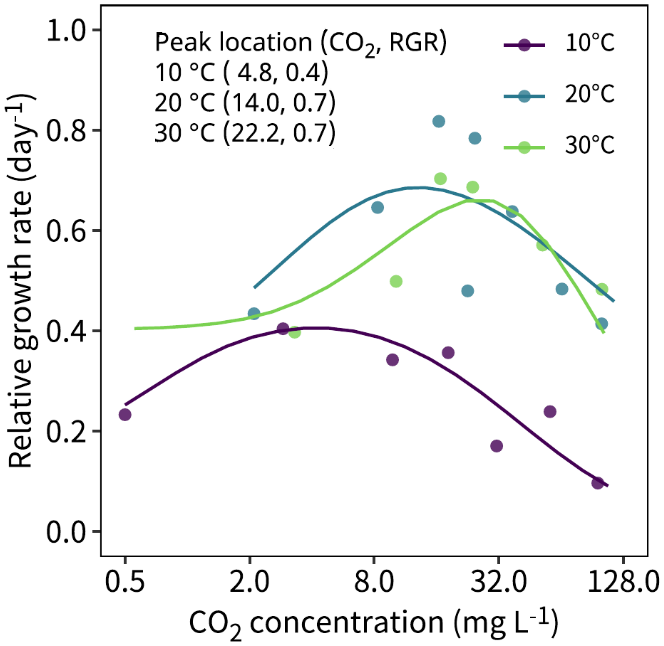

Figure 1. The RGR (day^{-1}) of *U. prolifera* in several CO_2 concentrations for 6 days' cultivation.

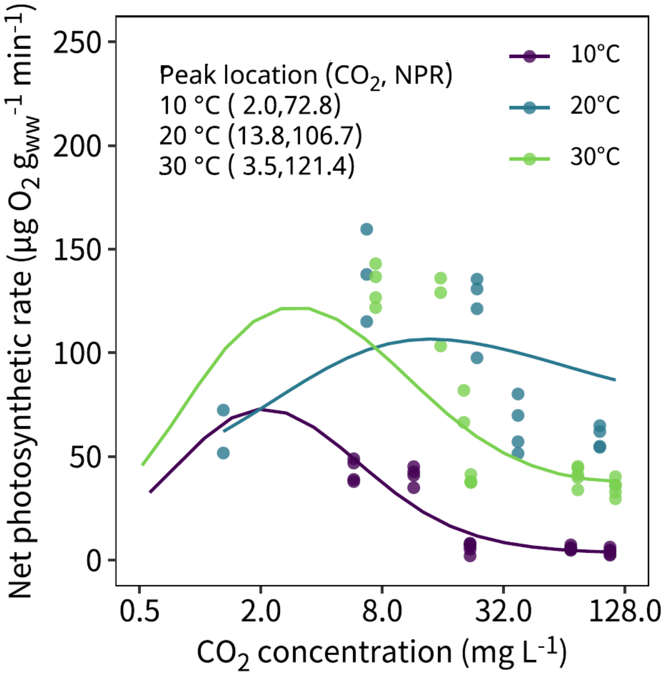

Figure 2. The NPR (µg O_2 g_{ww}^{-1} min^{-1}) of *U. prolifera* in several CO_2 concentrations (n = 5)

4. CONCLUSIONS

This study aimed to determine the optimal CO_2 concentration for the production of *Ulva prolifera*. Our results indicated that the optimal concentration varied with temperature. However, these values should be considered as guidelines rather than absolute limits for CO_2 supply. Furthermore, the results of net photosynthesis rates exhibited significant variability, reducing their reliability. The reasons why growth is promoted by increasing CO_2 concentrations remain unclear, necessitating further investigation into the underlying mechanisms. A clearer understanding of these mechanisms would enable us to more effectively supply optimal amounts of CO_2 in response to environmental changes.

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Exploring the Impact of Marine Debris on *Zostera marina* Ecosystem Productivity

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ABSTRACT

Seagrass meadows (i.e., *Zostera marina*), a vital component of coastal ecosystems, are facing degradation due to anthropogenic impacts such as marine debris and climate change. The relationship between marine debris and seagrass ecosystems is a subject of ongoing research, with the long-term effects of marine debris on seagrass productivity yet to be fully understood. This study aims to fill this gap by investigating the impact of marine debris removal on seagrass ecosystems, a crucial step in understanding and mitigating the effects of human activities on seagrass ecosystems. Two experiments were conducted in a seagrass ecosystem in Arikawa Bay, Nagasaki Prefecture, Japan, from April 2023 - July 2024. The first experiment evaluated the effect of removing marine debris (restored site) and allowing marine debris to persist (impacted site) on the coverage of seagrasses. The seagrass coverage was evaluated by assessing a total of 340 observation quadrats. Marine debris was collected and classified based on its material (plastic, metal, net/rope, glass/ceramic, cloth and rubber); total mass was recorded. The second experiment assessed the difference between the Net Ecosystem Productivity (NEP) of the impacted and restored seagrass beds using dissolved oxygen loggers. The first experiment revealed an increase in seagrass coverage of the restored area. The second experiment showed higher NEP (g C m^{-2} $month^{-1}$) in the restored site (mean±SD: 7.44±11.7) compared to the impacted site (mean±SD: 5.05±12). Our findings suggest that marine debris removal may positively contribute to seagrass ecosystem productivity. However, we are continuing to collect data to confirm these results.

Keyword: Dissolved oxygen/ Marine debris/ Net ecosystem productivity/ Seagrass/ *Zostera marina*

1. INTRODUCTION

Seagrasses are aquatic plants with organs and tissues similar to other flowering plants. Seagrass anatomy is separated into two parts, above and below ground. The above-ground part comprises shoots and leaves, and the below-ground part comprises roots and rhizomes/stems [1]. As a marine plant, seagrasses absorb carbon dioxide through photosynthesis [2], storing large amounts of organic carbon (OC) [3], and playing roles as a refuge and breeding ground for invertebrates and fishes [4].

Regardless of its benefits for the ecosystem, the presence of seagrass is suspected to be under threat due to the influence of marine debris. Marine debris is defined as all persistent manufactured or processed solid material disposed of or abandoned over coastal and marine environments [5], [6]. Currently, plastics have become the primary marine debris, accounting for about 80% of marine debris worldwide [7]. Therefore, plastic is widely considered a threat to marine ecosystems and wildlife [8], and many studies have documented the interaction between marine debris and nearly 700 species of marine wildlife [9], [10].

Our understanding of how marine debris pollution affects seagrass meadows is still evolving. Some studies suggest that seagrass can trap land-sourced debris [11]. Moreover, the trapped plastics could compete with seagrasses for space, reducing the availability of light and space, and thus affecting the growth of seagrasses [12]. Plastics alter seagrass architecture, prevent vertical rhizome growth, and increase seagrass vulnerability to invasion and sediment.

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While some studies are still ongoing, the potential for the long-term impact of marine debris in seagrass ecosystems remains unclear. We need further exploration of the effect of marine debris on seagrass meadows. This study explores the hypothesis that marine debris can affect the spatial extent and productivity of seagrass beds. We examine this hypothesis by removing marine debris and assessing how this influences seagrass growth and distribution.

2. METHODOLOGY

2.1 Location and sampling design

This study was conducted by skin diving every month from April 2023 to August 2024 in Arikawa Bay, Shin-Kamigoto, Nagasaki, Japan. The study site is in an area locally known as Yokoura (32° 59’ 17.9376” N, 129° 7” 5.3112” E). The sea floor is mainly sand interspersed with rocky substrate. Only *Zostera marina* was observed at the site and was found at depths between 2 m and 7 m. In this study, we separated the site into two sections and conducted two experiments. In the first experiment, we removed marine debris every month on half of the site to identify the effect of marine debris removal on seagrass distribution and coverage over time. In the second experiment, various environmental loggers were deployed to analyze and estimate the net ecosystem productivity of the seagrass bed.

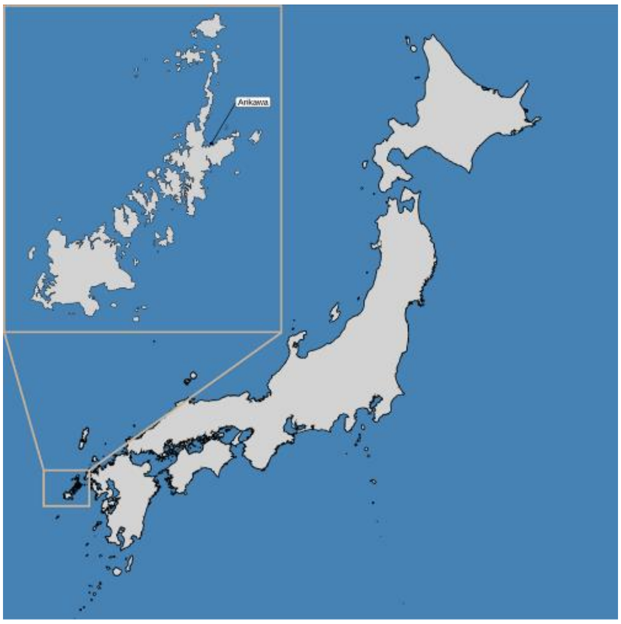

Figure 1. Study sites were located in Arikawa Bay, Shin-Kamigoto, Nagasaki, Japan.

2.2 Experiment 1

2.2.1 Marine debris removal

Marine debris was removed monthly. Initially, we separated the bay into two distinct sections. One section served as the impacted area, where marine debris accumulated naturally. The other section functioned as the restored area, which underwent monthly marine debris removal. Both designated sections of the site were characterized by pre-existing seagrass beds. Marine debris removal was done systematically, using a line transect so that seagrass coverage could be evaluated. A total of 10 lines were run across the site. Five transects for the restored section and five transects for the impacted section. Each line was approximately 70 m in length and spaced 5 m apart.

Macro-debris (size > 0.5 cm) was collected and classified based on material: plastic, net-rope, glass-ceramic, metal, cloth and rubber. After the collection, marine debris samples were washed with fresh water to remove sand, blotted dry, and weighed with a 0.1 g balance. Despite the six classified materials, we also grouped the marine debris materials into two groups: plastic-based material (plastic and net-rope) and non-plastic-based material (glass-ceramic, metal, cloth, and rubber).

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2.2.2 Seagrass cover analysis

The coverage of seagrass was done across each transect using a 50 × 50 cm photo-quadrat. At 2 m intervals, the quadrat was deployed, and an image was recorded with a digital camera (TG-6, Olympus). Images were analyzed to estimate coverage; a total of 310 quadrats were assessed every month. To analyze the coverage of seagrass, we adhered to the seagrass cover guidelines in the Guideline for the Assessment of Carbon Stock and Sequestration in Southeast Asia [13], which entails 11 standardized levels of percentage cover (5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100).

2.3 Experiment 2

2.3.1 NEP on seagrass beds

Net ecosystem productivity (NEP) on seagrass beds was done by monitoring various environmental variables during the study period. A total of 13 surveys were conducted from June 2023 - July 2024 for this study. A dissolved oxygen data logger (U26-001, Onset Computer Corporation, Bourne, MA, USA), wind speed sensor (S-WSB-M003, Onset Computer Corporation, MA, USA), and a datalogger (USB Microstation, Onset Computer Corporation, MA, USA) equipped with a PAR sensor (S-LIA-M003, Onset Computer Corporation, MA, USA) were used to record dissolved oxygen concentration, wind speed 1 m above the water surface and record Photosynthetic Active Radiation (PAR) light in the area of study.

The record sampling interval for all instruments was 10 minutes. The deployment positions of the instruments are in several locations. The dissolved oxygen data logger was placed 0 m and 1 m from the substrate of the seagrass Zostera marina beds in both impacted and restored areas. Meanwhile, the wind speed and surface PAR logger were placed 1 m above the water surface between the impacted and restored areas.

NEP was estimated using an open-water method, which integrates the environmental variables recorded using the data loggers [14].

2.4 Data analysis

To examine the seagrass coverage distribution and pattern, the spatial data representation was done using seagrass coverage and coordinates data on each seagrass point coverage analysis. All analyses were done with R version 4.4.1 (R Core Team 2024).

3. RESULTS AND DISCUSSION

3.1 Result

3.1.1 Marine debris

The amount of marine debris observed decreased over time as we removed marine debris (Fig. 2a). From the 16 surveys, a total of 31.1 kg of marine debris was collected. Nets were the most common debris materials. The net debris material is considered the highest marine debris by weight (40.9%) among the other materials, followed by ceramic (21.6%), metal (16.4%), plastic (9.35%), cloth (9.12%) and rubber (2.84%) (Fig. 2b). Interestingly, 90.73% of marine debris was found in the sandy area near the seagrass bed. In comparison, only 9.27% of marine debris was observed in the seagrass bed.

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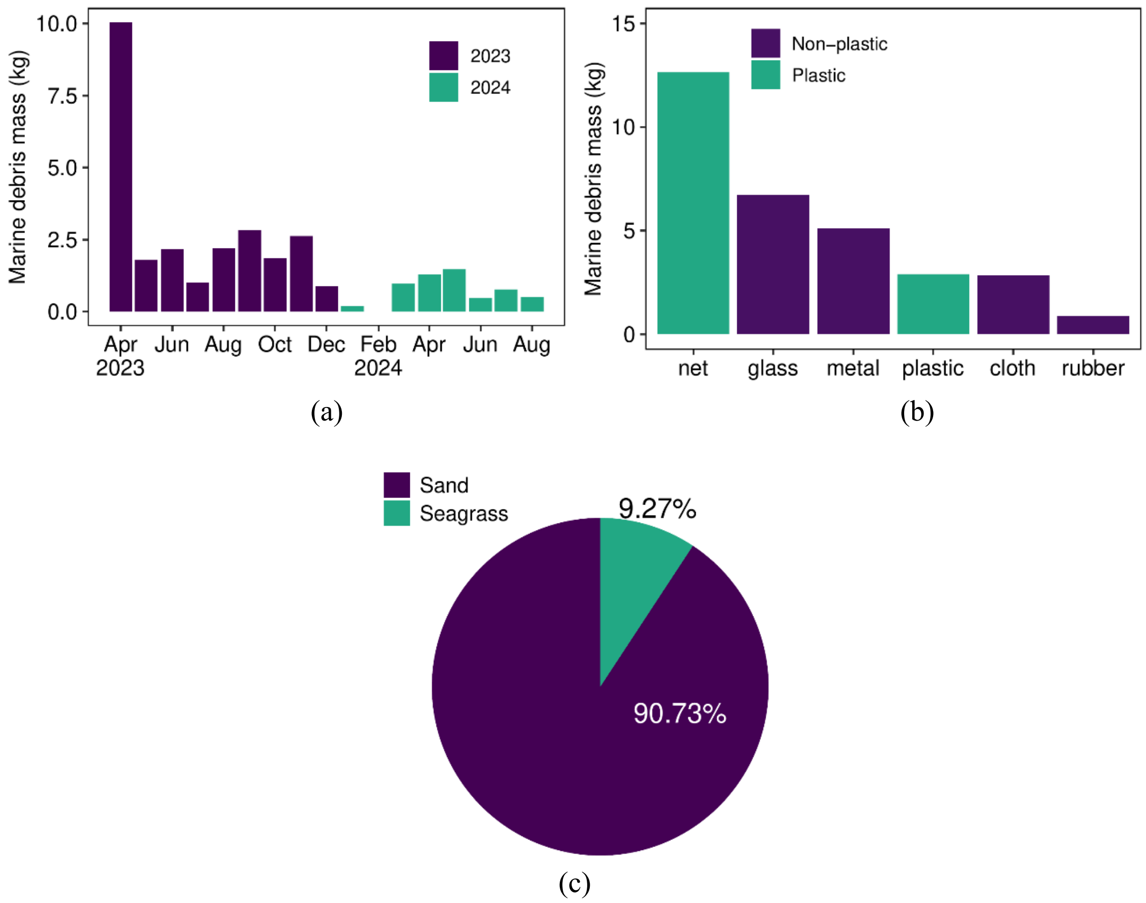

Figure 2. (a) Monthly marine debris mass, (b) Marine debris mass based on formed materials, (c) Marine debris percentage that was found based on location.

Based on our study, unvegetated areas, which are sand, store more marine debris than in the seagrass area. Moreover, marine debris observed in the sandy area was typically buried under the substrate, which allegedly could compete for space and affect seagrass distribution and growth [12]. Among the debris, the most common type was the net material, which was likely due to local fishermen repairing nets near the site. Note that the fishing nets that were being repaired were made up of polyamide (PA) fibres [15].

3.1.2 Seagrass cover

Seagrass coverage in 2023 was highest in July at both the impacted area (58.5%) and the restored area (50.3%). While in 2024, the highest seagrass coverage was in June for the impacted area (59.8%) and in July for the restored area (51.8%) (Figure 3a). Moreover, after one year of study between 2023 - 2024, the seagrass cover increment between impacted and restored areas were 6.03% and 20.1% respectively (Figure 3b). A Welch's t-test was done to examine how the seagrass coverage changed after one year. In the impacted area, the test revealed a $t(7.5)=-0.87$, $(P=0.4132)$, whereas in the restored area, $t(5.9)=-3.28$ $(P=0.0173)$.

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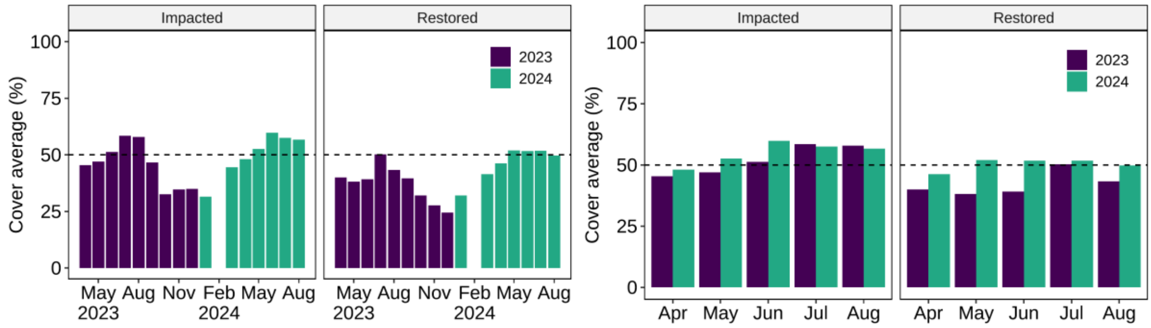

(a) (b)

Figure 3. (a) Monthly average of seagrass cover, (b) Seagrass cover increment from both areas after one year of study.

Our study shows that the effect of marine debris removal on the seagrass bed positively contributes to increased seagrass coverage and distribution. After one year of study (Fig. 3b), the average increase in seagrass coverage was 6 % in the impacted area. However, the average increase in seagrass coverage was 20 % in the restored area. It is relevant to note that the coverage of seagrass in the impacted area was initially higher than that of the restored area, which strongly suggests that marine debris removal greatly enhanced the increase in coverage of the restored area.

3.1.3 Seagrass Net Ecosystem Productivity (NEP)

The average net ecosystem productivity throughout the study was (mean±standard deviation) 5.05±12 g C m^{-2} day^{-1} for the impacted area and 6.83±11.1 g C m^{-2} day^{-1} for the restored area (Figure 4). The average monthly NEP was lowest during July and peaked during January to March. However, for the impacted area, NEP was negative (i.e., the ecosystem was heterotrophic) during both years of July. In contrast, in the restored area, NEP was only heterotrophic during the beginning of the study. It appears that after one year of removing marine debris, the restored area achieved an autotrophic state, given that the impacted area reverts to a heterotrophic state after one season.

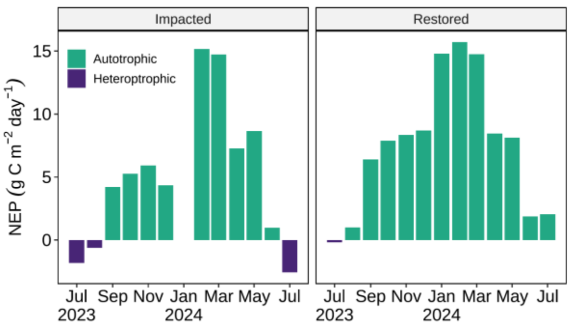

Figure 4. Monthly seagrass net ecosystem productivity estimation.

Based on our study, we suggest that the long-term effect of marine debris on seagrass beds is decrease in productivity. For example, fragments of plastic (e.g., high-density polyethene) buried in marine sediments negatively impact the growth and structure of the seagrass *Cymodocea nodosa* [16], which may have occurred at our site. Plastics accumulating in sandy sediments may inhibit the gas exchange between sediments and the overlying seawater, affecting oxygen exchange [12]. This suggests that not only oxygen but also the flux of other nutrients may be affected by accumulating marine debris, which will likely influence productivity. Recall that seagrass roots require oxygen for respiration, which is important for energy production. Consequently, interfering with oxygen exchange can lead to hypoxic conditions that can reduce the growth and biomass production of seagrasses [17]. Additionally, we

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suggest that marine debris in seagrass beds can physically interfere with root expansion and seed germination.

4. CONCLUSIONS

Marine debris in seagrass beds affects growth and productivity, likely due to physical stress. Our study suggests that removing marine debris has positive impacts since we observed increased seagrass coverage and productivity. However, the mechanisms regarding how marine debris affects coverage and productivity remain unclear. More studies are needed to reveal how marine debris affects seagrass meadows, not only the seagrass species but also the organisms associated with this ecosystem.

Acknowledgement

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Investigation of the Nutrient and Organic Matter Removal in Surface Water by Aquatic Plants: A Laboratory Scale Study

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ABSTRACT

The intensification of urbanization and industrial activities has precipitated a substantial influx of nutrients and organic pollutants into surface water systems, thereby exacerbating water quality degradation and posing significant threats to aquatic ecosystems and human health. Phytoremediation, characterized by the use of aquatic plants to sequester, metabolize, and remove contaminants from water bodies, emerges as a compelling, eco-friendly method. In this study, individual and combined cultivation experiments of three aquatic plants, including *Microsorum pteropus "Narrow"* (AQ1), *Cyperus haspan L.* (AQ2), and *Salvinia cucullata* (AQ3), in different water samples collected from landscape lakes were conducted. This study aimed to quantify the ability of these plants to enhance water quality by reducing nutrients (measured as Total Nitrogen - TN and Total Phosphorous - TP) and organic pollutant levels (measured as biological oxygen demand BOD_5), while also assessing their growth and adaptation during the experiment. Results showed that highest removal efficiencies of nutrients and organic matter were obtained in the case of AQ2. The combined cultivation ratio between AQ1 and AQ2 of 1:2 based on weight percentage (% w.t.) was also determined as the most appropriate design, since relatively similar removal efficiencies were found in both water samples: BOD_5 (29.8%), TN (66.7%), TP (91.7%), Coliform (64.9%) with internal landscape lake (TDT water sample) and BOD_5 (32.1%), TN (60.0%), TP (92.9%), Coliform (16.7%) with external landscape lake (HBN water sample). This study not only deepened the scientific understanding of plant-based water purification processes but also demonstrates their practical applications in enhancing urban water management practices sustainably.

Keyword: *Microsorum pteropus "Narrow"*/ *Cyperus haspan L.*/ *Salvinia cucullata*, aquatic plant/ Removal of nutrients and organic matter

1. INTRODUCTION

Surface water pollution in big city is a current concern since it affects the urban landscape and life quality of citizen. Ho Chi Minh city (HCMC), one of the largest cities in Vietnam, is also suffering from the negative impacts of water pollution. Due to the population growth of about 9 million people and a rapid urbanization, the nutrients and organic pollutants occurring in surface water systems are posing significant threats to aquatic ecosystems and human health. Thus, the treatment and regeneration of surface water resources has become an urgent priority in HCMC.

Traditional water treatment technologies, while effective, often entail the use of chemical agents that can disrupt aquatic life and lead to secondary pollution. Phytoremediation, characterized by the use of aquatic plants to sequester, metabolize, and remove contaminants from water bodies, emerges as a compelling, eco-friendly alternative [1-3]. During the phytoremediation, the organic matters and nutrients can be eliminated through different mechanisms including biological degradation by microorganism, settling, and filtration in which biological activities play the most important role [4]. Furthermore, heavy metals removal by phytoremediation have been reported by many studies [5-7]. In addition, aquatic plants also contribute on the environmental protection and increase urban aesthetics [2, 8]. Specifically, aquatic plants increase the habitat for aquatic animals, enhancing biodiversity and balancing the ecosystem.

Several common aquatic plants have been investigated by recent studies for the treatment of organic and nutrient pollutants in surface water systems, domestic and industrial wastewater sources, such as water hyacinth (*Eichhorina crassipes*) [9, 10], vetiver grass (*Vetiver zizanioides*) [11, 12], reed

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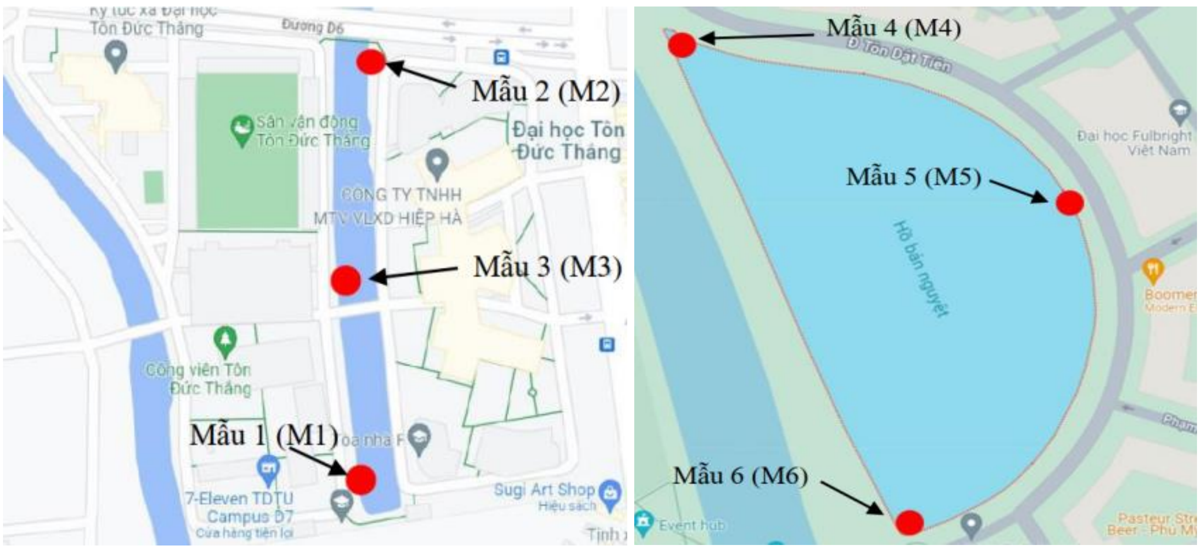
grass (*Phragmites australis*) [13, 14]. Among them, narrow-leaf fern (*Microsorum pteropus "Narrow"*), haspan plant (*Cyperus haspan L.*) and *Salvinia cucullata* are also capable of removing nutrients and organic matter from surface water [2, 8]. Specifically, study found that Cadmium could be accumulated by *Microsorum pteropus "Narrow"* with high capacity (i.e., 400 mg Cd/1kg dry mass) [15]. *Salvinia sp.* was reported to treat domestic wastewater during the phytoremediation process with high performance in removal of organic matters [16]. Although there are several artificial aquarium models using these three aquatic plants for the landscaping purposes, few experimental studies examined to demonstrate their capacity and practical applicability for treatment of organic and nutrients pollutants in surface water.

Therefore, in this study, three above aquatic plant species, including *Microsorum pteropus "Narrow", Cyperus haspan L., and Salvinia cucullata*, are employed in experimental designs in lab-scale, aiming to quantify the ability of these plants to enhance water quality by reducing nutrients and organic pollutant levels while also assessing their growth and adaptation during the experiment. The actual surface water samples are collected from landscape lakes in Ho Chi Minh City to stimulate the natural water sources. The results and findings are expected to contribute on the scientific database of aquatic organisms for surface water treatment. Therefore, this study not only deepened further understanding of plant-based water purification processes but also demonstrates their practical applications in enhancing urban water management practices sustainably.

2. METHODOLOGY

2.1 Raw surface water sampling

Two surface water sources in District 7, HCMC were investigated in this study, including (1) the TDTU water samples collected from the internal lake of a university campus and (2) the HBN water samples from a landscape external lake. For each water source, the sampling was conducted at 3 different positions as illustrated in Figure 1. Water samples collected were then mixed together to obtain the representative samples. The sampling was conducted in two batches for two different experiments. All samples before analysis were preserved according to the standard methods.



(a) (b)

Figure 1. Raw water sampling locations: (a) the TDTU and (b) the HBN water samples

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2.2 Water characterization

Water quality was analyzed and characterized by considering pH, BOD_5, total nitrogen (TN), total phosphorus (TP) concentration, and total coliform. All parameters were determined according the Vietnam national standards and specific analytical laboratory instruments (Table 1).

Table 1. Analytical methods and instruments

No	Parameters	Values (before experiment)		National analytical methods	Analytical instruments
		TDTU sample	HBN sample		
1	pH	7.48	7.66	TCVN 6492:2011	pH meter, model AD12 Adwa Instruments
2	DO	3.48	4.38	TCVN 7325:2015	DO Extech DO600-K
3	BOD_5	8.96	6.26	SMEWW 5210 B : 2005	
5	TN	3.26	3.36	TCVN 6638:2000	KjelMaster K-375, BUCHI
7	TP	0.27	0.21	SMEWW 4500 – P.D :20017	Genesys 10S UV-VIS
8	Total coliform	8600	5600	AOAC Official Method 991.14	Petrifilm plate E.Coli/Coliform Count (EC) 3M, code: 6404

2.3 Aquatic plant experimental cultivation

- *Aquatic plant sampling*

Three aquatic plant samples, including *Microsorum pteropus "Narrow"* (AQ1)*, Cyperus haspan* (AQ2), *and Salvinia cucullata* (AQ3), were natural and collected from suburban areas of Ho Chi Minh City. After removing the impurities on the branches and leaves, these aquatic species were grown individually for 07 days in clean water tanks to remove the remaining dirt and increase the ability to adapt to the water environment before moving to the experimental cultivation step.

- *Experimental cultivation design*

Eight plastic reactors (53 x 37 x 29 cm in size, weight of 150 g, with a capacity of 25 liters) were used for each cultivation experiment, in which 6 reactors were used for cultivation of 3 aquatic plants with 2 surface water samples taken from landscape lakes as described in section 2.1 and 2 reactors were employed as control samples (without aquatic plants) (Table 2). Depending on the experiment, individual or mixed aquatic plant species were cultivated in each reactor accordingly. The aim of experiment 1 is to assess the capacity of individual plant species for removal of nutrient and organic matter, while experiment 2 is designed to explore synergistic effects in mixed plant cultures and determine the most effective ratios (by mass) for pollutant removal.

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Table 2. Experimental cultivation design

No.	Reactor ID	Type of aquatic plant (Total fresh weight, gram[(a)])	Type of surface water	Remark
Experiment 1 - individual aquatic plant cultivation				
1	TDT1_0	No aquatic plant	TDTU water samples (mixed samples obtained from 3 sampling sites M1, M2, M3_phase 1)	Control sample
2	TDT1_1	AQ1 (162.72 gram)		Reactor 1
3	TDT1_2	AQ2 (164.82 gram)		Reactor 2
4	TDT1_3	AQ3 (153.0 gram)		Reactor 3
5	HBN1_0	No aquatic plant	HBN water samples (mixed samples obtained from 3 sampling sites M4, M5, M6_phase 1)	Control sample
6	HBN1_1	AQ1 (157.62 gram)		Reactor 4
7	HBN1_2	AQ2 (159.34 gram)		Reactor 5
8	HBN1_3	AQ3 (145.0 gram)		Reactor 6
Experiment 2 - Combined aquatic plant cultivation at different mass ratio, based on results of Experiment 1				
1	TDT2_0	No aquatic plant	TDTU water samples (mixed samples obtained from 3 sampling sites M1, M2, M3_phase 2)	Control sample
2	TDT2_1	AQ1 and AQ2[(b)]		Ratio of 2:1
3	TDT2_2			Ratio of 1:2
4	TDT2_3			Ratio of 1:1
5	HBN2_0	No aquatic plant	HBN water samples (mixed samples obtained from 3 sampling sites M4, M5, M6_phase 2)	Control sample
6	HBN2_1	AQ1 and AQ2 [(b)]		Ratio of 2:1
7	HBN2_2			Ratio of 1:2
8	HBN2_3			Ratio of 1:1

[(a)]Total fresh weight of aquatic species was determined on the first day of the cultivation experiment.
[(b)]The selection of combined aquatic plant in experiment 2 was determined based on the results of experiment 1.

Each experiment was performed with a water loading of 23 liters/first day of the experiment. During the experiment (30 days), surface water was not supplemented in the reactors in order to accurately determine the treatment efficiency of the investigated aquatic species during the experimental period. The sampling and analysis of water quality parameters, including pH, dissolved oxygen (DO), BOD_5 concentration, total nitrogen (TN), total phosphorus (TP) and total coliform, were carried out sequentially at specific time to evaluate the treatment efficiency. The analytical method is presented in Table 1.

In addition, study also monitored the growth performance, biomass accumulation, and health of the plants over the experimental period to determine their resilience and adaptability to urban water conditions. For this, several parameters, such as the total weight, root length, leaf size, and biomass of aquatic plants were monitored and considered.

3. RESULTS AND DISCUSSION

3.1 Changes of water quality in individual aquatic plant cultivation (Experiment 1)

The results of the individual cultivation experiments for 03 types of aquatic plants during 30 days showed that each aquatic plant has different ability in the removal of nutrients and organic matter, depending on their biological characteristics.

Specifically, for organic matter measured by BOD_5 concentration, all three AQ1, AQ2, and AQ3 species, in general, did not show high efficiency. After 30 days of cultivation, the highest BOD_5 removal efficiency was found in the AQ3 case (13.9% - reactor TDT1_3 and 14.0% - reactor HBN1_3, Table 3). The biodegradation of organic matter in cultivation experiments basically removes dissolved organic compounds. The remaining organic matter and settled solids can be only removed through sedimentation. This biodegradation mechanism occurs when dissolved organic compounds are carried into the biofilm layer attached to the submerged part of the plant and decomposed by microorganisms, mainly bacteria and fungi, living in the roots. The high-density root system is the adhesion medium of the microorganisms growing in water; increasing the contact density between microorganisms and the

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water source. Accordingly, aquatic plants facilitate microorganisms to carry out the biodegradation process. They also help transport oxygen into the root zone through diffusion [3].

Table 3. Water treatment efficiency of individual aquatic plant cultivation (Experiment 1)

Parameters	Treatment efficiency (%) of different reactors, corresponding to specific aquatic plant					
	AQ1 plant		AQ2 plant		AQ3 plant	
	Reactor TDT1_1	Reactor HBN1_1	Reactor TDT1_2	Reactor HBN1_2	Reactor TDT1_3	Reactor HBN1_3
BOD_5	13.9%	14.0%	KĐ	KĐ	11.2 %	14.8 %
TN	60.7%	50.0 %	82.1 %	66.7%	36.9 %	44.4 %
TP	76.0 %	72.2 %	92.3%	86.9%	22.0 %	26.0 %
Coliform	Not satisfy	Not satisfy	Not satisfy	Not satisfy	Not satisfy	Not satisfy

Regarding nutrient parameters (i.e., TN and TP), the highest TN removal (82.1% - TDT12 and 66.7% - HBN12) and TP removal (92.3% - TDT1_2 and 86.9% - HBN1_2) were found in the case of AQ2 (Table 3). The nutrient treatment efficiency of aquatic plants has been report by several studies due to following mechanisms: (i) simple amino acids can be absorbed directly by plant roots, (ii) aquatic plants secrete some specific enzymes to break down organic N, P compounds into simple compounds that they can absorb, and (iii) the microbial community living in the root zone of plants has the ability to mineralize organic compounds to provide mineral nutrients for plants [1, 17].

However, in term of Coliform reduction, none of investigated aquatic plants showed positive results since the analysis found that the number of Coliform did not change much during the 30 days of experiments. This indicates that the phytoremediation mechanism activated by these aquatic plants may not be efficient for Coliform removal.

3.2 Growth performance of aquatic plants

In order to evaluate the growth and biomass increase of aquatic plants during the 30 days experimental cultivation, the study consider the changes of total weight, the length of leave/ branch/ petiole diameter, and the length of root (Table 4).

Results showed that three aquatic plants have adapted and grown strongly with the experimental conditions. The plant morphology and pigmentation were well developed based on the actual observation. Most of criteria monitored during 30 days of cultivation were increased positively, indicating the growth of aquatic plants to biodegrade organic matter and nutrients in water. The cultivation was carried out in static condition of laboratory, where the effects of other environmental factors (e.g., water flow, air, light, temperature, and other recalcitrant pollutants) were ignored. The actual conditions of environment may affect the growth rate and treatment efficiency of plants.

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Table 4. Evaluation of the growth and biomass increase of aquatic plants

Criteria	AQ1 plant				AQ2 plant				AQ3 plant			
	TDT water		HBN water		TDT water		HBN water		TDT water		HBN water	
	1st day	30th day	1st day	30th day	1st day	30th day	1st day	30th day	1st day	30th day	1st day	30th day
Total weight (g)	162.72	186.68	157.62	179.07	164.82	169.82	159.34	170.31	153.00	132.70	145.00	122.98
Length of leave/ branch/ petiole diameter (cm)	13.8	15.5	11.75	14.63	82.2	100.4	88.6	97/7	1.6	2.5	1.5	2.5
Length of root (cm)	-	-	-	-	18.9	22.9	22.1	25.6	2.6	3.3	2.9	3.5
Number of branches	22	30	25	32	-	-	-	-	-	-	-	-

3.3 Changes of water quality in combined cultivation at different mass ratio (Experiment 2)

Based on the resulted obtained in Experiment 1 (Table 3), the AQ1 and AQ2 were chosen for the combined aquatic plant cultivation experiment (Experiment 2). The cultivation was carried out at different mass ratios of 1:2, 2:1 and 1:1 as shown in Table 2. Results showed that each ratio had different treatment efficiency of nutrient and organic matter, depending on the biological characteristics of the dominant species during the cultivation (Table 5 and 6).

Table 5. Treatment efficiency of nutrient and organic matter of combined cultivation at different mass ratio (Experiment 2)

Parameters	Treatment efficiency of combination of AQ1 and AQ2 plant, (%)					
	Mass ratio of 2:1		Mass ratio of 1:2		Mass ratio of 1:1	
	Reactor TDT2_1	Reactor HBN2_1	Reactor TDT2_2	Reactor HBN2_2	Reactor TDT2_3	Reactor HBN2_3
BOD_5	19.6 %	17.9 %	29.8 %	32.1 %	17.9 %	0.5 %
TN	66.7 %	78.6 %	66.7 %	60.0 %	74.4 %	63.6 %
TP	69.9 %	75.0 %	91.7 %	92.9 %	86.1 %	85.7 %
Coliform	Not satisfy	Not satisfy	14.9 %	16.7 %	16.2 %	Not satisfy

Specifically, all 03 combination ratios of AQ1 and AQ2 plants have relatively low BOD_5 treatment efficiency (i.e., < 35%, Table 5). A similar trend for both water samples investigated were found in the combination ratio of 2:1 since the BOD_5 treatment efficiency is about 17 - 19%. In contrast, there was a significant difference in BOD5 treatment efficiency with the combination ratio of 1:1, in which an efficiency of 17.9% was obtained with reactor TDT2_3 and only 0.5% was found with reactor HBN2_3. The combination ratio of 1:2 has the best BOD_5 treatment efficiency (i.e., 29.8% with reactor TDT2_2 and 32.1% with reactor HBN2_2). Overall, the results of individual cultivation in experiment 1 and combined cultivation in experiment 2 indicated that the treatment efficiency organic matter of AQ1 and AQ2 in surface water was actually not high as expected.

However, for the nutrients removal, all combined ratios of AQ1 and AQ2 showed better results since the treatment efficiency of TN and TP were over 60% (Table 5). Especially, a very high treatment efficiency of TP (i.e., over 90%) was achieved with the combination ratio of 1:2 for both water samples (i.e., TDT2_2 and HBN2_3).

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In term of Coliform removal, different results were found in each reactor. The most positive response (i.e., 14.9% at reactor TDT2_2 and 16.7% at reactor HBN2_2) was also obtained with the combination ratio of 1:2. Other investigated ratios of AQ1 and AQ2 did not demonstrate the ability to remove bacteria in both water samples.

The changes of organic matter and nutrients concentrations along with total coliform over time in 02 combined cultivating reactors of AQ1 and AQ2 species at the ratio of 1:2 (i.e., reactor TDT2_2 and HBN2_2) are shown in Figure 2.

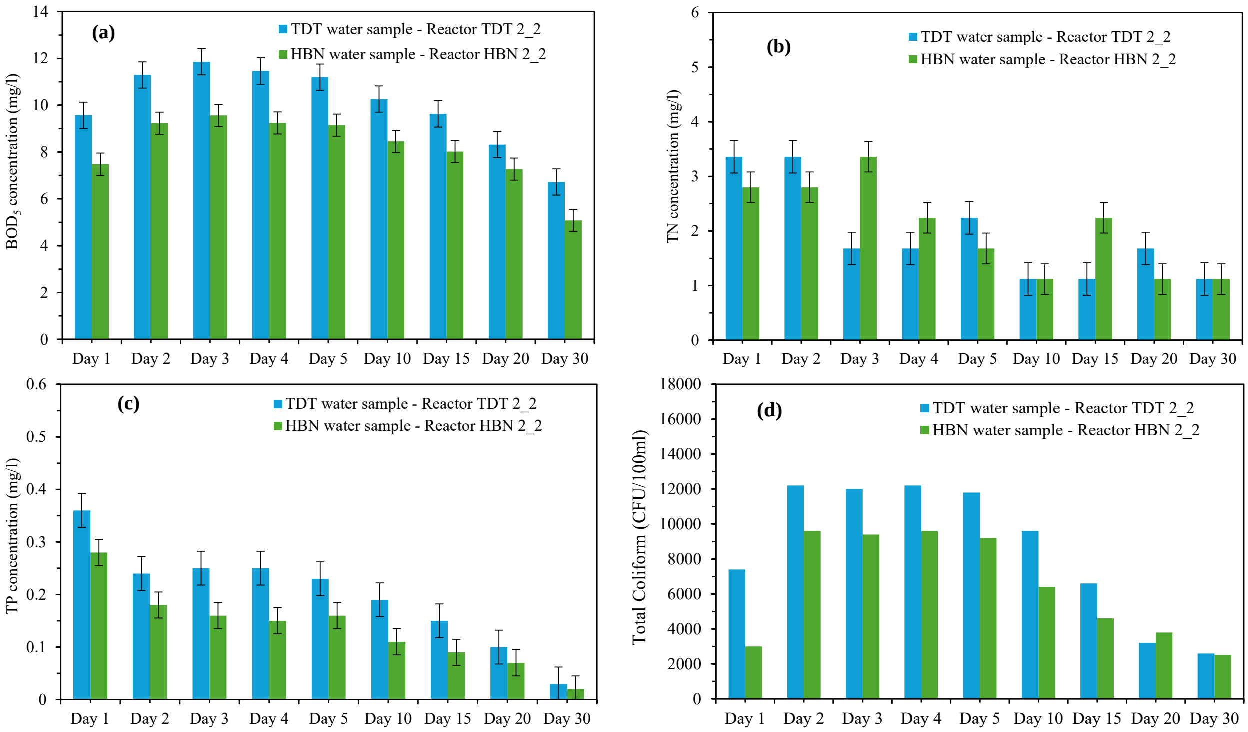

Figure 2. Changes in (a) BOD_5, (b) TN, (c) TP concentration and (d) total coliform in 02 combined cultivation reactors (TDT2_2 and HBN2_2) at the mass ratio of 1:2)

Table 6. Evaluation of water quality after 30 days of combined cultivation of AQ1 and AQ2

Parameters	TDT water sample			HBN water sample		
	Ratio 2:1, TDT2_1	Ratio 1:2 TDT2_2	Ratio 1:1 TDT2_3	Ratio (2:1) HBN2_1	Ratio (1:2) HBN2_2	Ratio (1:1) HBN2_3
pH	7.07±0.19	6.17±0.16	7.61±0.15	6.92±0.12	6.24±0.13	7.35±0.16
BOD_5 (mg/l)	7.93±0.42	6.72±0.49	8.16±0.58	6.01±0.62	5.08±0.46	7.23±0.67
DO (mg/l)	5.86±0.20	4.57±0.20	4.97±0.28	6.43±0.21	5.41±0.11	5.76±0.13
TP (mg/l)	0.11±0.01	0.03±0.01	0.05±0.02	0.07±0.02	0.02±0.01	0.04±0.02
TN (mg/l)	1.12±0.05	1.12±0.03	0.86±0.02	0.60±0.02	1.12±0.02	1.02±0.04
Total coliform (CFU/100 ml)	12.800	2.600	6.200	12.000	2.500	8.400
Classify of water quality based on national standard QCVN 08:2023/ BTNMT	Level D	Level B	Level C	Level D	Level B	Level D

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Water quality in cultivation reactors at different combination ratios was then compared with QCVN 08:2023/BTNMT - the national technical regulation on surface water quality in Vietnam. The results showed that the combined cultivating reactor of AQ1 and AQ2 at the mass ratio of 1:2 helped improve the quality of both surface water samples. Specifically, the water quality can reach level B according to QCVN 08:2023/BTNMT - Table 6). This is an important result to affirm the applicability of this study to implement the cultivation in the actual situation.

4. CONCLUSIONS

Based on laboratory experiments and data analysis in this study, some conclusions were drawn as follows:

1. The study demonstrated successfully the ability of *Microsorum pteropus "Narrow" (AQ1), Cyperus haspan L. (AQ2),* and *Salvinia cucullata (AQ3)* to reduce the organic matter and nutrients through phytoremediation, in which *Cyperus haspan L. (AQ2)* showed better performance.

2. The combination of *Microsorum pteropus "Narrow" (AQ1), Cyperus haspan L. (AQ2)* with a mass ratio of 1:2 in cultivation reactor could help to improve the surface water quality and reach the level B of the national standard QCVN 08:2023/BTNMT of surface water, which confirms the roles of aquatic plant to enhance urban water treatment and management.

3. Results from the study promote the development of a scalable phytoremediation model that can be integrated into urban water management strategies, emphasizing sustainability and ecological benefits.

4. However, the study was conducted in a laboratory scale to mitigate the effects of natural factors. Therefore, it is suggested that further work should be carried out in the scale of natural lakes to consider the effects of dynamic water flow and pollution load to more accurately determine the ability of these aquatic species for treatment of organic matter and nutrients. This helps to demonstrate the practical applicability of this method to improve the quality of urban surface water sources.

Acknowledgement

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Thai Universities Performance in Global Sustainability Rankings for Educational Institutions

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ABSTRACT

In 1972, the term 'sustainability in higher education' was first introduced in the Stockholm Declaration, which highlighted the interdependence between humanity and the environment in achieving environmental sustainability. There are three major global university sustainability rankings: UI GreenMetric World University Ranking, Times Higher Education (THE) Impact Ranking, and QS World University Ranking: Sustainability. The UI GreenMetric World University Ranking evaluates universities based on six categories: setting and infrastructure, energy and climate change, waste, water, transportation, and education. The THE Impact Ranking assesses how university activities contribute to the United Nations Sustainable Development Goals. Meanwhile, the QS World University Ranking: Sustainability measures a university's effectiveness in addressing environmental, social, and governance (ESG) issues. In 2023, 55 Thai universities participated in the UI GreenMetric World University Ranking, 65 in the THE Impact Ranking, and 7 in the QS World University Ranking: Sustainability. Thai universities perform relatively well in the UI GreenMetric World University Ranking and THE Impact Ranking. However, there are notable gaps that need addressing in the QS World University Ranking: Sustainability.

Keyword: University/ Sustainability/ UI GreenMetric/ THE Impact Ranking/ QS World University Ranking: Sustainability

1. INTRODUCTION

Universities are essential in fostering a sustainable future by educating future leaders and integrating sustainability into their practices [1], [2]. This involves addressing environmental and social concerns, and adjusting policies and operations to mitigate negative impacts on the environment and achieve the 17 sustainable development goals of the United Nations [3], [4]. There is a high demand for research on universities as actors within sustainable development processes [5]. While there has been an increase in interest and implementation of sustainability in universities, challenges remain, such as better integration of environmental management into curricula and research [6]. Several models and guidelines have been developed to facilitate the integration of sustainability into higher education institutions, providing systematic action plans and transition management approaches [7], [8]. Additionally, the university community must rethink environmental policies and practices to contribute to sustainable development at various levels, with potential economic, environmental, and social consequences [9]. Official statements increasingly recognize the role of universities in sustainable development, leading to the creation of a culture of sustainability embedded in university management [10].

The measurement and assessment of sustainability in universities are crucial for evaluating their efforts and progress towards sustainability [11]. This process involves the use of important indicators such as decreased consumption, centrality of sustainability education, and cross-functional or cross-institutional integration [12]. Recently, three global methodologies have emerged to measure and evaluate the sustainability progress of universities: the UI GreenMetric World University Ranking, the Times Higher Education (THE) Impact Ranking, and the QS World University Ranking: Sustainability.

Sustainability has become a key concern for Thai universities, with many making notable advancements in areas like environmental management, social responsibility, and the 17 Sustainable Development Goals (SDGs). Additionally, the Sustainable University Network of Thailand (SUN

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Thailand) has been officially established since 2016 to further support these efforts. The networking serves as a collaborative platform for universities in Thailand to share knowledge, strategies, and best practices related to sustainability [13].

This paper aims to evaluate the performance of Thai universities in global sustainability rankings. The core concepts of three global sustainability rankings including the UI GreenMetric World University Ranking, the THE Impact Ranking, and the QS World University Ranking: Sustainability were presented. The analysis of Thai universities performance in three global sustainability rankings was discussed.

2. GLOBAL SUSTAINABILITY RANKING

The UI GreenMetric World University Ranking is the first global sustainability ranking system that assesses universities' efforts in environmental sustainability, aiming to promote green campuses and sustainable development [14], [15]. It was introduced by the University of Indonesia in 2010 and evaluates universities based on indicators related to education, research, and the environment [14]. Participating universities can use the ranking as a framework to examine their performance and contribute to global sustainable development [16], [17]. The ranking system covers six areas, including setting & infrastructure, energy & climate change, waste, water, transportation, and education, and universities are ranked based on their total scores in these areas [18].

THE Impact Ranking was launched in 2019 by the Time Higher Education. These rankings evaluate institutions on various criteria such as their research, stewardship, outreach, and teaching practices related to the United Nations' Sustainable Development Goals (SDGs). A total of 251 indicators, spanning all 17 SDGs, were used to determine rankings. The calculation involved scoring primarily based on SDG 17, with the top three results from the remaining 16 SDGs also considered [19].

The QS World University Rankings: Sustainability is a global sustainability ranking of universities that assesses their performance across a range of environmental, social, and governance (ESG) challenges. It is designed to provide students with a unique lens on which institutions are demonstrating a commitment to a more sustainable existence. Total score is calculated based on three pillars, which are social impact (45%), environmental impact (45%), and governance (10%) [20].

3. THAI UNIVERSITIES IN GLOBAL SUSTAINBILITY RANKING

Sustainability in Thai universities has become a prominent focus as institutions seek to address environmental challenges and contribute to sustainable development. They are increasingly recognizing the importance of sustainability and are taking steps to integrate it into their education, research, and operational activities. This section demonstrates Thai universities performance in the global sustainability ranking, which are the UI GreenMetric World University Ranking, THE Impact Ranking, and QS World University Ranking: Sustainability, respectively. The ranking results from three global ranking in year 2023 were gathered to analyse the Thai universities performance.

The contributions of ASEAN universities and Thai universities in the UI GreenMetric World University Ranking during the year 2021-2023 were illustrated in the Figure 1 and 2. The number of Thai universities participating in the UI GreenMetric World University Ranking has increased from 39, 47 and 55 in year 2021, 2022 and 2023, respectively. Figure 3 demonstrates the Thai universities ranking in top 500 ranked of the UI GreenMetric World University Ranking in year 2023. It can be seen that 61.8% of Thai universities was ranked in the top 500 of UI GreenMetric World University Ranking.

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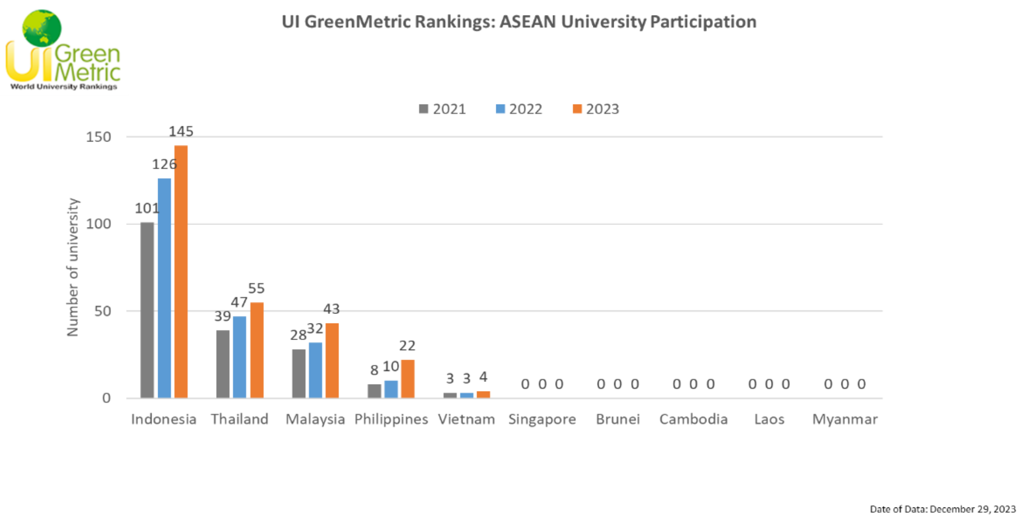

Figure 1. The contribution of ASEAN universities in the UI GreenMetric World University Ranking.

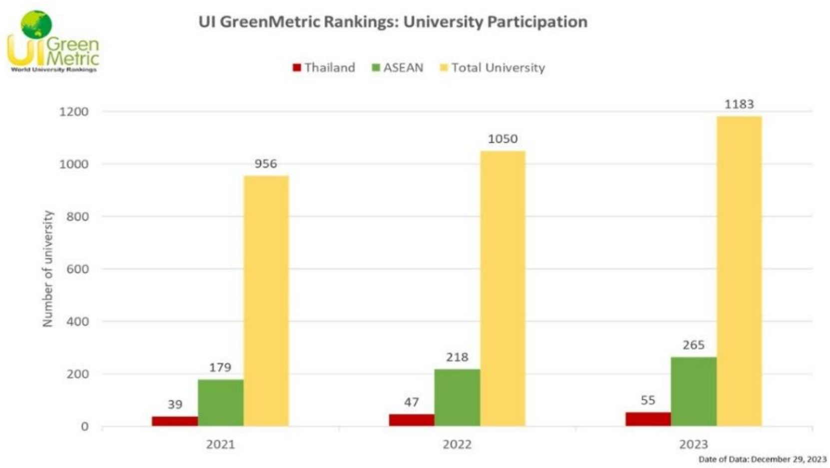

Figure 2. The contribution of Thai universities in the UI GreenMetric World University Ranking.

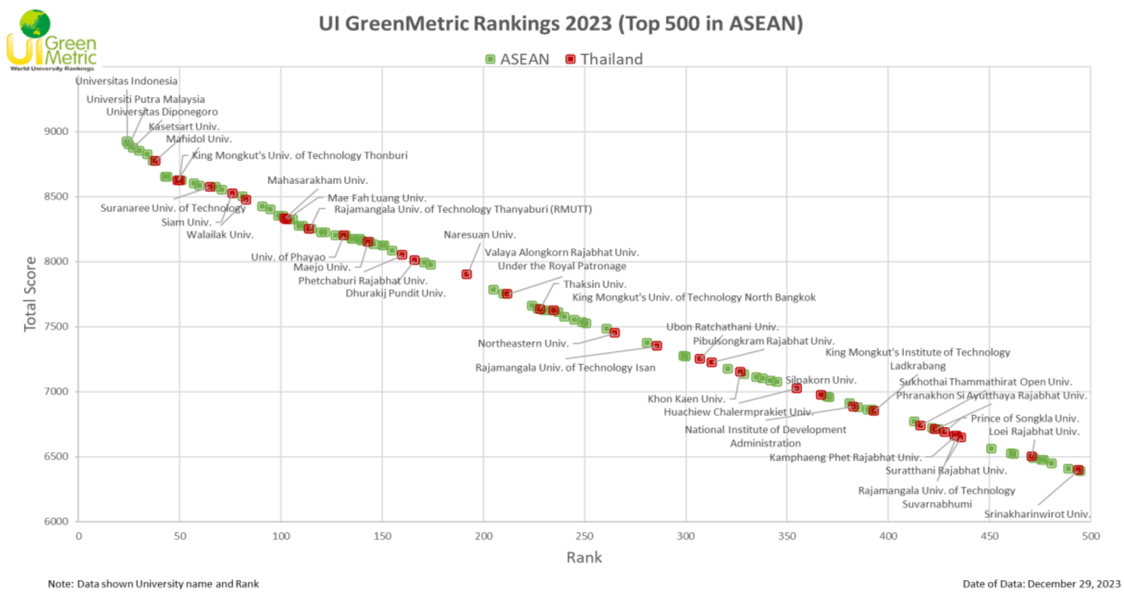

Figure 3. Thai universities performance in the top 500 of UI GreenMetric World University Ranking.

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Figure 4 presents the contribution of Thai universities in the THE Impact Ranking from year 2019 to 2023. The number of Thai universities participating in the ranking has increased annually due to implementation of SDG policy from the Ministry of Higher Education, Science, Research and Innovation of Thailand [20]. The Thai universities performance in THE Impact Ranking 2023 are illustrated in Figure 5. Only 29% of Thai universities were ranked among the top 600 in the THE Impact Ranking year 2023. More than 50% of Thai universities were ranked in range of 1,000-1,000+.

The QS World University Rankings: Sustainability is the latest global ranking focused on sustainability in educational institutions. Contributions from ASEAN universities remain limited (Figure 6). In 2023, only 7 Thai universities participated, increasing to 13 in 2024. Figure 7 illustrates Thai universities performance in the top 500 QS World University Rankings: Sustainability year 2024. Seven Thai universities have secured a position within the top 500 of the QS World University Rankings: Sustainability. The number and performance of Thai universities in this ranking were limited due to a lack of familiarity with the ESG concept, which has not been widely implemented in university policies in Thailand.

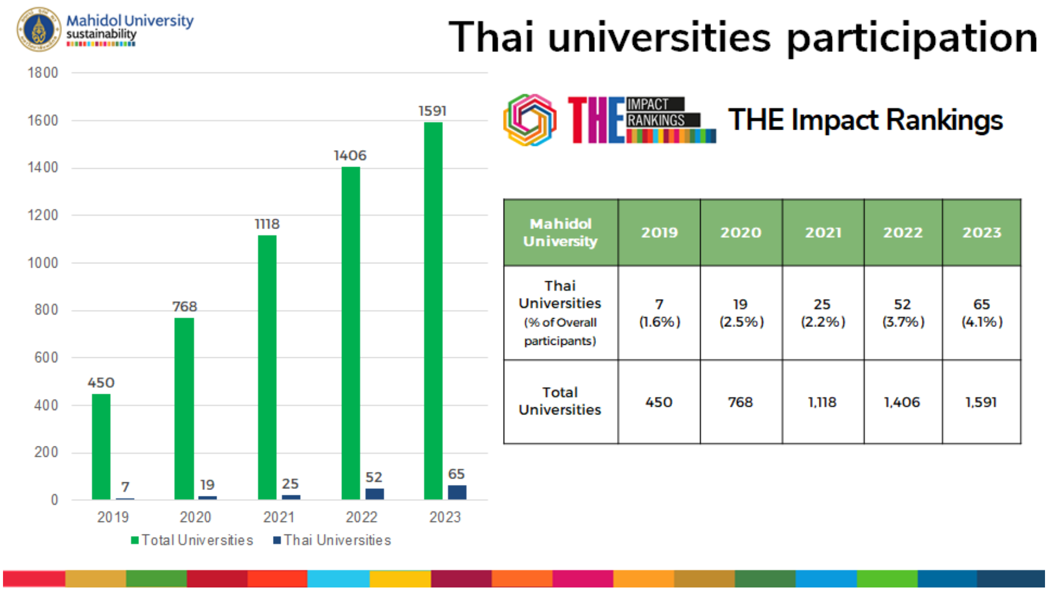

Figure 4. The contribution of Thai universities in the THE Impact Ranking.

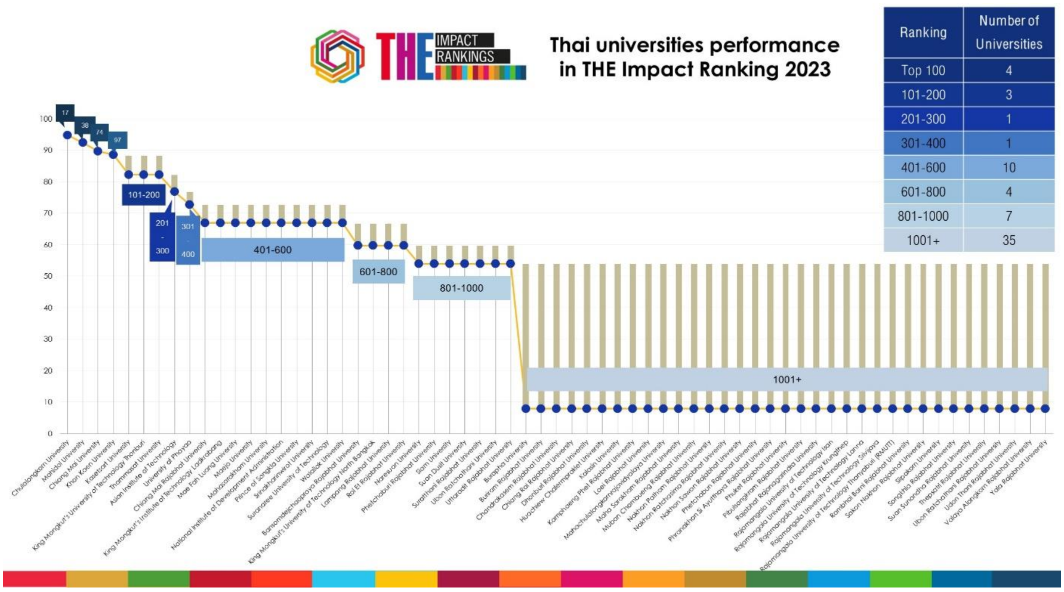

Figure 5. Thai universities performance in THE Impact Ranking 2023.

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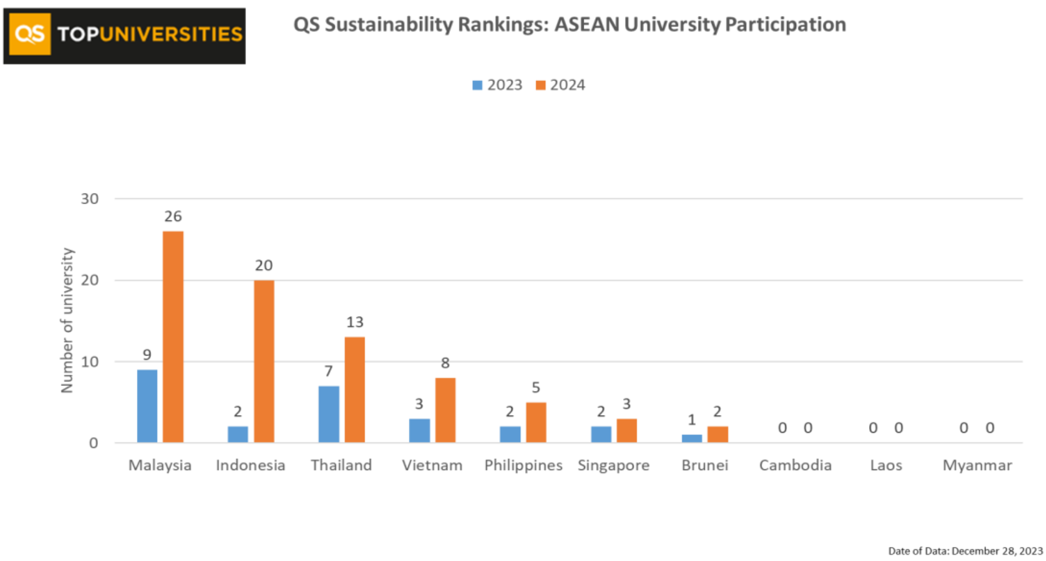

Figure 6. The contribution of ASEAN universities in the QS World University Rankings: Sustainability.

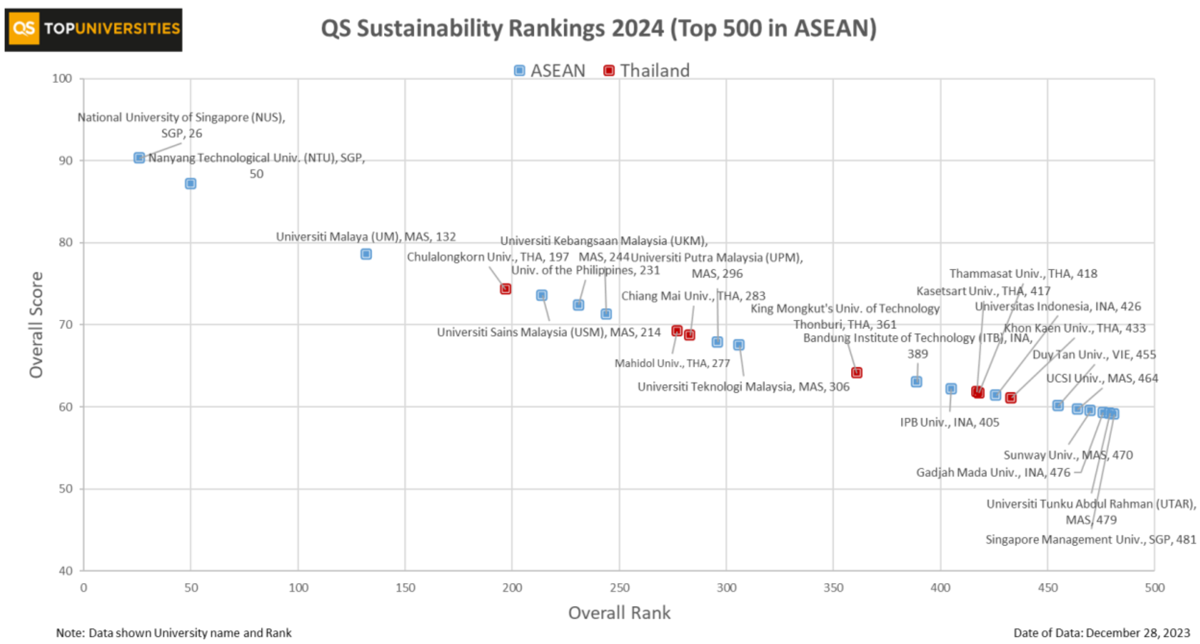

Figure 7. Thai universities performance in the top 500 of the QS World University Rankings: Sustainability.

4. CONCLUSIONS

A global sustainability ranking for educational institutions evaluates universities based on their commitment to sustainability practices and principles. The rankings typically assess factors such as activities contribution to SDGs, environmental impact, social impact, governance, research output, teaching and learning, and campus operations. Thai universities perform relatively well in the UI GreenMetric World University Ranking and THE Impact Ranking. However, there are notable gaps that need addressing in the QS World University Ranking: Sustainability. The growing participation of Thai universities in the global sustainability ranking for educational institutions reflects a commendable commitment to sustainability and ESG principles.

To improve their performance in global sustainability rankings, Thai universities should actively promote sustainable practices across all levels of the institution. Faculties, administrators, staff, and

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students all have a critical role in accelerating progress toward sustainability. This can be achieved by making university operations more environmentally friendly through implementing policies that reduce energy consumption, promote the use of renewable energy, and decrease greenhouse gas emissions. In addition, fostering partnerships with communities and international organizations to create positive social impacts is essential.

The Faculty of Environment and Resource Studies, for example, can contribute its expertise to support Mahidol University's sustainability performance by integrating environmental issues and sustainability into research, curricula, and professional services and training. Promoting sustainable organizational development is another area where the faculty can implement. These strategies align with indicators used to evaluate a university's sustainability efforts and help enhance its overall performance in global rankings.

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The Precautionary Behavior Against PM2.5 Exposure

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ABSTRACT

This article presents an integrated theoretical framework combining Protection Motivation Theory (PMT), Precautionary Principles (PP), and the Precaution Adoption Process Model (PAPM) to analyze precautionary behavior in response to PM2.5 exposure. The framework examines how various information channels influence decision-making processes, from awareness to action, through cognitive assessments and stages of precaution adoption behaviors. By incorporating a public attention index based on internet searches, the framework links individual-level processes and population-level indicators of concern regarding PM2.5 issues. This integration offers insights for environmental health research and risk communication, informing targeted strategies to promote protective behaviors against air pollution and other environmental threats. The framework suggests that effective interventions should be tailored to different stages of awareness and decision-making, considering various information sources and their impacts. Potential applications include enhancing risk communication strategies, targeting specific demographic groups, and addressing barriers to the adoption of protective behaviors.

Keyword: Environmental health behavior/ PM2.5 exposure/ Precaution Adoption Process Model (PAPM)/ Precautionary Principles (PP)/ Protection Motivation Theory (PMT)

1. INTRODUCTION

In recent years, PM2.5 (fine particulate matter with a diameter of 2.5 micrometers or less) has emerged as a serious environmental and public health concern, particularly in developing countries experiencing rapid population growth. PM2.5 can remain suspended in the airborne for long periods and penetrate deep into the respiratory system [1]. Long-term exposure to PM2.5, even at low levels leads to premature mortality and other adverse health effects [2-3]. PM2.5 originate from diverse sources, both outdoor and indoor environments, meaning that even areas with seemingly clean air can have high PM2.5 levels due to indoor activities such as burning wood or coal for heating and cooking [4-5].

In 2019, Thailand ranked as the 28th most polluted country among 98 countries, with an annual average PM2.5 concentration of 24.3 micrograms per cubic meter. By 2020, an annual average PM2.5 concentration was recorded at 18.1 micrograms per cubic meter, moving Thailand to 57th place in the rankings. Thailand's PM2.5 level, while improved, remained four times above the WHO's recommended annual air quality guideline value [6].

To reduce the negative effects of PM2.5 exposure, individuals take preventive actions to manage their exposure levels. These range from short-term proactive defensive behaviors (such as using indoor air purifiers or wearing protective masks outdoors) to longer-term passive avoidance strategies (such as avoiding outdoor activities during high PM2.5 periods or relocating to areas with better air quality) [7].

This article presents a pertinent literature on the integration of Protection Motivation Theory (PMT), Precautionary Principles (PP), and the Precaution Adoption Process Model (PAPM) to develop a conceptual framework for analyzing precautionary behavior in response to PM2.5 exposure. The framework examines how various information channels influence decision-making processes, from awareness to action through cognitive assessments, stages of precaution adoption behaviors. In addition of incorporating a public attention index based on internet searches, the framework links individual-level processes and population-level indicators of concern on PM2.5 issue.

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This integrated framework offers insights for environmental health research, risk communication, and inform targeted strategies to promote protective behaviors against air pollution and other environmental threats. Suggesting that the effective interventions should be tailored to different stages of awareness and decision-making, considering various information sources and their impacts. Policies could focus on enhancing risk communication strategies, targeting specific demographic groups, and addressing barriers to adoption of protective behaviors.

2. LITERATURE REVIEW

Theories and principles provide comprehensive framework for understanding how individuals perceive and respond to environmental and health risks. Protection Motivation Theory (PMT) explains the cognitive processes behind threat assessment and coping strategies. Precautionary Principles advocates for preventive action despite to the threat, which can be observed in both proactive defensive and passive avoidance behaviors. Precaution Adoption Process Model (PAPM) outlines the stages individuals go through when deciding to take protective action. Public Attention Index to PM2.5 Exposure offers a practical measure of public engagement with PM2.5 issues through internet search behavior.

2.1 Protection Motivation Theory (PMT)

The PMT is a psychological framework developed by R. W. Rogers [8]. explores the cognitive processes involved in threat appraisal and coping appraisal, providing insights into how people perceive threats and how threats motivate individuals to adopt protective behaviors. The theory is widely used in health psychology, risk communication, and behavior change interventions.

Threat Appraisal: The cognitive process by which individuals evaluate the level of danger posed by a particular threat, involves with: Perceived severity, refers to individuals' assessment of how serious or severe the consequences of the threat would be if it occurred. Perceived vulnerability, refers to an individuals' belief about their personal likelihood of experiencing the threat.

Coping Appraisal: The cognitive process by which individuals assess their ability to cope with a threat and the effectiveness of the recommended protective action, involves with: Response efficacy, refers to belief that the recommended protective action will be effective in reducing or eliminating the threat. Self-efficacy, refers to individuals' confidence in their ability to perform the recommended protective action. Response costs, refers to perceived costs associated with taking the protective action such as money and time, which are crucial factors to consider.

The theory determines level of protection motivation. A high perceived severity and vulnerability of threat appraisal tends to increase protection motivation, and leading to a higher likelihood to adopting protective behaviors of coping appraisal. Understanding threat appraisal is key for promoting protective behaviors through effective interventions and messaging. Whereas, coping appraisal complements threat appraisal by ensuring individuals feel capable of addressing perceived threats.

2.2 Precautionary Principles (PP)

The PP defines a new standard of risk management when the existence of risk is subject to some scientific uncertainty. It was introduced at the 1992 Rio Conference in Article 15, stated that "where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing effective measures to prevent environmental degradation" [9]. The concept of precautionary is strongly linked to the effect of arrival of information over time in sequential models as well as to the situations in which there is ambiguity over probability distributions [10]. Therefore, the principle as applied to individuals' behavior can be understood through proactive defensive and passive avoidance behavior, which provide a framework for analyzing how individuals respond to potential risks when faced with the threats.

Proactive Defensive Behavior: This refers to actions that individuals take to actively protect themselves from perceived threats. The purpose is to seek control or mitigate the risks while still

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actively engaging with the risk. This involves investing in protective equipment or technology, making backup plans, actively seeking information and expertise, or engaging in developing skills for effective risk management.

Passive Avoidance Behavior: This refers to avoiding situations or activities perceived threat as potentially risky. The purpose is to reduce the risk by limiting exposure to potential threats. This involves avoiding certain activities or environments, opting out of decisions with uncertain outcomes, or maintaining to the plan even the change presents potential risks.

PP has become a key approach in risk management that has been widely adopted and applied across various fields [9-10]. It often discussed in relation to policies and environmental contexts, and can also be applied to studying individual behavior. The principle emphasizes the dynamic nature of sequential decision-making with evolving information. Importantly, it's worth noting that individuals employed proactive defensive and passive avoidance behavior at the same time.

2.3 Precaution Adoption Process Model (PAPM)

The PAPM is a stage-based model that describes the process individuals go through when deciding whether to take protective action against a health threat. The model illustrates series of stages aims to explain how an individual comes to decisions to take action and how individuals translate the decision into action. Unlike other health behavior models, such as the Health Belief Model, the model explicitly includes unawareness and inaction stages and also provides a more detailed description of the process leading up to action [11].

PAPM proposes that individuals' decisions can be categorized into discrete stages. Each stage is characterized by specific patterns of beliefs, behaviors, and informational needs. The specifics of these stages are: Stage 1: Unaware, individuals have no knowledge of the health issue or any related precautionary measures. They are completely unaware of the potential risks or the need for preventive action. Stage 2: Unengaged, individuals have become aware of the health issue but have not yet considered taking action. They recognize the existence of the problem but remain detached from it personally. Stage 3: Undecided, individuals actively consider the advantages of taking precautionary action. They weigh the pros and cons but haven't reached a conclusion. This stage is marked by uncertainty and information-seeking behavior. Stage 4: Decided not to act, some individuals make a conscious decision not to take any precautionary action. This decision is based on their assessment of the situation, which may include perceived low risk, high costs of action, or other personal factors. Stage 5: Decided to act, some individuals have made a firm decision to adopt the precautionary behavior. They have moved past the phase of consideration and are now committed to making a change, although they have not yet begun implementing it. Stage 6: Act, this final stage represents the crucial transition from intention to actual behavior change. In this stage, individuals initiate taking precautionary behavior.

The transition through stages is not always linear, individuals can move backward as well as forward or skip stages. Importantly, awareness of the treats doesn't always lead to engagement or action. PAPM addresses the overlooked early stages and the gap between deciding to act and taking action, enabling more targeted interventions and communication strategies in public health efforts.

2.4 Public Attention Index to PM2.5 Exposure (PAI_PM2.5)

The Public Attention Index for PM2.5 exposure (PAI_PM2.5) is a proxy measure designed to quantifying public attention to PM2.5 issues through online search behavior in Thailand, which reflects public's threat appraisal and information-seeking in response to perceived PM2.5 risks. Individuals' expressions of concern toward the risk from PM2.5 exposure could be detected by online search to locate the resolutions to the problem (internet search behavior) such as reading media news online or searching for relevant information about PM2.5 exposure. The index estimates public attention to PM2.5 issues in Thailand by analyzing internet search data across 77 provinces. The methodology involves collecting monthly search data, selecting terms most correlated with actual PM2.5 levels,

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and calculating the index using a formula that normalizes search volumes. The resulting index is then validated against actual PM2.5 levels, economic and social costs, and willingness to pay for pollution reduction. This method provides a comprehensive understanding of public reactions to air quality changes, enabling policymakers to assess perceptions and develop effective interventions for environmental health.

3. METHODOLOGY

3.1 Conceptual Framework

Figure 1 is the study's conceptual framework presents an integrated conceptual framework of the Precaution Adoption Process Model (PAPM), Protection Motivation Theory (PMT), Precautionary Principles (PP), and Public Attention Index to PM2.5 Exposure (PAI_PM2.5). This integration demonstrates how external factors (exposure levels and information availability) and internal processes (threat perception and coping strategies) work together to move individuals through stages of awareness and action regarding to PM2.5 exposure. It shows both the cognitive progression through the PAPM stages, and the factors influencing this progression in the determinants section.

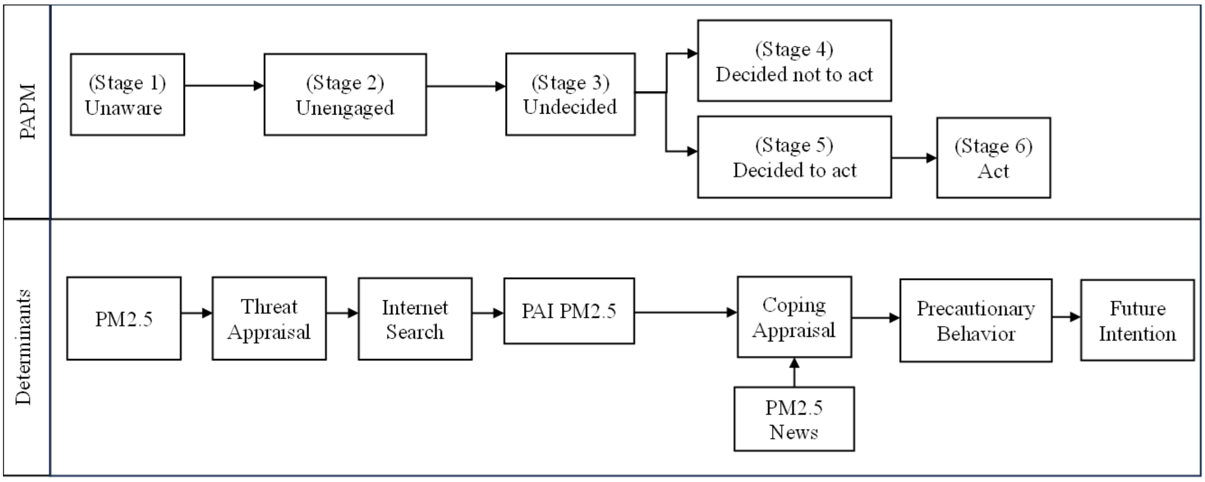

Figure 1. Conceptual Framework

The PAPM section outlines stages from "Unaware" to "Act" which illustrating the progression of awareness toward decision-making. The determinant section outlines the specific determinants related to PM2.5 exposure that influence progression through the PAPM stages, starting with the severity of PM2.5, leading through threat appraisal, internet search, and public attention index for PM2.5 exposure, to coping appraisal, precautionary behavior, and future intention.

The framework highlights the crucial roles of internet searches, news and information on the issue of PM2.5 exposure in shaping public attention, and subsequent decision-making stages. It demonstrates the effects of information sources on precautionary behaviors. Table 1 and Table 2 provide detailed information on how each component in the framework is defined and measured.

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Table 1. The Notation and Definition of Variables in Conceptual Framework

Notation	Definition
PM2.5	The 24-hour average of PM2.5 concentration levels in micrograms per cubic meter. This reflects the actual severity of PM2.5.
Threat Appraisals	A combination of perceptions of the severity of potential harm (perceived severity) and the likelihood of experiencing that harm (perceived vulnerability), towards a perceived severity of the risk from PM2.5 exposure. This derived from PMT.
Internet Search	Internet search term on the issue of PM2.5, the secondary data collected across 77 provinces of Thailand, provided by Google Trends. This reflects the information-seeking behavior related to PM2.5.
PAI_PM2.5	Public attention index for PM2.5 exposure. This reflects the attention on the issue of PM2.5.
Coping Appraisal	An assessment of precautionary action according to the concept of PMT involves assessing the effectiveness of potential protective actions (response efficacy) and ability to successfully implement these actions (self-efficacy).
PM2.5 News	News and information on the issue of PM2.5 which can be categorized according to the source (formal and informal) and types (on-line and off-line).
Precautionary Behavior	An action on how people respond to the threat of PM2.5 exposure. This encompasses proactive defensive behavior such as wearing masks and passive avoidance behavior such as avoiding polluted areas.
Future Intention	An individual's planned future behavior or decisions in response to PM2.5 exposure risks. This reflects how individuals' awareness, perceptions, and chosen precautionary behaviors impact their decision-making regarding future actions related to PM2.5 exposure.

Table 2 illustrates the stages of the PAPM in relation to public awareness and response to PM2.5 pollution threats. The table integrates key concepts from PMT, including threat appraisals and coping appraisals, while also considering internet search behavior and precautionary actions. Each of the six stages is clearly defined and associated with specific determinants, providing a comprehensive view of how people progress in their understanding and response to PM2.5 exposure risks.

Table 2. Description of Conceptual Framework

PAPM Stages	Determinant	Definition
Stage 1: Unaware	- PM2.5	In this initial stage, individuals have no knowledge or awareness about the harmful effects of PM2.5 exposure or how to protect themselves from it. The only relevant factor here is the actual PM2.5 level which is defined as the 24-hour average of PM2.5 concentration levels in micrograms per cubic meter. At this point, despite being exposed to PM2.5, individuals have not formed any opinions about it due to the lack of awareness.
Stage 2: Unengaged	- Threat Appraisals - Internet Search	As individuals move into this stage, they develop some knowledge and awareness about the harmful effects of PM2.5 and potential protective measures, but not yet become actively engaged with the issue. Because, an individual may believe that the issue is irrelevant to them. After perceiving the risk from PM2.5 exposure (called Threat Appraisals in PMT), individuals express of concern toward the risk from PM2.5 that could be detected by online search to locate the resolutions to the problem (called Internet Search Behavior) such as reading media news online or searching for relevant information about PM2.5 exposure. The Public Attention Index for PM2.5 (PAI_PM2.5) is formed at this stage, reflecting the level of public attention to the PM2.5 issue as measured by internet search behavior.
Stage 3: Undecided	- PM2.5 News - PAI_PM2.5	Individuals have knowledge and awareness about harmful and protective measures but are uncertain about taking action due to limited knowledge. Therefore, individuals in this stage actively seeking information which influenced by public attention for PM2.5 (PAI_PM2.5) and news on the issue of PM2.5 (PM2.5 News).
Decision making (Stage 4 and 5)	- Coping Appraisal - Precautionary Behavior	Once individuals perceive harmful and engages with the problem of PM2.5, they will decide whether or not to act in such precautionary activities based on their preference to cope with the PM2.5 risk. This decision-making process, known as Coping Appraisals in PMT.

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PAPM Stages	Determinant	Definition
Stage 4: Decided not to act		Individuals being aware and engaged, some decide not to take protective action against PM2.5 exposure. This could be due to low perceived threat, low response efficacy, or low self-efficacy. The decision in this stage is influenced by their assessment of coping strategies
Stage 5: Decided to act		Individuals being aware and engaged, some decide to take preventive action against PM2.5 exposure, which based on adopted precautionary preference. This decision is influenced by their evaluation of effective coping strategies.
Stage 6: Acting	- Future Intention	In this final stage, where decisions turn into actions, and these actions shape future intentions regarding PM2.5 exposure response. Individuals have taken preventive action to protect themselves against PM2.5 exposure. Their behavior influences future intentions regarding PM2.5 exposure.

3.2 Econometric Model

Logit regression is a statistical method used for examining the relationship between a binary dependent variable and a set of independent predictor variables that can be continuous or categorical [12]. Let there be N observations and k characteristics (exogeneous variables) on each observation, $(n = 1 \ldots\ldots N)$. The dichotomous qualitative response model is defined as:

$$y_n^* = X_n\beta + u_n \qquad ;(n = 1, \ldots, N) \qquad (1)$$

$$y_n = \begin{bmatrix} 1 \; if \; y_n^* \geq 0 \\ 1 \; if \; y_n^* < 0 \end{bmatrix}$$

Where; β denotes the $k \times 1$ vector of unknown coefficients. u_n denotes the error term. X_n denotes the $1 \times k$ vector of exogenous variables. y_n^* denotes the unobservable dependent variable. The observable dependent indicator variable y_n takes the value 1 with probability p_n and the value 0 with probability $1 - p_n$. Due to the assumption on error term is $i.i.d$ of logit regression. Thus, the logistically distributed p_n is given by:

$$p_n = \frac{1}{1 + \exp(-X_n\beta)} \qquad (2)$$

3.3 Empirical Model

For the empirical analyses, this study employs the Logit regression to analyze precautionary behavior in response to PM2.5 exposure, with an emphasis on how various information channels influence these behaviors. The models are defined as:

$$BEHAVIOR_n^k = \beta_1 PAIPM25_n + \beta_2 PM25_n + \beta_3 NEWS\_SOURCE_n^k + \beta_4 NEWS\_TYPES_n^k + \beta_5 DEMOGRAPHIC_n + \beta_6 CONTROL_n + u_n \qquad ;(n = 1, \ldots, N) \qquad (3)$$

$$BEHAVIOR_n^k = \begin{bmatrix} 1 & if & BEHAVIOR_n^k \geq 0 \\ 0 & if & BEHAVIOR_n^k < 0 \end{bmatrix}$$

Where; $BEHAVIOR_n^k$ denotes types k of precautionary behavior against PM2.5 exposure of individual n, consists of proactive defensive and passive avoidance behavior which is dummy variable equal to 1 if individuals n adopts proactive defensive behavior and 0 if individuals n adopts passive avoidance behavior. PAI_PM25_n denotes public attention index for PM2.5 issue of individual n. The value is presented in a range of 0 to 100. $PM25_n$ denotes the 24-hour average of PM2.5 concentration levels in micrograms per cubic meter of the province in which individual n is inhabited.

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$NEWS\_SOURCE_n^k$ denotes PM2.5 news from source k that individuals n perceive, consist of formal source (e.g. government departments and agency, news agency, media broadcasting, etc.) and informal source (e.g. friends and relatives, community leader, influencer, youtuber, etc.) which is dummy variable equal to 1 if individuals n perceive PM2.5 news from formal source and 0 if individuals n perceive PM2.5 news from informal source. $NEWS\_TYPE_n^k$ denotes types k of PM2.5 news that individuals n perceive, consists of on-line and off-line media which is dummy variable equal to 1 if individuals n perceive PM2.5 news from on-line media, and 0 if individuals n perceive PM2.5 news from off-line media.

$DEMOGRAPHIC_n^k$ denotes group of variables that represents demographic characteristic of individual n, consists of $MALE_n^D$ is gender of individual n which is dummy variable equal to 1 if individual n is male, and 0 if individual n is female; AGE_n is age of individual n; $SICKNESS_n^D$ is health condition of being respiratory patient of individual n which is dummy variable equal to 1 if individual n is being a respiratory patient, and 0 if otherwise; $MARRIED_n^D$ is marital status of individual n which is dummy variable equal to 1 if individual n is currently married, and 0 if otherwise. $EDUCATION_n^D$ is highest education attainment level of individual n in group of no educational attainment, primary school, secondary school, high school, undergraduate, and graduate. $OCCUPATION_n^D$ is occupation type of individual n in group of students, public servant, full-time employee, self-employed, farmer, part-time employee, retired, and unemployed.

$CONTROL_n^k$ denotes group of control variables of individual n that consists of $LN(INCOME\_R)_n$ is log total income of individual n; $LN(INCOME\_HH)_n$ is log total income of individual n's household; $CORES(ELDERLY)_n^D$ is coresident status of individual n and elderly aged 60 and over in the same house dummy variable equal to 1 if individual n live with elderly aged 60 years and over, and 0 if otherwise; $CORES(CHILDREN)_n^D$ is coresident status of individual i and children aged below 12 years in the same house which is dummy variable equal to 1 if individual n live with children aged below 12 years, and 0 if otherwise; $CORES(SICKNESS)_n^D$ is coresident status of individual n and respiratory patient in the same house dummy variable equal to 1 if individual n live with respiratory patient, and 0 if otherwise. u_n denotes the error term.

4. DISCUSION

The analyzing of human cognition and behavior of are inadequate under the explanation by a single theory, necessitating multiple perspectives for comprehensive understanding more efficiently. This article presents an integrated framework of Protection Motivation Theory (PMT), Precautionary Principles (PP), and the Precaution Adoption Process Model (PAPM) that provides a comprehensive view of how various information channels influence individuals' perceptions, motivations, and adoption of precautionary action throughout the decision-making process. PAPM explains the transition process of how individuals adopt precautionary behavior, from being unaware of a risk (PM2.5 exposure) to taking or not taking the precautionary action. While PMT explains how individuals assess PM2.5 threats and protective measures based on perceived severity, vulnerability, and coping ability in determining their adoption of precautionary behaviors.

Contributions of the integrated framework in combining cognitive processes of the risk from PMT which offering insights into why some take action against PM2.5 risks while others do not, the response against the risk from PP, and behavior change stages from PAPM. Firstly, this reveals how differences in information types and sources impact behavior across different awareness and decision-making stages, which helps identify critical points for more targeted and effective public health communication to promote health protective policies related to the risk from environmental, especially from PM2.5 exposure and potentially other environmental health-related behavior. Second, it enables a more dynamic analysis of behavior change, examining how factors such as risk perception and efficacy beliefs evolve over time and influence progression through the PAPM stages. Third, this framework also corporate contextual factors, demographic characteristics, to illustrating their potential impact on both cognitive processes and stage progression. Last, the integration bridges

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individual-level cognitive processes (PMT) with population-level indicators (public attention index for PM2.5 exposure), offering a more comprehensive view of public response to the risk from PM2.5 exposure. This novel integration contributes to the theoretical framework of health behavior change and potentially informing future research in environmental health and related fields.

5. CONCLUSION

This article presents an innovative integrated theoretical framework combining Protection Motivation Theory (PMT), Precautionary Principles (PP), and the Precaution Adoption Process Model (PAPM) to comprehensively understand precautionary behavior against PM2.5 exposure. This integration offers key contributions to environmental health behavior research, including comprehensive behavioral analysis, insights into information impact across awareness stages, dynamic behavior change analysis, incorporation of demographic influences, and bridging individual and population-level indicators.

The framework enhances the understanding of how individuals respond to environmental health risks, particularly PM2.5 exposure, from initial awareness to taking preventive action. This offers a foundation for future research in environmental health, potentially informing more effective public health interventions and policy development. Therefore, understanding how individuals progress from unawareness to action on PM2.5 risks can inform strategies for promoting protective behaviors and policies addressing air quality and other environmental health concerns.

Conflict of Interest

The authors declare that there is no conflict of interest.

Acknowledgments

This article, titled "The Precautionary Behavior Against PM2.5 Exposure" represents a crucial component of the doctoral dissertation "Household’s Defensive Behavior for Reducing Air Pollution Exposure from PM2.5 in Thailand" by Miss Pailin Suntigul submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy Program in Economics (International Program) at Chulalongkorn University.

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Strategies for Achieving Net Zero Emissions in the Beverage Industry: A Case Study from Thailand's Carbon Footprint Analysis

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ABSTRACT

Parties to the United Nations Framework Convention on Climate Change (UNFCCC) are required to provide detailed accounting of their country's greenhouse gas emissions from various activities for reporting to the UNFCCC secretariat. The latest assessment of Thailand's greenhouse gas emissions shows that the energy sector is the largest emitter, followed by the agricultural sector, the industrial processes and product use sector, and the waste sector. The global beverage industry is a significant contributor to greenhouse gas emissions and climate change, with the majority of emissions stemming from raw material procurement, production processes, and transportation activities. The production process, in particular, relies heavily on resources and energy from fossil fuels. In the case of alcoholic beverages, fermentation by-products generate a substantial amount of carbon dioxide emissions during production. Various methods and strategies have been proposed to mitigation greenhouse gas emissions in the beverage manufacturing industry, including the use of bioenergy as a substitute for fossil fuels. Installing solar cell to reduce electricity consumption aligns with energy efficiency and energy saving policies. Waste management based on circular economy principles, along with expanding forest areas for carbon sequestration in line with carbon capture and storage guidelines are key strategies. These methods support the goals of carbon neutrality and achieving net zero emissions in the future.

Keyword: Carbon Neutrality/ Greenhouse Gases/ Bioenergy/ Carbon Capture Storage/ Net-Zero Emissions

1. INTRODUCTION

The global beverage industry significantly contributes to greenhouse gas emissions and climate change, with the majority of emissions arising from raw material sourcing, production processes, and transportation activities. The production process, in particular, depends heavily on resources and energy derived from fossil fuels, which are burned to power machinery. In the case of alcoholic beverages, fermentation by-products further contribute to carbon dioxide emissions during production.

Alcohol production and consumption in Sweden contribute to climate change, yet this is rarely discussed. The environmental impact of alcohol, from its production processes to the resources consumed and waste generated, plays a role in the ongoing climate crisis, but its effects often go unnoticed. A report titled Climate Impacts of Consumption in Sweden, produced by the state research institute RISE in collaboration with the Karolinska Institute, examined the dietary habits (including food, beverages, and alcohol) of 50,000 Swedes. The findings reveal that alcohol is a significant contributor to Sweden's overall climate impact. Alcohol accounts for 3% of the average per capita greenhouse gas emissions from food and drink consumption, with wine being the largest emitter of greenhouse gases among all alcoholic beverages [1].

According to the BBC's climate change food calculator, alcohol-particularly beer-contributes to climate change [2]. When calculating the emissions from consuming one pint (568 ml) of beer, or drinking 3 to 5 times per week, the impact becomes evident. This level of consumption aligns with the low-risk drinking guidelines set by the National Health Service. It was found that this level of alcohol consumption still results in greenhouse gas emissions of up to 139 kilograms per year. Additionally, a significant portion of emissions from the beverage category comes from tea, coffee, and alcoholic beverages. When combined with cake, biscuits, and confectionery, it was revealed that 24% of all food-related greenhouse gas emissions come from mostly non-essential foods and drinks. Therefore, avoiding

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alcoholic beverages not only promotes health and safety but also plays a key role in addressing climate change. Reducing alcohol consumption helps lower greenhouse gas emissions associated with the production, packaging, and transportation of alcoholic beverages.

Thailand has conducted a significant study to assess the carbon footprint of alcoholic beverages, titled an assessment of the carbon footprint of beer products [3]. The study assessed the carbon footprint of beer products and proposed strategies to reduce greenhouse gas emissions from the brewing process. Using life cycle assessment based on cradle-to-grave (business-to-consumer: B2C) principles, the evaluation covered bottled beer (620 ml), canned beer (320 ml), and keg beer (30 liters). The study found that the carbon footprint of bottled beer, canned beer, and keg beer is 0.3602, 0.1184, and 5.9021 kilograms of carbon dioxide equivalent per unit, respectively. The raw material acquisition process contributes the most to greenhouse gas emissions, accounting for 47%, followed by the production process at 36%. To reduce these emissions, the study recommends focusing on increasing the reuse of old bottles, minimizing damage during bottle washing, and increasing the use of natural gas for steam production instead of fuel oil.

The global food and beverage system does not operate in isolation; rather, like many other systems, it is interconnected and integrated with other sociotechnical systems [4]. Agriculture and food production are closely linked sociotechnical systems; however, in this context, we consider them a subset of the global food and beverage system. Interconnections with other significant sociotechnical systems are illustrated in Fig. 1. The energy sociotechnical system-including coal mines, power plants, transmission grids, heat networks, gas pipelines, and electricity distribution networks- supplies a significant portion of the electricity, heat, steam, and raw fuels (such as natural gas and oil) essential for food and beverage production, with the food sociotechnical system as a whole accounting for approximately 30% of global energy consumption. The transportation system encompasses automobiles, delivery trucks, as well as roads, marine transport, and ports.

The United Kingdom the food industry sits as a moderately energy intensive industry compared to others, and also an industry with moderately high energy costs. That is, the food and beverage industry is more energy intensive than printing, and spends more on energy costs as a percentage than motor vehicle manufacturing, printing, or textiles [5]. The energy intensive aspects of the industry cut across food supply and agriculture to preparing, transporting, packaging and serving food or beverages.

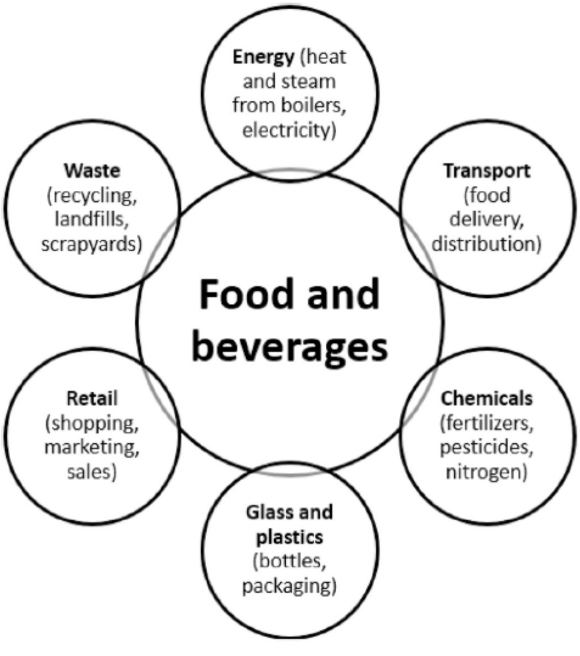

Figure 1. Intriguing connections between food and beverages and other technological systems [6].

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Table 1 Multi-scale solutions to sustainability challenges across three food and beverage products.

Part of system	Beer	Soft drinks
Raw materials	Barley agriculture: Improved irrigation practices and fertilizer management	Sugarcane agriculture: Effective land management and judicious fertilizer use
Food processing	Beer brewing:: Enhanced water recovery and energy-efficient mashing and malting	Sugarcane processing: Wastewater treatment and management of slurry and sludge
Packaging and retail	Glass bottling: Eco-friendly packaging and refrigeration optimization	Plastic bottles: Incorporating recycled materials and steering clear of polyethylene terephthalate
Consumer use	Households: Enhancing the efficiency of domestic refrigerators	Opting for low- to no-sugar alternatives (e.g., diet soda)
End-of-use and waste	Recovery: Recycling of bottles	Recycling initiative: Bottle recovery

Source: Authors modification of [6]

Thailand has driven the policies and strategies of nation. To continuously reduce the impact of global warming by creating a master plan to support climate change 2015-2050 and a road map for reducing greenhouse gases for the country 2021-2030. Which is a policy mechanism for operations in order for the country to achieve its greenhouse gas reduction goals as set forth [15]. Net zero greenhouse gas emissions but there is still a part that is a technology road map. Utilization and carbon storage to analyse the development status of Carbon Capture Utilization and Storage: CCUS technology, technology trends. Marketing information Including the needs of the energy and industrial sectors. and analyse the connection between carbon capture and storage (CCS) technology and carbon capture and utilization (CCU) technology in the world and Thailand. As well as presenting important policy issues, goals, directions, guidelines for research and development of CCUS technology, and a time frame for solving challenging issues appropriate to the Thai context, and support the goal of net zero carbon emissions appropriate to the Thai context [7].

This is because forests play an important role in the world's carbon balance. It is both a storage and a source of carbon release, causing it to affect changes in the amount of carbon dioxide in the atmosphere. The forest ecosystem accumulates carbon in both the trees and the soil through the process of plant photosynthesis. The breathing of living things and the decomposition of microorganisms in the form of carbon dioxide. Carbon stored in trees and soil has been defined as natural carbon stores divided into five sources, including above-ground carbon storage sources, underground carbon deposits, carbon stores in dead trees, carbon stores of plant remains, and carbon storage in the soil [14].

2. METHODOLOGY

2.1 Assessing the carbon footprint of the organization

The process of evaluating an organization's carbon footprint involves preparing an inventory of greenhouse gas emissions to determine the overall carbon footprint. This assessment consists of 5 main steps: [8]

1. Defining Organizational Boundaries: This step establishes the limits within which the organization evaluates and collects data on greenhouse gas emissions and absorption. This includes emissions from beverage production facilities, such as those producing beer, soda, and drinking water.

2. Defining Operational Boundaries: This step involves establishing the operational boundaries that reflect greenhouse gas emissions associated with each activity within the organization's limits. emissions are scope into three types:

Scope 1: Direct emissions and absorption of greenhouse gases generated by the organization. This includes emissions arising directly from various activities, such as stationary combustion, combustion during transport, emissions from the production process, leakage of substances, and other related activities.

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Scope 2: Indirect emissions and absorption of greenhouse gases associated with energy use, which includes emissions from the generation of electricity, heat, or steam imported for use within the organization.

Scope 3: Other indirect emissions and absorption of greenhouse gases that occur from activities not included in Scope 1 and Scope 2. Organizations can measure or evaluate these emissions for additional reporting, though it is not mandatory. Examples include emissions from general solid waste, paper usage, raw material transportation, product distribution, employee commuting, off-site corporate business activities, and packaging materials.

3. Identification of Greenhouse Gas Emission Sources: This step involves identifying the sources of greenhouse gas emissions and evaluating the organization's carbon footprint. It includes assessing emissions sources, collecting data, and utilizing GHG emission factors to calculate greenhouse gas emissions (as shown in Equation 1).

$$\text{GHG (kg } CO_2e) = \text{Activity data} \times \text{EF (kg } CO_2e) \quad (1)$$

Where; GHG represents the total amount of greenhouse gases emitted. Activity data refers to information about activities that generate greenhouse gas emissions. EF (GHG Emission Factor) denotes the factor used to quantify greenhouse gas emissions.

4. Preparation of Greenhouse Gas Inventory: This step involves gathering data to calculate the total amount of greenhouse gases from all three activities. It includes categorizing and summarizing the types of greenhouse gas emissions.

5. Assessing and Managing Uncertainty: This critical step evaluates the quality of the collected data on greenhouse gas emissions and absorption. It addresses uncertainties that arise from calculations using greenhouse gas emission factors sourced from various references.

2.2 Mitigation strategies to reduce greenhouse gas emissions for achieving carbon neutrality

Proposing a plan to reduce greenhouse gas emissions to achieve carbon neutrality in the drinking water industry, by assessing the company's structural readiness, physical characteristics, and the availability of green spaces at each plant. To implement projects aligned with the company's chosen policy for reducing emissions and enhancing carbon storage, initiatives may include the bioenergy project, the expansion of solar panel installations, energy efficiency and conservation projects, circular economy and waste management initiatives, and carbon capture and storage efforts.

3. RESULTS AND DISCUSSION

3.1 Sources of greenhouse gas emissions in the beverage industry

The results of a study on emission sources and greenhouse gas assessments in the beverage industry, conducted across 8 plants- including beer, soft drink, and drinking water factories- identified greenhouse gas emissions categorized by scope as follows: Fig. 2 The greenhouse gas emissions assessment revealed that Plants A, B, and C, which are all alcoholic beverage production facilities, have high emissions. In Scope 1, these emissions primarily result from the burning of fossil fuels to power machinery, coupled with significant carbon dioxide generation from the alcohol fermentation process. Scope 2 greenhouse gas emissions were found to be relatively high, primarily due to the significant use of electricity, which is a critical utility in the production process. In Scope 3 for all plants, greenhouse gas emissions were exceptionally high. This is largely due to the resource- intensive nature of the beverage production industry, which involves activities such as raw material acquisition, transportation of raw materials, waste generation, and product distribution logistics.

Scope 1: The list of sources includes fuel combustion in steam generators, emergency fire extinguisher fuel combustion, generator fuel combustion, maintenance unit fuel combustion, chemical combustion in the laboratory, fuel combustion from corporate vehicles, carbon dioxide emissions from

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alcohol fermentation processes, methane emissions from septic tanks, hydrofluorocarbons; HFC emissions from refrigerants, and nitrous oxide emissions from fertilizer use activities.

Scope 2: List of electrical energy usage from purchase

Scope 3: This includes emissions from purchased goods and services, tap water consumption, paper usage in the office, chemical use, transportation and distribution, waste generated from operations, business travel, employee commuting, and additional transportation and distribution activities.

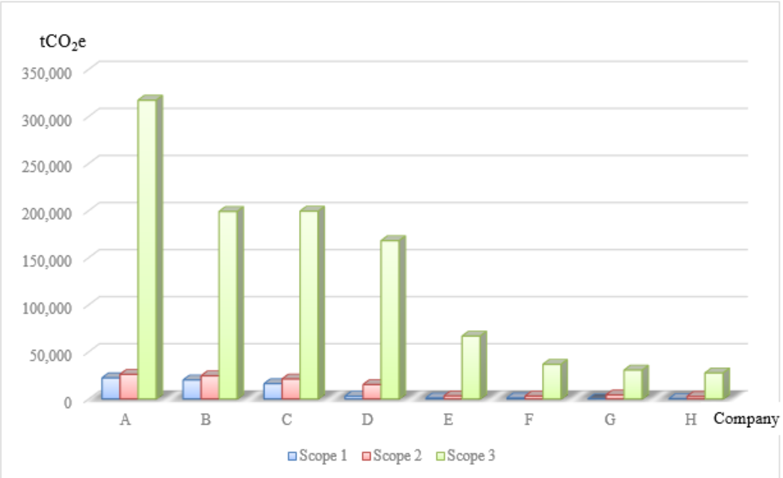

Figure 2. Results of the study on emission sources and greenhouse gas emissions in the beverage Industry

3.2 Reducing greenhouse gas emissions in the beverage industry

3.2.1 Bioenergy

Bioenergy with Carbon Capture and Storage (BECCS) refers to any energy pathway in which CO_2 is captured from biogenic sources and permanently stored. Currently, approximately 2 million tons of biogenic CO_2 are captured annually, primarily in bioethanol applications. Based on projects currently in the early and advanced stages of deployment, CO_2 capture from biogenic sources could reach approximately 60 million tons per year by 2030. However, this falls significantly short of the nearly 185 million tons of CO_2 per year projected to be captured from biogenic sources by 2030 in the Net Zero Emissions by 2050 scenario. To convert recent momentum into operational capacity, targeted support for carbon dioxide removal (CDR), particularly for BECCS, will be essential.

Energy content in solid, liquid, and gaseous products derived from biomass feedstock's and biogas, including solid bioenergy, liquid biofuels, and biogas. The use or production of bioenergy products in a way that prevents CO_2 generated by combustion, oxidation, or fermentation from entering the atmosphere and contributing to climate change. Since the captured carbon is biogenic in origin- having integrated into plant matter relatively recently, often within the last 1-2 years- it can be considered removed from the atmosphere, thus reducing total greenhouse gas levels, if it is permanently sequestered, for instance, through geological CO_2 storage. Bioenergy with carbon capture and storage entails capturing and permanently storing CO_2 from processes that convert biomass into fuels or directly burn it to generate energy. Since plants absorb CO_2 during their growth, this approach effectively removes CO_2 from the atmosphere [9].

Organic by-products and waste can be utilized for biogas production through anaerobic digestion. This methane-rich gas can fuel combined heat and power plants, satisfying both thermal and electrical demands. Furthermore, agricultural residue biomass can serve as an auxiliary biofuel. In the beverage production industry, there is potential to apply bioenergy-related technologies to manage raw materials from the alcohol fermentation process. The waste generated can be utilized to produce biomass energy or serve as the primary raw material for biogas production plants. This approach emphasizes waste

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management by reducing methane emissions, rather than disposing of waste in landfills or through composting.

3.2.2 Solar cell

The environmental impact of energy-intensive food and beverage manufacturing has come under increased scrutiny, driven by rising regulatory pressures and shifting consumer preferences that compel industries to decarbonize. As one of the primary sources of greenhouse gas emissions in the agri-food value chain, manufacturing operations represent a crucial lever for enabling the sector's transition to net-zero and enhancing climate resilience. In this context, integrating green energy solutions that reduce emissions by harnessing renewable, low-carbon energy sources present a compelling value proposition for food and beverage producers.

Solar photovoltaics can be installed on the roofs of processing plants, warehouses, and administrative buildings to generate emission-free power for local use. Any surplus energy produced can be fed into the grid, providing additional revenue through net metering.

3.2.3 Energy efficiency and energy saving

Many applications in the food and beverage industry, such as fans, pumps, compressors, and conveyor belts, typically operate at partial load. However, they often rely on mechanical control methods like valves, brakes, and throttles to regulate speed. In such systems, the motor performs more work than necessary, leading to energy loss through mechanical speed control.

Reduce electrical energy consumption and CO_2 emissions through energy efficiency solutions and services. Plug-and-play digital solutions securely gather data from applications, offering deeper insights into operational status and providing a true indication of the condition of the installed equipment. By collecting and analyzing information directly from your powertrain, cloud-based technologies help to understand and predict potential downtime, enabling maintenance services to be scheduled at the most convenient times [10]. Switching forklift fuel from fossil fuels to electricity to reduce greenhouse gas emissions within the organization.

3.2.4 Circular economy and waste management

One effective approach is to adopt a circular economy model. This involves shifting away from a linear production and consumption model-where resources are used and then discarded-to a more circular system that emphasizes the reuse and recycling of materials. Embracing a circular economy can yield numerous benefits for the beverage industry, including waste reduction, cost savings, and the creation of new revenue streams. Additionally, it can help mitigate the environmental impact of production by lowering carbon emissions and conserving water resources. In this context, beverage industry companies must adopt a holistic approach to sustainability, examining their entire supply chain-from raw materials to consumer disposal. Implementing circular economy principles can foster a more sustainable and resilient beverage industry that benefits both the environment and financial performance.

As we confront global challenges such as climate change and resource depletion, the beverage industry, along with other sectors, must adopt a proactive approach to sustainability. Embracing circular economy principles can be a powerful strategy in achieving this goal and fostering a more sustainable future for all. The emergence of the circular economy highlights the importance of upcycling materials to achieve zero waste and extending a product's life cycle for as long as possible-countering the prevalent use of disposable plastic packaging in the food and beverage industry. This shift has illuminated the environmental impact of companies' various practices and manufacturing processes [11].

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3.2.5 Carbon capture storage

Carbon capture utilization and storage (CCUS) is a term that refers to a group of technologies that can help achieve a variety of global energy and climate goals. CCUS entails the extraction of CO_2 from large point sources such as power plants or from industrial facilities, which run on fossil fuels and biomass. CO_2 can also be directly extracted from the atmosphere. If the CO_2 is not used on site, then the gas is compressed and transferred using a pipeline or other means to be used in a variety of applications. The CO_2 is stored via injection of the gas deeply into geographic formations such as depleted oil and gas reservoirs or saline formations [12], [13]. Expanding green spaces and planting forests within the factory, or establishing a Memorandum of Understanding (MOU) with relevant agencies and forest landowners, are effective methods for offsetting the organization's carbon emissions.

4. CONCLUSIONS

Environmental sustainability and the fight against climate change share the common goal of reducing greenhouse gas emissions, but they differ in scope and approach. Understanding the distinction between carbon neutrality and net zero emissions is essential for grasping their roles in addressing climate change. Carbon neutrality refers to balancing the amount of carbon dioxide released into the atmosphere with the amount removed through reforestation, renewable energy use, or purchasing carbon credits. It focuses specifically on offsetting carbon emissions.

Net zero emissions, on the other hand, addresses all greenhouse gases that contribute to global warming, not just carbon dioxide. Achieving net zero is crucial because it targets the reduction of all emissions responsible for rising global temperatures. Both concepts are critical but vary in their scope and impact such as, climate mitigation, environmental responsibility, economic opportunities and social equity.

In summary, the beverage industry can play a pivotal role in achieving carbon neutrality and net-zero greenhouse gas emissions. By adopting these key strategies, the industry contributes to combating climate change and supporting the transition to a more sustainable future. This begins with actively participating in the reporting of its greenhouse gas emissions and implementing measures for carbon sequestration.

Acknowledgement

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Assessment of Greenhouse Gas Emissions and Reduction Strategies: A Case Study of Foundry Plant in Thailand

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ABSTRACT

This study aimed to assess the potential greenhouse gas (GHG) emissions from a foundry or metal casting company. The primary sources of emissions used to analyze were the production processes, energy consumption, and associated GHG emissions, focusing on electricity usage from handling raw materials to producing the finished product. Various production units used electricity, including furnaces, casting equipment, and other systems. This process followed the Intergovernmental Panel on Climate Change (IPCC) guidelines and relevant emission factors to calculate the amount of GHG emissions caused by electricity use. Key emission hotspots were identified, and actionable strategies to mitigate its environmental impact through GHG reduction were also proposed. The collected data showed that the average electric power consumption for the entire plant in 2022 and 2023 was 640,644 and 550,183 kWh, respectively, for the casting product. Foundry plants emitted 3,725,145 and 3,125,480 kg CO_2eq from their electricity consumption in 2022 and 2023, respectively. The average carbon intensity is 0.489 kg/kWh; however, the carbon intensity of iron-casting production varies based on the production process, raw material, and energy mix. It found that induction melting furnaces consumed more electrical power than other production processes, accounting for 71.22% of total electrical power consumption and 67.28% in the plant. Optimizing furnace efficiency and installing a solar rooftop as a captive power plant could reduce the electrical power consumption.

Keyword: Foundry/ Greenhouse gas emission/ Greenhouse gas reduction/ Carbon intensity

1. INTRODUCTION

The urgency of addressing climate change is undeniable. As the world grapples with the increasingly severe impacts of global warming, it's imperative that every industry sector take concrete steps to reduce its greenhouse gas (GHG) emissions. Hannah et al. [1] reports a 73.2% increase in energy usage in electricity, heat, and transport, a 24.2% increase in energy use in industry, and a 7.2% increase in energy-related emissions from the manufacturing of iron and steel. The foundry industry, a key player in the global manufacturing supply chain, is no exception. This research paper examines the potential GHG emissions from foundry, a metal casting company located in Thailand, highlighting the urgent need for sustainable practices within the industry. Foundries, by their very nature, rely heavily on energy-intensive processes. Melting, casting, and finishing operations often involve high temperatures, demanding significant electricity consumption, which in turn translates to significant GHG emissions.

Casting industry is among the weighty CO_2-emitting industrial areas; therefore, every action in the direction of sustainability plays a vital role in carbon emissions reduction Mitterpach et al. [2]. The foundry minimized the overall impact of its main processes on environmental quality by implementing environmental measures, particularly its technological methods. These methods focused on reducing the demand for raw materials and other materials, energy consumption, release of emissions to the atmosphere, water use, and creation and production of solid waste, as well as increasing the quality of drained water.

The implementation of the EU Carbon Border Adjustment Mechanism (CBAM) will significantly impact foundries in Thailand, especially those exporting cast iron to the EU. Here are the key issues that foundries in Thailand will face:

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1. Increased costs: CBAM will require Thai cast iron to pay an additional carbon tax, resulting in increased production and export costs. Foundries may need to adjust their selling prices to offset the increased costs, which could affect their ability to compete with competitors from other countries.

2. Technical adaptation: Foundries will need to improve their production processes to be more efficient and reduce greenhouse gas emissions. They may need to invest in new technologies, such as energy-efficient smelting, renewable energy, greenhouse gas management, and recycling.

3. Lack of data: To calculate the CBAM carbon tax, detailed greenhouse gas emissions data are required. Foundries in Thailand may not have enough data or the ability to manage it.

4. Future uncertainty: CBAM is still in its infancy and is constantly evolving. Thailand's foundries need to be ready for policy uncertainty, constant change, and ongoing adaptation.

5. Impact on the supply chain: Foundries might need to switch raw material suppliers. Adjusting the manufacturing process to comply with CBAM standards could potentially impact the supply chain and customer relationships.

6. Difficulty in accessing the market: CBAM may be a barrier to exporting cast iron products to the EU, as it may make Thai products more expensive and uncompetitive with products from other countries.

Carbon pricing has recently gained further momentum from the European Union's (EU) plan for the Carbon Border Adjustment Mechanism (CBAM). The CBAM aims to align the greenhouse gas (GHG) emission costs in imported products with those within the EU [3]. Among these strategies, the considers carbon pricing to be a cost-effective way to achieve emission reductions.

This research paper takes a comprehensive approach to assess the GHG emissions of a foundry and proposes actionable actions to reduce them. The study analyzes the company's manufacturing processes, energy consumption data, and associated GHG emissions, focusing on electricity consumption as the primary source of emissions. This analysis helps identify key GHG emission hotspots, leading to the development of targeted strategies to reduce the foundry's environmental impact. The research uses the Intergovernmental Panel on Climate Change (IPCC) guidelines and associated emission factors to quantify GHG emissions associated with electricity consumption, providing a starting point for the foundry to use as input and guidance in implementing its actions concerning the European CBAM.

2. METHODOLOGY

2.1 Collection plant information

This research adopts a comprehensive approach to assess GHG emissions at a foundry plant in Nakhon-Pathom, Thailand. The study utilizes data from the company's operational records, encompassing a detailed examination of the production processes, energy consumption patterns, and subsequent GHG emissions. The data collections comprise the electrical power consumption of the entire plant and the electrical power consumption of melting furnaces for the years 2022 and 2023 (Table 1).

2.2 Production process analysis

The research delves into the intricate steps involved in metal casting, from the initial raw material handling to the final finished product. This meticulous analysis aims to identify the specific GHG emission sources inherent in each stage of the production process. The process diagram is created comprehensively with the resources for sand mold and core making. The diagram indicates the resource used for iron melting. The diagram can assist in an overview of plant resources, processes, waste, and GHG emissions for finding out the solution of GHG reduction.

This research meticulously analyzes the electricity usage across various production units, including furnaces, casting equipment, and auxiliary systems. The data collection involves compiling detailed records of electricity consumption across all operational areas of the foundry plant.

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Table 1. Electricity consumption for each production process.

Process	Electricity consumption (kWh)		Process	Electricity consumption (kWh)	
	2022	2023		2022	2023
Core making	23,370	22,755	Molding	212,515	206,923
Shakeout	77,216	75,148	Air compressor	597,911	582,177
Sand preparation and mixer	638,134	621,341	Dust collection system	157,263	153,125
Melting furnaces	5,343,960	4,579,142	Cooling tower	75,468	73,482
Shotblast	66,880	65,120	Grinding	208,278	202,797

2.3. GHG emission calculation

The Intergovernmental Panel on Climate Change (IPCC) guidelines and relevant emission factors to quantify GHG emissions associated with electricity usage were utilized. This rigorous approach ensures accurate and reliable calculation of GHG emissions based on established international standards. The emission factor is considered based on the last update by IPCC 2013 GWP 100a V1.03 on the Thai National LCI Database, TIIS-MTEC-NSTDA (with TGO electricity 2016-2018). The GHG emissions of electricity consumption on each process are calculated by Eq (1):

$$\text{GHG (kgCO}_2\text{e)} = \text{Electricity Consumption (kWh)} \times \text{Emission factor (kgCO}_2\text{e/kWh)} \quad (1)$$

3. RESULTS

3.1 Metal casting process

Fig. 1 depicts the metal casting process. There are 8 processes:

1) The core-making process involves machines that have both electricity and gas options. The machine uses gas to heat the filling until it hardens. To remove moisture, the filling in an electric oven was heated.

2) The sand preparation process involves machine-feeding the metal product into the foundry sand after separating it from the mold. Next, sand was extracted, sorted by size, and assessed for strength to transform it into foundry sand. Sand mixer, where sand will mix with various binders once it possesses the appropriate properties. Various binders, such as sea sand, bentonite, starch, resin, etc., are based on the suitability and properties of the casting sand required.

3) The molding process involves the machine utilizing the necessary patterns to create the desired mold shape. A pattern plate mounts the patterns. A sand supply system provides the machine with mixed molding sand and a binder. The machine automatically places a layer of sand onto the pattern plate. A compaction mechanism, such as a vibrating table or a pressing action, compresses the sand around the patterns to achieve the required mold strength. After compacting the sand, we form the top half of the mold. We bring the two halves of the mold together and press them into one complete mold. Next, we finish the sand mold and prepare it for the next step.

4) The metal melting process involves adding metals and additives to the raw material of each type of cast iron in the furnace. The alloys include silicon, pig iron, carbon, silicon carbide, manganese, sulfur, fire-cutting iron, and other substances such as inoculant, magnesium, and redux brick, which are used to adjust the quality of the metal. The temperature of metal melting in the induction furnace has to be increased up to 1,550 °C.

5) The pouring process, where workers scoop up the melted iron with a small ladle and pour it into the sand mold. An automatic machine initiates a second process, which involves pouring the melted iron into the mold. This process cools both the sand and the casting products. Before entering the sand separation process, the iron-poured sand mold moves on a track and cools down with air.

6) Shakeout, in which a vibrator separates the sand from the casting metal. Next, the vibrator transports the sand to the sand mill preparation process, where it becomes the new casting mold. The casting metal is subjected to a variety of processes, including shot blasting, blasting, and metal grinding.

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7) Sand blast/shotblast, where a machine applies sandblasting or metal pellets to the casting surface to remove sand, improve the metal surface, remove burrs and sharp edges, increase strength, and create pressure on the surface.

8) Grinding process, where the worker grinds some cast iron on an automatic grinding machine to remove the edges of the metal surface once more.

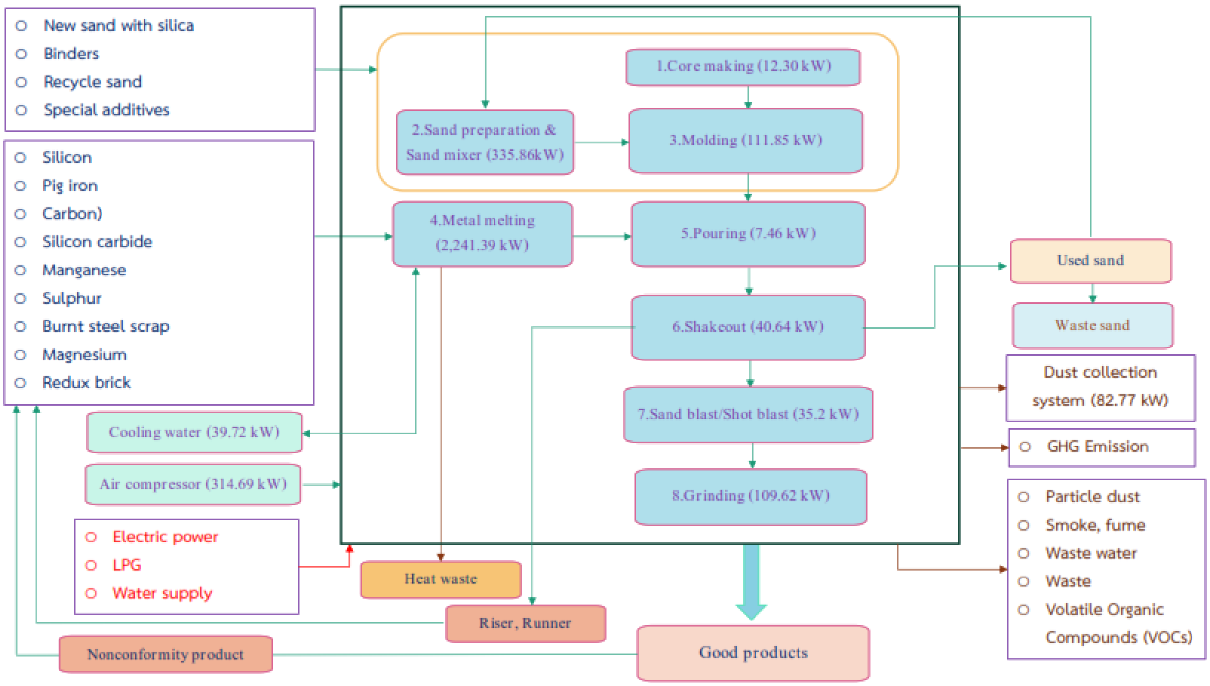

Figure 1. Flow diagram for metal casting process.

The foundry's annual production of cast iron products (Fig. 2a) in 2022 and 2023 was 651,550 and 587,500 kg, respectively, which varied from 487 to 747 tons for 2022 and 503.5 to 636 tons for 2023. In 2022 and 2023, March and January had the highest product capacity, while December and April had the lowest. In 2022 and 2023, the total product was 7,752 and 6,866.6 tons, respectively. It was observed a direct variation in electricity consumption with production. The plant's average electricity consumption was 640,644.10 kWh/month in 2022 and 580,183.30 kWh/month in 2023 (Fig. 2b). The peak load electricity consumption for 2022 was 694,319.40 kWh in March, and for 2023 it was 615,603.00 kWh in July. Therefore, the energy consumption for 1 kg of product varied between 0.915-1.091 kg/kWh in 2022 and 0.986-1.1.035 kg/kWh in 2023.

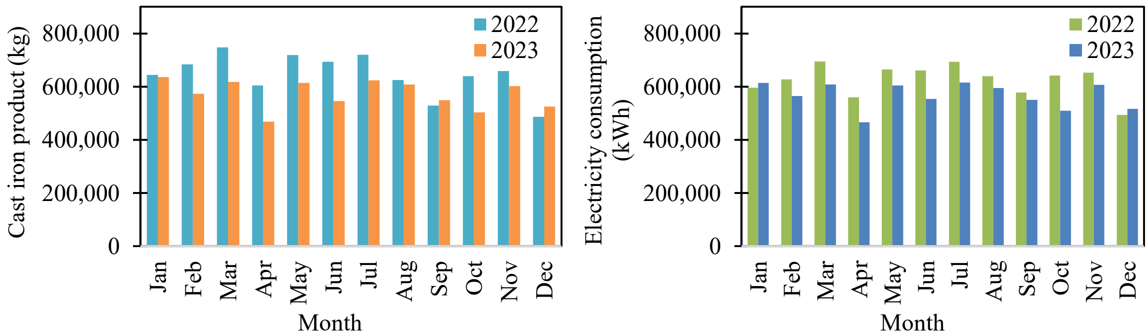

Figure 2. Annual data for metal casting products (left) and (b) electricity consumption (right).

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3.2 GHG emission from electricity consumption

The amount of electricity used significantly contributes to its overall carbon footprint. The plant's electricity consumption from the casting metal process in Fig. 2 resulted in GHG emissions of 3,750.87 tons CO_2e and 3,402.41 tons CO_2e for 2022 and 2023, respectively (Fig. 3). The entire plant's average carbon intensity is 0.489 kg CO_2e/kWh.

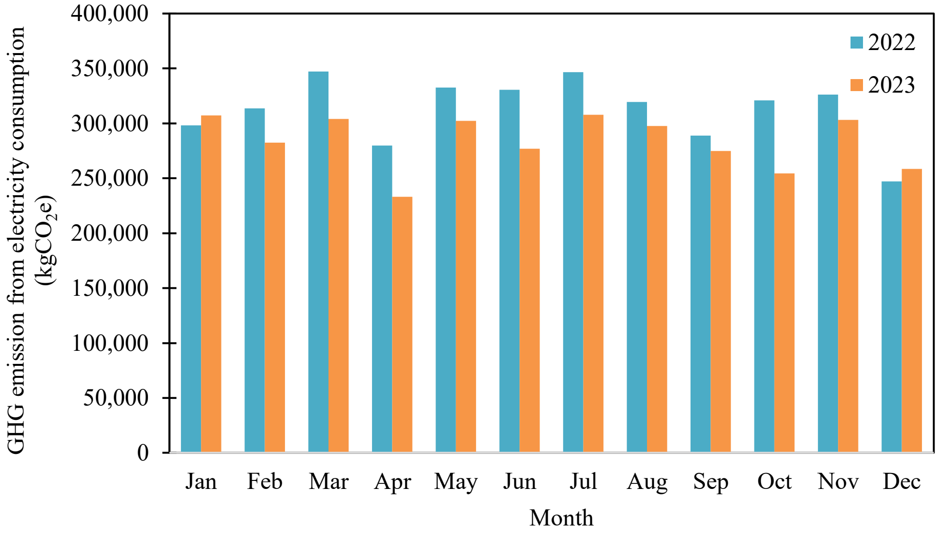

Figure 3. GHG emission from electricity consumption of metal casting process.

4. DISCUSSION

4.1 Carbon intensity

It is essential to note that the carbon intensity of iron casting production is dynamic and varies based on factors such as the production process, raw materials, and energy mix. Induction melting furnaces, due to their high energy demands, exhibit a higher carbon intensity than other production processes. In 2022, induction furnaces accounted for 71.22% of the plant's total electricity consumption, increasing to 67.28% in 2023. According to Sirintip et al. [4], the CO_2 intensity of semi-finished steel products was 0.44 tCO_2e/ton, whereas the CO_2 intensity of finished steel products was 0.17 tCO_2e/ton.

4.2 Key emission hotspots

The research identified three key emission hotspots within Foundry's operations. Electricity consumption is consistent with production. To consider the electricity reduction potential relating to GHG emissions, in the other manufacturing processes except for induction furnaces, electricity is mainly supplied to motors in machines such as belt conveyors, sand mixer machines, shot blasting machine molding machines, oscillating machines, bucket elevators, induced draft fans (ID fans), grinding machine, etc. that are not too high in electricity power consumption.

4.2.1 Electric furnaces

Induction furnaces, crucial for melting metal, consume a substantial amount of electricity, contributing significantly to GHG emissions. The electrical power consumption of induction melting furnaces was higher than other production processes; they were 71.22% in 2022 and 67.28% in 2023 of total electrical power consumption in the plant. The most energy-intensive process is metal melting, whether in an induction furnace or a cold or hot blast cupola.

The process is intrinsically inefficient due to the high temperatures of approximately 1500 °C. Depending on whether the melting occurs in an induction furnace or a blast cupola, two different strategies need to be considered. Adopt the correct feedstock conditions, prevent overheating, and operate at the maximum power input level in the former optimization processes. A well-insulated lid

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can reduce heat losses; the furnace coils must be duly cooled at a temperature of 40-45 °C that allows a heat recovery useful only for building heating via low temperature terminals or for DHW. The best measure to improve efficiency in blast cupolas is to pre-heat the combustion air, which requires suitable heat exchangers that can withstand both temperature and corrosion. According to Lazzarin et al. [5], the high temperature of the flue gas enables the powering of both steam direct cycles (Rankine) and the easier activation of ORCs, even after the air combustion pre-heating process.

4.2.2 Casting equipment

The various casting processes, which include sand mixing, equipment transportation by belt conveyor, core making, and molding machines, significantly contribute to the foundry process and increase GHG emissions.

Recycling waste foundry sand in the construction industry would save a lot of resources [2]. Composite technologies enable energy savings of approximately 8.92% and 6.99% per unit casting, in both single small batch and batch casting manufacturing processes. Although casting has a similar energy efficiency to additive manufacturing, the time consumption per unit is much lower, which has significant application value. Compared to traditional casting methods, composite technologies save 6.99% energy in mass production, reduce 11.06% carbon emissions, and save 5.571 h in manufacturing per unit casting [6].

4.2.3 Auxiliary systems

Supporting equipment, including pumps, compressors, and air conditioning units, also contributes to energy consumption and GHG emissions, albeit to a lesser extent than the furnaces and casting operations. The Cooling Dry Air (CDA) system in the fab was classified as a two-pressure level system using a heated-type dryer. Compared to the original data, the highest energy savings for the CDA system was 3,050 MWh. That is, the CDA system's energy consumption decreased by 8.17%. This energy savings constituted 1.81% of the overall energy consumption of the fab [7].

4.3 GHG reduction strategies

Based on the identified emission hotspots, the study proposes actionable strategies to reduce GHG emissions at Foundry with the Energy Efficiency Improvements Approach (EEIA).

4.3.1 Furnace optimization

Implementing modern, energy-efficient furnaces with advanced control systems can significantly reduce electricity consumption during melting operations.

The IMF achieves the melting temperature of iron at about 1250 °C. The molten metal temperature is further raised to 1450 °C to compensate for the transfer and pouring heat losses. Apart from this, heat is lost as radiation from weekly insulated portions such as the IMF coil cradle assembly, ladle, and tundish attached to the CCM. Good quality thermal insulation should limit the external temperature of these surfaces to a maximum of 65 °C. The thermal imaging technique was used to study the radiation heat losses from various surfaces. The process of tapping molten metal, transporting it in a ladle, and pouring it into a casting primarily results in heat loss. Reduce the transit time to cut down on heat loss from radiation during the process [8].

The model predictions and real-time melting showed a good correlation between 81% and 95% when parameter fitting techniques were used on the measured operational data of the induction furnaces at different times of melting. Effective material balancing and controlled charge can reduce energy consumption by comparing the mass composition of a current molten bath and melting time. Onigbajumo et al. [9] observed the melting time as a function of the molten bath's elemental charge composition and the overall scrap material charge.

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4.3.2 Casting process optimization

Optimizing casting cycles and implementing energy-saving techniques can help to reduce electricity consumption. When the pouring station is located far from the furnace, the design of the casting process impacts energy consumption and operating time. This is due to the need to raise the iron temperature to compensate for the decrease in melt iron temperature on the way to the pouring station. This, in turn, prolongs the furnace operation, leading to an increase in GHG emissions. Three types of sand-casting carbon source models were built by three categories of process design parameters analysis of sand mold casting. so as to predict the carbon emission of sand mold casting. The feasibility of the proposed method for estimating the carbon emission in the process design stage was validated by using a practical example. Hu et al. [7] demonstrated a significant decrease in carbon emissions through the comparison of two process design schemes based on this method.

4.3.3 Motor efficiency

Upgrading motors and pumps to higher-efficiency models can minimize energy waste and contribute to a more sustainable operation. The benefits of using IE3 motors extend beyond these cost savings on energy bills and include a return on investment. Furthermore, investing in high-efficiency motors not only reduces operating costs, improves reliability, and achieves long-term financial sustainability, but also contributes to the energy conservation and sustainability goals of businesses and industries [8].

4.3.4 Solar photovoltaic (PV) system

Installing 1,547.83 m^2 of photovoltaic PV solar cells on the roof results in a total power output of 700.92 kWp. It will be installed together with a 6-unit 90 kW inverter at latitude 13.7275 and longitude 100.2904. Tests conducted revealed an average global output of 5.1 ay $kWh/m^2/day$ on a tilted plane. The plant has received the electric power generation from the photovoltaic PV solar cells. The investment in this PV solar installation will pay back within 4 years.

Raksakulkarn et al. [10] conducted a study on 45 industrial estates, identifying a total area of 94,126 rai. This area represents a potential roof area for installing solar rooftops, with a total installed capacity of 1421.05 MW, which equates to a GHG reduction potential of 0.95 $MtCO_2e$. The level 2 assessment of the GHG reduction potential from all aerial photographs shows that the industrial estates and IEAT head office have a total roof area of 38,222,516 square meters. Of this, 5,452,726 square meters have solar rooftops installed, while the remaining roof area is 32,769,790 square meters without solar rooftops. The potential roof area for installing solar rooftops is 6,553,958 square meters, representing a total installed capacity of 773.02 MW, which represents 0.52 $MtCO_2e$ of GHG reduction potential [10].

4.3.5 Waste management and recycling

Implementing a comprehensive recycling program for scrap metal, sand, and other materials can minimize waste, reduce the need for raw material extraction, and decrease GHG emissions associated with material production. Mining and smelting of ores provide the raw materials for iron smelting. The process of obtaining raw iron and raw materials for steel production generates a significant amount of greenhouse gas emissions.

Casting aluminum with 100% primary material causes more global warming than cast iron, but using 60% secondary material reduces the impact compared to cast iron with 80% primary and 20% secondary material [11].

Abdelshafy et al. [12] found that the smelting process and renewable energies play a role in decreasing the carbon footprint. In terms of the input materials, the results demonstrate that increasing the steel scrap content achieves significant reductions in CO_2 emissions. An alloy composition with a 25% steel scrap content leads to a minimum carbon footprint of 650 kg CO_2e/ton. The amount of steel scrap directly affects the amount of CO_2 emissions. When a cast component uses more steel scrap, it

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leaves less primary metal to fill it. Since the mining of metal ore emits CO_2, recycling metal scrap positively impacts carbon emission control by preventing the extraction of new metal. According to one ton of steel scrap used, it protects the environment from 1.5 tons of CO_2 emissions [13].

4.3.6 Waste heat recovery

Utilizing waste heat from furnaces for preheating or other processes can improve energy efficiency and minimize reliance on external heat sources, such as the pre-heating of the ladle, the pre-heating of another induction furnace located nearby before melting the iron, and the pre-heating of the sand core in the core-making process. These comprehensive strategies, if implemented effectively, have the potential to significantly reduce Foundry's environmental footprint and contribute to a more sustainable future for the company and the broader manufacturing industry.

The foundries waste more than 50% of their energy on melting the raw materials, which then solidify in sand molds. Muthuraman [14] suggested that the heat released during molten metal solidification is used to preheat the raw materials. Durgesh et al. [11] found that the heat-recovery capacity varied depending on the insulation of the raw materials and the water moisture content in the casting sand.

4.4 Dust collection systems

Different factors such as particle characteristics, flue gas, temperature, fine or coarse, abrasive, sickly or non-sickly, cost, and efficiency can influence the selection of air emission control equipment in a foundry. Typically, foundries utilize four types of dedusting technology:

1) Filter bags are ideal for capturing small dust particles, 0.2–0.5 μm, but they are not suitable for capturing particles with high humidity and heat.

2) Wet scrubbers were applied for capturing particles with corrosive properties and high heat resistance (0.1–1.0 μm) and spray scrubbers for dust larger than 5 μm.

3) Cyclone was installed for capturing large dust of 15–40 μm, not suitable for capturing particles smaller than 10 μm.

4) An electrostatic precipitator is not suitable for capturing sticky dust but is effective in capturing particles smaller than 1 μm.

Dust control technologies involve installing bag filters and cyclones to regulate emissions from melting processes. Wet scrubbers capture water-soluble compounds like sulfur dioxide (SO_2) and chlorides. The adoption of cyclones as pretreatments and use of bag filters typically enables emission levels of 10 mg/Nm^3 or less. The large amount of sand used in lost mold casting generates dust emissions during the various molding stages and produces on-metallic particulates, metallic oxide particulates, and metallic iron.

Casting, shakeout, and finishing processes emit non-metallic particulates. The prevention and control techniques for particulate matter arising from casting and molding include installing dry dust collection technologies, such as bag filters and cyclones, instead of wet scrubbers, particularly in green sand preparation plants. Dry techniques facilitate the simple collection, transportation, and recirculation of dust in the sand mixing process, thereby preventing the production of effluent from wet scrubbers. Casting and finishing shops, in particular, use filters on exhausts; while molding and casting shops employ vacuum cleaning.

It was recommended to install closed dedusting units in working areas [15] and [16]. Since shotblasting and grinding produce similar particulates, a filter bag is a suitable tool for these processes. However, emission control devices, such as the dedusting system, are not appropriate for controlling or reducing greenhouse gas emissions. In addition, Skoromny et al. [17] recommended to simply scale up the dust collection system by replacing several low-capacity collectors with one general-capacity collector. Energy consumption at the collector manufacturing stage reduced 3–10 times and ensured a significant reduction in operation energy consumption of the dust collector during its service life.

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5. CONCLUSIONS

The average electric power consumption for the entire plant in 2022 and 2023 was 640,644 and 580,138 kWh, respectively, for the casting product. They emitted 3,725,145 and 3,125,480 kg CO_2eq from their electricity consumption in 2022 and 2023, respectively. The average carbon intensity is 0.489 kg/kWh. The electricity consumption, particularly for melting and casting processes, is the primary source of GHG emissions at the foundry. While the company's annual production of cast iron products varied, the reliance on electricity for these processes results in substantial CO_2 emissions. Strategies for GHG emission reduction include optimizing furnace efficiency, utilizing modern and advanced control systems, implementing energy-saving techniques during casting processes, and upgrading to higher-efficiency motors and pumps. Installing a solar rooftop as a captive power plant could significantly reduce electricity consumption from the grid, thereby decreasing the company's overall carbon footprint. By implementing strategic and comprehensive GHG reduction plans, foundries can not only reduce their environmental impact but also enhance their competitiveness and achieve a sustainable future.

Recommendations:

- To quantify energy consumption and identify specific areas for improvement, conduct a detailed energy audit.
- Develop a comprehensive GHG reduction plan incorporating the proposed strategies by implementing a robust monitoring and evaluation system to track progress toward reduction targets.
- Reduced raw material use by recycling steel scrap reduces the need for virgin iron ore mining and processing, which are energy-intensive and produce significant GHG emissions. By using scrap, foundries can decrease the demand for new raw materials.

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Exploring Greenwashing Awareness Among Thai Retail Investors Towards Sustainable Investment Trends

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ABSTRACT

In an era where environmental consciousness is reshaping financial markets, the deceptive practice of "greenwashing" threatens to undermine the integrity of sustainable investments. This study investigates how Thai retail investors navigate the complexities of greenwashing in Thailand's burgeoning sustainable finance sector. As global investment trends increasingly embrace sustainability, this research explores whether investors can distinguish genuine environmental initiatives from clever marketing ploys. Employing a qualitative approach, the study engages 30 Thai retail investors through semi-structured interviews, unveiling the intricacies of investor awareness and decision-making in the face of potential greenwashing. The research constructs a narrative of how information flows shape investor perceptions and choices. Moreover, highlights the complex relationship between greenwashing awareness, risk perception, and investment choices, emphasizing the need for comprehensive education and policy interventions. This research not only illuminates the challenges faced by Thai investors but also serves as a call for aligning investor values with authentic environmental sustainability. By exposing the hidden risks threatening the foundation of sustainable finance, the study contributes to the growing body of literature on greenwashing awareness and its impact on investment decisions in emerging markets.

Keyword: Sustainable Investment/ Greenwashing Awareness/ Retail Investor/ ESG Funds/ Sustainable Development

1. INTRODUCTION

The global financial landscape is undergoing a significant transformation, driven by an unprecedented surge in sustainable investments that integrate Environmental, Social, and Governance (ESG) considerations. This shift is reshaping markets worldwide, with Thailand's emerging sustainable finance sector at the forefront of this revolution. The exponential growth of the global green finance market provides compelling evidence of this trend. From a modest $5.2 billion in 2012, the market has expanded to an impressive $540.6 billion in 2021 from Reuters, (2022) [1], underscoring its growing importance in driving sustainable economic development.
In Thailand, this global trend is mirrored in the nascent ESG Fund sector, which has exhibited notable traction among investors despite its recent establishment. In 2024, the sector achieved an overall asset value growth rate of approximately 3.3%. Analysis of fund composition reveals a predominant focus on equity investments, accounting for over 76% of assets, followed by mixed funds and fixed income funds. Notably, fixed income funds have demonstrated the highest growth rate at 30.6% in

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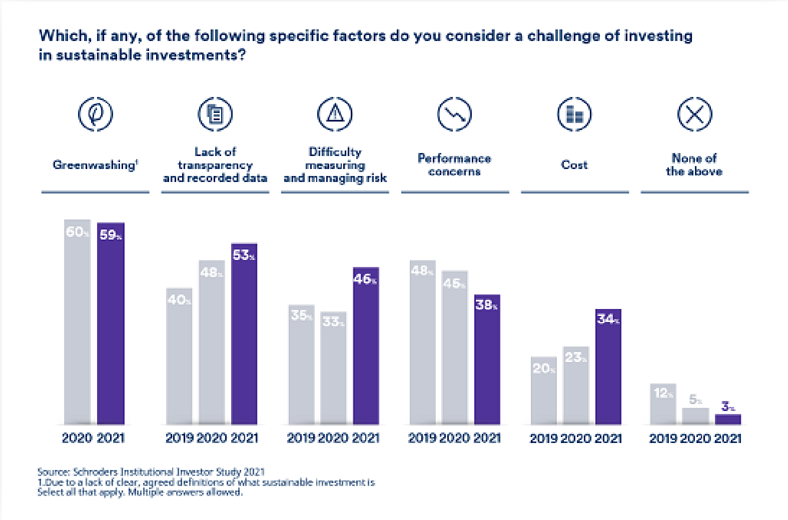

Figure 1. A challenge of investing in sustainable investment (Schroders, 2021)

However, this rapid growth in sustainable finance has brought to light a significant challenge: greenwashing. As firms increasingly disclose large quantities of ESG data while potentially maintaining poor ESG performance, it creates a significant barrier to genuine ESG integration in investment decisions Ellen Pei-yi Yua (2020) [3]. This disconnects between reported and actual sustainability practices not only undermines the integrity of the sustainable finance market but also potentially misleads well-intentioned investors. The ethical dimension of this issue by Tirole (2010) [4] stated that stakeholders demand corporate social responsibility to maintain legitimacy in the market. This connection is particularly relevant given observation that companies frequently employ greenwashing techniques to cultivate favourable perceptions. Raise investors' concern about greenwashing (59%) and the lack of openness and data surrounding sustainable investing (53%) remain the primary concerns (Schroders, 2021) [5].

Therefore, this research lies in addressing this growing challenge of greenwashing in Thailand's sustainable investment landscape. The study explores through the retail investor lens that might be affected by greenwashing. By examining Thai retail investors' awareness of greenwashing and its impact on their investment choices. The insights gained are vital for various stakeholders - from financial institutions seeking to build trust, to regulators working to protect investors, to policymakers striving to foster a truly responsible investment environment. Ultimately, this research is essential for ensuring the authenticity and effectiveness of sustainable investing practices and aims to support the development of a more transparent and sustainable investment environment. By doing so, it contributes to the broader goal of aligning financial markets with sustainable development objectives, both in Thailand and globally.

2. METHODOLOGY

2.1 Research design and sampling

This study employs a qualitative approach to explore greenwashing awareness among Thai retail investors, utilizing in-depth, semi-structured interviews with a purposively sampled demographic. The research design targets current retail investors as defined by The Stock Exchange of Thailand (2021) [6], with specific inclusion criteria to ensure relevance and depth of insights. Eligible participants must have invested in ESG funds, including Thai ESG funds, or related funds and have a minimum monthly income of 25,000 baht after tax. This income threshold, derived from previous research on Thai retail investors (Songkietsak, 1999) [7], helps ensure participants have the financial capacity for meaningful investment activities. The study involved 30 Thai retail investors

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who met these criteria, participating in interviews lasting 45-60 minutes each. These sessions, conducted both online and offline to ensure broad accessibility, consisted of 20 questions designed to probe participants' awareness and attitudes towards greenwashing in sustainable investments. By including a diverse range of perspectives and experiences, the study aims to gain comprehensive insights into how individual investors perceive and understand the concept of greenwashing in investment practices, contributing to a more nuanced understanding of this phenomenon within the Thai retail investment sector.

2.2 Questionnaire development

The development of the research questionnaire was a crucial step in ensuring the collection of comprehensive and relevant data to address the study's objectives. The questionnaire was designed to explore greenwashing awareness among Thai retail investors in sustainable or ESG funds, with a focus on their understanding, perceptions, and decision-making processes. The questionnaire structure followed a semi-structured, open-ended format, allowing for flexibility in responses while maintaining consistency across interviews. This approach was chosen to facilitate an in-depth exploration of real-world situations and experiences of retail investors. The questions were carefully crafted to probe into various aspects of greenwashing awareness and its impact on investment decisions.

To achieve the research objective, the questionnaire was developed as follows:

1. Demographic Information:
   - Initial questions focused on gathering participants' demographic features.
2. Greenwashing Awareness and ESG Fund Knowledge:
   - This section employed structured test based on a 5-point Likert scale, to collect specific data on greenwashing awareness.
   - Questions probed participants' basic knowledge of ESG mutual funds.
3. Influencing Factors and Sustainable Finance Recognition:
   - The final section explored factors influencing greenwashing awareness.
   - Questions inquired about types of sustainable finance recognized by participants.
   - Participants were asked about their preferred fund types.

The questionnaire structure was based on the Hierarchy of Effects model [8], establishing a research framework that guided question formulation. This framework addressed three key areas: Awareness/Knowledge, Preferences, and Purchase.

The complete questionnaire consisted of five sections, structured as follows:

Section 1: Screening Questions Included screening questions that developed short inquiries, asking participants to choose from a predefined set of responses, such as yes-no answers, to screen for income, age, investment type, basic knowledge of ESG funds, and investment experiences.

Section 2: Demographic Information Collected demographic information about participants, such as their gender, degree of education, and other relevant questions.

Section 3: Perspective on Sustainable Investment and Awareness of Greenwashing; Assessed participants' awareness of greenwashing practices in the investment industry and their understanding of behavioural criteria in sustainable investing.

Section 4: Investment Behaviour of Retail Investors; Investigated the behavioural patterns of retail investors in relation to ESG investments, including decision-making processes and investment strategies.

Section 5: Influencing Factors of Retail Investor Decision-Making Explored the factors that influenced retail investors' decision-making processes when it came to ESG investments.

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Open-ended question: When evaluating ESG fund marketing materials, how much weight do you give to these statements, such as “committed to sustainability” or “environmentally conscious”? Rating scale: Not important at all (1) / Somewhat (2) / Moderately (3) /Very (4) / Extremely important (5) Follow-up question: "Can you tell me more about what makes a company's communication about ESG investments effective or ineffective in your view?

The questionnaire underwent a thorough pilot testing process to ensure its effectiveness and reliability. Initially, a group of five participants, representative of the target population but not included in the final study, were interviewed using the draft questionnaire in Thai. These participants provided feedback on question clarity, relevance, and overall interview experience. The researcher also noted observations on participant reactions and timing. Based on this feedback and observations, the questionnaire was revised, with questions being reworded, reordered, added, or removed as necessary. A second round of pilot testing with three new participants was conducted to verify the effectiveness of the revisions. After final minor adjustments, the questionnaire was finalized in both Thai and English. This rigorous process aimed to maintain the integrity of the research objectives while ensuring the questionnaire was user-friendly and effective in eliciting the desired information from participants.

2.3 Data collection

Data collection for this study took place from May to mid-July 2024. Each interview lasted approximately 45 to 60 minutes per participant. To accommodate participant preferences and ensure maximum comfort, interviews were conducted through a mix of video conferencing and in-person meetings, depending on the convenience of each participant. In-person interviews were held at quiet place or their workplace corner if available. While online interviews used secure video conferencing platforms. The semi-structured interviews followed a prepared questionnaire, which guided the conversation while allowing for flexible exploration of topics as they arose. Participants volunteered their time and insights without any monetary incentives, demonstrating a genuine interest in contributing to the research on ESG investments and greenwashing awareness. Overall, the level of cooperation from participants was high. They showed genuine interest in the topic and were generally forthcoming with their thoughts and experiences. Most participants engaged actively in the discussions, often providing detailed responses and examples. In a few cases, additional probing questions were necessary to elicit more comprehensive answers.

The data collected from these interviews was deemed sufficient for the study’s objectives. The responses provided rich, in-depth insights into participants’ awareness of greenwashing and their decision-making processes regarding ESG investments. The variety of perspectives gathered allowed for a comprehensive analysis of the research questions. It was essential to stress the importance of maintaining confidentiality and anonymity during these interviews, as well as highlighting the advantages of taking part in the research. Interview recordings were captured via audio recording devices, then fully transcribed word-for-word, and subsequently de-identified to safeguard participant privacy. Through this approach, the study aimed not just to gather data, but to weave a tapestry of understanding. By fostering trust and flexibility, the study hoped to paint a vivid picture of greenwashing awareness among Thai retail investors, one insightful interview at a time.

2.4 Data analysis

The data recordings from retail investors were meticulously transcribed and subsequently translated into English. The collected interview data underwent a comprehensive qualitative analysis process using thematic analysis with a deductive approach. This method was chosen to systematically identify, analyze, and interpret patterns of meaning within the dataset. The analysis process began with a thorough familiarization of the data, where researchers carefully read through all interview transcripts.

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Following this, a deductive approach was applied, using predetermined themes based on the research questions and existing literature on greenwashing and ESG investments. This approach allowed for a focused examination of the data while remaining open to emerging themes. Human text-based data coding was conducted using Microsoft Word. Researchers utilized the comment and highlighting features in Word to mark relevant text segments and assign codes. This method allowed for a detailed, line-by-line analysis of the transcripts, ensuring that contextual nuances were captured. Codes were then grouped into broader themes, with researchers paying careful attention to the relationships between different codes and themes. The coding process was iterative, with researchers regularly reviewing and refining the codes and themes to ensure consistency and accuracy. To enhance reliability, researchers coded a subset of the data.

The findings from the qualitative data were subsequently discussed in a descriptive manner, highlighting the implications of greenwashing awareness among investors in the context of sustainable finance.

Alongside with a scaling assessment component utilizing a structured test based on a 5-point Likert scale. The scale assessment, comprising five questions, was designed to evaluate participants' ability to discern between genuine ESG claims and potential greenwashing tactics. The questions were formulated based on guidelines established by The Office of the Securities and Exchange Commission (2022) for fund managers regarding appropriate language use in promoting Sustainable and Responsible Investing Funds.

3. RESULTS AND DISCUSSION

3.1 Results

The study encompassed a diverse cohort of participants, with ages ranging from 26 to 51 years (median age: 39.5 years). Educational attainment was notably high, with 73% of participants holding graduate degrees and the remaining 27% possessing undergraduate qualifications. The occupational distribution was heavily skewed towards employment, with 97% of participants being employees and only 3% identifying as business owners.

Income levels varied considerably among the participants, total income after tax, the findings indicate that a considerable majority of participants, specifically 3% (1 individual), reported a monthly income between 25,000 and 45,000 baht. A smaller proportion of participants fell into the next income bracket: 7% (2 individuals) earned between 45,001 and 65,000 baht. 17% (5 individuals) earned between 65,001 and 85,000 baht, and 23 % (7 individuals) earned between 85,001 and 100,000 baht. Notably, a significant portion, 50% (15 participants), reported a monthly income exceeding 100,000 baht. These results provide valuable insights into the financial profiles of the surveyed group, which may significantly influence their financial behaviors and preferences.

Table 1. Demographic data (N=30)

	Frequency	Percent (%)
Gender		
Male	10	33%
Female	20	67%
Age		
25-30 years	2	7%
31-40 years	15	50%
41-50 years	12	40%
>51 years	1	3%
Education		
Graduate	8	27%

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Table 1. Demographic data (N=30) (cont.)

	Frequency	Percent (%)
Post-Graduate	22	73%
Occupation		
Employee	29	97%
Businessowner	1	3%
Income (baht)		
25,000 - 45,000	1	3%
45,001- 65,000	2	7%
65,001-85,000	5	17%
85,001-100,000	7	23%
>100,000	15	50%
Investment experiences		
> 1 years	6	20 %
1-5 years	6	20 %
6-10 years	8	27%
> 10 years	10	33%

The findings reveal a diverse spectrum of investment experience among the participants. Specifically, 20% (6 individuals) reported less than one year of investment experience, while an equivalent proportion of 20% (6 participants) indicated between one and 5 years of experience. A slightly larger segment, comprising 27% (8 participants), fell within the 6-10 years' experience range. Notably, a significant portion, constituting 33% (10 individuals), possessed more than 10 years of investment experience. Investment behaviors among participants demonstrated significant heterogeneity, investors who actively managed their portfolios throughout the year. A substantial proportion employed a Dollar-Cost Averaging (DCA) strategy, characterized by regular, fixed-interval investments irrespective of market conditions. This approach was particularly prevalent among those who conceptualized investing as a long-term wealth accumulation tool. Conversely, another segment adopted a more intermittent investment approach, making larger but less frequent investments. These investors often strategically timed their investments to coincide with tax incentives, typically investing once or twice annually to maximize tax benefits associated with specific investment products. Notably, investment behaviors were strongly influenced by tax considerations across all income levels. Participants consistently demonstrated acute awareness of the tax implications of their investments, with many timings' substantial investments towards the end of the tax year to optimize tax benefits. The study also revealed an interesting intersection between tax incentives and sustainable investing, with the appeal of Environmental, Social, and Governance (ESG) funds often amplified when offered as tax-advantaged products, effectively combining financial incentives with sustainable investing objectives.

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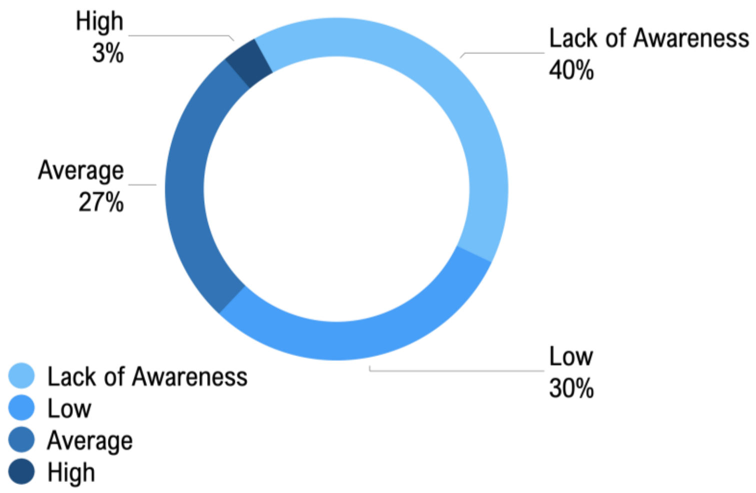

Figure 2. Level of Greenwashing Awareness of Participants(N=30)

The results of this assessment revealed a significant disparity in greenwashing awareness among Thai retail investors. In Figure 2, the study categorizes investor-specific characteristics into four types: This distribution underscores a substantial knowledge gap in the market, potentially leaving many investors vulnerable to greenwashing practices in their sustainable investment decisions. Level of Greenwashing Awareness identified as following:

Investors with a Lack of Awareness, a significant portion, 40% (12 out of 30) of participants, demonstrated a complete lack of awareness or knowledge about greenwashing. This group either had never encountered the term or possessed only a limited understanding of the concept, underscoring a substantial knowledge gap within the investor population.

Investors with a Low Awareness, a considerable proportion of participants (30%, 9 out of 30) exhibited basic awareness of greenwashing, recognizing the term and its general implications in sustainable investing. However, this awareness was often superficial, with these investors demonstrating a rudimentary understanding of the concept without fully grasping its nuances or associated risks.

Investors with an Average Awareness, the largest group of participants (27%, 8 out of 30) displayed an average level of awareness. This suggests a more developed understanding of the concept, including some knowledge of specific greenwashing practices and their implications for sustainable investments. However, their comprehension may still lack the depth required for sophisticated analysis of greenwashing tactics.

Investors with a High Awareness, a minimal subset of participants (3%, 1 out of 30) demonstrated an advanced level of awareness. This individual showed a more substantial comprehension of greenwashing practices and their potential impact on investment decisions, indicating a nuanced understanding of the issue.

These findings highlight a considerable disparity in greenwashing awareness among Thai retail investors. While approximately 30% of participants have some level of familiarity with the concept, ranging from average to high, a significant portion remains unaware and low of greenwashing practices. This distribution underscores the clear need for targeted educational initiatives to bridge the knowledge gap and enhance investors' understanding of greenwashing tactics and their implications in the context of sustainable investing. The relatively small proportion of investors with high level of awareness further emphasizes the importance of developing more comprehensive and accessible information resources to elevate overall investor knowledge in this crucial area of sustainable finance.

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3.2 Discussions

3.2.1 Understanding of greenwashing awareness amongst Thai retail investors

This study examines the complex landscape of greenwashing awareness among Thai retail investors. The findings reveal varied levels of greenwashing awareness across different demographic groups, highlighting the intricate relationship between investment experience, socioeconomic factors, and the ability to discern greenwashing practices. The findings of this study offer insights into the level of greenwashing awareness among Thai retail investors within the context of sustainable investment.

The analysis reveals that a majority of Thai retail investors (70%) demonstrate a lack to low level of awareness and the 30% demonstrate average to high of awareness regarding greenwashing practices, exhibited low awareness amongst Thai retail investors. Which aligns with Zhang's (2024) [9] observation that the awareness and monitoring of greenwashing among retail investors in developing country remain largely unexplored in many contexts. The Thai case study provides empirical evidence to support this claim. This lack of awareness is particularly pronounced among less experienced investors, suggesting a potential generational and educational divide in sustainable investing knowledge. Moreover, a complex interplay between occupation, income, and greenwashing awareness, the business owner's high awareness level, coupled with their high-income status, presents an intriguing case. However, the limited representation of business owners in the sample (n=1) precludes definitive conclusions about a broader relationship between business ownership and enhanced greenwashing awareness. Additionally, among Thai retail investors who are employees, the varied awareness levels across different income brackets suggest that income alone may not be a determining factor in greenwashing awareness. The absence of high awareness in this group, despite some members sharing the same high-income bracket as the business owner, further complicates the picture. This disparity hints at the potential influence of factors beyond income, such as educational background, professional experience, or personal interest in sustainable investing. While previous studies have shown a growing awareness of greenwashing in Europe İbrahim Topal (2019) [10], Thai retail investors reveal highlighting a notable disconnect between global trends and investor knowledge. This research suggests that Thai retail investors significantly lag behind their Western counterparts. This disparity is particularly striking given the increasing number of ESG funds and products available in Thailand, as noted by Adireksombat (2023) [11].

Moreover, in context of this study shown that awareness of greenwashing and investment experience is complex and non-linear. Investors with over 10 years of experience display a relatively even distribution across awareness levels, with a slight skew towards lack of awareness and average awareness. It may support the study stated that consumers tend to trust and use products labelled as environmentally friendly, highlighting the potential vulnerability of investors to similar claims in financial products by Dr. Sudhadhara Samal (2023) [12]. This unexpected finding challenges the assumption that extensive experience necessarily correlates with heightened awareness of emerging investment issues like greenwashing. The presence of high awareness exclusively within this group, albeit in small numbers, indicates that while long-term experience can potentially lead to sophisticated understanding, it is not a guarantee. In the other hand, personal values related to sustainability showed a strong correlation with greenwashing awareness. As awareness levels increase, the influence of personal values becomes more pronounced, suggesting that fostering strong personal convictions about sustainability could be a key driver in enhancing greenwashing awareness and critical evaluation of sustainable investment claims. This aligns with Massazza's (2021) [13] research, which found that retail investors are motivated by personal expression and alignment with values when investing in sustainable assets. While this study distributes of greenwashing awareness among different investment experiences and income groups, it highlights the complexity of these relationships. The findings emphasize the importance of considering multiple demographic factors in understanding and addressing greenwashing awareness in the context of sustainable investing.

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3.2.2 The impact of awareness of greenwashing on investment decision

This study endeavours to elucidate the relationship between awareness of greenwashing practices and the investment decisions of Thai retail investors. Unexpectedly, the study found no direct link between Thai retail investors' degrees of awareness of greenwashing and their changes in investing decision or practice. There are no appreciable shifts in the current investing strategies were seen across these categories, despite a range of knowledge levels, from lack of knowledge to average degree of awareness. Regardless of their level of awareness, participants consistently showed no variation in their investment behaviours. A crucial finding from this study reveals a significant the alignment from the study of Dr. Rajsee Joshi, (2014) [14] observation that awareness of green finance products does not invariably lead to investment in such products underscores the complexity of factors influencing sustainable investment decisions. This complexity is further emphasized by findings in this study on the interplay between awareness and investment decision.

Also, the primary reason is investors heavily dependent on their investment income for financial stability may prioritize short-term profitability over long-term sustainability concerns. This profit-centric focus could potentially lead to reduced attention to greenwashing practices, as immediate financial returns take precedence. Conversely, our findings indicate that individuals with diversified income sources and a robust financial foundation may be more inclined to consider the broader implications of their investments, including sustainability factors. Meanwhile, the study revealed that 47% of Thai retail investors rely on the information provided by their trusted sources, such as friends and family, rather than conducting their own extensive research. This reliance highlights the importance of social networks in building confidence and suggesting that these social influencers influence their investment choices. Furthermore, observation from the study shown the role of internet information and financial influencers in online platforms in shaping investment decisions has become increasingly significant in the digital age (Wissem Ajili Ben Youssef, 2024) [15]. The study indicates that online review and social interactions can heavily influence individual investors, often leading them to replicate the investment decisions of those they perceive as knowledgeable or sophisticated. For instance, the opinion from peer investor who appear financially savvy are particularly impactful, especially on social trading platforms where followers may lack the expertise to critically assess the information presented.

This reliance on internet postings underscores the phenomenon of herding behaviour, where investors imitate the actions of others, often disregarding their own research or analysis. Consequently, while the internet provides a wealth of information, it can also lead to decisions driven more by sentiment and social influence than by sound financial and sustainability principles of sustainable investment. This dynamic illustrates that trust and confidence are not only foundational to individual investment decisions but also play a significant role in shaping the broader investment landscape, especially as investors navigate the complexities of sustainable finance.

3.2.3. The influence of investment decisions among Thai retail investors government policies and incentives

The introduction of tax incentives for ESG investments in Thailand highlights the complex interplay between government policy, retail investor behaviour, and sustainable investing. The influential relationship between government policy and the incentives provided is a key driver of sustainable investment in Thailand, particularly highlighted by the recent establishment of the Thailand ESG Fund (TESG). This fund, which offers tax deductions for individual taxpayers investing in sustainable practices, has been shown to significantly influence Thai retail investors' decision-making processes which is aligned with the study Dr. Rajsee Joshi they would prefer to invest / increase their investment in Green Investment Products if they were incentivized. A study indicates that all participants' investment in ESG primarily due to the tax incentives associated with

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the TESG, which allows investors to deduct up to 30% of their income, capped at 300,000 baht per year, provided they hold the investment for a minimum of eight years (SEC, 2023) [16].

Highlighted on the result, there's a risk that investors may prioritize short-term tax benefits over genuine ESG principles, potentially leading to market volatility if funds are withdrawn when incentives expire, or more profitable opportunities arise elsewhere. This scenario underscores the challenges policymakers face in balancing financial attractiveness with meaningful sustainability progress. It also highlights the need for robust investor education, comprehensive monitoring mechanisms, and the development of a mature ESG investing ecosystem. Moreover, the impact of trust in term of decision-making on Thai retail investor confidence is further emphasized by the acknowledgment of third-party verification as a critical factor which aligned with (Makarabhiromya, 2022) [17]. The effectiveness of such policies in driving lasting change in investor behaviour and achieving sustainability outcomes remains to be seen, making this an important area for ongoing research and policy evaluation in Thailand and other emerging markets.

3.2.4 Implications for stakeholders

The findings of this research on greenwashing awareness among Thai retail investors have far-reaching implications for various stakeholders in the sustainable investment ecosystem. For fund managers, the study emphasizes the critical need to prioritize genuine sustainability efforts and transparent communication to build trust and maintain competitiveness. Regulators are called upon to establish robust frameworks and enforcement mechanisms to combat greenwashing, ensuring the integrity of the sustainable investment market. Thai retail investors are encouraged to become more informed and vigilant in their investment decisions, critically evaluating sustainability claims. The sustainable investment market in Thailand faces pressure to adapt by promoting verifiable, genuinely sustainable products to meet the growing demand for responsible investments. This research underscores the importance of collaboration among all stakeholders to foster a transparent, accountable, and thriving sustainable investment ecosystem that aligns with Thailand's Sustainable Development Goals. As awareness of greenwashing increases, these collective efforts will be crucial in shaping a more responsible and sustainable financial landscape in Thailand.

4. CONCLUSION

- **At the main objective of this study**

Regarding this study exploring in can be conclude that the majority of Thai retail investors' greenwashing awareness level is low, with 70% (21 out of 30) exhibiting a lack or low. This knowledge gap potentially leaves Thai retail investors vulnerable to greenwashing practices in their investment decisions. Moreover, the study found no significant correlation between demographic factors and greenwashing awareness levels, challenging assumptions about the relationship between education or income and understanding of complex financial concepts. Unquestionably, there is unrelated between greenwashing awareness and investment decision, as no significant changes in investment behaviours were observed across different levels of greenwashing awareness. This suggests that awareness alone may not be sufficient to drive alterations in investment strategies, pointing to the influence of other factors such as financial incentives and social influences. The study also highlighted the significant role of external influencers in shaping investment decisions. Social networks, online information, government policies, and third-party assurances all emerged as important factors influencing Thai retail investors' choices in sustainable investing. Notably, government initiatives like the Thailand ESG Fund (TESG) and its associated tax incentives have substantially impacted investment decisions. In conclusion, while Thai retail investors show low levels of greenwashing awareness and the impact of this awareness on investment decisions is complex and not straightforward. The findings emphasize the need for comprehensive educational initiatives, critical thinking skills development, and policy interventions to enhance awareness and translate it into informed investment action.

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- **Limitation and recommendation for future research**

(1) The relatively small sample size of 30 investors, while potentially adequate for qualitative insights, may constrain the robustness of quantitative analyses. This limitation could impact the study's ability to achieve high confidence levels and statistical significance in its findings.

(2) Expanding the scope of research to include diverse stakeholders, such as institutional investors and fund manager will provide a more comprehensive understanding of greenwashing awareness and sustainable investment trends. Tracking changes over time will allow researchers to assess how perceptions and behaviors evolve in response to new regulations and market developments.

(3) To build upon the current research, which is still in the early stages of understanding ESG funds in Thailand, future studies should consider broader demographic studies, longitudinal approaches, investigations into the impact of regulatory frameworks, and comparative analyses between Thailand and other countries with similar economic and environmental contexts.

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Exploring Extended Producer Responsibility in Thailand: Progress and Opportunities for Alternative Waste Management Policy

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ABSTRACT

Waste management, particularly plastic waste, is one the significant environmental challenges in Thailand. Extended Producer Responsibility (EPR) has emerged as a key policy approach, holding producers accountable for their products throughout their lifecycle, including take-back, recycling, and final disposal. This study examines the progress of EPR implementation in Thailand through document reviews, content analysis, and interviews with the business sector. The study aims to identify key outcomes and challenges associated with implementing EPR. Findings indicate that Thailand has made considerable progresses in adopting EPR, notably through the introduction of the Sustainable Packaging Management Act and enhanced collaboration among industry, government, and citizens. These initiatives are fostering innovative and collaborative waste management strategies by integrating businesses and consumers into the process with shared responsibilities. However, the research also highlights challenges, particularly the need for greater industry acceptance and enhanced consumer participation. Effective EPR implementation relies on businesses' willingness to embrace their responsibilities and consumers' commitment to engaging in recycling and waste reduction practices. While supportive legislation provides a necessary framework, the ultimate success of EPR in Thailand depends on widespread commitment from both the business sector and the public. The study emphasizes the importance of fostering broad acceptance and cooperation from all stakeholders to address challenges and achieve long-term improvements in waste management and sustainability.

Keyword: Extended Producer Responsibility (EPR)/ Plastic waste management/ Sustainable Packaging Management Act/ EPR implementation/ Thailand

1. INTRODUCTION

The use of plastic has been increasing globally [1, 2] offering benefits to lifestyles and consumption patterns in many ways. The key driving forces behind this trend include population growth, rapid urbanization, and industrial expansion [3]. The durability of plastic enhances user convenience and ensures safety and freshness for food consumers, thus benefiting the economics of various products [4]. Furthermore, plastic is relatively inexpensive to produce and can be designed for packaging at low costs, with the potential for recycling at multiple levels [4]. Plastics are then used in many sectors ranging from household, domestic, food and product packaging, industry production [3]. Approximately one-third of plastic consumption is attributed to packaging applications, particularly plastic bags and containers [4]. However, the rise of plastic consumption has also resulted in significant sustainability concerns over plastic pollution and its environmental impacts on soil, rivers, climate change, ecosystem, wildlife, including marine species [1, 3, 5, 6].

Several disposal methods of reuse, recycling, incineration and landfill have been implemented to manage plastic waste. Emerging approaches such as thermal cracking and carbonization for the reutilization of waste plastics have also been developed [1]. It is predicted that the plastic production stage (processing and disposal) could emit 6500 Mt equivalent of CO_2 up from 1781 in 2015 [7]. While significant concerns regarding plastic waste and pollution stem from unsustainable production and consumption patterns, inadequate disposal methods post-consumption, insufficient collection systems, and mismanagement during post-collection or post-processing operations [3]. Furthermore, recycling is significantly promoted with the integration of circular economy (CE) concepts. Aiming to convert waste materials into valuable products, thereby improving effectiveness. Consequently, these strategies, along with waste reduction initiatives, are increasingly adopted as primary waste management policies

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[8]. However, recycling efforts have been facing challenges, particularly due to the mixing of plastic waste with municipal solid waste without proper sorting [9]. A lack of effective waste separation behaviour among consumers is also one of the major contributing factors [10].

Although global plastic production in industry decreased in 2020 due to the COVID-19 pandemic and lockdown measures [5, 11]. The pandemic also transformed consumer lifestyles, leading to increased reliance on online food delivery, plastic bags, food containers, and packaging for online shopping. As a result, there was a notable increase in the volume and composition of waste generation [12]. This indicates the need to also address consumer behaviours related to waste reduction and waste sorting. Increasing awareness of the consequences of waste can facilitate this change [4]. Overall, current waste management approaches for plastics illustrate the primarily focus on the post-consumption stage or end-of-pipe processes. This presents that there are still limitations in their effectiveness, as they rely on waiting for consumer behaviour changes or new innovations for disposal.

In response to the challenges posed by plastic waste, various policies and legislation are being implemented to ban plastic use or reduce plastic waste and its associated pollution [13]. One significant policy innovation is Extended Producer Responsibility (EPR), which shifts responsibility for plastic waste management to manufacturers. The European Union (EU) defines EPR as a policy principle to foster the entire life cycle of the product system, extending the manufacturer or producer's responsibilities to include take-back, recycling, and final disposal [14]. This approach requires producers to cover expenses throughout the product's life cycle, including waste collection, waste treatment, and consumer awareness initiatives [15]. It is more effective for producers to implement changes that reduce environmental, economic, and social impacts rather than relying solely on consumers. EPR provides incentives for manufacturers to improve product design towards eco-design and ensures responsible end-of-life management to improve recyclability [5]. The concept of EPR has been adopted and implemented in legislation across countries worldwide.

Thailand has faced a critical challenge in managing plastic waste. In 2023, the country generated 3.03 million tons of plastic waste, accounting for 11.25% of the total waste produced, with a significant portion consisting of single-use plastics (SUP). However, only 0.75 million tons (or 25%) was recycled, while 2.18 million tons (72%) was disposed of alongside other waste [10]. Historically, despite the extensive use of plastics in Thailand, there has been a lack of specific and stringent legislation regulating plastic waste, in contrast to many other countries. As a result, past approaches primarily relied on voluntary initiatives and awareness campaigns by organisations rather than formal measures to reduce plastic consumption [16, 17].

In response to the need for improved management various waste management plans have been developed, including the Plastic Action Plan, which intends to address critical issues related to plastic waste management. However, this plan has met with resistance due to its perceived inconvenience for daily use and its negative effect on plastic producers [17]. The country has also implemented a policy to ban the import of plastic scrap and promote the utilization of domestic plastic scraps [18]. Simultaneously, the mismanagement of plastic waste, particularly in packaging, has resulted in substantial economic costs [19]. The lack of adequate infrastructure for plastic waste management further complicates the situation, as limited consumer actions to reduce plastic waste and sort their waste have also increased costs and burdens on municipalities [10]. Furthermore, increasing plastic utilisation requires incentives to enhance recycling based on CE [17]. Considering these challenges, Thailand is currently in the process of adopting EPR principles, marked by the proposal of legislation focused on packaging waste management.

Therefore, this study aims to explore the current situation and progress of the implementation of EPR in Thailand, focusing on the ongoing progress involving relevant stakeholders, including the business sector. The study examines Thailand's interests and progress in adopting EPR, the legislative integration of EPR, and the perspectives of businesses and related organisations regarding EPR practices and how they respond to the adoption of EPR.

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2. METHODOLOGY

In this study, a variety of data sources related to the development and implementation of EPR in Thailand were collected and analysed as part of a qualitative research approach. This process aimed to describe the progress made and the rationales behind it. Multiple data collection methods were used. Document review is used to systematically collect and review documents relevant to EPR activities and progress in Thailand [20]. This also presents supporting evidence for assessing the progress over time [21]. While offering insights into stakeholders' accounts and opinions on EPR-related initiatives. Relevant keywords were searched in both Thai and English, such as "EPR", "EPR Act", "EPR activity", "plastic waste", "plastic law", "plastic packaging legislation" and "plastic waste management". It included not only government sources but also contributions from collaboratives, the business sector, international organisation and experts engaged in EPR initiatives and advancements. This comprehensive search aimed to cover a broad range of EPR related content, including research, reports, publications, policy documents, legislation, and business reports from diverse stakeholders. This effort also aims to explore regulations related to plastic waste management and EPR. Thus, establishing a foundational understanding of the EPR regulatory landscape, which is crucial for advancing EPR implementation in the country. Additionally, since EPR is a recent development, online news and articles were included to provide updates on EPR and its implementation. However, because this is secondary data, there could be limitations regarding the accurate interpretation of the content and the intentions.

The documents selected for this study were based on specific inclusion criteria, emphasising their direct relevance to the research topic and questions. Criteria included the organisation's (public or private) vision, strategies, and activities related to EPR or sustainable waste management, as well as previous challenges, particularly regarding plastic waste management. The review also considered policies, plans, and strategies on EPR and CE, including legislation on plastic waste management or packaging. Studies that primarily emphasised technical or scientific processes, such as waste calculations, recycling techniques, and incineration, were rejected, as were those that did not specifically address plastic waste or packaging. Additionally, studies focusing solely on the BCG (Bio-Circular-Green Economy) or 3Rs (Reduce, Reuse, Recycle) without mentioning CE or EPR were excluded. The selection process prioritised credible sources, including peer-reviewed articles and reliable publications, resources relevant to context of Thailand were included. This selection contributed meaningfully to the research objectives and the specific situation of EPR development in Thailand.

In-depth interviews were also conducted with representatives from two organisations, one business group and one international organisation engaged in sustainable use of resources. They were selected for their extensive experience and long-term involvement in EPR and waste management. Additionally, they have collaborated with various companies, stakeholders, and communities over the years. Their participation in several meetings also provides valuable insights, opinions, feedback, and information relevant to the development of legislation on EPR. Although the number of organisations selected for the interviews is small, the insights gathered from these experienced representatives are particularly valuable, especially given that EPR is a relatively recent concept. The aim of the interviews was to gather detailed information on EPR-related activities and to explore how stakeholders, aside from the government, perceive the overall progress of EPR and are concerned on its legislative aspects. Conducted in March 2024 via an online platform, the interviews featured a predetermined set of questions that captured perspectives on the EPR principle, sustainable waste management in Thailand, and the Sustainable Packaging Management Act.

The semi-structured interview format offered flexibility and allowed for the exploration of respondents' active involvement in EPR initiatives, including ongoing projects, future strategic plans, collaborative efforts, and the rationale behind these activities. Additionally, the interviews addressed respondents' views on the implementation of EPR through the Sustainable Packaging Management Act and their contributions to promoting environmental sustainability and effective waste management practices in Thailand. Interview guides were developed to align with the research questions and

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objectives to ensure the validity and reliability of the data collected from the interviews and its interpretations. Additional questions tailored to the specifically characteristics of each organisation were incorporated to collect more detailed insights into their opinions. This facilitated a more focused conversation and strengthened the validity of the findings by ensuring that the interviews addressed relevant topics. Additionally, the details of the pilot projects and their EPR related activities were cross verified with previous studies and reports to ensure accuracy.

The direct stakeholder engagement provides a detailed understanding of EPR progress by also considering the legislative landscape and the perspectives of key stakeholders. Ultimately, it offers a comprehensive view of the complexity surrounding waste management and EPR in the country. Subsequently, the research is then carried out using content analysis to analyse the information obtained as a descriptive response to the key themes related to EPR progress, the implementation of legislation, and EPR practices [22]. This analysis integrates various data sources and generates a wide range of stakeholder perspectives to support the arguments and conclusions presented in the study.

3. RESULTS AND DISCUSSION

Thailand’s journey toward comprehensive waste management has been marked by significant milestones, notably the second National Waste Management Action Plan (2022–2027) developed by PCD. This plan follows the Solid Waste Management Master Plan (2016–2021) and aims to address the ongoing environmental and public health impacts of waste pollution, while also responding to evolving challenges and aligning with sustainable development goals and national strategies. Key initiatives include adopting CE principles such as BCG, 3Rs, implementing the Polluter Pays Principle (PPP), fostering public-private partnerships in waste management, and embracing concept of EPR [23]. Among these efforts, EPR is one of the most recent concepts introduced to waste management in Thailand.

The concept of EPR was introduced in Thailand in 2000 in response to concerns about the potential impacts of the EU’s Directive on Waste Electrical and Electronic Equipment (WEEE) [24], given Thailand’s status as an exporter to the EU. This initiative sparked interest among environmental organisations in applying EPR principles to manage challenging scrap products in the country. Although these initial efforts were unsuccessful, they laid the groundwork for later implementations of EPR in waste management. This section discusses Thailand’s progress and efforts toward the introduction and adoption of EPR, as well as the challenges that lie ahead.

3.1 Progress and activities on the introduction of EPR in Thailand

Several progress developments have been made over the years, as follows:

1) Research

The potential of introducing and adopting EPR have been examined by various environmental research institutions and academic organisations. Research in 2009 highlights the prospect of implementing EPR in non-OECD Asian countries, including Thailand, specifically in relation to WEEE [24]. This study identifies challenges associated with the introduction of EPR legislation while also outlining opportunities for legislative development that could also be applied by other countries.

A more recent study conducted in 2022 appointed by the Pollution Control Department (PCD) aimed to prepare and develop legislation on packaging based on EPR and CE [25]. It presents collaborative projects involving multiple sectors, including PCD, environmental research institutes, and international development organisations [23]. It focuses on developing a policy framework for EPR for packaging waste, with activities that include the rethinking of plastics within the context of CE to address marine litter. The project aims to collect feedback on legal proposals for sustainable packaging waste management based on EPR principles. Various stakeholders, including government agencies, local organisations, academic institutions, NGOs, and the business sector were invited to meetings to provide data and insights. This project seeks the potential to transform waste management practices and promote CE through the proposal of a legal framework.

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Moreover, potential impacts and implications of plastics value chains, market and ecosystem based on the introduction of EPR in Thailand were studied, commissioned by an environmental research institute [26]. It also examined the changes of market, opportunities, policies, potential regulatory shifts in food-grade packaging of rPET. Information was collected through several methodology, such as review of EPR policy, desk research and in-depth interviews with plastic value chain stakeholders.

This illustrates that there are a number of studies on EPR, highlighting the recognition of its importance in promoting sustainable waste management practices and reducing environmental impacts. Additionally, these studies indicate that stakeholders in Thailand are actively obtaining knowledge to drive EPR principles forward.

2) On-going promotion effort on ERP by various stakeholders

Numerous efforts have been undertaken over the years to promote both knowledge and progress regarding the implementation of EPR in Thailand. In 2019, the Packaging Recovery Organisation Thailand (PRO-Thailand Network) was established and later officially inaugurated in 2023. Driven by the vision of seven major companies [27] to promote collaboration in advancing EPR. They aimed to work alongside other stakeholders, including brand owners, product manufacturers, packaging producers. Several activities have been carried out, such as partnerships in initiatives and pilot projects focused on post-consumer packaging collection, recycling, and educating the public [28, 29, 30].

Activities, progress, achievements, knowledge and updates on EPR have been reported across several platforms, including social media in recent years since 2020. Where they are presented in the form of posts, articles, news, infographics, and video clips. For example, Facebook pages of organisations such as PCD, the Thailand Institute of Packaging and Recycling Management for Sustainable Environment (TIPMSE), Greenpeace Thailand, Chula Zero Waste Project, SD Thailand, and PRO-Thailand Network provide updates covering a wide range of topics. These updates include basic information about EPR, collaborations and projects, developments regarding legislation and its mechanisms, the status of legal initiatives, upcoming meetings and projects, takeback programs, and concepts related to CE and packaging waste management.

Furthermore, seminars, workshops, and training sessions on EPR have been conducted. For example, TIPMSE organised seminars for the business sector to facilitate adaptation to international EPR regulations and policies, particularly those established by the EU, which mandates that all packaging on the market must be reusable or recyclable by 2030. Member countries are required to participate in EPR programs, taking responsibility for packaging throughout its lifecycle by gradually increasing recycling rates. Although this regulation has not yet been enforced with export partners, it is likely to be implemented in the future. In anticipation of these forthcoming regulations, producers are invited to share their perspectives and prepare for participation in the voluntary EPR PackBack program, which focuses on collecting packaging in advance of the mandatory phase [31].

This is in line with the seminars organised by PRO-Thailand Network in 2023, which focused on lessons learned from successful EPR mechanisms, PRO, in other countries. Thus, aimed to enhance awareness of EPR principles, policies and operations of voluntary PRO [29]. It also sought to engage producers within the packaging supply chain, encouraging their collaboration with the PRO-Thailand Network to support the implementation of EPR policies and prepare for the forthcoming waste management practices.

Government agencies have also organised Thai-EU expert workshops in 2023 to share knowledge and experiences regarding best practices in EPR for packaging and CE. It aims to support Thailand's establishment of a mandatory EPR system, a key component of the country's Action Plan for Waste Management. Participants from various sectors, including industry, academia, and civil society, attended the workshop. There was also a discussion on trade barriers related to environmental standards. Additionally, future meetings with the Bangkok Metropolitan Administration and recycling businesses were expected to prepare for the upcoming EPR legislation [32].

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These activities and collaborations illustrate the efforts of the business sector to prepare for the adaptation of EPR. They also present opportunities for businesses to align with international policies, which have significant impacts on their production processes and corporate strategies.

3) Pilot projects

Another significant effort driving voluntary EPR is the collaboration among various organisations, including producers, retailers, collectors, along with TIPMSE, under the Federation of Thai Industries, through the PackBack program. These stakeholders work together on projects to promote EPR principles, policies, and innovations in packaging management, such as recycling processes, storage systems, and drop-off points for used packaging. Pilot EPR projects were initiated in Chonburi province, known as the Chonburi CE City Model project, which demonstrates the potential of EPR in managing packaging waste and collecting data on glass recycling [33, 34]. This project aims to create a packaging waste collection and management model shaped by local circumstances [34]. It is anticipated that the program will expand from three pilot projects in three municipalities to eleven municipalities [35].

Interviews with participants provided additional insight into a collaborative community-based project in Koh Yao District, Phang Nga Province, which aims to strengthen a resilient waste management value chain from the islands to the mainland to tackle marine plastics. This project serves as a successful model for community waste management for other areas. It also benefits the food and beverage industry, especially considering the ongoing adjustments to packaging regulations. Highlighting the importance of building on community efforts to facilitate larger-scale collaborations, addressing environmental challenges and promoting sustainable practices through awareness campaigns, policy advocacy, and practical interventions.

Business groups and international organisations also collaborated on a project to support EPR practices, leading to significant changes in packaging return in Ngao and Bang Non, Ranong Province [35]. Interviews with respondents revealed that the project helped separate recyclable materials and involved local recyclers, enabling them to integrate these materials into an effective waste management system. It was designed to resonate with community behaviours and preferences. Thus, partnering with local stores to encourage customers to return post-consumer packaging in exchange for products. It sought to highlight the value of packaging even after use, promoting its return. The project achieved an impressive collection rate, recovering ten tons of used packaging [35]. It also encouraged business groups to further apply their strategies in other areas. The effort demonstrates another significant progress in adopting EPR feasibility of establishing a recycling system that integrated EPR principles while awaiting regulatory enforcement.

Therefore, as one of the respondents emphasised the critical role of the private business sector, particularly packaging producers, in receiving key information and actively participating in shaping the country's policy direction. These pilot projects provide invaluable lessons and opportunities for urban policymaking and infrastructure investment. Effective infrastructure planning is essential, as inadequate systems can pose significant challenges for waste management, especially with the city's expansion and the prospect of urbanisation in certain areas.

This section demonstrates that interest in EPR in Thailand has existed for some time. However, there is a notable gap between earlier research and more recent studies and developments. This could suggest there was either absence of interesting, lack of engagement, movements or delays in implementing EPR. It is criticised that despite recommendations for the country to advance its EPR initiatives over the past 10-15 years, one of the obstacles has been inequality within the business sector, with some larger companies expressing strong opposition to such measures [36]. Nevertheless, evidently EPR has recently received renewed attention. These ongoing efforts present collaborative commitments to adopting EPR principles among various stakeholders, including government agencies, businesses, producers, collectors. They underscore the importance of staying informed and adapting in anticipation of upcoming EPR legislation in Thailand and the broader international context. These

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efforts provide a valuable basis for businesses to rethink packaging design, productions and collection processes. Challenges also emerge, such as the lack of concrete measures to incentivise participation from the producer sector and insufficient recycling technology. Nevertheless, there is a continued push within Thailand to embrace EPR principles, as seen in the ongoing initiatives aimed at strengthening EPR compliance through enforceable regulations.

3.2 The introduction of the Draft sustainable Packaging Management Act (Draft Packaging Act)

Although pilot projects are already in place to drive voluntary EPR, it is also suggested that the establishment of EPR legislation may be necessary [37]. This legislation would facilitate the transition to mandatory EPR implementation in the future. In 2024, four legislative frameworks have been drafted and are currently undergoing a public hearing process to collect comments and recommendations for amendments. These frameworks aim to develop legal tools for waste and packaging management, incorporating EPR concept [34]. One of these frameworks is the Draft Sustainable Packaging Management Act (Draft Packaging Act) which aims to also incorporate EPR and CE in packaging waste management through legislation. This section discusses the key points of this Draft Packaging Act [38].

Key measures to promote sustainable packaging management outline the essential components of the EPR system. This includes specifying the types and categories of packaging covered, mandating a buyback or deposit and refund system, and restricting the production and use of certain packaging types, particularly single-use items. The framework establishes fees to compensate for environmental damage, which will support ecosystem cleanup and restoration efforts. Additionally, government agencies are responsible for reducing packaging use, promoting material efficiency, and increasing public awareness. An information system is also required to facilitate registration and compliance.

The industrial sector encounters additional requirements, including guidelines for support from local government organisations and those involved in collecting used packaging. It outlines methods for calculating management fees that responsible operators, who join as members, must pay. If used packaging cannot be collected and reused as targeted, these operators are required to pay a compensation fee for any resulting environmental damage. While municipalities facilitate the storage and reuse of used packaging, empowering local government organisations to manage packaging sustainably. As for waste sorting, no individual is permitted to dispose of used packaging with other waste. Used packaging must be placed only in the designated containers provided by the local administrative organisation. The owner or resident of the building is responsible for separating used packaging from other waste types before delivering it to the local government organisation.

The EPR concept in the Draft Packaging Act defines the responsibilities of organisations involved in packaging management, particularly in collecting, sorting, and reusing used packaging. It emphasises the importance of labelling requirements while also imposes fines for violations to ensure compliance, enforcement of buyback systems, restrictions on certain packaging, obligations for compensation fees, and establishes return points for packaging. It also requires detailed packaging management plans from producers and industries. While local government organisations are tasked with collecting, storing, and reusing used packaging, thereby promoting effective waste separation practices

One of the key mechanisms established is the Packaging Producer Responsibility Organisation (PRO), responsible for managing packaging in accordance with the Draft Packaging Act. Serving as a mediator between the legislation and producers, it facilitates networking activities and collaborations that promote sustainable waste management under EPR principles, highlighting significant involvement from businesses in various joint projects. Overall, the Draft Packaging Act intends to promote EPR and CE by aligning with solid waste management goals and providing a framework for sustainable packaging practices.

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3.3 Stakeholders perspectives on the adoption of EPR practices packaging waste management

This section presents key points from interviews with respondents, offering insights into stakeholders' perceptions of current EPR principles. It discusses their efforts to embrace EPR, the opportunities available to them, and their perspectives on the implementation of the Draft Packaging Act and the future of EPR practices.

As discussed in previous sections and highlighted in the interviews, information collected in this study is also partially aligned with the reviews of existing EPR implementations and stakeholder interviews and documentations [23, 26] that summarised and proposed key recommendations for the prepare of the adopting EPR system while also address plastic waste management Thailand. Several stakeholders have actively engaged in EPR activities, particularly in the business sector. This willingness is evidenced by collaborations among business companies and other stakeholders, including pilot projects aimed at strengthening community livelihoods. Respondents expressed that these projects focus on fostering cooperation and resilience between organisations and communities, creating interconnected and sustainable impacts. Their project also assisted local communities in developing and improving living conditions sustainably. This commitment is exemplified by the focus on sustainable waste management practices, such as offering products that are 100% recyclable or made from recycled materials. Nonetheless, while beverage packaging is recyclable, foil snack packaging poses a challenge due to its non-recyclability. In response, the producer also explores alternatives and innovations to address this issue. This demonstrates a proactive interest in supporting waste management and sustainable production practices, including eco-design, which reflects EPR principles among producers. Furthermore, respondents emphasised that sustainability is a key component of the production process, as reflected in their activities and projects. Stakeholders, particularly in the business sector and among producers, actively engage in initiatives aimed at enhancing environmental practices and promoting responsible waste management. Through these collaborative efforts, certain producers demonstrate their commitment to contributing positively to environmental conservation and sustainability.

Interviews offer the perspectives into the progress of introducing EPR to the business sector and other stakeholders with the claim that many organisations have already adopted EPR practices well before the introduction of the Draft Packaging Act and will continue to participate, although at varying levels of involvement. Some may engage more actively if their business is directly impacted, while others might step back to focus on different sustainability issues, given that the groundwork has already been established.

Despite their involvement in providing feedback on the Draft Packaging Act, there is still a lack of comprehensive understanding of its specifics, leading to confusion and uncertainty on some topics. Stakeholders suggested that the government prioritize circulating detailed information about the Draft Packaging Act and make it accessible to all parties, including producers and the public. This information should be distributed through various channels, such as official websites and public announcements, originating from a single, authoritative source for accuracy. Centralising this information would help stakeholders access key information and requirements, address compliance concerns, and focus on specific actions. Additionally, the government should provide the content of the Draft Packaging Act along with supplementary materials, such as explanatory guides, FAQs, and case studies, to clarify its implications and implementation processes. These resources would significantly assist stakeholders in understanding the Draft Packing Act and its potential impacts. Therefore, suggesting that by enhancing information distribution and ensuring consistency and reliability, the government can effectively reduce confusion and improve stakeholders' understanding of the Draft Packaging Act, especially for stakeholders that will directly comply with the Draft Packaging Act such as producers. This transparent and inclusive approach is crucial for fostering trust, encouraging compliance, and facilitating the smooth implementation of the Draft Packaging Act.

Respondents also noted that incorporating economic mechanisms and establishing a PRO present promising opportunities for sustainable packaging practices. However, careful consideration and ongoing assessment are essential to ensure that the Draft Packaging Act meets its goals while

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minimising the effects. Although incentives for producers to adopt sustainable packaging should include the true environmental costs in fee calculations, there are concerns about the challenges of accurately assessing the environmental impact of packaging materials. This could result in inequities or unintended consequences in fee structures, potentially undermining the intended benefits of the economic approach. Currently Thailand is primarily focused on packaging, which is differed from the successful EPR implementations in other countries, such as those in the electronics sector in Europe. Highlighting broader opportunities for Thailand to expand its EPR implementation in the future. Additionally, the Draft Packaging Act requires producers to include EPR labels on their products, providing essential guidance on proper disposal and recycling practices [36]. This labelling not only informs consumers regarding information about the product and its packaging but also promotes responsible waste management in line with EPR principles.

3.4 Alternative waste management policy

The Thai government has prioritised waste management, particularly in response to plastic pollution, which was announced as national priority in 2018 [37]. The initiative includes policies and plans aimed at tackling plastic waste generated from two major sources of industrial processes and households. While previous management initiatives primarily relied on CE, BCG and 3Rs, the efficiency of plastic waste reduction could be further enhanced by considering the plastic value chains [39]. Therefore, EPR can be proposed as add-on strategy [39] or as alternative waste management policy that incorporates a broader range of responsible stakeholders. Importantly, as EPR would emphasise environmentally friendly packaging solutions and product life cycles. This would align with the targets set by the by Roadmap on Plastic Waste Management (2019-2030) and the Action Plan on Plastic Waste Management Phase 1 (2020-2022) that led to a nationwide ban on four types of plastic waste and the replacement of SUP with more environmentally friendly products [36, 40]. Furthermore, Thailand is also set to transition to sustainable plastic waste management, with the goal of recycling or reusing 100% of plastic waste by 2027 [41]. The adoption of EPR would also correspond with voluntary measures stated in Thailand's Roadmap. Which aims to reduce plastic production and SUP consumption while establishing effective management systems for post-consumer [42]. The adoption of EPR through the Draft Packaging Act then presents an opportunity to address the existing legal gaps, particularly regarding the responsibilities of plastic producers, including their financial obligations in post-consumption waste treatment [36, 43].

While the introduction of the Draft Packaging Act, is expected to generate positive economic outcomes, including reducing municipal waste management expenses due to decreased waste volume and improved waste collection system. Additionally, production costs may decline through material recycling, potentially enhancing the global competitiveness of producers. However, concerns exist that EPR could lead to higher operational costs for producers due to changes in product design from the beginning, designing, to disposal and the establishment of collection systems, which may ultimately result in increased product prices. It is important to ensure that these costs are not fully passed on to consumers. Nonetheless, it also faces uncertainties regarding its effectiveness in changing producer and consumer behaviours. Concerns have been raised about the potential impact on small and medium-sized enterprises (SMEs), which may struggle to adapt due to budget constraints. As EPR policies can negatively affect small producers, who often lack the resources to comply with regulations. Consequently, the costs of adoption and necessary changes may be passed on to consumers [5]. Additionally, effective post-consumption infrastructure, particularly for waste management and collection, is essential for adopting EPR. This infrastructure is crucial for achieving a zero-waste business model reducing overall waste [5].

In addition to government agencies, other sectors also play vital roles in facilitating and incentivizing sustainable approaches. The effective implementation of waste management legislation requires strict, transparent, and equitable enforcement to hold both consumers and producers accountable for their waste generation and management practices. Furthermore, transparency in both the legislation and enforcement not only builds trust among stakeholders but also fosters a culture of

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compliance. Significant changes in consumer behaviour are also essential for achieving sustainable reductions in plastic waste [44]. Therefore, addressing waste separation behaviour among consumers is then a crucial first step in fostering effective waste management and CE practices, similar to argument by Marks et al. [37]. Moreover, EPR policies must be equitable and inclusive, ensuring that all segments of society, including marginalised communities, have access to waste management services and resources. This involves addressing social and economic differences that could impact waste management practices. While also considering the community's unique socio-economic and cultural conditions, thus adapting to solutions that reflect local conditions and preferences are more likely to succeed.

Focusing on product's life cycle, including collection rather than solely on recycling, EPR can enhance recycling rates, expand waste collection locations and services, and reduce the amount of plastic waste that ends up in landfills. Thereby breaking the cycle of plastic pollution [45]. This comprehensive approach is particularly important due to the significant contributions of plastic to greenhouse gas (GHG) emissions [46]. Highlighting the needs to address this issue and lowering its GHG emissions which is currently accounted for 4.5% of global emissions [47]. The study on GHG emissions from plastic consumption in Thailand estimated that the country's plastic waste emits 2887.04 tonCO_2eq/day or 1.05 million tons/year [46]. Which lead to consequences such as an increase in Thailand's mean maximum temperature, climate change, and adverse effects on the natural environment [46, 48].

This underscores the necessity for strategies to reduce plastic consumption and improve plastic waste management practices, particularly in enhancing recycling efficiency and source separation. Such measures can increase economic value and reduce GHG emissions by approximately 3.87 and 3.17 times, as reported in the study conducted in Rayong [48]. The adoption of EPR can facilitate transformative changes by mitigating plastic pollution, promoting production efficiency, lowering GHG emissions associated with new material production, and ensuring that plastic producers take comprehensive responsibility for both their products and the collection process. Since GHG emissions from end-of-life plastic waste vary by country due to different waste management systems [45], the adoption of EPR as an alternative waste management policy presents another approach to potentially reduce GHG emissions. This can assist the country achieve its goal of GHG emissions reduction by 30-40% by 2030, with the target of reaching carbon neutrality by 2050 and net zero GHG emissions by 2065 [41].

The adoption of EPR for sustainable waste management depends not only on regulatory measures and industry acceptance but also on achieving alignment among all stakeholders toward a common goal. Together with awareness campaigns, collective understanding and commitment among consumers of sustainable waste management practices. Along with the fostering of shared vision and commitment to sustainability can create a lasting impact on waste management efforts. EPR can offer an approach to address the inefficiencies in current waste management practices. Thus, driving transformative changes by reducing plastic pollution, promoting production efficiency through CE, and GHG emissions reduction.

4. CONCLUSIONS

Thailand has actively promoted various policies aimed at improving waste management practices, with EPR emerging as a key alternative opportunity. This concept shifts responsibilities to producers, requiring them to oversee the entire lifecycle of their products, thereby promoting a more sustainable and responsible waste management strategy. Additionally, the commitment of consumers and stakeholders is also essential for establishing sustainable waste practices. The following conclusions can be drawn:

1. EPR is one of the waste management policies in Thailand to achieve sustainable waste management, highlighting efforts to adopt its principles for the future. Collaborative activities, projects and pilot studies highlight the potential of EPR in improving sustainable waste management practices.

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However, stakeholders have identified limitations within the proposed Draft Packaging Act, suggesting that the government should address these concerns to ensure effective implementation. While, achieving success will also require time, as consumer participation is necessary. Raising awareness and educating the public on this waste reduction and sorting practices are also keys for effective implementation.

2. The potential of the Draft Packaging Act could contribute to reducing the government's burden in managing used packaging, which previously relied on local municipality administrative organisations. Currently, they lack the capacity to effectively collect, and sort used packaging for sustainable management, including recycling or conversion to fuel energy. The Draft Packaging Act also addresses fee collection, directing fees from non-recyclable packaging waste to environmental agencies, which will use the funds to support the country's environmental maintenance.

3. The offering of economic incentives to producers for adopting EPR principles, along with penalties for non-compliance, can serve as a positive mechanism to foster a more responsible and eco-friendly manufacturing landscape.

4. The development of policies, legislation, strategies, and interventions based on EPR can contribute to alternative pathway for Thailand to achieve net zero emissions. By prioritising recycling, improving waste sorting, and promoting environmentally friendly packaging. These efforts facilitate the reductions in plastic waste and GHG emissions related to plastic production.

5. Future studies could explore deeper into policymakers' perspectives on the challenges and limitations identified by the business sector regarding the proposed Draft Packaging Act. By examining these perspectives, researchers can gain valuable insights into the regulatory landscape, potential policy changes, and strategies for overcoming barriers to effective waste management and EPR implementation.

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Generating Low Lipid and Protein Food Waste Hydrolysate by a Dilute Sulfuric Acid Thermohydrolysis for Biorefinery Applications

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ABSTRACT

Food waste holds great potential as a sustainable resource for biorefinery applications. Still, its efficient use is hindered by the simultaneous solubilization of lipids and proteins during polysaccharide hydrolysis, which disrupts downstream fermentation processes. This study investigates the use of dilute sulfuric acid thermohydrolysis to produce food waste hydrolysate with high reducing sugar but low lipid and protein content. The initial food waste was ground and dried before undergoing hydrolysis. Thirty grams of dried food waste were mixed with 1500 mg of oil solidifier, then 180 mL of 5% H_2SO_4 solution added. The mixture was then agitated at 200 rpm and heated to 100°C for 180 minutes. This process resulted in a hydrolysate containing 66.52 mg/mL reducing sugar, 13.66 mg/mL lipid, and 2.02 mg/mL protein. These results demonstrate a viable approach to producing a more fermentation-compatible food waste hydrolysate, contributing to the advancement of sustainable biorefinery technologies and the valorization of food waste as a resource.

Keyword: Reducing sugar content/ Lipid content/ Protein content/ Biorefinery/ Food waste valorization

1. INTRODUCTION

Managing food waste (FW) has become increasingly urgent due to its significant environmental and economic impacts. Globally, more than 2 billion tons of FW are generated annually, contributing to greenhouse gas emissions and resource depletion [1]. In Thailand, whose population exceeds 70 million, FW generation averages 79 kg per capita annually [2]. This trend poses a looming environmental threat for the future. Moreover, conventional disposal methods, such as landfilling and incineration, are unsustainable and waste valuable resources that could be repurposed [3].

FW contains a total sugar content ranging from 25.5 to 143 g/L and a carbon-to-nitrogen (C/N) ratio of 9.3 to 36.4 [4, 5]. Depending on the type, FW's lipid content ranges from 5%-33% [6, 7]. FW also exhibits a total volatile organic content (VOC) ranging from 82% to 96%, providing a significant energy source for microorganisms in biorefinery applications [8]. Utilizing FW in biorefineries presents a promising approach to meeting energy and biochemical needs, addressing environmental challenges, and sidestepping the food-versus-fuel debate [3, 9].

A promising approach to FW valorization is its conversion into hydrolysates, which serve as substrates for various biorefinery applications, including biohydrogen, biomethane, and bioethanol [10-12]. Hydrolysis is crucial for breaking down polysaccharides within organic waste into simpler saccharides, as their large molecular size cannot penetrate bacterial or fungal cell membranes [13]. Thus, FW is more convenient and cost-effective as a substrate than monomer or dimer-based alternatives, particularly after hydrolysis. The composition of FW hydrolysate (FWH) is critical; high levels of lipids and proteins can hinder fermentation and complicate downstream processes. Lipid concentrations above 6 g/L can cause inhibition, rapid pH drops, and floating sludge in the bioreactor [14]. Similarly, protein contents exceeding 8 g/L can result in a low C/N ratio, hindering biorefinery production [15].

Various methods can be employed for FW hydrolysis, including enzymatic hydrolysis, supercritical CO_2 fluid extraction, and dilute acid thermohydrolysis [16-18]. Dilute acid thermohydrolysis is energy efficient, uses readily available chemicals, and is cost-effective compared to other methods [18]. Moreover, H_2SO_4 (sulfuric acid) is commonly used in dilute acid

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thermohydrolysis for various organic wastes because of its lower corrosiveness [18-20]. Dilute sulfuric acid thermohydrolysis has been shown to solubilize low lipids into hydrolysate from various feedstock since lipids have limited solubility in water [18, 21, 22]. When applied for a short duration (60–180 minutes) at lower temperatures (80–160 ºC) and acid concentrations lower than 6%, it prevents protein solubilization into the hydrolysate [23].

This study investigates the use of dilute sulfuric acid thermohydrolysis to generate FWH. By controlling the factors affecting reducing sugars, proteins, and lipids solubilization, we aim to produce an FWH rich in reducing sugars with minimal contamination from lipids and proteins.

2. METHODOLOGY

2.1 Chemicals and initial food waste source

Sulfuric acid, 3,5-dinitrosalicylic acid, and Coomassie Brilliant Blue R 250 were procured from Loba Chemie (Australia), while the oil solidifier (powder) was purchased from SC Johnson (Japan), with the remaining chemicals purchased from Univar Solutions (USA) and RCI Labscan (Bangkok).

The FW used in this study was collected from the canteen around Sirindhorn International Institute of Technology-Thammasat University, Rangsit Campus, Thailand. The FW was collected weekly for a month to account for its variability. Only rice, noodles, flour, vegetables, side dishes, and meat wastes were used; no bones or other hard parts were used. The FW was then ground for 30 seconds, put in a tightly tied plastic bag, and stored in a freezer (-4ºC) for further study.

2.2 Characterization of dried food waste

The drying process of the initial FW was carried out at 60°C for 48 hours. Dried FW was then reground and sifted with mesh size 8 to obtain particle size lower than 0.5 mm. The obtained dried FW was characterized by the total solids (TS), total volatile solids (TVS), and ash content, which includes gravimetric moisture measurement at 105°C for three hours and ignition of the dried FW at 550°C for one hour, respectively [24]. At room temperature, the degassed 1:10 mixture of dried FW and deionized water pH was measured using a pH meter [25]. The dried FW protein was extracted using the salt/alkaline method, and the protein content was quantified using the Bradford method [26]. The dried FW crude lipid content was determined using the modified Folch method [27]. The dried FW carbohydrate content was determined using the calculation: carbohydrate (%) = 100 % - (% moisture + % protein + % lipid + % ash) [28].

2.3 Dilute sulfuric acid thermohydrolysis of dried food waste

In this dilute acid thermohydrolysis procedure, about 18-30 g of dried food waste was mixed with 500-1,500 mg of oil solidifier within a 500-mL round-bottom flask, followed by the addition of 180 mL of 1-5 % H_2SO_4 solution. The mixture was then agitated at 0-200 rpm and heated to 80-100°C for 60-180 minutes. The factors level applied are detailed in Table 1. Upon completing hydrolysis, the resulting mixtures were allowed to cool at room temperature and transferred to a 200-mL glass beaker. Twenty mL of deionized water was added to a 500-mL round-bottom flask to recover any remaining mixtures and then combined with the beaker's contents. The mixtures underwent centrifugation at 8,000 rpm and 15°C for 15 minutes to separate suspended solid particles. The supernatant was further filtered through Whatman filter paper no. 1. After neutralizing the supernatant to pH 7 by adding 50% NaOH, the precipitate was separated by centrifugation at 8000 rpm and 15°C for 15 minutes. The clarified FWH was then stored in a refrigerator at 4°C for subsequent analysis.

The analysis encompasses three parameters: reducing sugars, lipid, and protein content within the FWH samples. Reducing sugar content was determined by spectrometry based on a colorimetric reaction with 3,5-dinitrosalicylic acid [18]. Crude lipid content is determined using the modified Folch method, as defined by Min and Ellefson [27]. The protein content was quantified using the Bradford method [26].

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Table 1. The factors level applied in dilute sulfuric acid thermohydrolysis

Factor level	Dried food waste (g)	Oil solidifier (mg)	H_2SO_4 concentration (%)	Temperature (°C)	Agitation (rpm)	Duration (minutes)
Lower	18	500	1	80	0	60
Middle	22.5	1000	3	90	100	120
Upper	30	1500	5	100	200	180

2.4 Data analysis

The FWH reducing sugar, lipid, and protein content (mg/mL) was measured at each factor level and compared to identify which level simultaneously produced the highest reducing sugar content and the lowest lipid and protein content.

Where; CF is carbon footprint (CO_2e per unit product), AD is activity data (mass/volume/kWh/km), and EF is emission factor GHG (CO_2e per unit) is the default emission factor of a given GHG by type of resource use. In addition, the emission factor used is shown in Table 2.

3. RESULTS AND DISCUSSION

3.1 Dried food waste characteristics

FW typically exhibits an acidic pH ranging from 3.9 to 6.7, differing from other organic wastes like manure, green waste, and sewage sludge [29]. Wu et al. [25] reported the prevalence of lactic acid bacteria in FW, which aid in natural fermentation by decreasing pH. Drying FW in this study aimed to stabilize nutrient content and pH. Maintaining moisture below 10% is advantageous as it reduces microbial activity, diminishes biological degradation, and simplifies storage [18]. The dried FW characteristics are shown in Table 2.

Table 2. The dried food waste sample characteristics

pH	Moisture (%)	TS (%)	Ash (%)	TVS (%)	Total carbohydrate (%)	Lipid (%)	Protein (%)
4.37	6.26	93.74	6.96	86.78	59.90	14.85	12.03

*%: w/w

According to Carpenter and Savage [30], FW typically contains 57-85% carbohydrates, 15-38% proteins, and 0-5% lipids on a dry basis, varying by season and location. The carbohydrate content of dried FW corresponds with the existing literature, whereas the protein content is diminished, and the lipid content is elevated. The protein degradation in FW occurs when the food is subjected to cooking processes such as frying, boiling, or steaming [6]. The standard approach involves separating and trans-esterifying grease in FW to produce biodiesel, while the solid portion can be composted into biofertilizer [7]. However, anaerobic digestion or integrated bioconversion approach seems to have more potential to repurpose FW's high carbohydrate content.

Furthermore, the observed TVS value indicates a notably high VOC content. A high VOC content ranging from 82-96% implies a substantial energy source for microorganisms involved in biorefinery processes [29]. Defending the type of FW, studies observed ash contents ranging from 2% to 10% [6]. FW ash content of the sample indicates a high concentration of minerals and metals essential for bacterial growth and activity in fermentation systems [6, 31, 32]. The detailed characterization of FW underscores its potential as a highly promising substrate for biorefinery applications.

This study further processed dried FW using dilute sulfuric acid thermohydrolysis. Two substrates, FWH and post-hydrolysis FW, are recovered through filtration. However, this paper will focus solely on FWH, with post-hydrolysis FW to be investigated in future studies.

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3.2 Food waste hydrolysate characteristics

Reducing sugar, lipid, and protein content in the FWH is important in assessing its potential use as a substrate for biorefinery applications. Figure 1 shows the FWH characteristics based on the level of the factors applied.

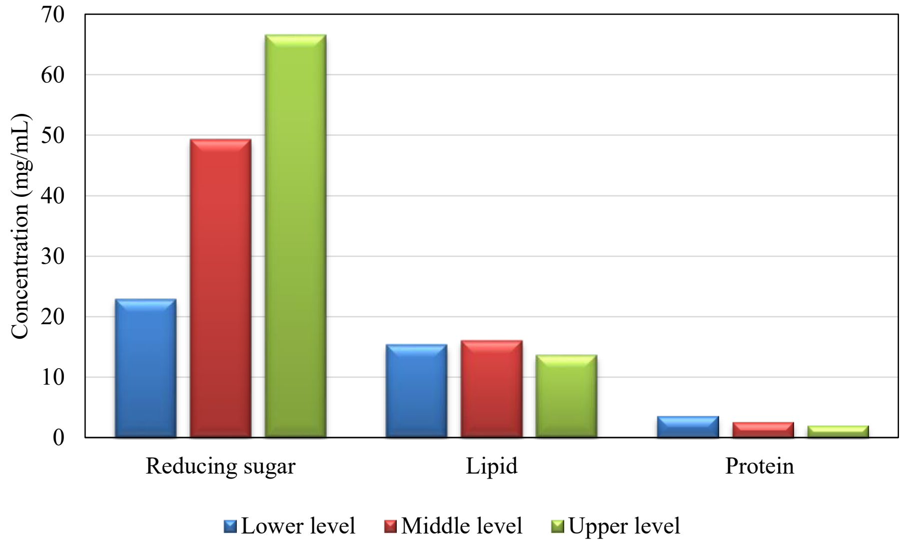

Figure 1. The reducing sugar, lipid, and protein content of food waste hydrolysate based on the level of the factors applied

The FWH-reducing sugar content increases proportionally with the level of factors applied. Hydrolyzing 30 g of dried FW in this study yields more FWH-reducing sugar and lowers water demand than smaller substrate amounts. Vallejos et al. [33] also found that a high substrate loading or low solution-to-solid ratio, between 1-11 mL/g, can significantly improve operational sustainability. Agitation is crucial in hydrolysis, especially with a low solution-to-solid ratio, as it helps maintain uniform concentration, pH, and temperature while reducing particle size [34]. In this study, 200 rpm agitation combined with a particle size of less than 0.5 mm led to a higher reducing sugar content.

The FWH lipid content slightly increases proportionally from the lower to the middle level of the applied factors. However, it decreases when the upper level is used. Higher temperatures and more oil solidifiers enhance oil absorption efficiency [35]. As a result, at 100°C and 1,500 mg oil solidifier, a lower FWH lipid content is observed despite the dried FW weight increases. Nevertheless, this study shows that lipid concentrations in FWH remain significantly high across all experiments, reaching up to three times the maximal level (6 mg/mL) for biohydrogen production. Therefore, the lipid content in hydrolysate is also contingent upon the substrate used.

In contrast to reducing sugar and lipids, raising all factor levels decreases FWH protein content. Laursen et al. [36] support this finding, noting that increased temperature and acidity—beginning at 60°C with 2% citric acid—lead to milk protein aggregation. Similarly, FWH protein aggregation may also occur and can be separated from hydrolysate by filtration and centrifugation. Protein content is important when using hydrolysates for subsequent fermentation applications. Protein content in the hydrolysate above 8 mg/mL leads to an imbalanced C/N ratio, encouraging bacterial overgrowth and protein degradation into ammonium (NH_4) through the consumption of H_2 molecules, ultimately lowering hydrogen production [5, 15]. According to a study by Mustatea et al. [23], extended hydrolysis periods ranging from 18 to 72 hours with 6.26% HCl used under vacuum conditions at 100-160 °C are necessary for dilute acid thermohydrolysis for thorough hydrolysis peptide bonds. As a result, the hydrolysis processes in this study can boost the yields of reducing sugars but not proteins. However, the low protein content of FWH is advantageous for subsequent fermentation processes, as an ideal C/N ratio of 10-30 promotes optimal microbial growth [29].

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Despite the upper level of factors applied resulting in a higher reducing sugar and lower lipids and protein in hydrolysate than other levels, further study should investigate different components of FWH, including 5-hydroxymethyl furfural, furfural, and phenolic compounds. These compounds, produced by dilute sulfuric acid thermohydrolysis, are known to reduce the yield of biorefinery applications [37, 38]. Besides, the hydrolysis processes' safety, energy efficiency, and environmental impact should also be considered.

Furthermore, the FWH dilution is a viable alternative approach, where the optimal reducing sugar concentration ranges from 10 to 20 mg/mL, as shown by Wang and Yin [4]. A two- or three-fold dilution can achieve the desired reduction of sugar and lipid concentrations. Selecting compatible or less lipids-sensitive biorefinery applications can also be applied. Lee et al. [39] used leather fleshing waste containing 49% lipids for biomethane production, achieving a yield of 200 mL CH_4/g VS. Additionally, optimizing the configuration of dilute sulfuric acid thermohydrolysis within the range of applied factor levels is essential for achieving the optimal balance of reducing sugars, lipids, and proteins, enhancing biorefinery applications.

4. CONCLUSIONS

Based on laboratory experiments and data analysis in this study. Some conclusions were drawn as follows:

1. The initial FW sample is rich in carbohydrates, indicating a highly promising substrate for biorefinery applications.
2. Dilute sulfuric acid thermohydrolysis effectively extracts significantly reducing sugars from dried FW while minimizing lipid and protein solubilization.
3. Optimum configurations produced an FWH containing 66.52 mg/mL reducing sugar, 13.66 mg/mL lipid, and 2.02 mg/mL protein.
4. Adjusting the dilution or optimizing the process configurations can further refine the content of reducing sugars, lipids, and protein to the desired levels.

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Boosting Tourism Resilience Through Enhanced Disaster Mitigation: A Case Study of Batu City

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ABSTRACT

As one of the leading tourist destinations in East Java, Kota Batu faces significant challenges due to the abundance of tourist attractions that are vulnerable to disaster damage. This places the tourism sector, which is the backbone of the local economy, in need of special attention in policy planning. This study adopts a comprehensive approach, combining policy analysis, spatial analysis using Geographic Information Systems (GIS), and public perception research. Through this approach, the study identifies the most disaster-prone tourist areas and assesses the gap between policy planning and on-the-ground implementation. The research findings indicate that, although Kota Batu has a disaster management policy framework in place, its implementation still faces various challenges. Factors hindering the success of this policy include inadequate inter-agency coordination, limited competent human resources, minimal budget allocation, and low participation from the community and tourism industry stakeholders in disaster mitigation and adaptation processes. Furthermore, the significant economic reliance on the tourism sector means that any disruption caused by disasters has a significant impact on the welfare of the local community. This study also highlights the importance of better integration between the tourism sector and disaster mitigation policies. Stakeholders in the tourism sector, including the government, tourism operators, and the community, need to collaborate in enhancing the resilience of tourist areas through the development of adaptive infrastructure, strengthening the capacity of local human resources, and introducing more effective early warning systems. Increasing awareness of disaster risks among tourists is also a crucial element in maintaining the sustainability of tourism in Kota Batu. The conclusion of this research suggests that stronger collaboration between the tourism sector and disaster management is essential for maintaining economic and environmental sustainability in Kota Batu. The findings and insights from this study can serve as a guide for local governments in designing and implementing more effective disaster management policies, especially in areas that rely heavily on the tourism sector.

Keyword: Tourism/ Policy/ Disaster/ Collaboration development

1. INTRODUCTION

Tourism can be defined as temporary travel from one's place of residence to a specific destination. This activity is not intended for permanent settlement or livelihood, but rather for satisfying curiosity and exploring new environments [1]. According to [2], tourism encompasses all activities related to travel or visits to a particular area or place for purposes such as recreation, learning, or other goals, without the intention of settling or earning a living. Kota Batu, a leading tourist destination in East Java, faces significant natural disaster risks, including landslides, flash floods, and earthquakes. To achieve sustainable tourism, it is essential to strike a balance by involving all stakeholders and fostering collaboration to create environmentally friendly tourist sites, engage local communities, and attract visitors [3]. The flash flood that occurred in Kota Batu in 2017 demonstrated the widespread impacts of such disasters, not only causing physical damage to numerous tourist attractions but also leading to a significant drop in visitor numbers. The financial losses sustained by the tourism industry, along with the social impacts on communities reliant on the sector, underscore the urgency of addressing disaster vulnerability. This is particularly important given the vital role tourism plays as the backbone of Kota Batu's economy.

Therefore, disaster mitigation efforts in the tourism sector are crucial to ensuring the sustainability of this industry in the future. According to [4], mitigation refers to a series of actions taken to reduce disaster risks, including both physical infrastructure development and increasing public

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awareness and capacity in facing disaster threats. Tourism disaster resilience refers to a destination's ability to respond to, adapt to, and recover from disasters. This resilience relies heavily on preparedness, mitigation planning, and effective coordination between local governments, tourism industry stakeholders, and the community.

In the context of disaster mitigation, Kota Batu needs to implement systematic measures to minimize the negative impacts of disasters on tourism infrastructure. This includes developing disaster-resilient infrastructure, implementing early warning systems, and educating the public and tourism industry players about disaster risks and management methods. Additionally, fast and efficient recovery mechanisms are needed post-disaster to restore tourist destinations to their original state. Based on the analysis of several previous studies, various indicators and methods have been identified as key focus areas in the context of tourism and mitigation efforts (Table 1).

Table 1. Previous studies

Researcher	Indicator	Method and Analysis	Findings
Lasaiba, M. A. (2024)	• The use of early warning technology (earthquake sensors, weather radars, applications). • Resilient tourism infrastructure. • Public education and preparedness. • Comprehensive risk planning and management. • Monitoring and evaluating disaster risks using modern technology.	• Qualitative • Data Synthesis • Literature Selection	Disaster mitigation plays a crucial role in protecting lives and assets, as well as supporting the growth of tourism in island regions. Resilient infrastructure, public education and preparedness, and early warning technology have proven effective in reducing the impact of disasters and accelerating the recovery of the tourism sector. Case studies in Bali, Lombok, and North Sulawesi provide empirical insights into the importance of inter-agency collaboration in disaster mitigation efforts.
Wahyuwidyaningrum, W., and Kaseng, A. W. S. (2024)	• Classification of tourist destinations based on the type of tourism (nature, artificial, cultural, special interest). • Classification based on the type of threatening disaster (floods, landslides, forest fires, extreme weather). • Implementation of early warning systems (EWS) to identify disaster signs. • Provision of evacuation facilities and evacuation routes. • Accessibility of nearby healthcare facilities. • Provision of hazard detection devices and emergency communication tools.	• Qualitative • Observation, Interviews, and Literature Review • Qualitative Descriptive Analysis • Classification Analysis	There are eight types of disaster mitigation implemented at tourist destinations in Ngargoyoso District. These mitigation efforts include a combination of structural and non-structural measures, which have met the seven components of disaster mitigation. The study also identified that tourist destinations have implemented various strategies to enhance disaster resilience, such as early warning systems and the provision of evacuation facilities.

Source: Authors, 2024

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Table 1. Previous studies (cont.)

Researcher	Indicator	Method and Analysis	Findings
Utami, S., Ihsan, and Rasyid, A. R. (2018)	• Identification of tourist attractions, accommodations, restaurants, amusement rides, and photo spots. • Analysis of factors such as land use, infrastructure, rainfall, slope gradient, fault presence, and geology. • Mapping and time series analysis from 1995 to 2018.	• Qualitative & Quantitative • Observation, Interviews, and Documentation for Primary Data, as well as Literature Review for Secondary Data. • Spatial Overlay Analysis	The landslide vulnerability levels in Anggeraja District are categorized into three classes: low risk, moderate risk, and high risk, determined by factors such as slope gradient, rainfall, and fault presence. Additionally, the tourist area at Mount Nona has various facilities, including natural tourist attractions, accommodations, and amusement rides, which have the potential to increase visitor numbers but require effective disaster risk management. Landslide incidents in 2004 and 2017 caused significant infrastructure damage, primarily due to heavy rainfall and a lack of vegetation on the slopes, which reduced soil stability.
Hofisah, U. A., Sarjanti, E., and Suwarsito. (2020)	• Connectivity between attractions • Development and promotion of tourist sites • Travel time from the nearest terminal • Availability of public transportation • Location signage • Road conditions • Physical condition of tourist attractions • Environmental cleanliness • Safety • Disruptions from natural disasters	• Qualitative • Observation • Documentation • Classification Analysis • Class Interval	The tourism potential in Belik District has a varied classification. Based on the analysis, the internal potential is categorized into three classifications: low, moderate, and high, with predetermined maximum and minimum scores. Additionally, the external potential also shows similar results, where several indicators such as accessibility and support for the development of tourist sites contribute to the existing potential classification, indicating opportunities for further development in the tourism sector.

Source: Authors, 2024

Disaster management in the tourism sector of Kota Batu is intrinsically linked to the policies outlined in the Spatial Planning Regulation (RTRW). The RTRW serves as a crucial instrument for regional management, governing land use, including disaster risk mitigation measures. In Kota Batu's RTRW, spatial planning must encompass the identification and management of disaster-prone areas to prevent their inclusion in tourism infrastructure development, thereby reducing associated risks. However, a significant gap exists between policy formulation and its implementation in practice. One of the primary challenges is the insufficient integration of disaster mitigation planning within the RTRW and tourism development initiatives. As a result, numerous tourist destinations in Kota Batu, such as Jatim Park 2 and Taman Selecta, remain situated in high-risk zones, particularly vulnerable to landslides triggered by heavy rainfall.

Additionally, challenges in implementing these policies include a lack of coordination among agencies and low community participation in disaster mitigation planning. This study aims to address these challenges by conducting a thorough analysis of how the RTRW policy in

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Kota Batu has incorporated disaster mitigation aspects, specifically concerning the tourism sector. It also seeks to evaluate the existing discrepancies between policy and actual implementation. The research adopts a comprehensive approach, combining policy analysis, spatial analysis through Geographic Information Systems (GIS), and public perception studies to identify the most disaster-prone tourist areas and assess the effectiveness of the implemented mitigation strategies. The findings from this study are expected to provide strategic recommendations to enhance the resilience of Kota Batu's tourism sector against disaster threats. Moreover, it aims to strengthen the implementation of RTRW policies, ensuring that tourism development in Kota Batu is both sustainable and safe from disaster risks.

2. METHODOLOGY

2.1 Research framework

A conceptual framework is a logical flow used to explain the relationships between concepts or variables in a research study. It helps illustrate how theories, previous findings, or specific assumptions are connected to the research problem being investigated. In the conceptual framework, researchers outline the cause-and-effect or correlation relationships among variables, which then serve as the basis for formulating hypotheses. The framework also functions as a guide for data collection and analysis, helping to clarify the direction of the research to make it more focused and systematic [5]. Below is the conceptual framework for the research titled "Boosting Tourism Resilience through Enhanced Disaster Mitigation: A Case Study of Batu City".

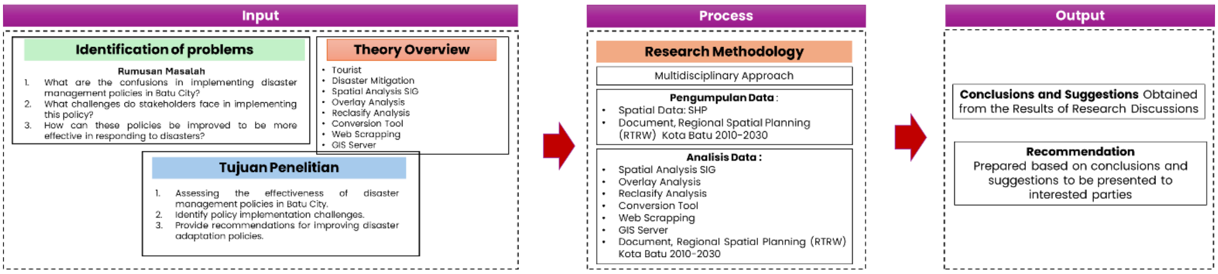

Figure 1. Research Framework

2.2 Research design

A multidisciplinary approach is a method for solving a problem by utilizing perspectives from various relevant disciplines. The disciplines used may come from the fields of Natural Sciences (IPA), Social Sciences (IS), or Humanities (IH) interchangeably. The application of these disciplines in addressing problems is carried out through diverse approaches [5].

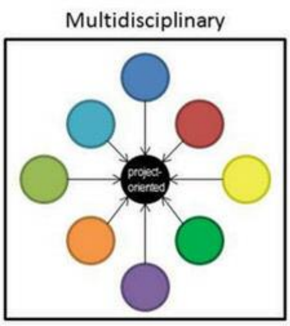

Figure 2. Multidicipline Approach (Source: https://shorturl.at/InbVs)

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2.3 Policy review

2.3.1 RTRW Kota Batu 2010- 2030

Table 2. Disaster-Prone Areas & Tourist Areas in Batu City

Protected Area	Disater Prone Areas	1. Disaster-prone areas include those susceptible to landslides and floods. 2. The areas at risk of natural disasters from landslides and floods include: a. The northern region of Kota Batu, which consists of the Mount Pusungkutuk, Mount Welirang, Mount Kembar, Mount Anjasmoro, and Mount Rawung areas in Sumber Brantas Village. The land use for this area includes forest, green open spaces, agriculture, tourism, residential areas, and warehouses, with a slope classification of less than 40%. b. The southern region of Kota Batu, which includes the Mount Panderman, Mount Bokong, Mount Punuksapi, and Mount Srandil areas in Oro-Oro Ombo Village. c. The western region of Kota Batu, which consists of the Mount Banyak area in Gunungsari Village; Mount Jeruk and Mount Kerumbung in Tulungrejo Village; and Mount Preteng in Gunungsari Village. d. The eastern region of Kota Batu, which includes the Mount Pucung area in Bulukerto Village and the Mount Gede area in Bumiaji Village. e. The residential area prone to landslides in Temas Village.
Cultivation Area	Tourism Area	1. The tourism areas consist of: a. Mountain nature tourism; b. Man-made tourism; and c. Cultural tourism.
		2. Mountain nature tourism includes: • Coban Rais Waterfall • Ecotourism at Cangar Hot Springs and the Arboretum in Sumber Brantas • Village • Paragliding festival and off-road circuit at Mount Banyak • Hiking activities at Mount Panderman • Mountain biking activities in Bumiaji Village • Village tourism • Agrotourism
		3. Man-made tourism includes: • Flower Garden in Sidomulyo Village • Zoo • Jatim Park recreation park, Selecta, and recreational gardens • Songgoriti, Batu Night Spectacular, and recreational gardens • Tirta Nirwana • Miniature World and animal museum in Oro-Oro Ombo Village • Cable car
		4. Cultural tourism includes: • Sedekah Bumi • Grebeg Desa • Sembrama Dance • Maulud of the Prophet Muhammad SAW • Dokar (traditional horse cart) tourism • Supo Temple in Songgoriti • Ganesha Statue • Tomb of Tuan Denger • Bima Sakti Selekta Lodge • Kartika Wijaya (Heritage Hotel) • Cangar Japanese Cave • Tlekung Japanese Cave • An-Nur Mosque • Old Church of Jago

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	• Kertarajasa Buddhist Vihara • Dewi Kwam Im Thong Temple • Tomb of Mbah Wastu • Tomb of Mbah Pathok

Source: Document, Regional Spatial Planning (RTRW) Kota Batu 2010-2030

2.4 Spatial analysis SIG

Geographic Information System (GIS) is a computer system designed to efficiently store and manage geographic information. This system allows users to manipulate geographic data in ways that support location-based analysis and decision-making. By using GIS, various types of information related to space and location can be managed, thereby supporting a wide range of applications in fields such as urban planning, environmental monitoring, and resource management . A similar viewpoint is expressed by Maguire , who emphasizes GIS from a technological perspective, focusing on functional aspects such as maps, databases, and spatial analysis. From these experts' perspectives, it can be concluded that GIS has a strong connection with computers and geospatial data.

As a system, GIS consists of various subsystems that form a whole. According to Maguire, the subsystems in GIS include various elements, starting from data input:

a. Data Input is the stage that involves the collection, preparation, and storage of spatial data or its attributes from various sources.
b. Data Output is the stage that serves to display or produce all or part of the database in either softcopy or hardcopy, in formats such as tables, graphs, or maps.
c. Data Management is the way the system organizes both spatial data and attribute tables into a database for easy access (retrieval).
d. Data Manipulation and Analysis is the stage that determines the information generated by the Geographic Information System (GIS).

GIS can depict a model of the real world on a computer screen, similar to how maps on paper represent the real world. Among the various subsystems of GIS, one feature that distinguishes it from other software is its ability to perform spatial and attribute analysis. The process of answering questions within GIS involves processing and managing large volumes of spatial and non-spatial data, which are then mathematically integrated by applying various arithmetic and logical operations to produce solutions or answers [8]

2.4.1 Overlay analysis

Overlay is an important process in (GIS) analysis. It refers to the ability to place the graphics of one map on top of the graphics of another map, and then display the results on a computer screen or in printed form. In short, overlay involves stacking one digital map over another digital map, along with their attributes, to create a composite map that contains attribute information from both maps. Overlay is the process of merging data from different layers. Simply put, overlay can be described as a visual operation that requires more than one layer to be physically combined [8].

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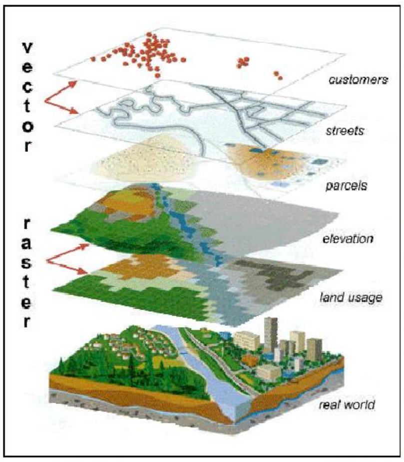

Figure 3. Example of Overlay picture in SIG

Referring to Figure 3, one of the implementations of GIS in this paper is to determine zones that support tourism resilience through enhanced disaster mitigation. This approach is carried out by utilizing GIS applications combined with various spatial data, including indicators that affect tourism resilience, which are then weighted. Thus, the analysis produced can assist in formulating more effective mitigation strategies.

2.4.2 RECLASIFY Analysis

Reclassification is the process of reclassifying data to produce new spatial data tailored to specific criteria or attributes. In this process, data that originally had various values or categories is reorganized or regrouped according to the desired analysis objectives. This grouping allows the data to be more easily interpreted and used in spatial analysis, as the different values in the original data are reduced or restructured into new categories that are more relevant to the user's needs. The result of this reclassification is a new map or spatial data that is more focused and aligned with the specific criteria that have been established.

Functions and Objectives of Reclassification:

1. Data Simplification: Reclassification is used to simplify raster data by grouping the original values into new classes. This helps users in analyzing the data in a more comprehensible manner.

2. Reclassification: This process allows users to reclassify data by changing the ranges of values or categories, for example, transforming elevation, rainfall, or population density data into specific categories such as low, medium, and high.

3. Spatial Analysis: Reclassification is useful in spatial analysis to determine areas that meet or do not meet certain criteria. For instance, in hazard zoning mapping, users can classify risk values from low to high.

4. Decision Making: The results of reclassification can aid in decision-making across various fields, such as spatial planning, environmental conservation, agriculture, or disaster mitigation, by simplifying complex data.

2.4.3 Conversion tool

The Conversion Tool is a feature used to convert or transform spatial data from one format to another within the context of GIS. Mapping often involves the use of various types of geographic data, whether in vector, raster, or other attribute formats, and sometimes it is necessary to convert this data to meet the needs of further analysis or processing.

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Types of Data:

1. RasterData: This is pixel- or grid-based data, such as satellite imagery, topographic maps, and other grid-based maps. Each pixel in a raster has a value representing specific information, such as elevation, temperature, or disaster intensity.
2. VectorData: Data that represents geographic features in the form of points, lines, or polygons. Examples include roads, rivers, administrative boundaries, and buildings. Vector data is more structured and precise compared to raster data, as it represents features with clear geometry.

2.4.5 Web scrapping

Web scraping is a technique used to automatically gather information from websites without having to copy it manually. The goal of a web scraper is to search for specific information and then collect it in a new web format. Web scraping focuses on obtaining data through retrieval and extraction. The benefits of web scraping include allowing the information collected to be more targeted, thus making it easier to search for specific content. Web scraping applications focus solely on how to acquire data through the retrieval and extraction of data with varying sizes.

Web scraping involves several steps, including:

1. Create Scraping Template: The developer studies the HTML document of the website from which information is to be extracted to identify the HTML tags that surround the desired information.
2. Explore Site Navigation: The developer analyzes the navigation techniques of the website to be scraped to replicate them in the web scraper application to be created.
3. Automate Navigation and Extraction: Based on the information obtained in steps 1 and 2, the web scraper application is created to automate the retrieval of information from the specified website.
4. Extracted Data and Package History: The information obtained from step 3 is stored in a database table.

2.5 Research data

This study involves the use of various types of data and different data sources, the details of which can be seen in the following table.

Table 3. Research Data

Data	Source	Description
RTRW City of Batu Policy Data 2010-2030	Public Works and Public Housing Office of Batu City	• Public Works and Public Housing Office of Batu City • Data obtained 24 September 2024,
Administrative Boundaries	Global Administrative Areas (GADM)	• Level 3 (District) and Level 4 (Village) administrative boundaries • Data accessed on September 25, 2024, downloaded from https://gadm.org/download_country_v.html
Distribution of Facilities	Google point of interest (POI)	• Using web scraping techniques via Instant Data Scraper • Data collected includes commercial facilities • Data accessed on September 25, 2024
Disaster Hazards	National Disaster Management Agency (BNPB)	• Using GIS Servers for connecting data • Data accessed on September 24, 2024, downloaded from https://gis.bnpb.go.id/server/rest/services

Source: Analysis Result, 2024

3. RESULTS AND DISCUSSION

3.1 Disaster hazards of Batu City

Batu City, known as a charming natural tourist destination, also faces various threats from natural disasters that can impact the safety of the community and the sustainability of its tourism sector. Located in a mountainous region with varied topography, Batu City is vulnerable to nine types of disasters: Flash

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Floods, Floods, Extreme Weather, Earthquakes, Landslides, Forest Fires, Droughts, Volcanic Eruptions, and Multi-Hazards. The nine types of disasters can be seen on the following map.

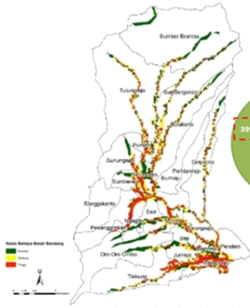

Figure 4. Batu City Flash Flood

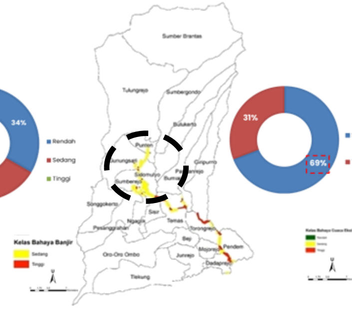

Figure 5. Batu City Flood Danger

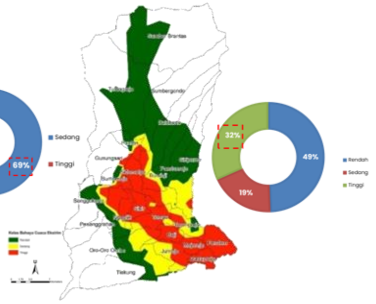

Figure 6. Batu City Extreme Weather

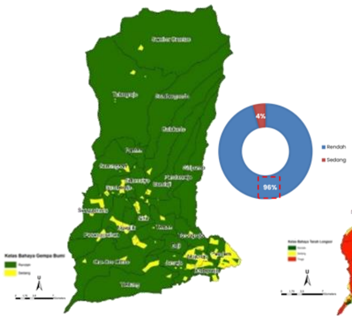

Figure 7. Batu City Earthquake

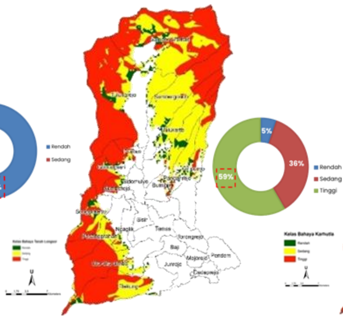

Figure 8. Batu City Landslide

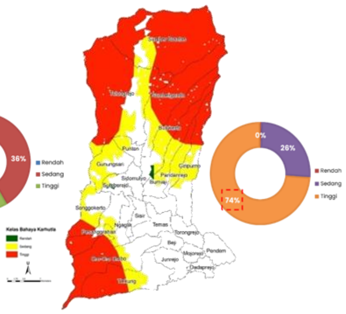

Figure 9. Dangers of Forest and Land Fires in Batu City

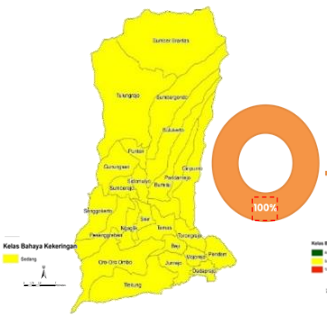

Figure 10. Drought in Batu City

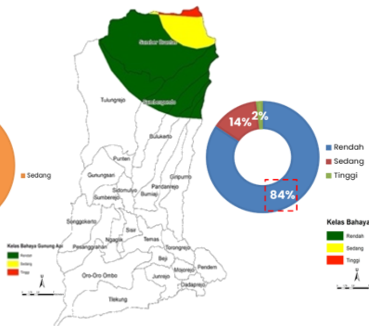

Figure 11. Batu City Volcano

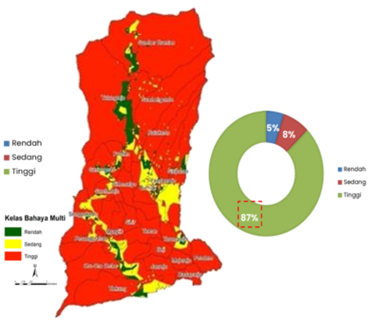

Figure 12. Multi Dangers of Batu City

Source: Inarisk BNPB, Processed 2024

The overlay analysis results regarding disaster hazards in Batu City indicate that most areas are categorized as having a high risk level for nine types of disasters, including flash floods, flooding, earthquakes, landslides, forest fires, and volcanic activity. In this context, the Batu City Spatial Planning Policy (RTRW) 2010-2030 plays a crucial role in formulating effective mitigation strategies. The RTRW includes sustainable spatial planning that directs the development of infrastructure and tourism areas to safer locations, thereby reducing disaster risks. The tourism sector, as one of the pillars of the local economy, needs protection from disaster impacts. Therefore, collaboration between the government and the community is vital in implementing mitigation measures, such as disaster risk monitoring, infrastructure improvement, and education about potential hazards. With this proactive approach, it is hoped that the negative impacts of disasters can be minimized, and the sustainability of the tourism sector in Batu City can be maintained.

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3.2 Disaster hazards in Batu City tourism

In addition to conducting overlay analysis to assess potential disaster hazards, data collection was also carried out regarding the existing tourist destinations in Batu City using web scraping analysis. This tourism data was then overlaid with information about the types of disasters that are most vulnerable or pose a high risk in the research area/Batu City. This way, we can better understand the relationship between tourist locations and the potential disaster threats that may arise in those areas. The types of disaster risks include: Multi Disaster, Flash Floods, Extreme Weather, Forest Fires, and Landslides. Below is the table data resulting from the web scraping of Batu City's tourism, which is overlaid with disaster hazards.

Table 4. Results of Tourism Web Scraping in Batu City Overlayed with High Disaster Hazards

Disaster Hazard Type	Number of Natural Tourist Attractions	Number of Man-Made Tourist Attractions
Multi-Hazard	49	49
Flash Flood	9	5
Extreme Weather	36	21
Forest Fires	2	0
Landslide	11	0
Total	107	75

Source: Scraping Analysis Results, 2024

Based on the data presented in the table, it can be observed that the total number of natural and artificial tourist destinations potentially affected by high-risk disaster hazards is significant. The natural attractions in Batu City encompass 107 destinations, while artificial attractions comprise 75 destinations. This information is crucial in relation to the Spatial Planning Policy (RTRW) of Batu City, as land management and planning must consider vulnerability to disasters. Within the RTRW policy, protecting natural tourist areas located in disaster-prone regions should be prioritized, given the high number of affected natural tourist destinations. Spatial planning in Batu City must align with disaster mitigation efforts to ensure the sustainability of the tourism sector and the safety of visitors. Furthermore, artificial attractions scattered across various areas also require attention in the context of infrastructure protection and risk management, ensuring that tourism development remains in accordance with the sustainability principles outlined in the RTRW.

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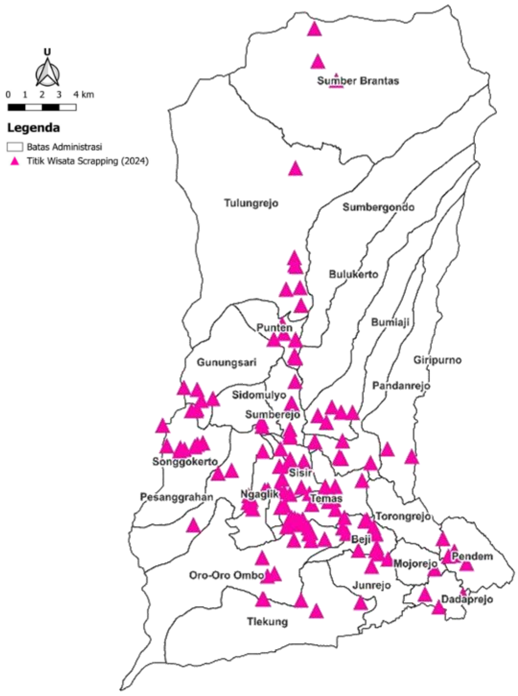

Figure13. Map of Batu City Tourism Scrapping Results (Source: Webscrapping Results, 2024)

4. CONCLUSIONS

The tourism sector in Batu City faces significant challenges related to disaster risks, particularly landslides triggered by heavy rainfall and insufficient vegetation. Despite the implementation of the Regional Spatial Planning (RTRW) Batu City as a mitigation measure, a gap persists between policy and real-world application, with numerous tourist destinations situated in high-risk areas. Additionally, the situation is worsened by a lack of coordination among agencies and low community participation in planning efforts.

This research employs a comprehensive approach that combines policy analysis, risk mapping using GIS, and public perception studies to identify disaster-prone areas. The study aims to recommend strategic measures, including:

1. Disaster Risk Challenges: The tourism sector faces significant threats, particularly from landslides due to heavy rainfall and insufficient vegetation.
2. Policy Gaps: Although the RTRW Batu City has been established as a disaster risk mitigation tool, there are discrepancies between policy planning and on-the-ground implementation, resulting in many tourist sites remaining in high-risk zones.
3. Lack of Coordination: The effectiveness of disaster mitigation policies is hindered by inadequate coordination among government agencies and minimal community involvement in planning.
4. Comprehensive Approach: This research integrates policy analysis, spatial GIS analysis, and public perception studies to pinpoint the most vulnerable tourist destinations.
5. Strategic Recommendations: It is crucial to undertake systematic steps in mitigation planning, such as developing resilient infrastructure, implementing early warning systems, and educating the community about disaster risks.
6. Sustainable Development: The recommendations aim to enhance the tourism sector's resilience to disaster threats and ensure that tourism development in Batu City is sustainable and safeguarded against risks.

By addressing these key areas, the study seeks to promote a more resilient and sustainable tourism sector in Batu City.

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Full Paper
Poster Presentation

Rearing potential of Yellow Mealworm (Larvae of *Tenebrio molitor* L.) on Food Wastes

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ABSTRACT

The demand for protein is increasing as the global population grows. Humans mainly obtain proteins from animals through unprocessed red meat, processed meat, eggs, milk, cheese, and yogurt. However, rearing livestock and poultry, which are necessary for the production of these products, has a significant impact on the environment. Many researchers have attempted to use insects as a protein resource for food and feed. In this study, we attempted to rear yellow mealworms (larvae of *Tenebrio molitor*) using food waste (i.e., unsold lunch boxes from a university coop and vegetable waste). Our results showed that mealworms could not grow when only food waste was used as feed. By contrast, mealworms grew when we used a mixture of food waste and wheat bran, which is commonly used to feed mealworms. Therefore, we can conclude that proteins can be produced and food waste can be reduced by rearing mealworms.

Keyword: Alternative protein/ Growth performance/ Sustainable development

1. INTRODUCTION

The global population is expected to exceed 10 billion people by 2059 [1]. As the population grows, the demand for food increases naturally. In particular, global per capita protein consumption is projected to increase by 3%–20.9% by 2050, compared to the 2012 levels, according to FAO scenarios [2]. These scenarios predict that this trend will be particularly pronounced in low-income countries due to economic development. Even in the scenario with the smallest increase in protein consumption, red meat consumption is projected to increase by 50.8% in Africa and 56% in Southeast Asia [3]. Proteins are essential for human health, and protein deficiency can lead to stunted growth and anemia [4]. Therefore, increasing protein production is crucial for improving nutrition in low-income countries as well as for global food security.

Currently, proteins are primarily obtained from animal sources, such as unprocessed red meat, processed meat, eggs, milk, cheese, and yogurt. However, the environmental impact of these protein sources is greater than that of other protein sources, such as beans [5]. Beef production requires large amounts of land, water, and feed. To obtain the same amount of protein, the land area needed to produce beef is approximately 50 times the area needed for growing legumes and 20 times the area needed for nuts. This demand for land has led to the conversion of rainforests into agricultural land for beef production in Brazil, resulting in decreased biodiversity and climate change [6-9]. To address these issues, there is growing interest in the use of edible insects as alternative protein sources for food and feed.

Edible insects, such as yellow mealworms (larvae of *Tenebrio molitor*), are farmed as a protein source not only for human food but also for livestock and fish feed [10-12]. The use of edible insects as food and feed has rapidly increased worldwide. In the EU, the use of four insect species, yellow mealworm, grasshopper (*Locusta migratoria*), house cricket (*Acheta domesticus*), and lesser mealworm (*Alphitobius diaperinus*), as food was authorized in 2021. Additionally, the use of processed animal proteins (PAPs) from eight insect species [i.e., banded cricket (*Gryllodes sigillatus*), black soldier fly (*Hermetia illucens*), common housefly (*Musca domestica*), domesticated silk worm (*Bombyx mori*), field cricket (*Gryllus assimilis*), house cricket (*Acheta domesticus*), lesser mealworm (*Alphitobius diaperinus*), yellow mealworm (*T. molitor*)] has been authorized as feed for poultry, pig, and

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aquaculture fish. This expanded utilization of edible insects is driven by two main factors: they can provide nutrients comparable to other protein sources, and the environmental impact of farming edible insects is much smaller than that of producing other protein sources [13-16]. In particular, edible insect farming emits lower amounts of greenhouse gases than pig and cattle farming [13]. The relative contribution of livestock in CO_2-equivalent emissions is up to 18% of the total greenhouse gas emissions [17]. This contribution is more than 10 times that in the rearing of edible insects [13]. Similarly, the water and land area required for rearing edible insects are much smaller than that needed for pigs and cattle [18, 19]. To further promote the utilization of edible insects, it is necessary to develop breeding methods that are more efficient and have an even smaller environmental impact than the existing methods. In this study, we examined the feasibility of rearing yellow mealworms using food residue to achieve these goals.

Previous studies have explored rearing conditions by changing environmental factors, such as temperature, humidity, light conditions, and density [20]. However, only some studies have focused on waste-based feed for yellow mealworms because wheat bran is commonly used as feed for yellow mealworms (but see [21-23]). In this study, we aimed to verify how food waste commonly consumed by humans affects the growth of yellow mealworms.

2. METHODOLOGY

2.1 Experimental insects

The yellow mealworm is the larval stage of *T. molitor* L. (Coleoptera: Tenebrionidae). This species produces an average of 250–500 eggs per pair. Oviposited eggs hatch in approximately 4 days at 26–30 °C. After hatching, the larvae (i.e., yellow mealworms) grow for an average pupation duration of 112–203 days. The duration of the larval stage is influenced by temperature and photoperiod [20]. Yellow mealworms prefer temperatures between 25 and 30 °C and a dark environment [24].

2.2 Preparation for yellow mealworms

For this study, yellow mealworms were obtained from colonies maintained at the Laboratory of Evolutionary Ecology in Nagasaki University, Japan. The mealworms were reared in plastic boxes (29.8 cm length × 21 cm width × 19.5 cm height) which were filled with approximately 10 cm of feed. Mealworms were reared on wheat bran supplemented with fresh carrot slices every 2 weeks. Stock colonies were kept under constant conditions, i.e., 20 °C, approximately 60% relative humidity (RH) and 12 h light/12 h dark cycle. For subsequent experiments, we used newly hatched larvae from colonies in the laboratory.

2.3 Rearing experiments

To examine the influence of food waste feeds on yellow mealworm growth, we selected unsold lunch boxes from a university coop and vegetable scraps (carrot and cabbage) as food waste feeds. Before the experiment, the feed was dried using a garbage dryer (MS-N53XD, Panasonic Corporation Tokyo, Japan) to reduce the water content and prevent rotting. Drying reduced the weight of lunch box residue and vegetable scraps by 50% and 90%, respectively.

We collected 4,000 yellow mealworms weighing 8–56 mg from the stocked colonies. Groups of 200 yellow mealworms were placed in 20 plastic trays (28.5 cm length × 19.4 cm width × 4.8 cm height), each filled with one of the following four feeds: 200 g wheat bran (n = 5), 100 g wheat bran + 100 g dried vegetables (n = 5), 100 g what bran + 100 g dried lunch box residue (n = 5), or 200 g dried vegetables (n = 5). Each week, we randomly selected ten yellow mealworms from each tray, weighed them, and returned them to their respective bats. Monitoring continued until half of the mealworms had pupated. No additional water was provided during the experiments.

At the start of the experiment, the weight of the mealworms, fed with different feeds, slightly differed (fed only wheat bran: mean ± s.e. = 25.72 ± 0.85 mg; fed wheat bran + dried vegetables: mean ± s.e. = 26.60 ± 1.81 mg; fed what bran + dried lunch box residue: mean ± s.e. = 29.86 ± 1.78 mg; fed

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only dried vegetables: mean ± s.e. = 22.32 ± 0.42 mg). There was a significant difference only between the weights of the mealworms that were fed a mixture of wheat bran and dried lunch box residue and dried vegetables (one-way analysis of variance [ANOVA], $F = 5.24$, $P = 0.01$, Tukey's HSD tests, $Q = 2.86$, $P = 0.006$). Furthermore, we did not test the influence of feeding only dried lunch box residue to the mealworms because the mealworms did not survive in a preliminary experiment.

2.4 Statistical analysis

To compare the weights of the mealworms fed different feeds, we performed a one-way ANOVA followed by Tukey's HSD test on the final weight measurements. These analyses were conducted using JMP Pro (version 17.0; SAS Institute, Inc., Cary, USA).

3. RESULTS AND DISCUSSION

3.1 Influence of food waste feeds on yellow mealworm weight

Over half of the yellow mealworms pupated within 10 weeks of the start of the experiment, except for those fed only dried vegetables. Conversely, mealworms fed only dried vegetables barely grew over 10 weeks (mean ± s.e. = 32.0 ± 0.92 mg) and did not pupate even after more than 15 weeks. These results show that dried vegetables alone are not suitable as feed for yellow mealworm rearing. This may be owing to the lack of water content in the dried vegetables because yellow mealworms showed the highest growth rate at over 70% RH [20], and wheat bran, which is commonly used as feed, contains approximately 10% water [25]. Therefore, water supply might enhance the growth of mealworms fed only dried vegetables.

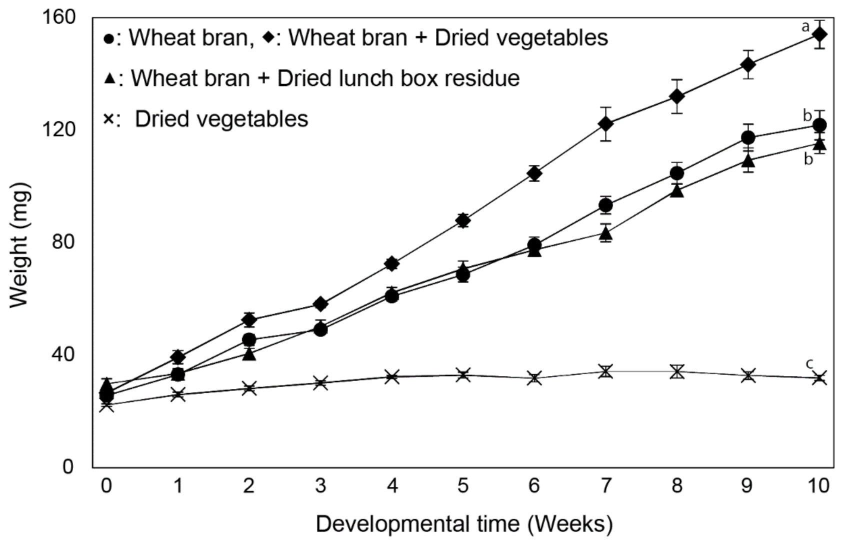

Figure 1. Change in weight of mealworms that were fed different feeds (mean ± s.e.). Lowercase letters refer to means that were significantly different in Tukey's HSD tests.

At 10 weeks, the mealworms, except for those fed only dried vegetables, increased in weight by five to seven times compared to their initial weight at the start of the experiment. The weight of the mealworms that were fed a mixture of wheat bran and dried vegetables (mean ± s.e. = 154.0 ± 5.02 mg) was significantly more than that of mealworms fed only wheat bran (mean ± s.e. = 121.8 ± 5.21 mg) and those fed a mixture of wheat bran and dried lunch box residue (mean ± s.e. = 115.42 ± 3.69 mg) (One-way ANOVA, $F = 161.89$, $P < 0.001$; Fig. 1). These results suggest that dried vegetables mixed with wheat bran can be used as feed for mealworm rearing (Fig. 1). Although none of the mealworms fed only dried lunch box residue survived in a preliminary experiment, these results also showed that a mixture of wheat bran and dried lunch box residue can be used as feed for mealworm rearing (Fig. 1). The results suggest that even feeds that are unsuitable on their own can be used for mealworm rearing

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when mixed with wheat bran. Mealworm rearing, thus, has the potential to reduce food and agricultural waste (e.g., chicken dropping and sugarcane bagasse).

The growth of mealworms fed a mixture of wheat bran and dried vegetables (carrots and cabbages) was better than that of mealworms fed wheat bran alone (Fig. 1). This result suggests that dried vegetables can compensate for the nutrients lacking in wheat bran, supporting the growth of mealworms. Generally, some nutrients (vitamin C, lycopene, etc.) are reduced by heating and drying in vegetables and fruits [26]. Similarly in carrots, vitamin C content is significantly reduced by heat processing [27]. On the other hand, the content of carotenoids (alpha/beta carotenes) is stable [27, 28]. Therefore, our results may be attributed to these carotenoids. Another study suggested that carrots positively affect the survival and growth of mealworms [29]. It was hypothesized that this effect was caused by the reduction of oxidative stress and stimulation of the immune system of mealworms owing to the carotenoids present in carrots. Oxidative stress negatively affects insect growth [30, 31]. Carotenoids can reduce oxidative stress through their role as antioxidants [32].

Our results indicate that food waste can be used as a feed for mealworm rearing. Wheat bran is the primary feed used in conventional mealworm-rearing methods. Although wheat bran is a by-product of flour production, its production has an environmental impact. Therefore, to decrease the environmental impact of mealworm rearing, the feed used should be changed from wheat bran to a mixture of wheat bran and food waste.

3.2 Future studies

In the present study, we focused on the effects of different feeds on mealworm growth. However, we did not assess the effect of different feeds on the nutritional composition of mealworms. Further studies are needed to compare the nutritive composition of mealworms fed only wheat bran with those fed a mixture of wheat bran and food wastes.

Furthermore, the selected food wastes could not be used as feed for mealworm rearing in this study. To decrease the environmental impact of mealworm rearing, it is necessary to identify food waste that can be used alone.

4. CONCLUSIONS

Based on the rearing experiments and data analyses conducted in this study. The following conclusions were drawn:

1. To reduce food waste by yellow mealworm rearing, we can use a mixture of wheat bran and food waste as feed because using food waste alone is insufficient.

2. To reduce environmental impacts, including CO_2 emissions, of protein production through edible insect rearing, we should promote the mass rearing of edible insects and develop efficient rearing methods.

Acknowledgement

This work was supported by JSPS KAKENHI Grant Numbers JP21H03558 and JP24H00744 and the Project for Enhancing the Environment to Create Innovation in Regional Core Universities 2023 from the Japan Society for Cabinet Office. We would like to thank Editage (www.editage.jp) for English language editing.

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Esterification of Acetic Acid and Ethanol for Ethyl Acetate Production by Vanadium Catalyst on Biochar Support

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ABSTRACT

Ethyl acetate can be synthesized by Fisher esterification reaction using acetic acid and ethanol for raw materials with acid catalysts. In this study, we firstly developed the solid acid catalyst of V_2O_5 supported on biochars for this reaction. The use of biochar as support is very interesting since it is renewable. Experimentally, the vanadium (V) catalyst was prepared by the incipient wetness impregnation method with various V contents from 3, 6, and 9 wt%. The supports used were biochars derived from two sources including bamboo and palm. After calcination, all catalysts were characterized using various techniques SEM-EDX, FTIR, XRD, ammonia-TPD, and N_2 physisorption to determine the physicochemical properties. To perform esterification, the liquid phase reaction of ethanol and acetic acid was conducted in the batch reactor using ethanol: acetic acid molar ratio of 1.5:1 with a total volume of 50 ml and 1 wt% of solid catalyst based on weight of acetic acid. The reaction occurred at 80 ºC for 40 minutes. The product distribution was analyzed by gas chromatography to determine acetic acid conversion and ethyl acetate selectivity. It was found that 9 wt% V_2O_5/biochar catalyst exhibited the highest activity having acetic acid conversion of 72% with ethyl acetate selectivity of 45%. It revealed that metal leaching occurred during the reaction. However, this study shows the new insight that biochars can be used for support for V catalyst with promising results in the esterification.

Keyword: Esterification/ Biochar/ Chemical Engineering/ Ethyl acetate/ Vanadium catalytic

1. INTRODUCTION

Ethyl acetate is an important chemical reactant and solvent which is the key volatile organic compound (VOC)[1]. Ester has a structure consisting of R-COOR$^{/}$, where R and R$^{/}$ are both alkyl and allyl groups. Ester is generally prepared by heating carboxylic acids R-COOH and alcohol R$^{/}$-OH until water is extracted[2]. Fischer esterification is a main process in the industry for the synthesis of ethyl acetate, this reaction starts using ethanol and acetic acid by a homogeneous acid catalyst. In commercial is interesting vanadium pentoxide V_2O_5; oxovanadium catalytic chemistry which utilized for the oxidation of organic compounds ex alcohols, ketones, aldehydes, organohalides, and carboxylic acids. It uses molecular oxygen form oxidizing agent[3] which has good dispersion and catalytic activity[4]. In addition, the biochars, pyrolysis supports, have begun to be developed because a pore structure mechanism is created based on physicochemical properties and porosity properties, and is used as support for the catalyst in chemical reactions and reducing agents in metallurgy[5]. For Initiation, the metal was embedded into the carbon structure by using a wet impregnation and calcination process for generate catalyst. Then analyzing their various properties; functional groups, surface area, pore volume, pore diameter, and adsorption/desorption isotherms. Analysis of structure, crystallinity, physical properties, morphology of catalysts, elements of catalysts, and gas chromatography also were analyzed [6] [7] [8] [9]. The advantage of using a heterogeneous catalytic in an esterification reaction is that the product can be easily separated and reused [10]

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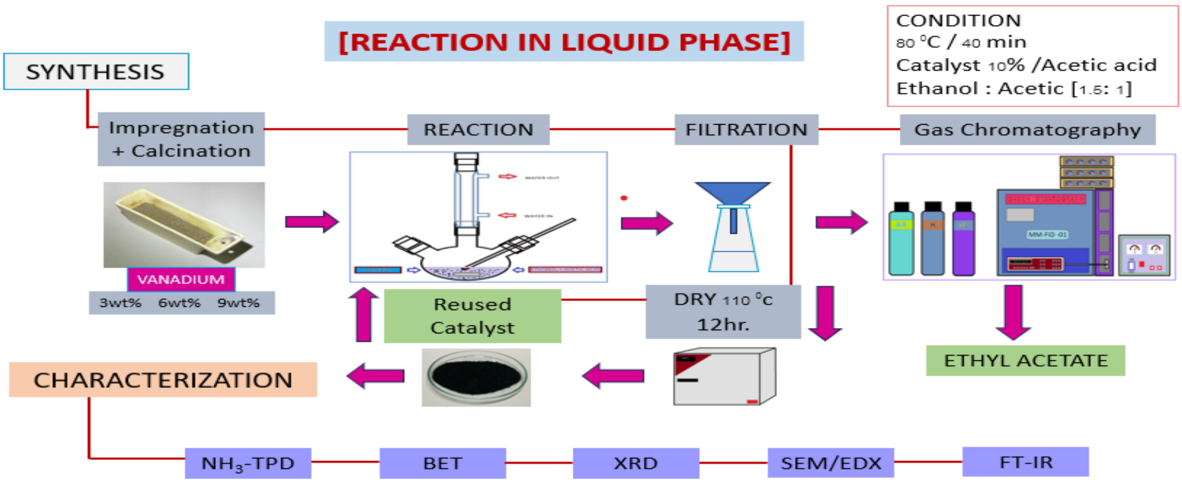

Figure 1. methodology for ethyl acetate reaction by vanadium biochar support

2. METHODOLOGY

2.1 Preparation of catalyst

Pyrolysis biochar from bamboo and palm were used as precursors for metal catalytic supporters. The materials were treated by the Pyrolysis Method with nitrogen purge gas. The first impregnation method was applied to the precursor, ammonium metavanadate. Synthesized vanadium catalysts on bamboo biochar pyrolysis support by grinding biochars for powder. Prepare vanadium metal using 3wt% 6wt% and 9wt% of ammonium (1.4205 g. 2.9317 g. and 4.5426 g.) dissolved in water by stirring with a magnetic stirrer for 20 min. The suitable weight supports of bamboo and palm pyrolysis biochar were 19.3814 g. 18.7234 g. and 18.0220 g according to 3%, 6% and 9% then ammonium metavanadate solution was add into biochar, mix well, and bring it into the oven at 110°C overnight. Then the metal impregnation for fixing catalyst on the supports and calcination with condition 550°C. 5 hr and keep the catalyst away from moisture.

2.2 Catalytic Characterization

Catalysts were characterized by the actual amount of the metal on the support and also catalyst components before and after the reaction. Scanning Electron Microscope and Energy Dispersive X-ray Spectroscopy (SEM-EDX) scanned the formation of vanadium on the surface and the percent of metal loading. Crystallization of samples in which vanadium catalyst synthesis was detected by powder X-ray Diffraction (XRD). The nitrogen adsorption-desorption isotherm measured the specific surface area of vanadium impregnation on support biochar by the BET method which analyzed pore volume and pore diameter together according to analysis nitrogen adsorption isotherm. The acid strength was characterized by Ammonium Temperature-Programmed Desorption (NH_3-TPD chemisorption) and Fourier Transform Infrared Spectroscopy (FTIR) of numerous peaks suggesting the multifunctional structure.

2.3. Reaction

The esterification reaction was conducted in a batch reflux system. A 50 ml glass round bottom flask, with acetic acid and alcohol molar ratio for each reaction (1:1.5). The addition of synthetic catalysts (10wt%/acetic acid %wt) were added in reaction was stirred at 80°C for 40 min. Finally liquid samples after removing the catalyst by centrifugation and filtration. The ethyl acetate and remained substance were analyzed by gas chromatography.

$$\text{Conversion (\%)} = \left(\frac{\text{Ethanol in} - \text{Ethanol out}}{\text{Ethanol in}}\right) \times 100 \quad \text{or} \quad \left(\frac{\text{Acetic Acid in} - \text{Acetic Acid out}}{\text{Acetic Acid in}}\right) \times 100$$

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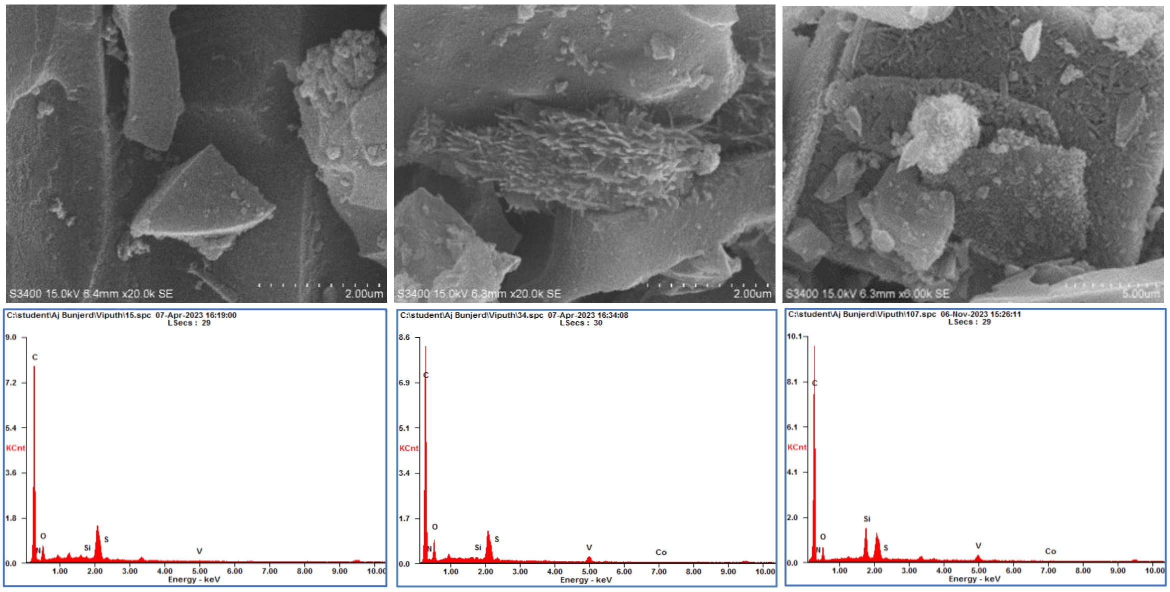
$$\text{Selectivity (\%)} = \frac{\text{Ethyl acetate} \times 100}{\text{All Product}}$$

$$\text{Yield of Ethyl acetate (\%)} = \frac{\text{Molar Ethyl acetate produced} \times 100}{\text{Molar Acetic Acid in}}$$

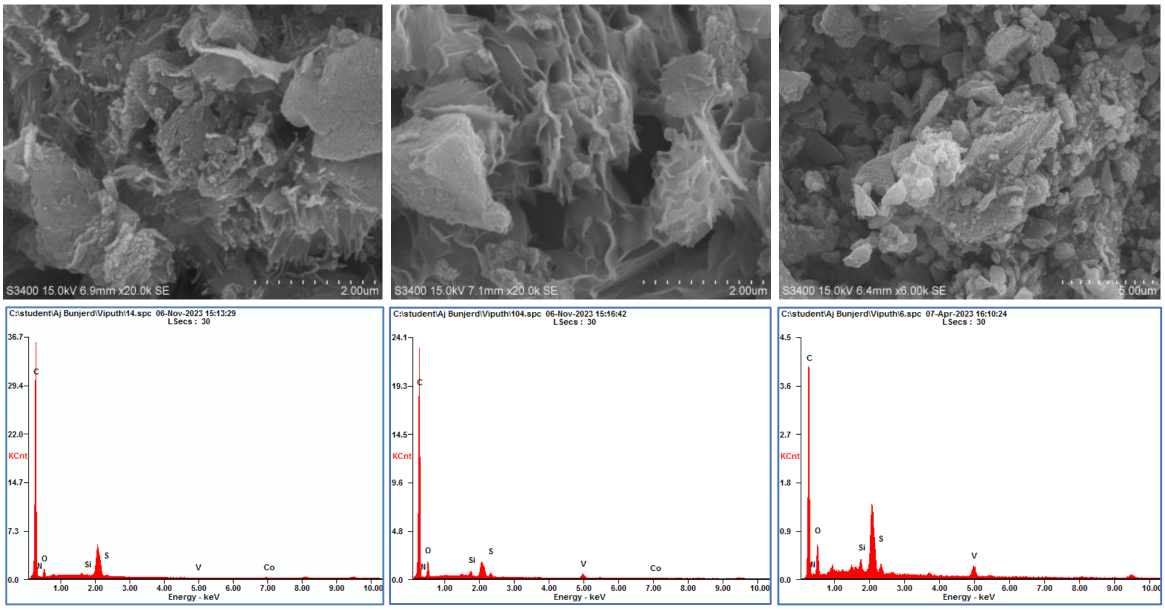
3. RESULTS AND DISCUSSION

3.1 Scanning electron microscope (SEM) and Energy dispersive X-ray spectroscopy (EDX)



Catalyst	3%-V-B	6%-V-B	9%-V-B
wt%	2.12	6.39	8.88

Figure 2. (SEM EDX) of 3%-V-B, 6%-V-B and 9%-V-B



Catalyst	3%-V-P	6%-V-P	9%-V-P
wt%	2.90	5.94	9.71

Figure 3. (SEM EDX) of 3%-V-P, 6%-V-P and 9%-V-P

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Metal distribution on the support from the analysis of SEM-EDX images, it was found that the vanadium on the surface and in the pores from the impregnation process and crystal sintering caused the oxygen bonding of vanadium metal and O vacancy [V=O]. Both biochar roughness surface position were raised by the dispersing formation of vanadium metal, which was very important and related to the vacancy position on both biochar surfaces. The crystal lattice by metal loading and calcination at 550°C was prepared for a reaction. In Figures 2 and 3 the characterization of the covering metal found the impregnated crystalline on the surface. The dispersion crystal plane caused increases in the surface area on the support by SEM image which was not to determine metal scattering because the disorder occurs the agglomeration which vanadium cluster was discovered that arrangement depended on many factors such as the preparation step, O vacancy catalyst properties, metal cluster, metal-support co-binding surface vacancies, temperature, and percent metal loading distribution by the EDX method according to the experiment.

$$\underset{\text{ETHANOL}}{CH_3CH_2OH} + \underset{\text{ACETIC ACID}}{CH_3COOH} \xrightarrow{V_2O_5 \text{ catalyst} + \Delta} \underset{\text{ETHYL ACETATE}}{CH_3COOCH_2CH_3} + \underset{\text{WATER}}{H_2O}$$

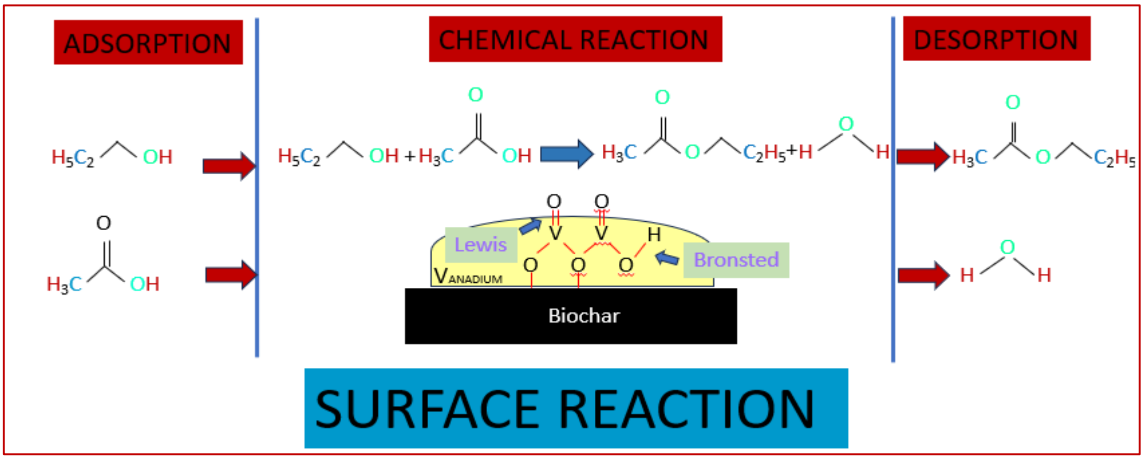

Figure 4. Vanadium catalyst on surface reaction for ethyl acetate production by esterification

3.2 Conversion and Yield of Ethyl Acetate

Table 1. Result Conversion and Yield of Fresh Catalyst and Reused Catalyst.

CATALYST	ETHYL ACETATE	ACETIC CONVERSION	SELECTIVITY	YIELD ETHYL ACETATE
FRESH	(g)	%	%	%
3%-V-B	3.43	31	6.9	10.83
6%-V-B	6.36	55	12.7	20.05
9%-V-B	10.43	72	20.9	32.89
3%-V-P	3.71	48	7.4	10.68
6%-V-P	6.51	39	13.0	20.51
9%-V-P	10.20	51	20.4	32.17
REUSED	(g)	%	%	%
3%-V-B	2.97	79	5.9	8.55
6%-V-B	4.66	61	9.3	13.43
9%-V-B	6.51	44	13.0	18.76
3%-V-P	2.79	88	5.4	7.80
6%-V-P	5.85	50	11.7	16.85
9%-V-P	6.34	42	12.7	18.26

_%-V-B ; percent loading Vanadium on Bamboo support.
_%-V-P ; percent loading Vanadium on Palm support.

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The result of esterification with gas chromatography (Table 1). This presents the efficiency of acetic acid conversion to ethyl acetate reached 72% and the product yield 32.89% (10.43 g.). By reaction conditions, the result of using the reused catalyst showed that percent acetic acid substance conversion was increased while ethyl acetate yield was decreased with volume of 44% effect to yield remained 18.76% (6.51g. ethyl acetate) respectively. So the activity of vanadium can be recovered and reused 1 time as a catalyst in a new reaction, but it was not possible to avoided the leaching effect of the metal.

3.3 X-ray diffraction (XRD) pattern of Catalyst

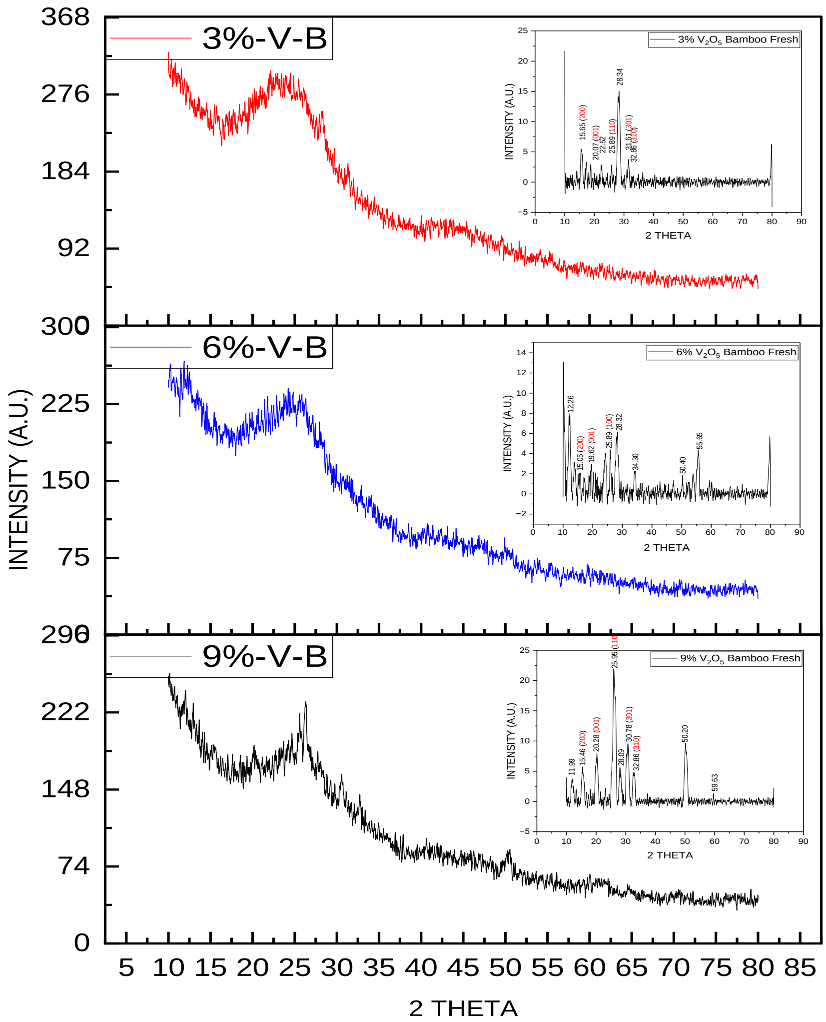

Figure 5. XRD Pattern of 3%-V-B, 6%-V-B and 9%-V-B

XRD results from calcination 550^0C method, diffraction of V_2O_5 peak $2\theta = 15.46^0, 20.28^0, 23.16^0, 26.95^0, 30.78^0, 32.86^0$ of [9%-V-B] is crystallization for high conversion in this method and diffraction of V_2O_5 peak $2\theta = 20.75^0, 26.49^0, 31.81^0$and 49.85^0 of [9%-V-P]. The metal shape related to the lattice plane of the crystals is as follows 15^0(200), 20^0(001), 26^0(110), 31^0(400), 32^0(011), 34^0(311), 41^0(002), 45^0(411), 47^0(600)[11]. The results of the V_2O_5 phase crystallinity on bamboo present the various plane shapes of three-dimensional space. The major plane observed by x-ray founded a lattices V_2O_5 parameter was orthorhombic species with lattices constants (a = 11.484 A˚ b = 3.556 A˚ c = 4.357 A˚) which referred by JCPDS card no. 41-1426 the peaks 2θ = 15.49, 20.35, 26.23 and 31.09 correspond to (200), (001), (101), (110) [12] formed formation and chemical interaction between vacancy groups on the biochar surface with V=O functionals. Thus the plane and arrangement of crystals on the biochar surface 20^0 (001) were investigated as not outstanding peaks from any metal loading on bamboo support and (6%-V-P and 9%-V-P) but were found obvious in 3%-V-P. The lattice 26^0(110) originates from a silica oxide[13]

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compound in material that was found in both biochar supports vanadium loading. Another result 41^0(002) lattice of graphite[14] was not occur in this catalyst. From observation the curve of 2-theta without smoothness may be caused by different chemical structures on the heterogeneous surface and vacancy of both biochar supports may affect XRD analysis.

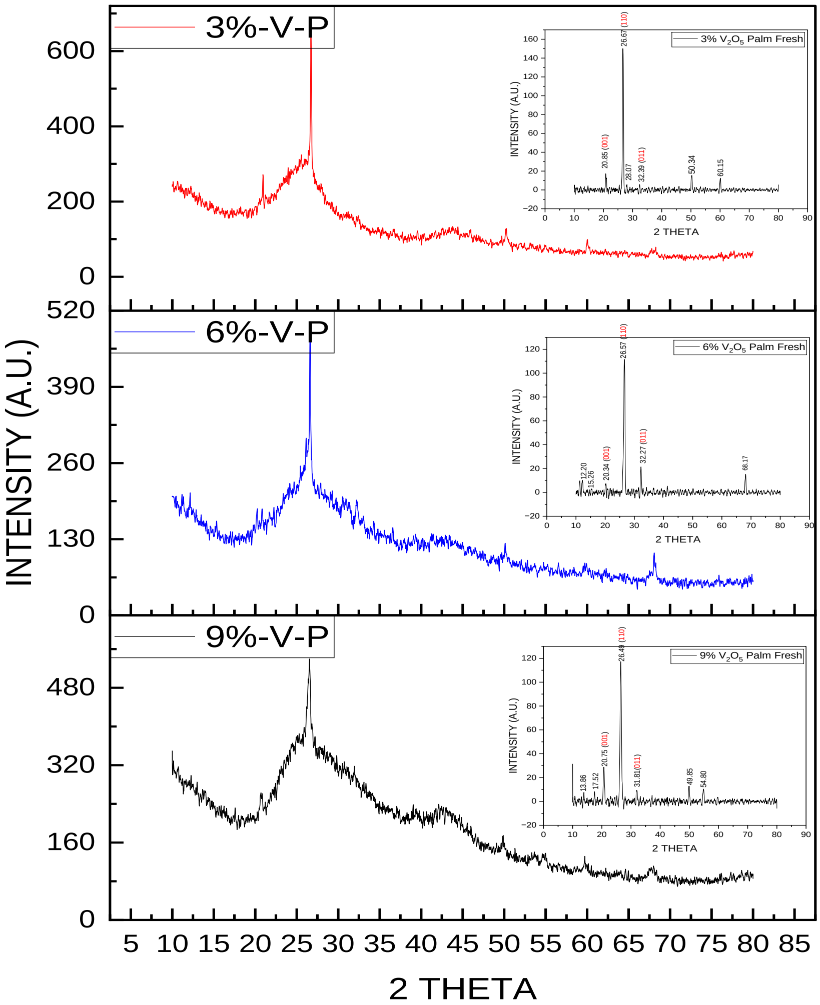

Figure 6. XRD Pattern of 3%-V-P, 6%-V-P and 9%-V-P

3.4 N_2 Physisorption (BET) pattern of Catalyst

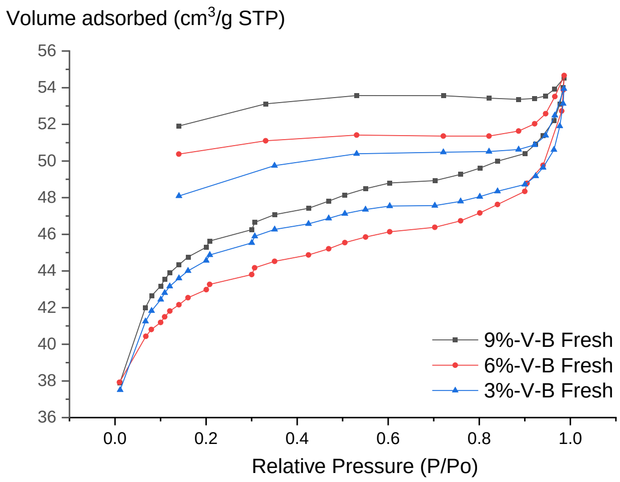

Figure 7. BET Fresh Catalyst 3%-V-B, 6%-V-B and 9%-V-B

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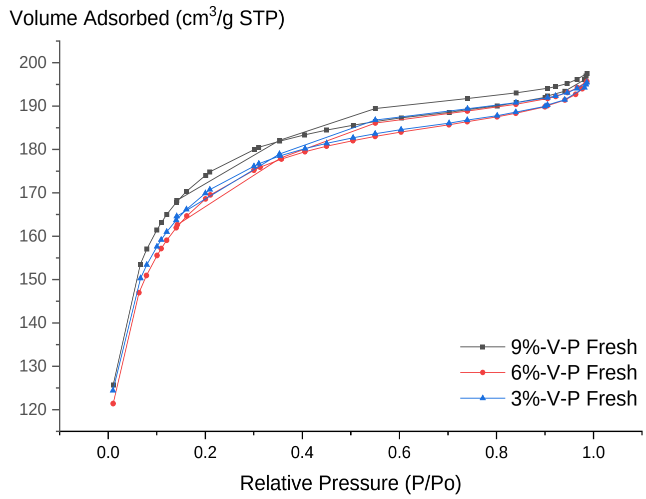

Figure 8. BET Fresh Catalyst 3%-V-P, 6%-V-P and 9%-V-P

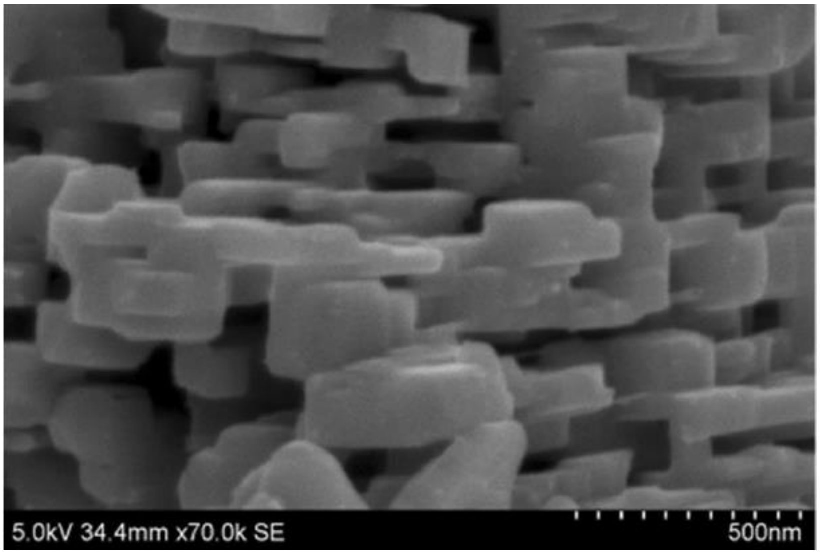

Figure 9. FESEM Image lattice of 1 g. V_2O_5 nanostructure grown by 550 C decomposition and agglomerate structure. [16]

Table 2. Result Physical Adsorption Fresh Catalyst

CATALYST	BET m^2/g	Pore volume cm^3/g	Pore diameter A
Fresh Catalyst			
3%-V-B	70.26	0.0413	24.07
6%-V-B	157.69	0.0835	21.70
9%-V-B	179.65	0.0947	21.10
3%-V-P	524.07	0.2717	20.72
6%-V-P	584.60	0.3007	20.65
9%-V-P	605.61	0.3046	20.24

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Table 3. Result Physical Adsorption Reaction 1 Catalyst

CATALYST	BET m^2/g	Pore volume cm^3/g	Pore diameter A
Reused 1 Catalyst			
3%-V-B	17.32	0.0199	46.00
6%-V-B	53.32	0.0376	28.22
9%-V-B	77.35	0.5476	28.31
3%-V-P	423.73	0.2244	21.18
6%-V-P	503.75	0.2687	21.33
9%-V-P	546.74	0.2879	21.03

BET Analysis is according to the surface area of 9% vanadium on bamboo was 179.65 m^2/g. Pore volume 0.0947 cm^3/g. Pore diameter by adsorption isotherm 21.1 A° was present hysteresis loop type IV isotherm of mesoporousity was excellent in size between 2-50 nm. Results found that the different surfaces of the support materials did not affect the conversion, and different loading of vanadium metal on bamboo and palm support when going through the pyrolysis process creates pore volume. Results from BET analysis, surface area values, found that palm is higher than bamboo which went through the pyrolysis process, it has a surface area of less than 100 m^2/g. while the palm is put through a process of increasing porosity, palm biochar has a high surface area in the range of 100-500 m^2/g. The area present increased by increase metal loading which the crystalline bonding together, are more bonding support. Refer to Figure 8. The lattice of V_2O_5 was decomposition and agglomeration after impregnation and used a temperature 550 C. The formation of nanorods increased the area on the surface and pore volume [16]. So 9%-V-B and 9%-V-P metal loading had BET (m^2/g) and pore volume more than other conditions. This reaction causes the leaching of metal from the supports. As a result, found the surface area decreases when recycled catalyst. Then the ethyl acetate decreased productivity. However, the utilization metal-biochar is more advantageous because it is less poisonous than strong acid chemicals. A pore diameter is the micropore range. The surface area of palm is rougher than the surface area of bamboo so palm biochar has more surface area than bamboo. The vacancies of biochars are interactions between metals which increasing loading of vanadium may affect the surface roughness and the plane crystalizes.

3.4 Ammonium Temperature-Programmed Desorption (NH_3-TPD) pattern of Catalyst

The strength of the acid sites of vanadium/biochar from peak shows the peak result of a strong acid by NH_3-TPD profiles was 400-700 °C. Acidity increases when added percent vanadium metal. Acid sites were important on the surface of the catalyst because the surface reaction was the main step for the conversion of a substance to a product. Bronsted site was a chemical species that was able to donate hydrogen cation H^+ to carboxylic acid to cause in the next step nucleophilic addition when an electron from alcohol was added to the center carbon. Hydrogen and electron transfer were important to activate esterification when the bronsted site increases. There is a tendency to increase the reaction forward due to the rate of protonation being related to the acidity of the protonation species that result from NH_3-TPD profiles curve from the experiment showing vanadium metal capacity in the high range of strong acid correlation with a high rate of protronation. Oxovanadium was related to the Lewis acid site which had a high electronegativity number. It had a strong acid by addition O functional which calculated by Equation $pK_a = - \log K_a$ when K_a = acidity constant.

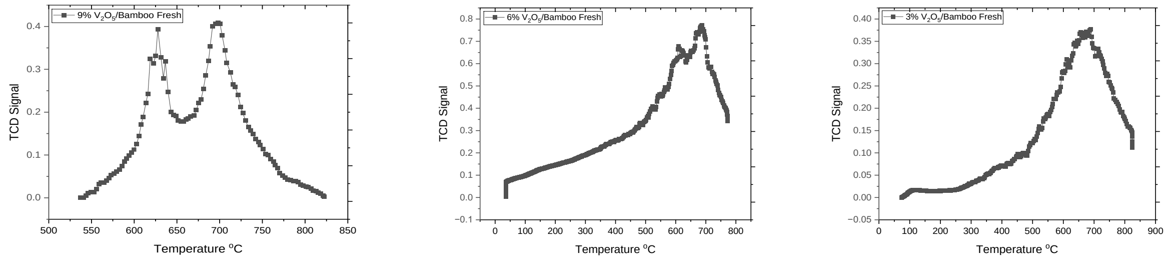

Figure 10. TPX 3%-V-B, 6%-V-B and 9%-V-B

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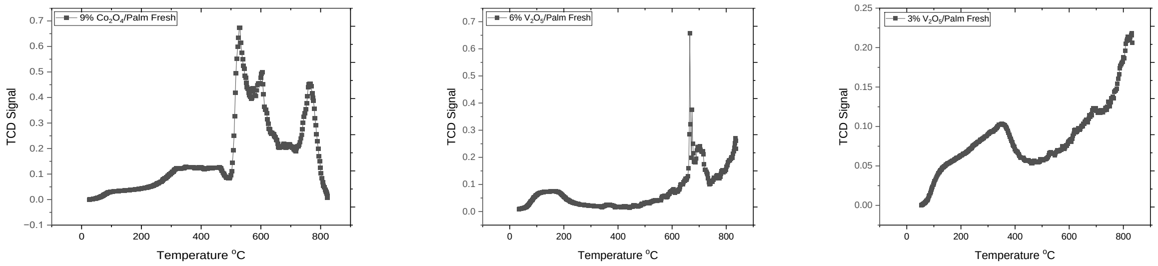

Figure 11. TPX 3%-V-P, 6%-V-P and 9%-V-P

3.5 *Fourier Transform Infrared Spectroscopy method*

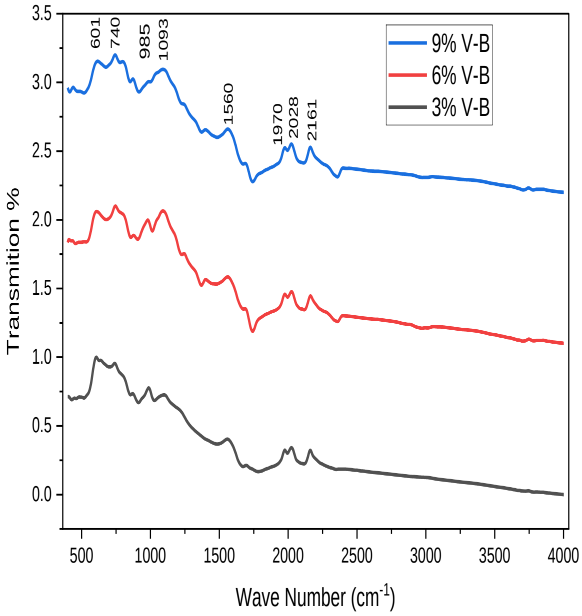

Figure 12. FT–IR study of 3%-V-B, 6%-V-B and 9%-V-B

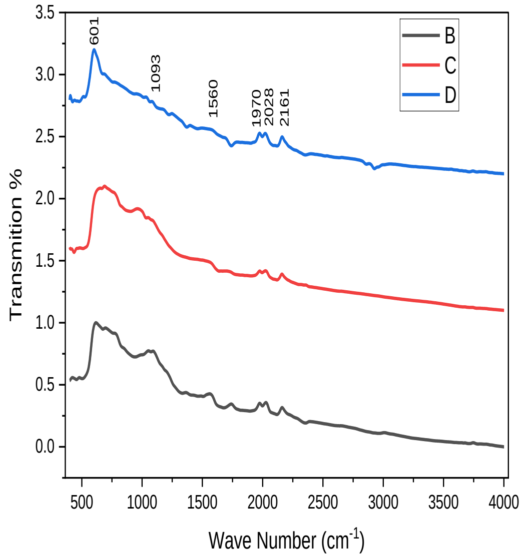

Figure 13. FT–IR study of 3%-V-P, 6%-V-P and 9%-V-P

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Adsorption of metal on the support surface using Fourier Transform Infrared Spectroscopy for studies vanadium catalyst structure on the biochar supports and surface organic functional groups. The stretching vibrations vanadium oxide (V_2O_5) were observed in the spectrum of peak region at position V=O (985 and 1093 cm^{-1}). FTIR spectrum of pure vanadium oxide showed a sharp band at 1020 cm^{-1} due to the V=O stretching vibration in vanadium oxide (1100-850 cm^{-1})[15]. While the stretching vibrations of (bridge oxygen) V–O–V (1038 cm^{-1}) [16]. Chemisorption by the oxide of vanadium [V=O] in order to vacancy region reacted with the vacancy position (result Table 4) on biochar surface together by impregnation and calcination method. his bonding was an important reused catalyst by mechanism of metal to hold up from unpredictable leaching conditions resulting in decreased vacancy region [V=O] on surface reaction.

Table 4. Biochar surface functional groups [14]

Vibration	Absorption band	Functional
O–H	2,900 cm^{-1}	phenolic groups
C=C	1,564 cm^{-1}	aromatic structure
O–H bending or C–O	1,425 cm^{-1}	phenol
C–H bending	1,384–1,402cm^{-1}	alkanes/alkyl
–C–OH bending	1,063 cm^{-1}	polysaccharides
C–H bending	874 cm^{-1}	*B*-glucosidic linkage
O–Si–O	461 cm^{-1} /800 cm^{-1}	silica

4. CONCLUSIONS

1. Based on study for vanadium supported by bamboo biochar used for esterification reaction was found that 9 wt% V_2O_5/biochar catalyst exhibited the highest activity having an acetic acid conversion of 72% with ethyl acetate selectivity of 45% by liquid phase reaction

2. The results of catalyst synthesis by impregnation and calcination method found the vanadium crystalline on surface biochar which detected the by catalytic characterization and found the activity of vanadium can be recovered and reused as a catalyst in a new reaction, but occurred leaching effect of the metal from catalyst.

3. The catalyze in a heterogeneous reaction of vanadium-biochar was propered for produce ethyl acetate because it can be easily separated and nontoxic also reduced pollution virtual green chemical and renewable.

Acknowledgement

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Plant-Based Solutions to Air Pollution in Bangkok: The Role of Urban Green Spaces

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ABSTRACT

In recent years, Bangkok has emerged as one of the most affected cities globally by air pollution, with rising levels of particulate matter 2.5 ($PM_{2.5}$) posing severe threats to human health and the environment. Urban Green Spaces (UGS) have proven to be a powerful tool in mitigating air pollution and other environmental hazards. This research explores how UGS can mitigate this issue by examining the correlation between UGS and $PM_{2.5}$ levels across urban and suburban districts in Bangkok. $PM_{2.5}$ concentrations are compared in areas adjacent to roads versus city parks. The methodology includes data collection from secondary sources and analysis using one-way ANOVA, independent-sample T-tests, and the Mann–Kendall test with Sen's slope. The findings reveal a steady increase in UGS across the most studied districts in Bangkok between 2008 and 2022, with notable expansions in the Ratchathewi, Pathumwan, Nong Chok, and Lat Krabang Districts. Regarding $PM_{2.5}$ concentrations, seasonal variations were observed, with higher $PM_{2.5}$ levels during the beginning and end of the year. Monitoring stations near roads consistently recorded higher levels, often exceeding the 24-hour standard, while park stations generally maintained lower $PM_{2.5}$ levels. However, some park stations occasionally exceeded acceptable levels. Comparative analysis showed that $PM_{2.5}$ concentrations were significantly lower in parks than nearby roads, with reductions ranging from 26% to 43%. This indicates that UGS effectively reduces $PM_{2.5}$ pollution, emphasizing the importance of incorporating green infrastructure in urban planning. These findings highlight the necessity for sustainable measures and ongoing efforts to manage air pollution, particularly during high-risk periods, to maintain improved air quality in Bangkok.

Keywords: Urban green space (UGS)/ Air pollution/ $PM_{2.5}$/ Bangkok/ Air quality mitigation

1. INTRODUCTION

Bangkok, the bustling capital of Thailand, has experienced rapid urban development, bringing significant environmental challenges. Air pollution has emerged as a critical issue, driven by a dense population exceeding 10 million, extensive traffic congestion, industrial activities, and biomass burning. Of particular concern is the rise of $PM_{2.5}$, fine particulate matter with diameters of less than 2.5 micrometers, which poses serious health risks to the city's inhabitants. These particles can penetrate the respiratory system, leading to various health problems, including respiratory and cardiovascular diseases.

Air pollution, defined as unwanted chemicals or substances that degrade air quality [1], is a growing threat in Bangkok. The World Health Organization [2] estimates that approximately 4.2 million people globally suffer from air pollution-related health issues yearly. The situation is particularly alarming in Bangkok, with annual $PM_{2.5}$ concentrations exceeding the WHO's recommended 10 µg/m³ limit. The city's air quality index (AQI) often reaches unhealthy levels, especially during the dry season from January to March, when $PM_{2.5}$ concentrations peak, reducing visibility and public health concerns [3].

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Urban green spaces (UGS) have been identified as a potential mitigating factor for air pollution in cities. Previous studies have shown that green spaces like parks, gardens, and tree-lined streets can reduce air pollution by capturing and filtering air-borne particles, including $PM_{2.5}$ [4]. Numerous studies worldwide have explored the relationship between urban green spaces and air quality, mainly focusing on $PM_{2.5}$ concentrations. Research consistently suggests that areas with more green cover tend to have lower levels of $PM_{2.5}$ compared to non-green or densely built-up areas. In London, a study by Nowak et al. [5] found that urban trees and green spaces contributed to reducing $PM_{2.5}$ concentrations by filtering air-borne particulate matter. The trees were estimated to remove 7-9 tonnes of $PM_{2.5}$ annually, improving air quality, particularly in neighborhoods with extensive tree cover. A study conducted in Beijing, China, where $PM_{2.5}$ levels are among the highest globally, revealed that parks and green belts played a crucial role in mitigating air pollution. Research by Chen et al. [6] showed that $PM_{2.5}$ levels were significantly lower in green areas compared to non-green urban areas, with reductions of up to 20-30% near large parks and forested zones. In Strasbourg, France, research by Wissal et al. [7] highlighted that green spaces, particularly large parks and tree-lined streets, contributed to lower $PM_{2.5}$ concentrations. The study found that areas with greater green cover reduced particulate matter by approximately 15%, indicating that even smaller urban green spaces can substantially impact local air quality. Similarly, a study in Mexico City by Baumgardner et al. [8] showed that urban forests and green spaces could remove around 8.8 tonnes of $PM_{2.5}$ annually. The study concluded that urban greening efforts could be a practical solution for improving air quality in megacities suffering from high levels of air pollution. Despite these benefits, Bangkok lacks sufficient green space, with only 7.59 m² per person based on the registered population, and even less when considering the total population [9]. This is significantly below the WHO's recommendation of at least 9 m² of green space per person [10].

Given the pressing nature of air pollution in Bangkok and the potential of UGS to alleviate it, this study aims to explore the relationship between the availability of UGS and $PM_{2.5}$ levels in urban and suburban districts of Bangkok. The research focuses on two key objectives: (i) identifying trends in UGS and $PM_{2.5}$ levels across the city; (ii) assessing differences in $PM_{2.5}$ concentrations between non-green areas (e.g., along roads) and green areas (e.g., city parks). By examining these factors, the study provides valuable insights for policymakers and urban planners, highlighting the importance of expanding and maintaining urban green spaces as a natural solution to Bangkok's air pollution crisis.

2. METHODOLOGY

2.1 Study area

Bangkok, Thailand's capital, is located at approximately 13.736717° N latitude and 100.523186° E longitude, with an elevation of 2.3 meters above sea level. As a central hub for transportation, finance, and commerce, the city faces significant air pollution challenges due to its dense population (10.72 million as of 2021), extensive traffic, and industrial activities. The city's climate is influenced by monsoonal winds, which impact the dispersion of pollutants. Bangkok's air quality is significantly impacted by $PM_{2.5}$, primarily from vehicular emissions, industrial activities, and biomass burning [11]. To monitor air quality, the Pollution Control Department (PCD) and Bangkok Metropolitan Administration (BMA) operate a network of monitoring stations. As of 2022, 23 PCD stations and 70 BMA stations measure pollutants like $PM_{2.5}$ and other key air quality parameters [12].

This study selected monitoring stations based on three criteria: location (urban vs. suburban), surrounding environment, and proximity (within 1 km between paired stations). This approach aimed to capture the variability in air pollution across different urban contexts in Bangkok. In the urban area, two pairs of monitoring stations were selected. The first pair includes Santiphap Park and Din Daeng Road, 953 meters apart. Santiphap Park is characterized by vegetation that may help reduce pollution levels, whereas Din Daeng Road experiences higher pollution levels due to heavy traffic and nearby tollways. The second pair comprises Lumpini Park and Rama IV Road, with a separation of 929 meters. Lumpini Park's greenery is expected to mitigate pollution levels in contrast to the high-traffic environment of Rama IV Road. In the suburban areas, two additional pairs of monitoring stations were

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chosen. The third pair includes Lat Krabang Park and Lat Krabang Road, which are 354 meters apart. Air pollution from airport activities, commuter traffic, and industrial operations impacts this area. The fourth pair consists of Nong Chok Public Park and Liap Wari Road, separated by 397 meters. Pollution sources in this area include vehicle emissions, nearby industrial sites, and transboundary smoke. This selection strategy ensured that paired stations in green and non-green areas were close enough to be subject to similar local meteorological and traffic conditions, allowing for a more accurate comparison of $PM_{2.5}$ concentrations between urban and suburban settings.

In non-green areas, traffic emissions are a predominant source of $PM_{2.5}$. Vehicular emissions can contribute significantly to particulate matter concentrations, often accounting for a substantial portion of overall $PM_{2.5}$ levels. Other anthropogenic sources, including industrial emissions and construction activities, can exacerbate $PM_{2.5}$ concentrations, especially during peak traffic times. Green areas, while typically benefiting from the natural filtration provided by vegetation, are not entirely free from $PM_{2.5}$ contamination. Resuspension of soil particles and organic matter can contribute to $PM_{2.5}$ concentrations, particularly during dry weather or through human activities such as park maintenance. Additionally, green areas near busy roads may experience infiltration of traffic-related pollutants, which can diminish the air quality benefits usually associated with vegetation. Advanced source apportionment techniques can be applied in future studies to accurately quantify the contributions of various PM2.5 sources in both green and non-green areas. These approaches help identify specific sources contributing to $PM_{2.5}$ levels, providing valuable insights for developing targeted interventions to improve air quality.

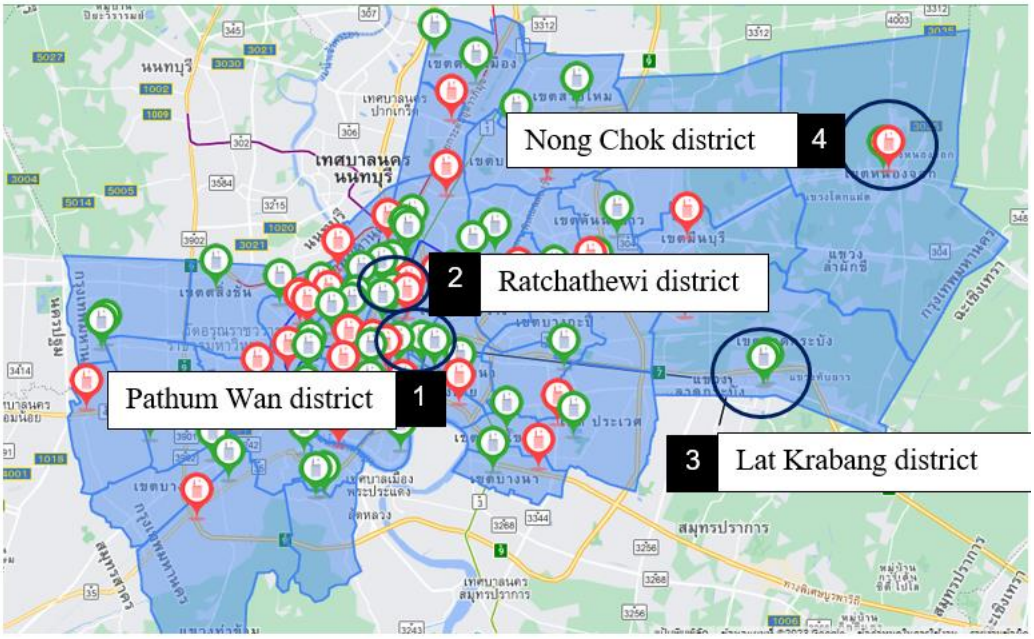

Figure 1. Selected air pollution monitoring stations in this study: Pair (1) and (2): stations located in the urban area; Pair (3) and (4) stations located in the sub-urban of Bangkok.

2.2 Data collection

2.2.1 Air pollution levels

Data on $PM_{2.5}$ concentrations are being collected from monitoring stations within the study area. This data, provided by the PCD and the Environment Department of the BMA, covers 2021 to 2022. The air pollution levels are recorded as average concentrations per 24 hours, allowing for a detailed analysis of particulate matter in Bangkok's urban and suburban areas. This study focuses on $PM_{2.5}$ concentrations based on data provided by government authorities. However, the dataset did not include environmental factors such as temperature, relative humidity, precipitation, and wind, which may also influence air pollution levels. Future research could benefit from integrating these variables better to understand the dynamics of $PM_{2.5}$ in different urban contexts.

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2.2.2 Urban green spaces

Information on UGS is obtained from the Bangkok Green Office and categorized by the Public Park Office and the Environment Department of BMA. The data includes all types of UGS, measured in square meters, and spans 2008 to 2022. This comprehensive dataset enables the study to evaluate the distribution and impact of green spaces on air quality across Bangkok.

2.3 Data analysis

This research employed quantitative methods to analyze and interpret the collected data, utilizing descriptive and inferential statistical techniques to examine the characteristics of UGS and $PM_{2.5}$ levels and their relationships.

The PCD and BMA data were represented graphically to assess trends in UGS and $PM_{2.5}$ levels from 2008 to 2022. One-way ANOVA was applied to evaluate variations in $PM_{2.5}$ concentrations over the years, determining whether there were significant changes in pollution levels over time. The Mann-Kendall test and Sen's slope estimator were employed to analyze UGS trends. These analyses were conducted using Microsoft Excel with the XLSTAT add-in.

An independent-sample t-test was used to compare $PM_{2.5}$ levels between monitoring stations near main roads and those within UGS in Bangkok's urban and suburban areas. The significance level (alpha) was set at 0.05, with the analysis performed using Minitab software.

3. RESULTS AND DISCUSSION

3.1 Trend of urban green spaces in Bangkok

3.1.1 Urban districts

Using the Mann-Kendall trend test, figure 2 illustrates the temporal trends in UGS within the Ratchathewi and Pathumwan Districts from 2008 to 2022. In the Ratchathewi District, significant upward trends were observed in neighborhood and pocket parks, with pocket parks expanding by 45% and neighborhood parks by 16% over the study period. The Sen's slope values indicate that neighborhood parks in Ratchathewi are increasing at an average rate of 3,946 square meters per year, while pocket parks are expanding at 2,560 square meters yearly. However, no significant growth was detected in community and street parks within this district.

Similarly, the Pathumwan District showed significant positive neighborhood, street, and pocket park trends. Pocket parks experienced an 83% increase, neighborhood parks grew by 76%, and street parks expanded by 30% between 2008 and 2022. The Sen's slope analysis reveals that neighborhood parks in Pathumwan are expanding at a rate of 5,302 square meters per year, pocket parks at 3,456 square meters per year, and street parks at 704 square meters per year. As with Ratchathewi, community and district parks in Pathumwan did not exhibit a significant trend in growth over the study period.

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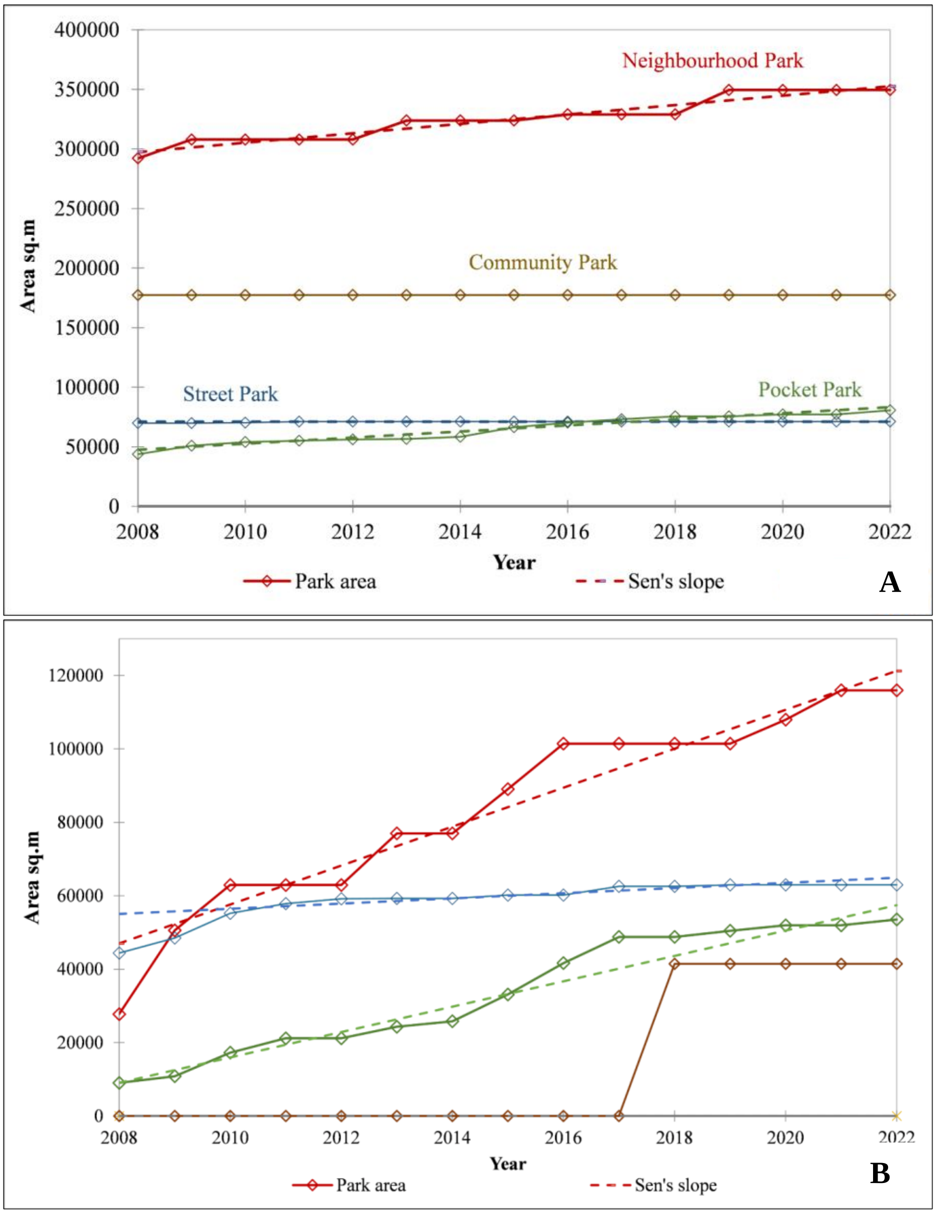

Figure 2. Mann-Kendall trend and Send's slope of UGS in the Ratchathewi (A) and Pathumwan (B) Districts from 2008 to 2022

3.1.2 Sub-urban districts

Figure 3 depicts the trends in UGS within the Nong Chok and Lat Krabang Districts from 2008 to 2022, utilizing the Mann-Kendall trend test. Significant upward trends were observed in Nong Chok District for neighborhood, street, and pocket parks. Street parks experienced a 38% increase from 2008 to 2022, pocket parks saw a 93% growth from 2014 to 2022, and neighborhood parks increased by 69% between 2013 and 2022. The Sen's slope analysis suggests that neighborhood parks in Nong Chok are expanding at 14,277 square meters per year, street parks at 9,520 square meters per year, and pocket parks at 4,224 square meters per year. Conversely, community parks did not exhibit a significant trend in growth during this period.

Similarly, the Lat Krabang District significantly grew in neighborhood, street, and pocket parks. Between 2008 and 2022, street parks increased by 91%, neighborhood parks by 88%, and pocket parks by 86%. According to Sen's slope estimates, neighborhood parks in Lat Krabang are growing at a rate of 10,516 square meters per year, street parks at 9,239 square meters per year, and pocket parks at 3,451 square meters per year. As in Nong Chok, community parks in Lat Krabang did not show a significant growth trend over the study period.

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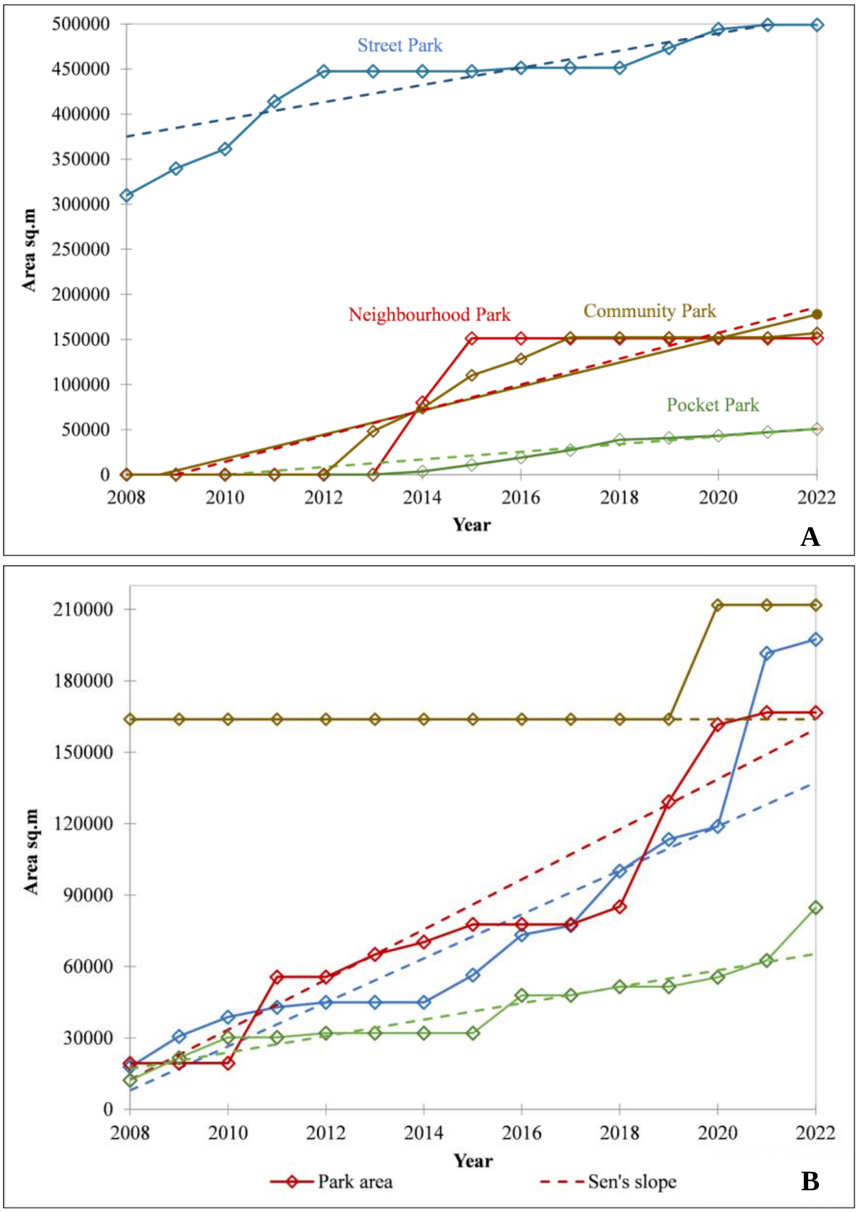

Figure 3. Mann-Kendall trend and Send's slope of UGS in the Nong Chok (A) and Lat Krabang (B) Districts from 2008 to 2022

In comparison between urban and suburban zones, the suburban districts of Nong Chok and Lat Krabang experienced a more robust and rapid expansion of UGS, particularly in neighborhood, street, and pocket parks, both in percentage growth and annual area increases. In contrast, the urban districts of Ratchathewi and Pathumwan saw slower growth, with only select park types expanding significantly, while community and district parks showed no notable growth across urban and suburban areas. This suggests that suburban districts are experiencing a more aggressive development of UGS, potentially due to larger available spaces, recent developments in residential zones compared to previous years, and different urban planning policies. These newer residential developments likely incorporate UGS as part of efforts to create more livable environments, contributing to the observed increase in green spaces. In comparison, urban districts face challenges due to denser populations and limited available land, slowing the pace of UGS expansion.

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3.2 Trends of $PM_{2.5}$ levels in monitoring stations near roads and parks

$PM_{2.5}$ concentrations in urban and suburban districts exhibited clear seasonal patterns across 2021 and 2022, with significantly higher levels observed between January to April and October to December. These periods often exceeded Thailand's 24-hour $PM_{2.5}$ standard of 37.5 µg/m³, particularly during colder months.

3.2.1 Urban districts

In the Ratchathewi District, the Din Daeng Road monitoring station consistently recorded high $PM_{2.5}$ levels, especially during the early and late parts of the year (Figure 4 A- red line). In 2021, several exceedances were observed, peaking at 106 µg/m³, while in 2022, the maximum concentration was slightly lower at 79 µg/m³. Despite a decrease in exceedance days, statistical one-way ANOVA analysis found no significant differences in the overall $PM_{2.5}$ concentrations between 2021 and 2022 ($p > 0.05$). At Santhiphrap Park, a similar seasonal trend was observed, with the highest levels in January, February, and December (Figure 4 A- green line). In 2021, there were 12 exceedance days (maximum 73 µg/m³), while 2022 saw only 3 exceedance days (maximum 69 µg/m³). Like Din Daeng Road, no significant difference was found between the two years (one-way ANOVA, $p > 0.05$).

In Pathumwan District, the Ratchadamri Road station showed elevated $PM_{2.5}$ levels from January to March and October to December (Figure 4 B- red line). The highest concentration in 2021 reached 89 µg/m³, with 20 exceedance days, compared to 73 µg/m³ and 10 exceedance days in 2022. The monitoring station at Lumpini Park, established in late 2020, followed a similar pattern, with significantly higher $PM_{2.5}$ concentrations in the early and late parts of both years (Figure 4 B- green line). The park saw 7 exceedance days in 2021 (maximum 71 µg/m³) and only 1 in 2022 (maximum 57 µg/m³), though the one-way ANOVA analysis again showed no significant difference between the years ($p > 0.05$).

3.2.2 Suburban districts

In Lat Krabang District, $PM_{2.5}$ levels near the road were highest from January to February and October to December, with 32 exceedance days in 2021 (peak 104 µg/m³) and 21 in 2022 (peak 84 µg/m³) (Figure 5 A- red line). Phanakhron Park followed a similar seasonal trend but had fewer exceedance days: 11 in 2021 (maximum 94 µg/m³) and only 2 in 2022 (maximum 60 µg/m³) (Figure 5 A- green line). Statistical analysis indicated no significant differences between the two years (one-way ANOVA, $p > 0.05$).

In Nong Chok District, the district administration and park stations showed seasonal peaks in $PM_{2.5}$ concentrations. The district administration station recorded 36 exceedance days in 2021 (maximum 97 µg/m³) and 17 in 2022 (maximum 78 µg/m³), while the park station had 16 exceedance days in 2021 (peak 85 µg/m³) and 8 in 2022 (peak 71 µg/m³) (Figure 5 B). Despite a reduction in exceedance days, the overall seasonal trends persisted, with no significant year-to-year differences (one-way ANOVA, $p > 0.05$).

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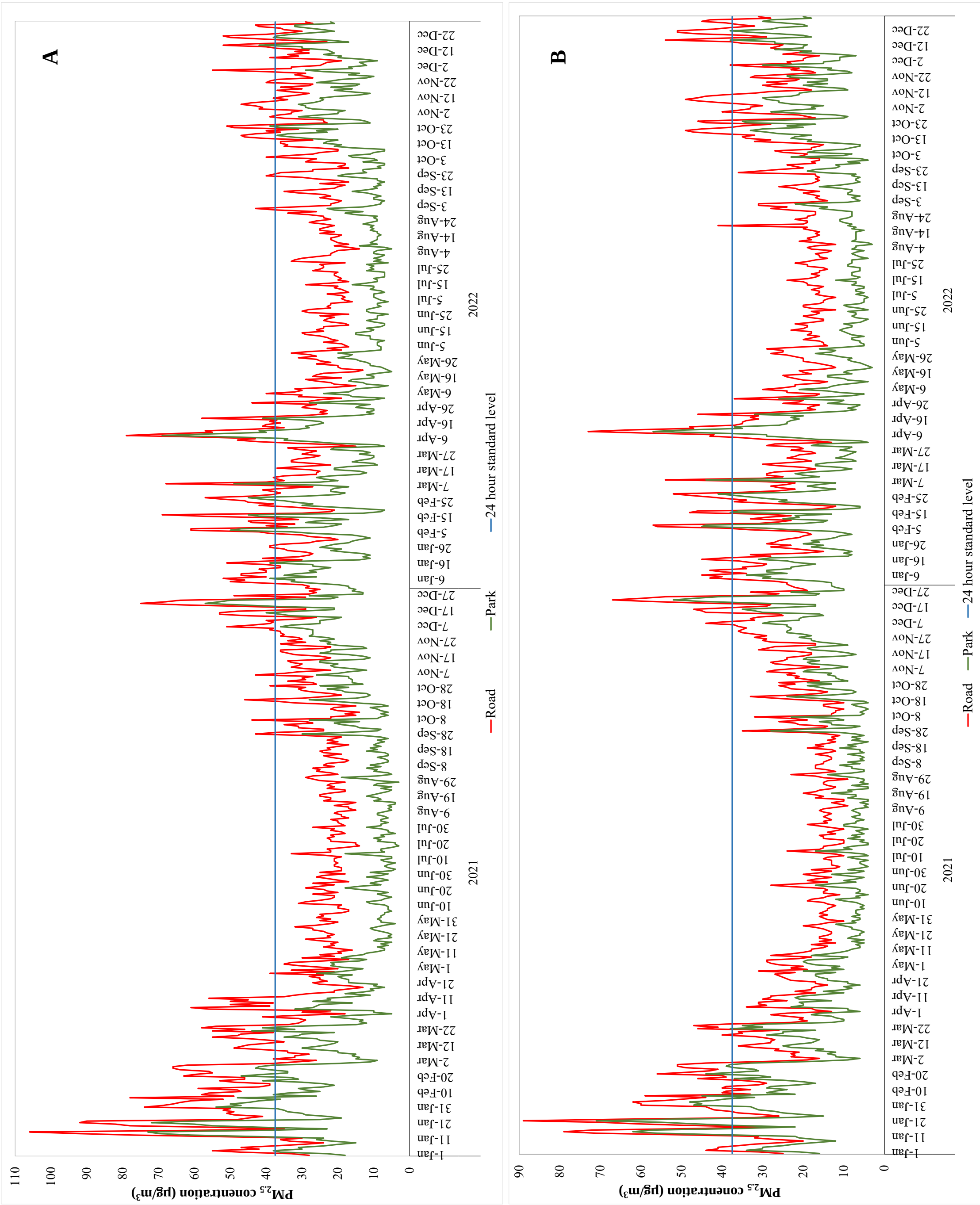

Figure 4. Daily $PM_{2.5}$ concentration of studied monitoring stations in the Ratchathewi (A) and Pathumwan Districts (B) in 2021 and 2022

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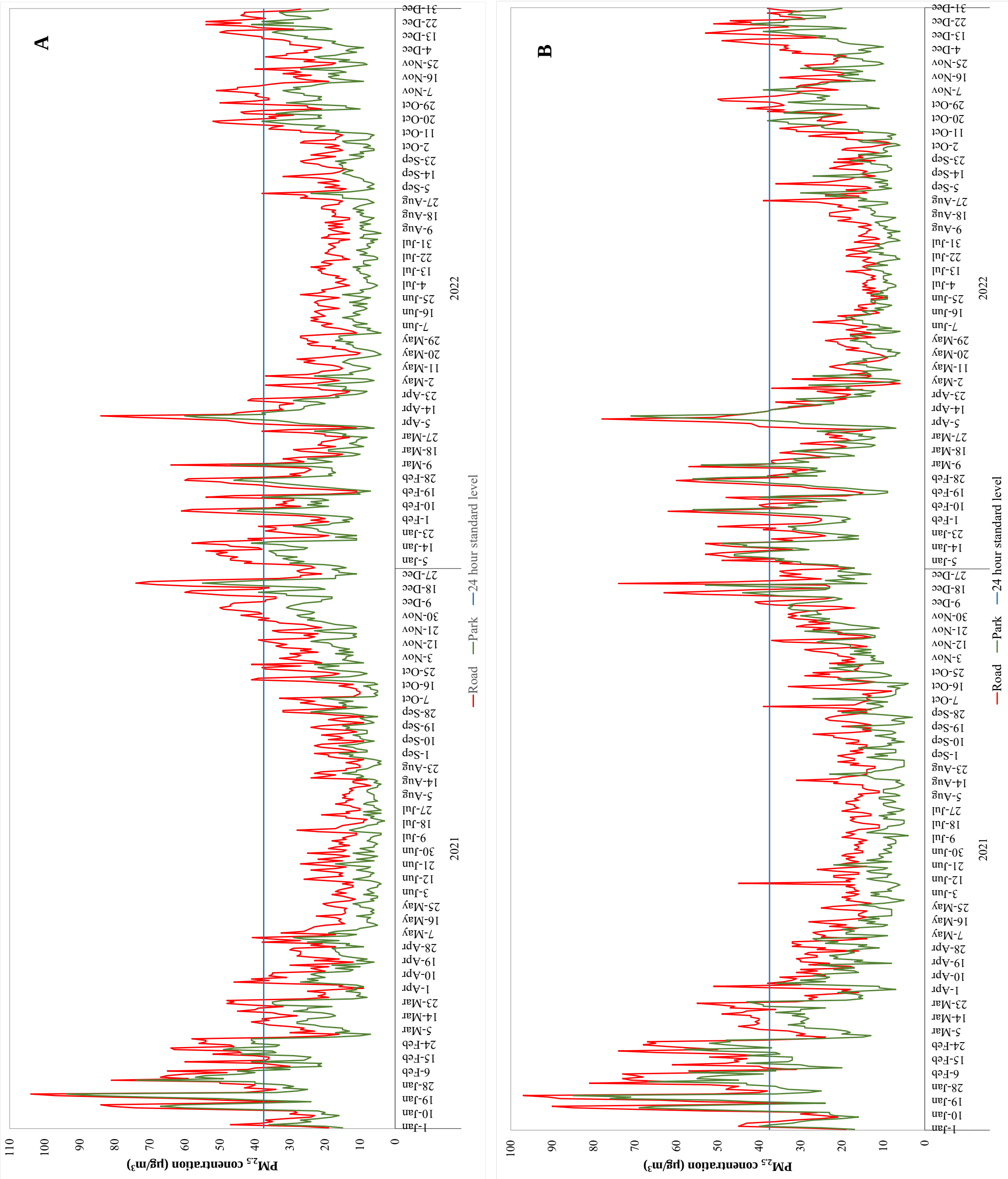

Figure 5. Daily $PM_{2.5}$ concentration of studied monitoring stations in the Nong Chok (A) and Lat Krabang (B) Districts in 2021 and 2022

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3.3 Comparative of $PM_{2.5}$ levels in monitoring stations near roads and parks

3.3.1 Urban districts

- *Ratchathewi District*

The mean daily $PM_{2.5}$ concentration at the monitoring station near Din Daeng Road was 32.5 µg/m³ in 2021 and 30.9 µg/m³ in 2022. In contrast, the monitoring station located within Santiphap Park recorded significantly lower mean concentrations of 18.1 µg/m³ in 2021 and 17.7 µg/m³ in 2022. The difference in $PM_{2.5}$ levels between the two stations was statistically significant (T-test, $p < 0.05$), with higher levels consistently observed near Din Daeng Road. These findings suggest that the monitoring station near Din Daeng Road, which is located closer to traffic and urban activities, experiences higher $PM_{2.5}$ concentrations compared to the station in Santiphap Park, a more green and sheltered area. The consistent disparity in $PM_{2.5}$ levels between the two stations highlights the impact of urban infrastructure and traffic emissions on air quality within a relatively small geographical area.

- *Pathumwan District*

The mean daily $PM_{2.5}$ concentration at the monitoring station near Rama IV Road was recorded at 24.7 µg/m³ in 2021 and slightly increased to 25.7 µg/m³ in 2022. In contrast, the monitoring station situated in Lumpini Park consistently measured lower $PM_{2.5}$ levels, with mean daily concentrations of 15.6 µg/m³ in 2021 and 14.97 µg/m³ in 2022. Statistical analysis using a T-test indicated a significant difference in $PM_{2.5}$ concentrations between the two stations ($p < 0.05$), with the station near Rama IV Road consistently exhibiting higher concentrations. These findings suggest that the proximity to Rama IV Road, a major urban traffic artery, contributes to the elevated $PM_{2.5}$ levels at that monitoring station compared to Lumpini Park, which benefits from its green space and distance from heavy traffic. This comparison emphasizes the critical role of traffic emissions in urban air pollution and highlights the importance of urban green spaces in mitigating air pollution levels.

3.3.2 Suburban districts

- *Lat Krabang District*

The mean daily $PM_{2.5}$ concentrations at the monitoring station near Lat Krabang Road were 27.8 µg/m³ in 2021 and 27.6 µg/m³ in 2022. In contrast, the monitoring station located in Lat Krabang Park recorded significantly lower mean daily concentrations, measuring 17.5 µg/m³ in 2021 and 16.91 µg/m³ in 2022. Statistical analysis using a T-test confirmed a significant difference in $PM_{2.5}$ levels between the two stations ($p < 0.05$), with consistently higher concentrations observed at the station near Lat Krabang Road. These findings suggest that the proximity of the monitoring station to Lat Krabang Road, a busy traffic route, is a major contributor to the elevated $PM_{2.5}$ levels observed there. In comparison, the station in Lat Krabang Park, which benefits from green space and distance from heavy traffic, consistently recorded lower $PM_{2.5}$ concentrations.

- *Nong Chok District*

The mean daily $PM_{2.5}$ concentrations at the monitoring station near Liap Wari Road were 27.7 µg/m³ in 2021 and 25.5 µg/m³ in 2022. In contrast, the monitoring station in Nong Chok Park recorded lower mean daily concentrations of 19.8 µg/m³ in 2021 and 2022. Statistical analysis using a T-test confirmed a significant difference in $PM_{2.5}$ levels between the two stations ($p < 0.05$), with higher concentrations observed near Liap Wari Road. These results suggest that the proximity of the monitoring station to Liap Wari Road, a major traffic route, contributed to the elevated $PM_{2.5}$ concentrations observed at that station. On the other hand, the station in Nong Chok Park, benefiting from its location within a green space and further from road traffic, consistently recorded lower $PM_{2.5}$ levels. This underscores the impact of traffic emissions on air quality in urban areas and highlights the mitigating role of green spaces like Nong Chok Park in reducing $PM_{2.5}$ pollution.

The lower $PM_{2.5}$ concentrations observed in parks compared to areas near roads can be attributed to several factors, with one primary mechanism being the presence of vegetation and green spaces. According to Qu et al. [13], parks generally have a higher density of trees and plants than urban

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areas near roads. Vegetation is a natural filter for particulate matter through dry deposition, where particles settle on surfaces like leaves and absorption via stomata and wax-covered surfaces. This natural filtering effect effectively reduces $PM_{2.5}$ concentrations in the air surrounding parks. Additionally, parks are often designed with physical barriers such as trees, buildings, or other structures that help shield them from direct exposure to road emissions. These barriers provide some level of protection against the transport of pollutants into park areas [14].

Another important factor is the dispersion and dilution of particulate matter. As $PM_{2.5}$ particles are emitted from vehicles and other sources near roads, they disperse and dilute as they move away from the source. This process allows particulate matter to become more diffuse, resulting in lower concentrations in areas further away, such as parks [13]. The distance of monitoring stations in parks from major roadways also plays a role. Since parks are often located further from busy roads, they experience less direct impact from traffic emissions, contributing to lower $PM_{2.5}$ levels [15].

3.4 Solutions for reducing air pollution

This research highlights the need to integrate green spaces into urban planning to mitigate air pollution. Variations in pollution levels across monitoring sites demonstrate the potential of green areas to act as natural filters, creating healthier environments for Bangkok's citizens. A key solution is implementing urban greening initiatives, including expanding parks, planting roadside trees, and creating green roofs, vertical gardens, and buffers near industrial zones. These efforts will increase vegetation and reduce air pollution in high-emission areas [16].

Collaboration with governmental, academic, non-governmental, and community organizations is essential. Government entities can create supportive policies and allocate resources, while NGOs and academic institutions can contribute research, advocate for sustainable practices, and implement educational campaigns. Community involvement ensures that green spaces meet local needs, promoting social cohesion and ownership of these projects [17]. Effective monitoring and evaluation will ensure these initiatives' long-term success and impact on air quality.

In addition to greening, air pollution control measures must be prioritized. Promoting sustainable transportation, such as public transit, electric vehicles, and bike-sharing, will help reduce vehicle emissions. Collaborating with industries to adopt cleaner technologies and enforce stricter environmental standards is crucial to reducing industrial pollution. Integrating green infrastructure into urban development plans is vital. City planners, architects, and environmental agencies should consider green spaces in transportation and building projects, contributing to a more sustainable and livable city.

4. CONCLUSIONS

This study investigated the relationship between UGS and air pollution across urban and suburban Bangkok districts. The analysis of UGS trends from 2008 to 2022 in urban and suburban districts reveals that suburban districts such as Lat Krabang and Nong Chok have experienced significant growth in neighborhood, street, and pocket parks, contributing to better air quality. Conversely, Ratchathewi and Pathumwan's more densely populated urban districts saw slower expansion in UGS, constrained by limited space and competing urban development pressures. The comparative analysis of $PM_{2.5}$ levels between monitoring stations near roads and parks shows that areas closer to major traffic routes, such as Din Daeng Road and Lat Krabang Road, consistently recorded higher $PM_{2.5}$ concentrations compared to stations located within parks, such as Santiphap Park and Lumpini Park. The significant differences in $PM_{2.5}$ levels between road and park sites emphasize the impact of vehicular emissions and the potential of green spaces to mitigate air pollution. These findings prove that integrating green spaces into Bangkok's urban landscape effectively reduces air pollution. Expanding UGS enhances the city's aesthetic and ecological value and creates healthier, more livable environments for its residents.

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Phenological changes in seaweed community structure and the diversity of fish communities in seaweed ecosystems

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ABSTRACT

Seaweed communities in coastal areas serve as crucial habitat for many organisms and serve to maintain high levels of biodiversity in coastal ecosystems. However, the loss of these communities because of climate change and increasing levels of marine debris is leading to a decline of biodiversity and remains a significant concern. We studied the occurrence of fish species within seaweed communities formed in the subtidal zone. To observe changes in community structure of fish communities, we conducted the study throughout the year in the coastal waters of Arikawa Bay, Shin-Kamigoto Town, Nagasaki Prefecture, where there are significant seasonal changes in seaweed communities. We recorded species, height, and coverage of seaweeds, and the species and abundance of fish, water temperature, and salinity. We hypothesized that as the species diversity, height, and coverage of seaweed communities increase, the species diversity of and abundance of fish also increases. The seaweed coverage and height peaked during April to June. The number of fish species peaked during July to October, however the abundance decreased during this period; data analysis suggests a strong correlation between seaweed and fish communities. Omnivores and benthic feeders were positively correlated with species coverage and a Procrustes analysis also suggests a strong correlation between seaweed communities and fish communities. Analysis is underway to elucidate the impact of marine debris.

Keyword: Biodiversity/ Community/ Ecosystem engineer/ Habitat structure/ Marine debris/ Seaweed

1. INTRODUCTION

Kenyon and Kridler (1969) was one of the first to report the ingestion of plastic debris by birds (*Phoebastria immutabilis*) which led to increased mortality and demonstrated that 74% of chicks that died before fledging had plastic debris in their stomachs. However, records indicate that plastics were observed in birds collected in the early 1960s [2, 3]. Interest in plastic debris steadily increased due to the publication of two seminal papers on plastic debris in the oceans. These reports of marine plastic pollution described the occurrence of plastic pellets and spherules on the ocean surface [4, 5, 6]. Thereafter, plastics have been reported from coastal environments and were observed in bays and beaches [7, 8, 9]. Besides the ingestion of plastics, marine organisms were also observed to be entangled in plastic debris [10, 11, 12]. It is now clear that plastic debris is entering the food chain. One of the first reports suggests that plastic particles found in fur seal feces were originally ingested by their prey fish, *Electrona subaspera* [13]. Clearly, the continued mismanagement and discharge of plastic debris into the oceans will influence the abundance and biodiversity of marine species.

Although the largest amount of plastic waste entering the ocean occurs in East Asia [14] and is accumulating in coastal environments, the region is also experiencing the effects of climate change. Water temperatures are increasing, marine heat waves have been reported, and the subsequent impacts to coastal ecosystems have been reported [15]. As plastic debris accumulates and water temperatures rise, we hypothesize that this will negatively influence the biodiversity of marine organisms in the coastal environment, both directly by decreasing the fitness of marine organisms and increasing rates of mortality and indirectly through the loss and degradation of habitat.

Macroalgae and seagrasses can create large communities forming habitat for a wide variety of marine organisms. Besides providing vital habitat [16, 17], these communities also absorb carbon

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dioxide [18], purify water [19], and protect coastlines from erosion [20]. Fish, squid, crustaceans, and other organisms use seaweed and seagrass communities as a place to shelter from predators [16, 17], feed [21], and spawn [22]. Fish that inhabit seagrass beds can vary in their distributional patterns, which are linked to habitat structure [23]. However, studies have often been of short duration [24, 25, 26], and very few have observed the response patterns of fish communities to structural changes in seagrass communities over longer time scales [25]. This is important, since macroalgae communities undergo significant seasonal changes in structure and biodiversity; the ecological impact of changes in macroalgae biodiversity and community structure is an important factor influencing the biodiversity of organisms observed near seaweed communities.

In seagrass and seaweed ecosystems, suffocation and entanglement caused by marine debris, along with warming water temperatures, are expected to led to changes in the structure of the ecosystem, reduce biodiversity, and disruption traditional ecological relationships. These changes may have short term effects, or these changes may be long-lasting. We are currently investigating a coastal ecosystem in Arikawa Bay, which is a north-facing bay in Nakadori Island, Nagasaki, Japan. Here, we are examining the effect of marine debris and warming water temperatures on the biodiversity and abundance of seaweed, seagrass, and fish species. This paper addresses the first half of our study, providing the details of the biodiversity of fish and seaweed species from two sites in Arikawa Bay. The second half of our study, which examines the effects of marine debris on these two sites will begin in April 2025. Therefore, at this stage of our research, we simply examine the association between fish and seaweed species composition in two rocky shores in the bay.

2. METHODOLOGY

We observed the diversity of seaweed communities and surrounding fish communities in the subtidal area of Arikawa Bay, Nakadori Island, Nagasaki Prefecture, Japan, from June 2023 to May 2024 (Fig. 1). Two study sites were established at Yokoura and Naname shown in Fig. 1. Yokoura is adjacent to an area where fisherman dry and repair nets, whereas Naname is not located to any fisheries activity. The sites were chosen due to the relatively larger inflow of fisheries debris in Yokoura when compared to Naname. Each study site is denoted by the initial letter of the study site and the study station number (e.g., Naname Station 2, N2). A study site was defined as a circle with a radius of 2 m around the landmark. Water temperatures were also recorded, since water temperature is one of the most important variables affecting the ecology of marine organisms [1, 27] We placed data loggers (Tidbit V2, Onset) on the sea bottom of each study site and measurements were recorded at 10-minute intervals. Data collection and logger maintenance was carried out as appropriate.

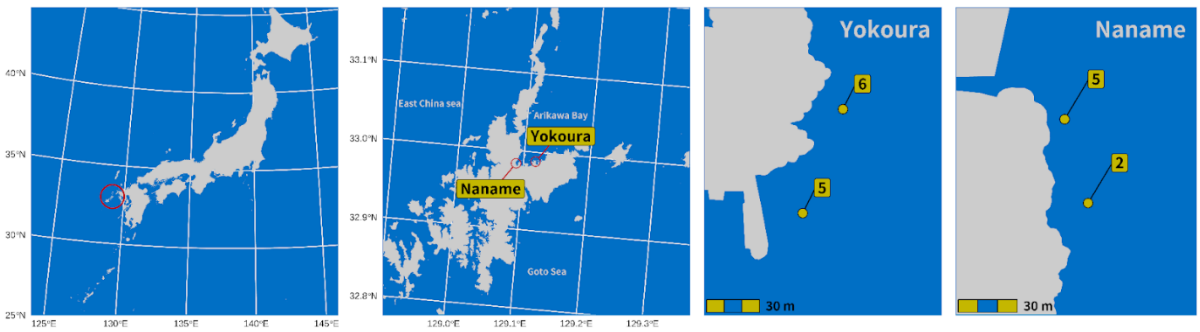

Figure 1. Study sites were located in Naname and Yokoura of Arikawa Bay, Nakadori Island, Nagasaki, Japan.

2.1 Fish communities

Observations of fish were made using time-lapse photography with underwater cameras. The recording interval was set at 10 minutes, and the cameras were recorded between 5 am and 8 pm in order to make observations during the bright hours between sunrise and sunset for about a week. From June 2023 to January 2024, the cameras were placed on the bottom once a month for one day and

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recorded for 24 hours. From March to May 2024, the cameras were floated 50 cm above the bottom, connected to weights on the bottom and recorded for about one week. The cameras were collected, and the data retrieved after recovery and the fish species that appeared were recorded. The species and number of appearances of individuals with whole bodies in the image were recorded. If species identification was difficult, genus or upper taxa were identified.

2.2 Seaweed communities

Observations of macroalgae species, height, and coverage were recorded. Macroalgae species and height were recorded with an underwater camera and visual inspection during skin diving. Every month from June 2023 to May 2024, macroalgae species were identified to the species level with images taken with a camera (TG-6, Olympus, Inc.). If species identification was difficult, individuals were identified to the family or genus level.

2.3 Statistical analysis

All statistical analyses were done using R version 4.4.1 [28]. The alpha diversity was determined for each site, station, and month by calculating the Shannon-Wiener index (1) [29] for fish and determining the species richness for both macroalgae and fish

Procrustes analysis [30] is a technique to measure morphological similarities and differences. It can also be used to estimate similarities in ordination-based matrices, such as those from a principal component analysis (PCA) [31]. Therefore, to determine the relationship between macroalgae communities and fish communities, first a PCA of the species richness for both the macroalgae and fish were determined. Next, the first two principal components of each PCA were used in the Procrustes analysis. A randomization test to examine the sum of residual deviations of the concordance matrix is used to test the statistical significance analysis at a level of 0.05 [25, 31].

$$H' = -\sum_{i=1}^{n} P_i \ln P_i \quad (1)$$

3. RESULTS AND DISCUSSION

During the study period we did not observe any fish communities in Y6 in June and September 2023, seaweed and fish communities or seaweed cover in December 2023 and February 2024 due to strong wind and wave effects and equipment trouble.

3.1 Fish communities

During the study period, we observed 31 species and 2300 individuals at station N2, 34 species and 3734 individuals at station N5, 44 species and 8763 individuals at station Y5, and 36 species and 6470 individuals at station Y6 (total 60 species and 21267 individuals). However, studies were not conducted at station Y6 in June and September 2023 due to poor weather. The species richness of the fish communities during the study was constant from 2023 July to 2024 January but increased from 2024 January to May at all study sites (Fig. 2).

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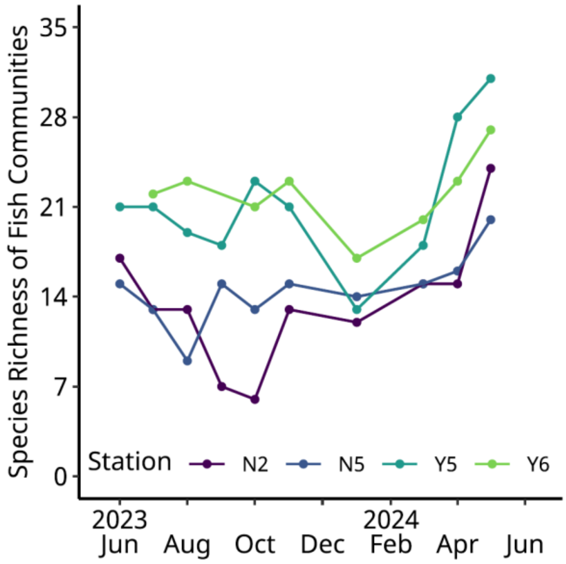

Figure 2. Species richness of fish communities determined from June 2023 to May 2024 at two stations in Naname (N) and two stations in Yokoura (Y) in Arikawa Bay, Nakadori Island, Nagasaki, Japan.

3.2 Seaweed communities

The species richness of the seaweed communities was 32 at station N2, 40 at station N5, 59 at station Y5 and 60 at station Y6 (84 species in total). Species richness at stations Y5 and Y6 appeared to decrease from the start of the study to a low during 2024 January and increase to a peak in 2024 April (Fig. 3). Species richness at stations N2 and N5 responded similarly (Fig. 3). Species richness generally decreased from June to October, which coincided with high water temperatures, and increased from January to April during the winter months (Fig. 3).

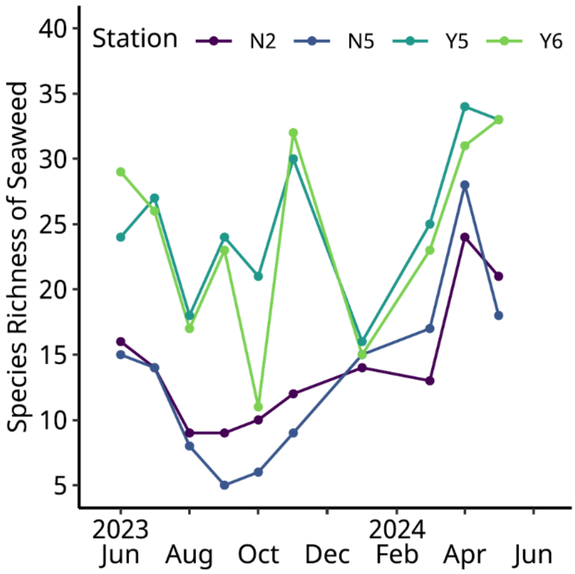

Figure 3. Species richness of seaweed communities determined from June 2023 to May 2024 at two stations in Naname (N) and two stations in Yokoura (Y) in Arikawa Bay, Nakadori Island, Nagasaki, Japan.

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3.3 Water temperature

During the study period, daily averages of water temperatures varied monthly (Fig. 4). The highest water temperatures were recorded in August in both Naname and Yokoura, with daily averages of 28.2°C in Naname and 27.8°C in Yokoura. In contrast, the daily average in February was 13.8°C in Naname and 14.7°C in Yokoura. Water temperature increased through August, decreased from September to February and increased again from March onwards. Although the sites were approximately 3 km in distance (straight-line distance), a small freshwater stream near the Naname site may have provided enough cold water to lower the water temperature at this site.

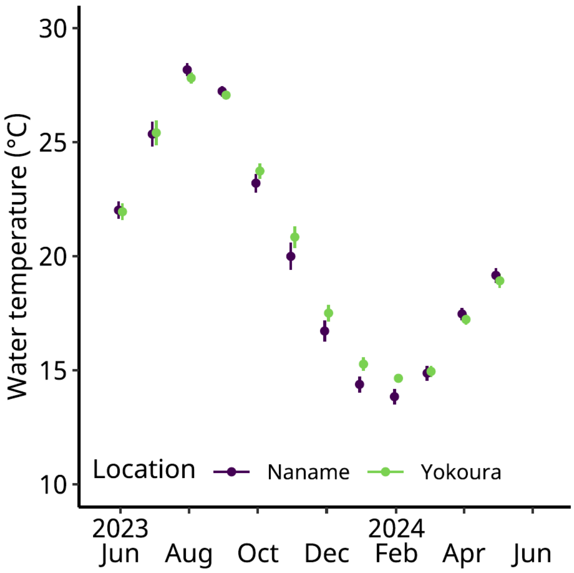

Figure 4. Average daily temperature and its 95% confidence interval determined from the Naname and Yokoura sites in Arikawa Bay, Nakadori Island, Nagasaki, Japan. Some error bars are smaller than the symbols.

3.4 Relationships between seaweed and fish communities

The species richness for fish and macroalgae communities were analyzed using principal components analysis (PCA). PCA is a technique to reduce the number of variables, to facilitate data interpretation. In the case where species abundance matrix is analyzed, PCA is used to reveal structure in the data. For the PCA of the fish community data, the first two principal components (PC) explained 36.7% of the variance revealing that the community can be roughly separated into two groups. Whereas in the macroalgae community, these components explained 30.7% of the variance (Fig. 5). The biplots of the PCA clearly shows separation among the communities observed at each station for either community.

The principal component space of the macroalgae and fish communities were subsequently analyzed using Procrustes analysis. Procrustes analysis indicated a strong correlation between the two communities, where the Procrustes sum of squares was 0.801 and the correlation coefficient was 0.446 ($P = 0.00075$). The projection of PC1 and PC2 also shows a distinct separation between the communities of both study sites (Fig. 6). However, the structure of the data suggests that the community composition of macroalgae and fish species were correlated. Similar correlations were observed in terrestrial ecosystems, where the species richness of animal communities was correlated with plant species richness [32]. Given that macroalgae provide shelter, food, and habitat to many fish species [33], animals inhabiting macroalgae communities likely served as prey for predatory fish species [34, 35, 36]. We hypothesize that the macroalgae communities examined in this study influenced the biodiversity of fish communities observed.

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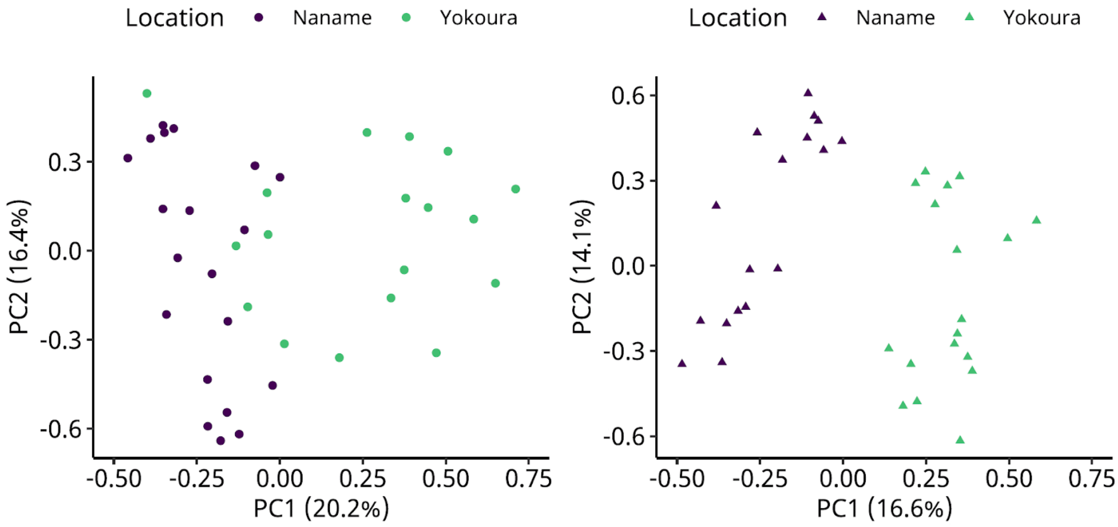

(a) (b)

Figure 5. (a) The PCA results of fish communities, (b) The PCA results of seaweed communities.

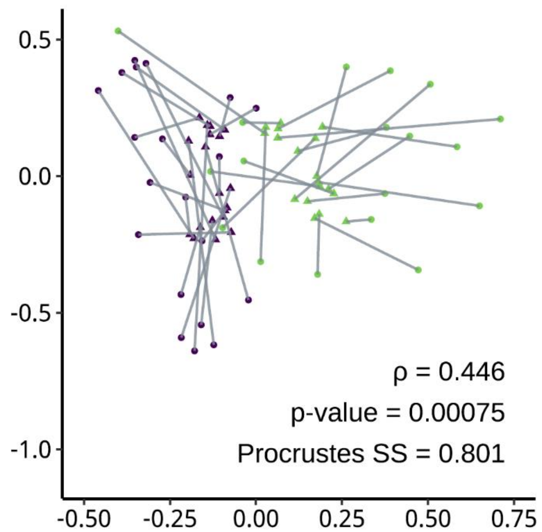

Figure 6. Procrustes Analysis with fish and seaweed communities.

4. CONCLUSIONS

The phenological response of macroalgae and fish species richness was clear in our observations. The Procrustean analysis also indicated that these communities were closely linked and were dissimilar across space. It is unclear as to what environmental variables drive the differences in these two sites, however we suggest that water temperature is one of the more important variables. Consider that the water temperatures during the winter were almost 1 °C colder at Naname compared to Yokoura. Such differences may have influenced the composition of both macroalgae and fish species.

Finally, as water temperature further increases because of climate change, more changes should be expected in patterns of species richness. Additionally, other environmental stressors will compound any effects of climate change. It is interesting to note that marine debris in coastal ecosystems are increasing in abundance and will compete for space with many sessile organisms. Coastal debris is increasing in abundance at Naname and Yokoura, and it remains to be revealed how this will affect the biodiversity of these areas in the near future.

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Assessing the Influence of Climate Change and Its Relationship on Mass Culture of Live Feed (Microalgae) in Outdoor System Conditions

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ABSTRACT

Climate change poses significant challenges to the cultivation of live feeds, crucial for the aquaculture industry. This study aims to explore the impact of climate change on the growth performance of microalgae used as live feed for marine aquatic animals, focusing on key challenges and potential solutions. Data from cultivating three microalgae species in a mass culture system under outdoor conditions in the Klongwan Fisheries Research Station (KFRS), Prachuap Khiri Khan province, Thailand, from January 2022 to December 2023, along with Geographic Information System (GIS) data on air temperature changes in the province during the same period, were analyzed. The assessment revealed that temperature fluctuation (TF) directly affected the specific growth rate (μ) of each live feed. Higher TF leading to a decreased in μ for two cultured live feeds, that is *Chlorella* and *Isochrysis*, with a negative temperature coefficient (Q10) of 0.04 and 0.00, respectively, for every 0.5°C increase in TF (r^2 = 0.94 and 0.38, respectively) from 31°C. In contrast, *Chaetoceros* showed a positive correlation between TF and μ, with a Q10 of 0.07, for every 0.5°C increase in TF (r^2 = 0.97) from 31°C. To mitigate these challenges, strategies such as using temperature-control measures (e.g., shading or insulation) and selecting temperature-tolerant strains of live feed can enhance the resilience of outdoor systems to temperature change, thereby maintaining productivity in fluctuating temperature conditions.

Keyword: Climate change/ Live feed culture/ Temperature fluctuations

1. INTRODUCTION

Climate change is a global phenomenon that poses significant challenges to various sectors, including agriculture and aquaculture [1]. In the aquaculture industry, the cultivation of live feeds, such as microalgae, is crucial for supporting the growth and development of marine aquatic animals. Microalgae were rich in essential nutrients and serve as an important source of food for many aquaculture species, including larval stages of fish and shrimp [2, 3].

The mass cultivation of microalgae in outdoor systems is preferred for its cost-effectiveness, scalability, and ability to produce large biomass. However, success in these systems heavily relies on environmental conditions such as temperature, light, and nutrients [4]. Climate change, with rising temperatures and more frequent extreme weather, poses significant challenges, particularly in outdoor settings where conditions are less controllable. Higher temperatures may boost growth rates but also increase vulnerability to thermal stress and shifts in species composition. Unpredictable weather can further destabilize optimal growth conditions [1, 5].

Research indicates that climate change affects microalgae productivity, composition, and diversity, but most studies are lab-based, with little data on large-scale outdoor systems. Understanding how rapidly changing climates, especially in regions like Southeast Asia, impact these systems is crucial for developing strategies to sustain and improve microalgae cultivation under changing conditions.

Thailand, with its robust aquaculture industry, presents an ideal setting to study the impacts of climate change on outdoor microalgae cultivation. The country has witnessed notable climatic changes in recent years, including rising temperatures and increasingly erratic weather patterns, making it a valuable case study for this research. Understanding these dynamics in relation to microalgae cultivation could offer important insights for other regions facing similar challenges. This study aims to evaluate the impact of climate change on the mass culture of live feed microalgae under outdoor conditions in Thailand. By assessing the growth performance of three microalgae species (*Chlorella* spp., *Isochrysis galbana*, and *Chaetoceros calcitrans*) and correlating this with Geographic Information System (GIS)

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data on temperature fluctuations, the research seeks to identify key challenges and potential solutions for maintaining productivity amidst variable temperatures. The outcomes of this study are expected to inform the development of strategies to strengthen the resilience of microalgae cultivation systems against climate change. These strategies will be essential for promoting sustainable aquaculture practices and supporting the broader goal of food security in regions vulnerable to environmental shifts.

2. METHODOLOGY

2.1 Study site and data source

The study was conducted at the Klongwan Fisheries Research Station (KFRS) in Prachuap Khiri Khan Province, Thailand. Prachuap Khiri Khan Province is located in the upper southern region of Thailand, covers an area of 6,367.62 square kilometers. It is positioned between latitude 10.9º - 12.6º N and longitudes 99.2º - 100.0º E. Three species of microalgae used as live feeds, including *Chlorella*, *Isochrysis* and *Chaetoceros* were cultivated in a mass culture system under outdoor conditions in KFRS area, from 2022 to 2023 (Figure 1).

Figure 1. A map showing the location of the live feed cultivation site (11º45´19´´N, 99º47´35´´E) at the Klongwan Fisheries Research Station (KFRS), located in Prachuap Khiri Khan province, Thailand, and the cultivation tanks for mass culturing of live feeds under outdoor conditions.

The original inoculum samples of the three species of marine microalgae (the diatom strains: *Chaetoceros calcitrans*; the green microalgal strains: *Chlorella* spp.; and the flagellate strains: *Isochrysis galbana*) were obtained from the Prachuap Khiri Khan Coastal Fisheries Research and Development Center, Department of Fisheries, Thailand.

Microalgal cultures were raised in 250 mL Erlenmeyer flasks containing sterilized sea water adjusted to a salinity of 28 ppt and enriched with liquid medium, Conway medium [6], with silicate added only for the diatoms and inoculated at 10% (v/v). The temperature-controlled room was maintained at 25±1°C under a 12 h light-to-12 h darkness photoperiod (12L:12D) using cool-white fluorescent lamps at a light intensity of about 1,000 Lux. These microalgae were cultured in the Erlenmeyer flasks until the cell density reached approximately 10^6 cells/mL. Each culture was finally scaled up into 1 L glass bottles and then used for mass culture [7].

For microalgal cultivation in mass culture system, the information utilized in this assessment will be derived from KFRS's outdoor mass cultivation of each microalgae type, spanning from January 2022 to December 2023. The cultivation process began with the inoculation of microalgae obtained from laboratory cultivation into a 200 L culture tank, with an inoculum to culture water ratio of 1:25 and a water salinity of 26±1 ppt. Nutrients were added based on the specific requirements of each microalgae type [6]. The microalgae were initially cultured in a 200 L tank for approximately 3 days before being transferred to a 2,000 L fiber tank (Figure 1), where they were cultivated for an extended period under an average water salinity of 26±1 ppt. The cultivation in this tank continues for around 5-7 days, or

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until the microalgae reach the end of their life cycle (death phase), repeated this cultivation method for each microalgae type on a monthly basis.

During the cultivation, algal cell samples were collected daily for estimation of cell density (in cells/mL). Cells were fixed with 5% formalin and then counted using a hemacytometer under a compound microscope at 40X magnification [7]. Subsequently, the data was averaged and the monthly growth was summarized for further analysis and synthesis.

2.2 Data collection

The specific growth rate (μ) of each live feed was measured every month of the mass cultivation under outdoor condition, with three replicate per month during of the culture period in January 2022 to December 2023, and the temperature fluctuation (TF) was recorded from Geographic Information System (GIS) data of ©WeatherSpark.com on air temperature changes in Prachuap Khiri Khan province during the same period and analyzed. In addition, the consistent rate of change in growth with temperature or temperature coefficient (Q10) of each live feed was analyzed. The μ and Q10 were calculated using equations 1 and 2, respectively:

$$\mu = \ln N2 - \ln N1 / t2 - t1 \quad (1)$$

$$Q10 = (\mu 2/\mu 1)\ 10/T2\text{-}T1 \quad (2)$$

Where; μ = the specific growth rate (day^{-1}), N1 = the cell count at time t1 (cells/mL), N2 = the cell count at time t2 (cells/mL), t1 = the first sampling time (day), t2 = the second sampling time (day), Q10 = the temperature coefficient , μ1 = the specific growth rate at temperature T1 (day^{-1}), μ2 = the specific growth rate at temperature T2 (day^{-1}), T1 = lowest value of the highest temperature in the year (°C), T2 = maximum temperature of the year (°C), and ln indicates the Napierian logarithm.

2.3 Data analysis

The collected data were consolidated and tallied in a spreadsheet and consequently analyzed using a statistical software package. The simple mean and percentage were the main descriptive statistics used to estimate the qualitative data. In addition, the relationship between TF and μ of each species of microalgae were examined using a simple linear correlation analysis and Pearson's correlation coefficient. A probability plot was used to test for normality before performing ANOVA. All analyses were performed using the IBM SPSS Statistics for Windows software (version 21.0; IBM Corp., Armonk, NY, USA).

3. RESULTS AND DISCUSSION

Figure 2 illustrates the geographic information depicting changes in air temperature in Prachuap Khiri Khan province from January 2022 to December 2023. The synthesis of this data reveals that the average lowest temperature of the highest temperature (*l*-T) and maximum temperature (*m*-T) in 2022 were 31.0°C and 36.0°C, respectively, and in 2023, were 31.0°C and 39.0°C, respectively. The total average *l*-T and *m*-T for the two years was 31.1°C and 37.0°C, respectively.

From average TF of the year, the assessment revealed that TF directly affected the μ of each live feed. For *Chlorella* and *Isochrysis*, higher TF led to a decrease in μ, with a negative Q10 of 0.04 and 0.00, respectively, for every 0.5°C increase in TF (r^2 = 0.94 and 0.38, respectively) from 31°C. In contrast, *Chaetoceros* showed a positive correlation between TF and μ, with a Q10 of 0.07, for every 0.5°C increase in TF (r^2 = 0.97) from 31°C. An r-square (r^2) value closer to 1 indicates a stronger tendency of the growth rate (μ) to be influenced by temperature fluctuation (TF). For example, in the study, *Chlorella* and *Chaetoceros* showed r^2 values of 0.94 and 0.97, respectively, which represent strong correlations. In contrast, *Isochrysis* had an r^2 of 0.38, indicating a weaker correlation. Therefore, the tendency is best represented when r^2 is close to 1 (Figures 3 and 4).

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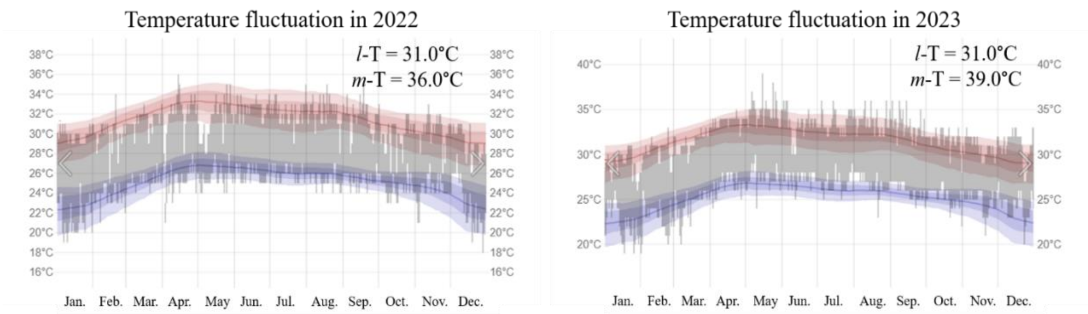

Figure 2. Annual temperature in Prachuap Khiri Khan province, Thailand (in 2022-2023); the graph illustrates the daily range of reported temperatures (gray bars), alongside the 24 h high (red bars) and low (blue bars) temperatures overlaid on the average daily high temperature values (faded red line) and daily average high and low temperature values (faded blue line), and showed average lowest temperature of the highest temperature (*l*-T) and maximum temperature (*m*-T) of the year (Data source: Adapted from geodatabase of ©WeatherSpark.com).

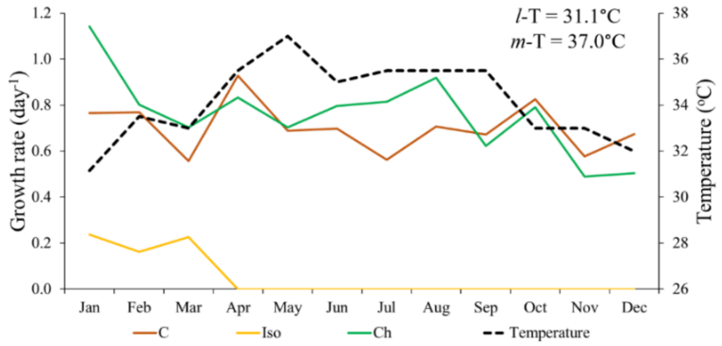

Figure 3. Average maximum temperatures fluctuation (TF) and specific growth rate (μ) of cultured three live feeds (C = *Chaetoceros calcitrans*, Iso = *Isochrysis galbana* and Ch = *Chlorella* spp.) in a mass culture system under outdoor conditions; *l*-T is lowest temperature of the highest temperature and *m*-T is maximum temperature of the year.

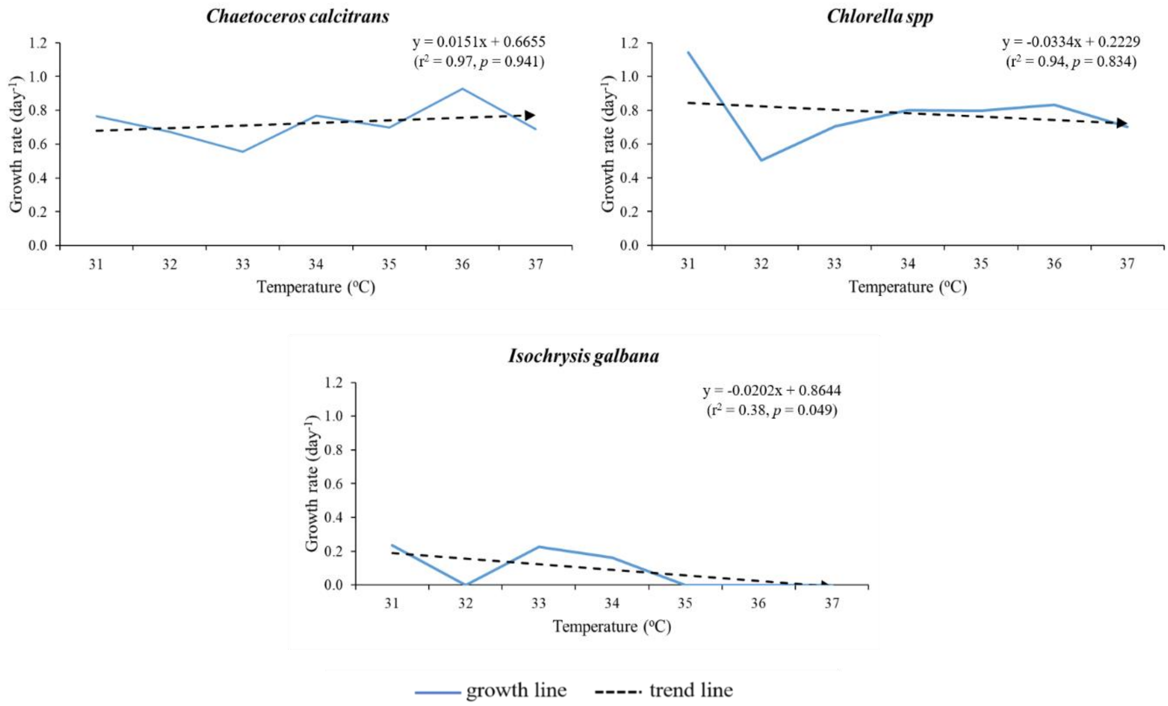

Figure 4. Correlation between maximum temperatures fluctuation (TF) and specific growth rate (μ) of each live feeds cultured in a mass culture system under outdoor conditions.

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In current study indicates that higher TF leads to decreased growth rates of *Chlorella* and *Isochrysis* used as live feed. This finding is consistent with previous studies that had shown the negative effects of temperature fluctuations on the growth and productivity of some microalgae, for example, *Chlorella vulgaris* [5, 8]. In contrast, *Chaetoceros* exhibited a positive correlation between TF and μ, suggesting that these species may be more resilient to temperature fluctuations. The ability of these species to thrive in fluctuating temperature conditions is an important factor to consider when selecting microalgae species for aquaculture systems exposed to variable environmental conditions. To mitigate the challenges posed by climate change, aquaculture practitioners can employ several strategies. Temperature-control measures, such as shading or insulation, can help stabilize water temperatures in outdoor culture systems, reducing the impact of temperature fluctuations on microalgae growth [9-11]. Selecting temperature-tolerant strains of microalgae, can also enhance the resilience of culture systems to temperature changes [12, 13], such as from this study, *Chaetoceros calcitrans* had the resilience of mass culture system under outdoor conditions to temperature changes than *Chlorella* spp. and *Isochrysis galbana*.

Additionally, the use of GIS data to analyze air temperature changes in the cultivation area provides valuable insights into the local climate dynamics and its effects on microalgae cultivation. By incorporating GIS data into culture management practices, practitioners can make informed decisions about site selection and microalgae species selection, ensuring the sustainability of live feeds cultivation operation in the face of climate change. Previous studies had demonstrated the extensive application of GIS in aquaculture, highlighting their ability to enhance efficiency in farming and production [14]. GIS can also play a crucial role in identifying strategies to mitigate or resolve issues stemming from climate change, which were anticipated to impact aquatic animals significantly [15].

Overall, this study demonstrates the importance of understanding the impact of climate change on microalgae cultivation and developing strategies to mitigate its negative effects. By implementing temperature-control measures and selecting temperature-tolerant strains of microalgae, aquaculture practitioners can enhance the resilience of their operations to climate change, ensuring a stable supply of live feed for marine aquatic animals.

4. CONCLUSIONS

This study emphasizes the significant impact of climate change, especially temperature fluctuations, on the mass cultivation of live feed microalgae in outdoor systems. The inverse relationship between temperature fluctuations and the specific growth rate of *Chlorella* spp. and *Isochrysis galbana* highlights the susceptibility of these species to temperature changes. Conversely, *Chaetoceros calcitrans* demonstrated a positive relationship, suggesting their potential resilience to temperature fluctuations. Understanding and addressing the effects of climate change on live feed cultivation are vital for aquaculture practitioners, as this knowledge can greatly contribute to the aquaculture industry's sustainability in the face of a climate change.

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Impact of Rising Air Temperatures on the Growth and Water Quality of Blue swimming Crab (*Portunus pelagicus*) Culture in Grow-Out Ponds: A Comparative Study of 2022 and 2023

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ABSTRACT

This study examined the effects of increased air temperatures on the growth and water quality of blue swimming crabs (BSC), *Portunus pelagicus*, cultured in grow-out ponds in Prachuap Khiri Khan province, Thailand, over the years 2022 and 2023. Geographic data indicated that the average lowest temperature and maximum temperature in 2022 were 31.0°C and 36.0°C, respectively, while these values increased to 31.0°C and 39.0°C in 2023. Consequently, the average maximum temperature fluctuation increased from 33.5°C in 2022 to 35.0°C in 2023. Analysis of BSC culture across five batches per year (n = 5) revealed no significant differences in initial carapace width (CL) and body weight (BW) between 2022 and 2023. However, at 90 days of cultivation, BSC in 2023 showed a significantly ($p<0.05$) lower mean BW (52.66±1.45 g) compared to 2022 (61.55±5.50 g), while CL remained statistically similar between the years. Additionally, the mean specific growth rate was lower in 2023 (6.25±0.03%/day) compared to 2022 (6.48±0.10%/day) ($p<0.05$). These findings suggest that BSC growth in 2023 was adversely affected by higher temperatures, likely due to climate change. Increased temperatures also led to variations in average water quality parameters, with higher salinity (35.40±1.19 psu) and water temperature (32.19±1.83°C) observed in 2023 (34.09±1.75 psu, and 31.13±2.05°C in 2022) ($p<0.05$). However, parameters such as pH, dissolved oxygen, total ammonia, nitrite, and alkalinity did not exhibit consistent changes in response to increased temperature fluctuation. This study underscores the need for adaptive management strategies to mitigate the impacts of climate change on aquaculture systems.

Keyword: Climate change/ Blue swimming crab culture/ *Portunus pelagicus*/ Temperature fluctuations/ Water quality

1. INTRODUCTION

Climate change was identified as one of the most pressing global challenges of the 21st century, with rising temperatures being a central concern. The increase in global average temperatures due to greenhouse gas emissions had far-reaching implications for various ecosystems and industries, including aquaculture [1]. Aquaculture, the farming of aquatic organisms such as fish, crustaceans, and mollusks, was particularly sensitive to changes in environmental conditions. Temperature fluctuations (TF) profoundly affected the growth, health, and productivity of aquatic species, leading to significant economic and ecological consequences [2, 3].

The blue swimming crab (*Portunus pelagicus* Linnaeus 1758), in this paper is referred to as BSC, was a key commercial species found in the coastal waters of tropical regions spanning the western Indian Ocean and eastern Pacific [4]. In 2020, fishery trends showed that BSC catches remained at their highest levels [2]. Notably, the demand for seafood increased while natural marine resources decreased due to overexploitation and habitat destruction, with the BSC being one of the species under threat in many Asian countries [5]. Developing culture methods for BSC represented a promising long-term solution to this issue. As a result, considerable research focused on BSC culture and related topics [6-9].

The growth of aquatic animals was profoundly influenced by various environmental factors, including temperature [3, 10]. The previous study confirmed that temperature had a direct impact on the growth of BSC, with the optimal reared temperature range as 28-31°C [6-9]. However, repeated studies on the effects of temperature previously reported were necessary, particularly studies conducted in grow-out pond conditions where environmental factors cannot be controlled as precisely as

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in laboratory settings. Specifically, the impact of TF on BSC rearing and the effects on other environmental factors, such as salinity changes during rearing, need further investigation. There are several reasons to study and confirm the effects of TF in field grow-out pond conditions. Firstly, to verify the consistency of previous findings under different study conditions. Secondly, to improve rearing methods, such as pond management practices, to optimize outcomes. Thirdly, testing under varying environmental conditions, such as annual TF, will provide a more comprehensive understanding of the impacts. Lastly, expanding the knowledge base through repeated studies will contribute to the better development of BSC rearing in field grow-out pond conditions.

Climate change, characterized by rising temperatures and unpredictable weather patterns, may impact BSC cultivation in pond systems over the long term. The aims of this study were to evaluated the effects of climate change, particularly increasing air temperatures, on the growth and water quality of BSC cultivation in grow-out pond. The research involved analyzing data from BSC reared in earthen ponds and correlating it with Geographic Information System (GIS) data on regional air temperature fluctuations. The knowledge gained from this study will be used as a basis for developing strategies to enhance the resilience of BSC culture in grow-out pond against the impacts of climate change.

2. METHODOLOGY

2.1 Study site and data source

The study was conducted at the Klongwan Fisheries Research Station (KFRS) in Prachuap Khiri Khan province, Thailand. Prachuap Khiri Khan province is located in the upper southern region of Thailand, covers an area of 6,367.62 square kilometers. It is positioned between latitude 10.9º - 12.6º N and longitudes 99.2º - 100.0º E (Figure 1).

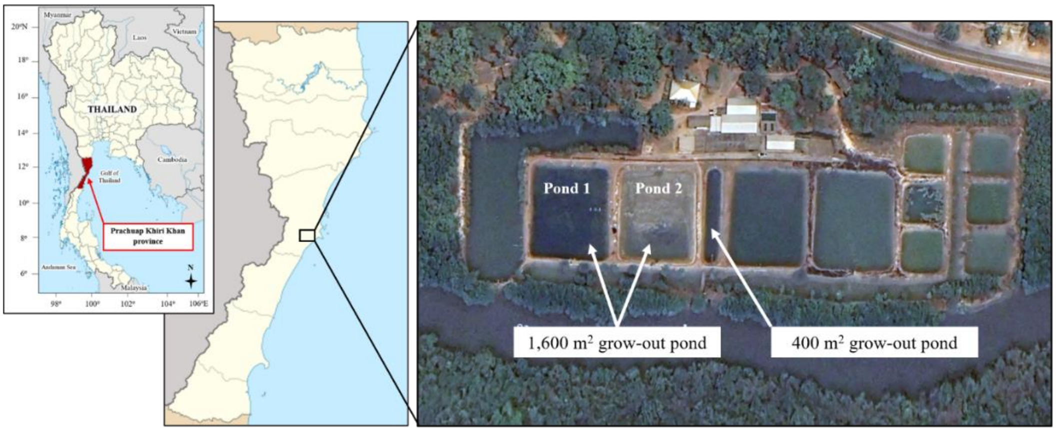

Figure 1. A map showing the location of the blue swimming crab (*Portunus pelagicus*) culture site (11º45´19´´N, 99º47´35´´E) at the Klongwan Fisheries Research Station (KFRS), located in Prachuap Khiri Khan province, Thailand, and the grow-out ponds of crab culture of this study.

The juvenile BSC, with a carapace width of approximately 1 cm or around 40-45 days post-hatch, were sourced from the KFRS hatchery and stocked into earthen ponds at a density of 3 crabs/m^2. The ponds included one 400 m^2 pond and two 1,600 m^2 ponds. Each year, crabs were reared in three batches in the 1,600 m^2 ponds and two batches in the 400 m^2 pond (five batches per year, n = 5). Each batch was cultured for 150 days to produce broodstock for academic purposes and KFRS's CSR activities.

The BSC was fed artificial shrimp feed as outlined by Oniam et al. [11]. During the first 30 days of the 120-day culture period, BSC was fed shrimp feed No. 2 (STARTEQC™, pellet size 0.8-1 mm, 38% protein) at a rate of 30% of body weight per day. From days 31 to 60, they were fed shrimp feed No. 4S (STARTEQC™, pellet size 3.5 mm, 38% protein) at 5% of body weight per day. After day 60,

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the feed was adjusted to 3% of body weight per day. Feeding occurred twice daily at 9:00 a.m. and 5:00 p.m.

During the culture of each batch of BSC, the water in the grow-out ponds was changed weekly, with approximately 30% of the water replaced each time. Additionally, water quality parameters were assessed twice a week at 6:00 a.m. and 2:00 p.m. These parameters included salinity, pH, dissolved oxygen concentration (DO), temperature, total ammonia, nitrite, and alkalinity, which were measured using analytical instruments and standard methods from APHA, AWWA, and WEF [12].

2.2 Data collection

Specific growth rate (SGR) of the BSC was evaluated at the 90-day culture mark by sampling 30 crabs per batch from each grow-out pond, with five batches per year from January 2022 to December 2023. The TF was recorded using Geographic Information System (GIS) data from©WeatherSpark.com on air temperature changes in Prachuap Khiri Khan Province during the same period and were subsequently analyzed. The SGR was calculated [8], using equations:

$$\text{SGR (\%/day)} = 100 \times [\ln \text{(final body weight)} - \ln \text{(initial body weight)}] / \text{culture period}$$

2.3 Data analysis

The collected data were consolidated and tallied in a spreadsheet. The data were then analyzed using a statistical software package. Variance was evaluated for the BSC growth and water quality data in grow-out ponds before conducting further statistical tests. Levene's test was used to assess the homogeneity of variances. Independent-sample t-tests were then performed to analyze differences in means for carapace width, body weight, SGR, and each water quality parameter between the years 2022 and 2023. All analyses were conducted at a 95% confidence level. The data were analyzed using IBM SPSS Statistics for Windows software (version 21.0; IBM Corp.; Armonk, NY, USA).

3. RESULTS AND DISCUSSION

The geographic data showed the changes in air temperature in Prachuap Khiri Khan province from January 2022 to December 2023, as shown in Figure 2. Analysis of this data indicated that the average lowest temperature of the highest temperature (*l*-T) and the maximum temperature (*m*-T) in 2022 were 31.0°C and 36.0°C, respectively. In 2023, these values increased to 31.0°C and 39.0°C, respectively. Overall, the average maximum temperature fluctuation (TF) in 2022 was 33.5°C, which was lower compared to the average maximum TF of 35.0°C recorded in 2023.

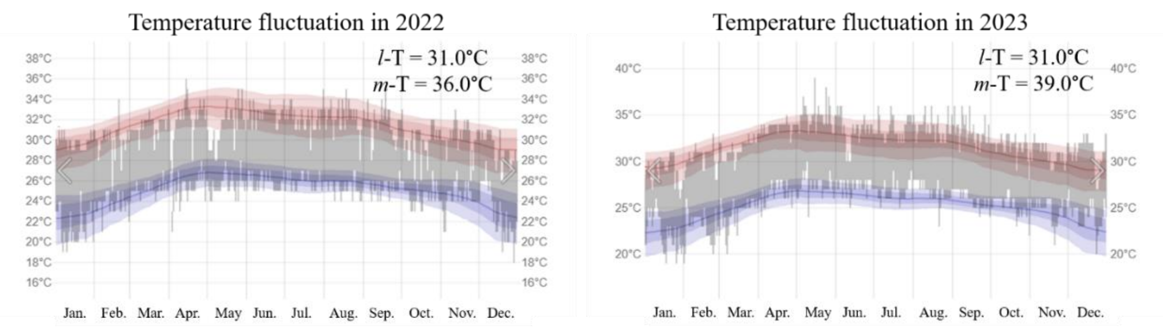

Figure 2. Annual temperature in Prachuap Khiri Khan province, Thailand (in 2022-2023); the graph illustrates the daily range of reported temperatures (gray bars), alongside the 24 h high (red bars) and low (blue bars) temperatures overlaid on the average daily high temperature values (faded red line) and daily average high and low temperature values (faded blue line), and showed average lowest temperature of the highest temperature (*l*-T) and maximum temperature (*m*-T) of the year (Data source: Adapted from geodatabase of ©WeatherSpark.com).

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From the synthesis and analysis of data on BSC culture in grow-out ponds, it was found that in 2022, the BSC had an initial carapace width of 1.08±0.23 cm and an initial body weight of 0.18±0.04 g. In 2023, an initial width and weight were 1.12±0.31 cm and 0.19±0.06 g, respectively. The mean initial size of the BSC released into the ponds were not significantly different (p>0.05). At 90 days of cultivation, BSC in 2023 had a lower body weight (p<0.05) compared to those from 2022, while the carapace width of BSC showed no significant difference (p>0.05) between the years. In addition, the BSC reared in 2023 had a lower mean SGR (p<0.05) than in 2022 (Table 1). This indicated that BSC reared in grow-out ponds in 2023 exhibited decreased growth compared to those in 2022, likely due to the effects of climate change during that year.

Table 1. Carapace width, body weight, and specific growth rate (SGR) of blue swimming crab (*Portunus pelagicus*) cultured in grow-out ponds in 2022 and 2023, for 90 days of the cultivation (mean ± SD).

Traits	Cultivation period (n = 5)		P-value
	In 2022	In 2023	
Initial carapace width (cm)	1.08±0.23[a]	1.12±0.31[a]	0.865
Initial body weight (g)	0.18±0.04[a]	0.19±0.06[a]	0.814
Final carapace width (cm)	8.72±0.58[a]	8.74±0.22[a]	0.893
Final body weight (g)	61.55±5.50[a]	52.66±1.45[b]	0.020
SGR (%/day)	6.48±0.10[a]	6.25±0.03[b]	0.026

Note: Means within a row with different superscripts are significantly different (p<0.05).

Furthermore, the increase in temperatures resulted in variations in the mean water quality parameters in the grow-out ponds between 2022 and 2023. Specifically, both mean salinity and water temperature exhibited an upward trend with increasing TF. Salinity increased from 34.09±1.75 psu in 2022 to 35.40±1.19 psu in 2023 (p<0.05), while water temperature increased from 31.13±2.05°C in 2022 to 32.19±1.83°C in 2023 (p<0.05). However, other water quality parameters, including pH, DO, total ammonia, nitrite, and alkalinity, did not show significant differences between the years and did not exhibit consistent trends in response to the increase in TF (Figure 3).

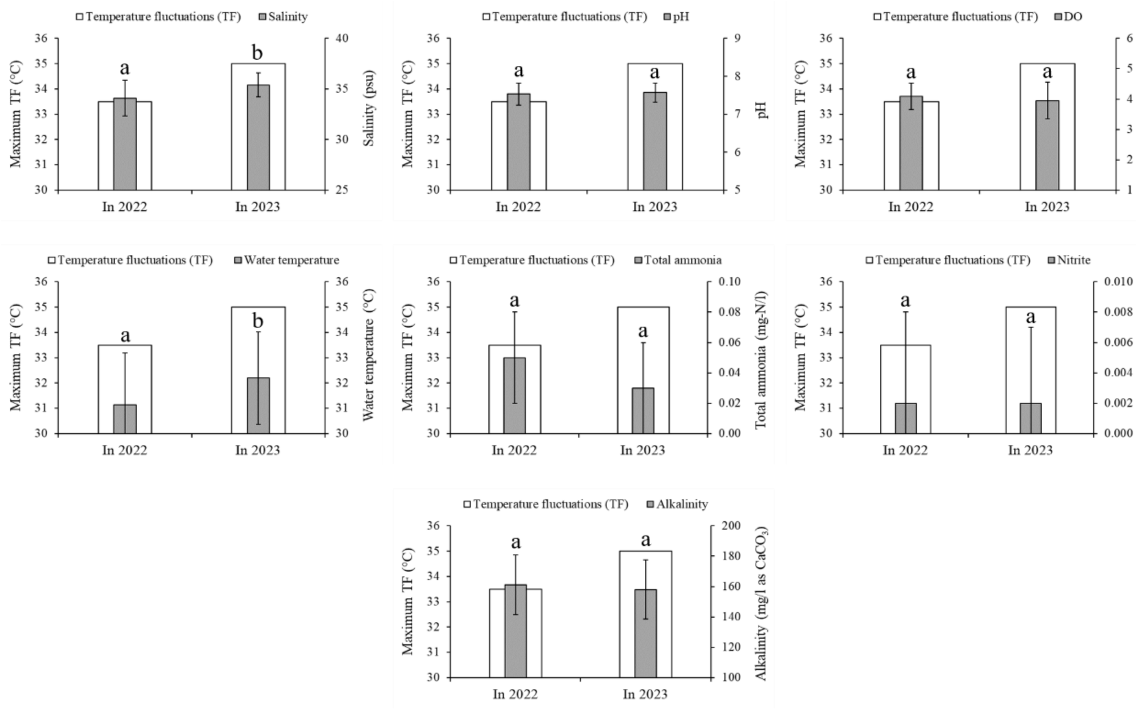

Figure 3. Trends in water quality changes in blue swimming crab (*Portunus pelagicus*) ponds in relation to climate warming from 2022 to 2023. Different lowercase letters above bars indicate significant (p<0.05) differences between 2022 and 2023. Error bars indicate SD.

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The impact of temperature on aquaculture had been extensively studied, with various research efforts focusing on how different temperature regimes affected aquatic species. The current study found that higher water temperatures negatively affected the growth of BSC, with the SGR of crabs showed a tendency to decline in warmer climates. Temperature played a crucial role in the culture of BSC, with optimal growth and health of this crab being highly dependent on maintaining suitable water temperatures of 28-31°C [6-9]. Temperature had a direct impact on the development and growth of BSC. Variations in temperature influenced the crab's feeding behavior; as temperatures rose, the crab's metabolism increased, leading to a higher demand for energy in the form of food. However, when the temperature exceeded the optimal range for BSC culture, it adversely affected growth. The growth rate declined as the crab expended energy to cope with the elevated temperatures, leaving less energy available for growth. Conversely, when temperatures dropped, the crab's metabolism decreased, reducing its food intake and slowing its growth [13, 14]. This temperature-related impact on growth was also observed in other crustaceans, such as white shrimp, *Litopenaeus vannamei* [15] and mud crab, *Scylla paramamosain* [16].

The increase in mean global temperature resulting from climate change and atmospheric warming subjected all organisms to potential thermal stress [17]. In aquaculture systems, climate change profoundly impacted operations by altering water temperature, salinity, and oxygen levels. Temperature changes influenced various critical factors, including metabolic rates, feeding behavior, disease dynamics, and the overall growth performance of cultured species [1, 18-20]. In the current study, it was found that although the average temperature in 2023 led to a significant increase in salinity level compared to 2022, the salinity remained within a tolerable range of 25-35 psu for the BSC cultivation, which did not impact its growth [6-9]. Additionally, other water quality parameters, such as pH, DO, total ammonia, nitrite, and alkalinity, were not significantly affected by the elevated temperatures and remained at levels that did not influence BSC growth [6-9]. Therefore, the reduction in BSC growth rates observed in 2023, compared to 2022, was attributed to the increase in the average maximum temperature, which was 1.5°C higher than in the previous year.

Higher temperatures were found to accelerate metabolic rates, increasing food consumption and growth in some species, such as shrimp and tilapia, while also raising oxygen demand and stress levels, which compromised health and survival. Moderate temperature increases enhanced growth and productivity, but excessive temperatures induced thermal stress, reduced oxygen levels, and heightened disease susceptibility, particularly in species with narrow temperature tolerance ranges, leading to significant declines in growth rate [1, 3, 21], as observed in this study. A comprehensive review by Thirukanthan et al. [19] highlighted the critical role of temperature management in marine crab aquaculture systems, emphasizing the necessity for advanced monitoring technologies and adaptive management practices to sustain optimal conditions for cultured species. Similarly, Azra et al. [20] reported that increased water temperatures significantly impacted the reproduction and development of brachyuran crabs, leading to reductions in growth, thermal resistance, maturation, spawning, and embryonic development. Additionally, Collins et al. [21] examined the economic implications of temperature changes, noting that rising temperatures could lead to increased production costs and reduced profitability due to associated challenges. Therefore, careful temperature management is essential to optimize growth performance and ensure the sustainability of BSC culture.

To address the challenges posed by climate change, aquaculture practitioners employed various strategies. Temperature-control measures, such as shading or insulation, were used to stabilize water temperatures in outdoor culture systems, reducing the impact of temperature fluctuations on aquatic animal growth, or the use of greenhouse concepts for cultivation was explored to further mitigate temperature-related issues [22, 23]. Additionally, the use of GIS data to analyze air temperature changes in cultivation areas provided valuable insights into local climate dynamics and their effects on aquatic animals. Integrating GIS data into culture management allowed for informed decisions on site and species selection, thus enhancing the sustainability of aquaculture operations amid climate change. Previous studies demonstrated that GIS significantly improves farming efficiency and helps develop

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strategies to address climate change impacts on aquatic species [24]. Studies indicated that incorporating climate projections into aquaculture planning and management can help mitigate these risks.

Overall, while some studies had indicated potential benefits of higher temperatures, such as accelerated growth, the primary concern remains the adverse effects of extreme temperature fluctuations. Future efforts should focus on developing temperature-resilient strains and implementing effective temperature control measures to mitigate these effects. Adaptation strategies will be crucial for sustaining aquaculture practices amid the challenges posed by climate change.

4. CONCLUSIONS

Based on data analysis in this study. Some conclusions were drawn as follows:

1. The study was conducted to analyze the impact of air temperature changes in Prachuap Khiri Khan province on the cultivation of blue swimming crab in grow-out ponds during 2022 and 2023. Geographic data indicated a temperature increased, with the average maximum temperature recorded at 36.0°C in 2022, which increased to 39.0°C in 2023. This temperature increase resulted in the average maximum temperature fluctuation rising from 33.5°C in 2022 to 35.0°C in 2023.

2. The analysis of crab cultivation data indicated that crab reared in 2023 exhibited lower mean body weight and specific growth rate compared to those reared in 2022, likely due to the effects of climate change during that year.

3. In terms of water quality, both mean salinity and water temperature showed an upward trend in 2023. However, other water quality parameters, including pH, dissolved oxygen, total ammonia, nitrite, and alkalinity, did not exhibit significant differences between 2022 and 2023.

4. Recommendations for future research, considering the impact of temperature changes on crab growth in grow-out ponds, it is recommended that future studies focus on improving cultivation methods to mitigate the effects of climate change. Additionally, further research on water conditioning techniques to maintain optimal water quality for crab growth under increasingly extreme temperature fluctuations is advised.

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Effect of Non-Thermal Plasma on Post-Harvest Quality of Tomato

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ABSTRACT

The goal of this experiment is to study the effect of NTP on the shelf life and quality of tomato. A new method of food preservation that is environmentally friendly is provided by NTP, a fourth state of matter that uses ionized gasses to destroy bacteria on fresh produce. There are two stages to the experiment. During the first stage, tomatoes are treated with NTP at different power levels and times: 5 kv 1 min, 5 kv 2 min, 5 kv 5 min,15 kv 5 min, 15 kv 10 min and 20 kv 5 min. Then, to determine the ideal power level and time for plasma treatment, 56 tomatoes are analyzed visually and by using colorimeter.In the second phase, destructive and non-destructive analyses are conducted using the selected power level and time from the first phase. In both the control and treatment groups, the non-destructive analyses include disease incidence, taking pictures, color changes and the destructive analysis includes Total soluble solids (TSS), firmness, pH, total lycopene content, and total phenol content.

Keyword: Non- thermal plasma/ Shelf life/ Tomato quality/ Food preservation

1. INTRODUCTION

Due to its distinct flavor, vivid color, and abundance of antioxidants such as lycopene, carotenoids, and chlorophyll, tomatoes are a favorite food in many countries. But as the storage period is extended, the high moisture content and respiration of postharvest tomatoes reduce their chlorophyll concentration and physical quality, causing the tomatoes to soften and turn red and causing financial losses. Traditional chemical preservatives can extend the shelf life of postharvest tomatoes, but they have little effect on tomatoes' ability to turn red, and their residue poses a risk to food safety [3].

The mechanisms of NTP technology used for microbial inactivation, is vital for extending the shelf life of fruits and vegetables. Reactive oxygen and nitrogen species (ROS and RNS), including hydroxyl radicals, nitric oxide, and ozone, are produced by NTP by ionizing air or gases that include oxygen [4].

DBD is generated by applying high voltage AC across the electrode, then ionization of the gas occurs in between the electrode which generates NTP near dielectric barrier [2]. In this experiment the tomato is indirectly exposed to the NTP. During indirect exposure the target is positioned away from the plasma discharge, as opposed to having plasma applied directly to the food items. This configuration makes sure that only reactive species with longer life cycles get to the target [10].

2. METHODOLOGY

Mid-ripe 56 tomato is used for this experiment. There are 6 treatment group with 5 kv 1 min, 5 kv 2 min, 5 kv 5 min, 15 kv 5 min, 20 kv 5 min, 15 kv 10 min and a control group (C) with each group having 4 replicates with 2 tomatoes on each replicate. In this experiment, argon was used as the working gas for all treatment group. The color of tomato was measured using colorimeter on day 0, 7, 14, 21, 28, 35, 46, 53, 60, and 67. The disease incidence and photo was clicked on day 0, 7, 14, 21, 28, 35, 46, 53, 60, 67, and 72. The average temperature and humidity were recorded using a data logger, with the temperature being 29.18°C and the relative humidity 93.83%. The result from this analysis is used to select appropriate power level and time for the main experiment.

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2.1 Disease incidence

Fungal growth symptoms on the fruit's surface were observed visually using a scale [9]. The percentage of DI was formulated using the following equation:

$$\text{Diseaseincidence (\%)} = \frac{\sum \text{(DI scale} \times \text{Number o f tomato fruit at the DI level)}}{\text{Total number o f tomato f ruit in the treatment} \times \text{The highest score (5)}} \times 100$$

2.2 Fruit marketability

The marketable tomato is given score 1 while the non-marketable are given 0. The marketability is analyzed using the formula [1]:

$$\text{Percentage marketability} = \frac{\text{Number of marketable fruits}}{\text{Total number of fruits}} \times 100$$

2.3 Color analysis

All fruit samples were allowed to ripen and monitored by taking optical measurements to track the progress of the color change. Color measurements will be taken using a MiniScan XE PLUS colorimeter at three positions per side (head, middle, and tip). Calibration of the colorimeter is important [7].

3. RESULTS AND DISCUSSION

3.1 Disease incidence

The treatments 15 kv 10 min and 20 kv 5 min are the most effective in reducing disease incidence in tomatoes, whereas the control samples and 15 kv 5 min have the highest disease incidence. The 20 kv 5 min treatment shows a mean disease incidence of 8.86%, which is comparable to the 15 kv 10 min treatment's lower value of 3.18%.

Table 1. LSD Test for disease incidence (%) comparing control and treatment groups (showing only significant comparisons $p < 0.05$)

Comparison	Mean difference	Std. error	Sig. (p-value)	95% Confidence interval
CONTROL vs. 15 kv 10 min	16.1364*	6.75	0.02	2.67 to 29.6
5 kv 5 min vs. 15 kv 5 min	-15.2273*	6.75	0.03	-28.7 to -1.76
15 kv 5 min vs. 20 kv 5 min	16.1364*	6.75	0.02	2.67 to 29.6
15 kv 5 min vs. 15 kv 10 min	21.8182*	6.75	0.00	8.36 to 35.3
15 kv 10 min vs. 5 kv 2 min	-14.3182*	6.75	0.04	-27.8 to -0.86

(* indicates significance at $p < 0.05$)

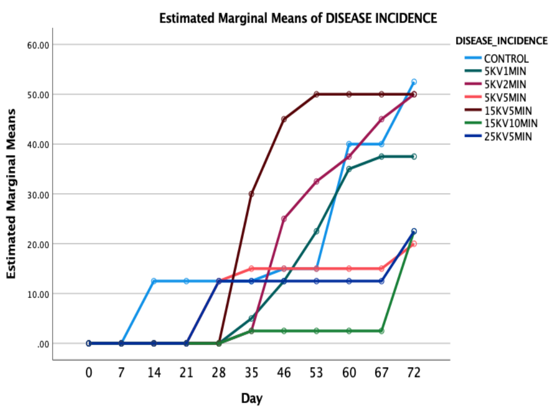

Figure 1. Disease incidence on tomato over 72 days

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The fungal growth was detected in tomatoes of both treatment and control group. The limited fungal growth on the higher voltage 20 kv could be due to the antifungal effects of plasma. According to a study in 2023, Reactive oxygen species (ROS) and Reactive nitrogen species (RNS) are the primary chemicals that give NTP its antifungal properties. The main sterol of the fungus cytoplasmic membrane, ergosterol, is essential for preserving the integrity of the cell. NTP lowers the concentration of ergosterol, which inhibits the growth and spread of fungus [8]. During plasma operation, the degree of microbial inactivation rises with increasing input power. High input voltage and frequency improve NTP microbial inactivation efficiency. The length of treatment is one of the key variables affecting how well plasma processing works. The efficiency of NTP can be affected by the type of gas used, how it is exposed, how the generator is set up, and the working environment. Noble gases such as argon cause bacterial cell death due to their high thermal conductivity and UV emission spectrum [5]. In the control group, one tomato showed signs of insect growth, while none of the tomatoes in the plasma-treated groups showed any signs of insect growth. This suggest that the plasma treatment may have prevented insect growth on the tomatoes.

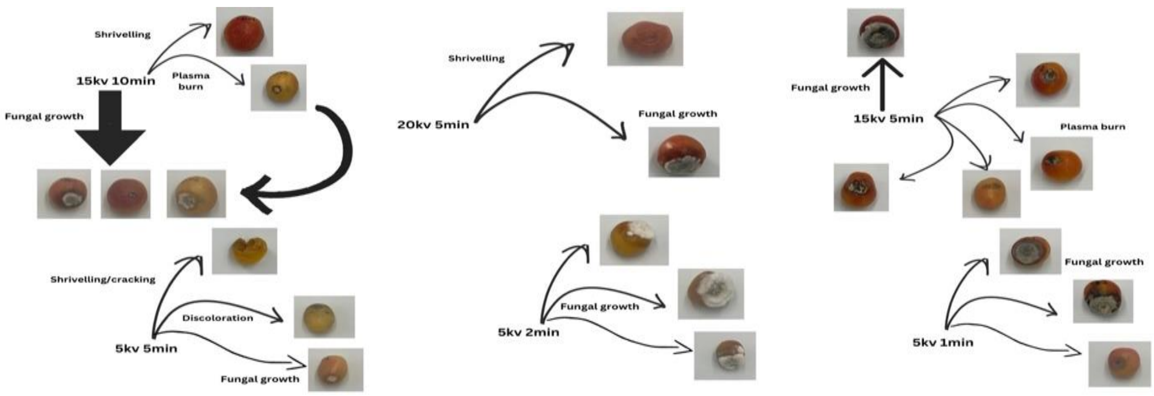

Figure 2. Effects of NTP treatment on tomato disease incidence and marketability over 72 days. Discoloration (not indicative of disease) is shown alongside symptoms of disease incidence (fungal growth, shriveling) and plasma-induced burns affecting marketability. Treatments: 5 kv/1 min, 5 kv/2 min, 5 kv/5 min, 15 kv/5 min, 15 kv/10 min, and 20 kv/5 min.

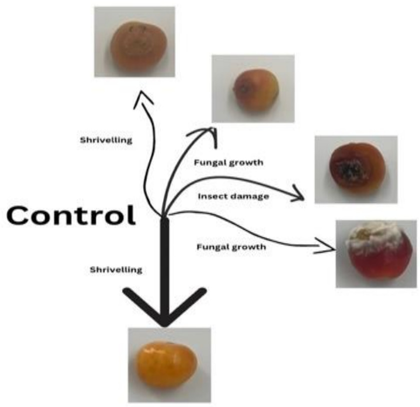

Figure 3. Visual representation of fungal growth, insect damage and shriveling in Control group.

3.2 Fruit Marketability

The marketability of all treatment group and control sample was 100 % on day 0 expect 15 kv 5 min with 87.5% due to visible plasma burn. The treatment group 20 kv 5 min has shown the highest marketability over time.

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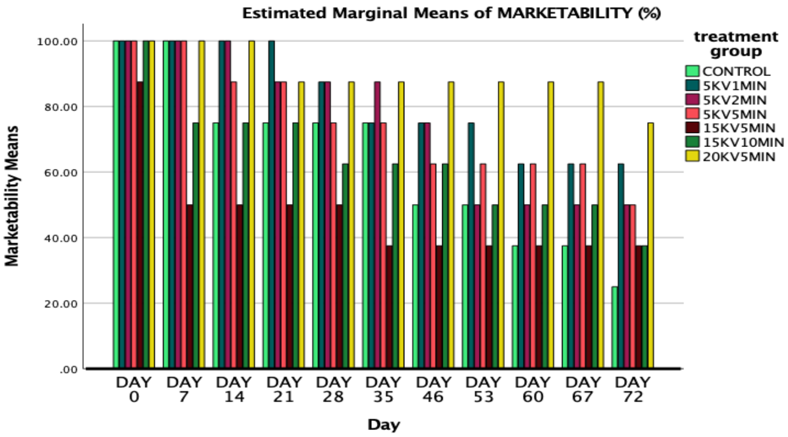

Figure 4. Estimated marginal means of marketability across 72 days

The tomatoes in the 15 kv treatments had visible plasma burns while the tomatoes in the 20 kv and 5 kv treatments did not show this type of damage. The reason for it can be the interaction between reactive species produced at varying power levels and treatment times. Higher plasma voltages have a capacity to produce more reactive oxygen species (ROS), which may increase oxidative stress and damage cell structure, which can result in burns [3]. The absence of burn in the higher concentration of 20kv could be due to having less reactive species concentration over time.

Table 2. Marketability of tomatoes at day 0 and day 72 across different treatments

Treatment	Day 0 (%)	Day 72 (%)
CONTROL	100	25
5 kv 1 min	100	62.5
5 kv 2 min	100	50
5 kv 5 min	100	50
15 kv 5 min	87.5	37.5
15 kv 10 min	100	37.5
20 kv 5 min	100	75

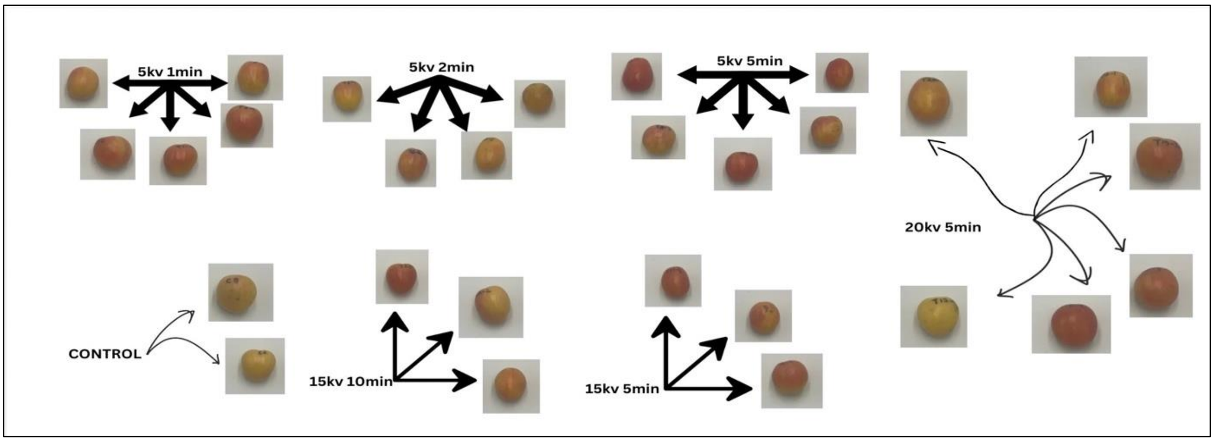

Figure 5. Marketable tomatoes from all cold plasma-treated groups and untreated control group at 72 days.

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3.3 Color analysis (chroma and hue angle)

The Tukey HSD comparisons indicate that no treatment pairs have statistically significant differences in chroma (all p-values are > 0.05). The control sample has the lowest chroma mean at 26.4541.

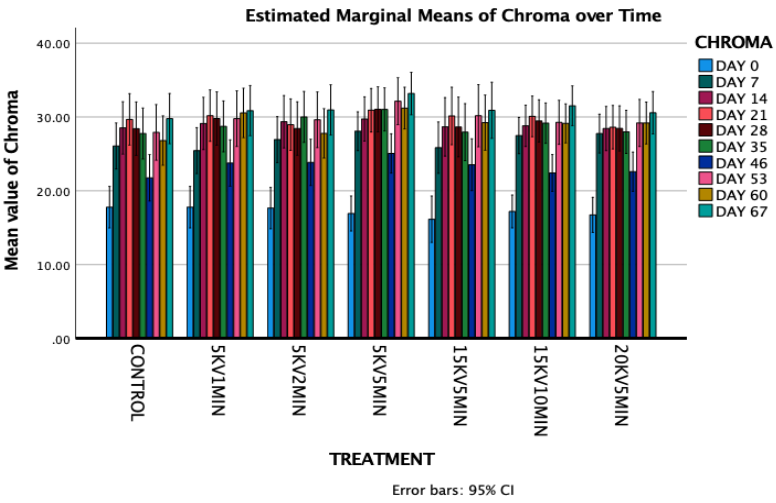

Figure 6. Chroma changes over time for different treatments

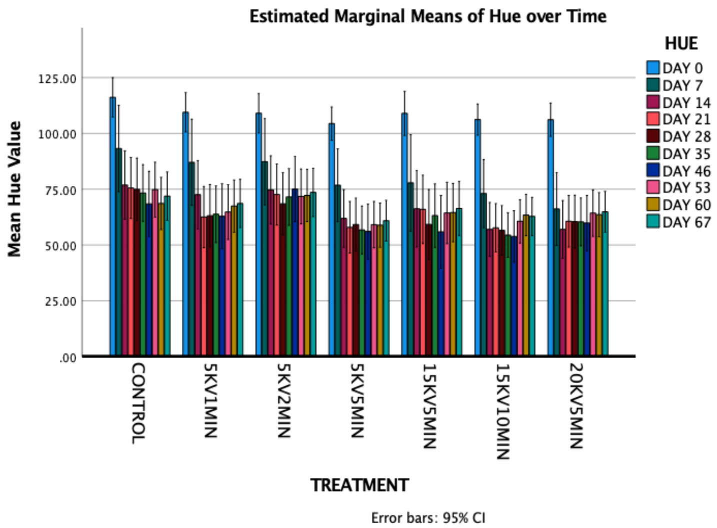

Figure 7. Hue changes over time for different treatments

At the beginning, every tomato in every treatment had a high hue value over 100. Based on the LSD post-hoc test results, there are no statistically significant differences between most treatment pairs for hue changes, given that all the p-values are above 0.05.

The color analysis showed the treatment group and control group's chroma and hue values did not differ significantly ($p > 0.05$). This result is similar with previous study, which found that cherry tomatoes treated with DBD in-package ambient pressure showed only slight changes in color [6]. According to the study conducted in 2016 [11], the L*, a*, and b* values of tomatoes treated with NTP did not show any significant changes. Moreover, there were no noticeable alterations in the tomatoes' color.

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4. CONCLUSIONS

In conclusion, while the NTP treatments influence the disease incidence of tomato, but it doesn't have a strong impact on the hue angle and chroma of the tomatoes. For the main experiment, 20KV 5MIN is selected because it offers effective disease incidence control and have no plasma burn and requires significantly less time. Due to this, it is the best option for industrial applications where speed and throughput are crucial.

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Abstract
Oral Presentation

Toward Net-Zero: Green Industry Prospects and Carbon Neutrality in Southeast Asia

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ABSTRACT

In recent years, extreme weather and natural disasters have occurred frequently, such as heat waves and wildfires sweeping the northern hemisphere these years, rare heavy rainstorms and snowstorms also taking place. These phenomena are generally attributed to global warming, which has achieved a broad global consensus in both mainstream academia and politics, and this consensus has been reflected in the strategic decisions of major Western countries and multinational enterprises. The Inflation Reduction Act passed by the United States last year is regarded as the most important climate legislation in the history of the United States, which is pointing out the direction for addressing climate change and the development of green and low-carbon industry, capital and other aspects. The EU's "carbon border adjustment mechanism" has also officially become an EU law last year, making the EU become the first economy to impose "carbon tariffs", which also make carbon truly become an important market element that is similar to technology, manpower, capital, etc.

However, three years of the epidemic have plunged the global economy into a quagmire, coupled with the sharp fluctuations in energy and resource prices caused by the Russian-Ukrainian war, and the global supply chain disorder caused between China and American, the key words of 'green' and 'low-carbon' were rarely taking place in press or social medias, and governments and enterprises around the world have turned their attention to the more urgent short-term crisis. In other words, although the process of global green and low- carbon transformation has indeed been delayed, this general trend is irreversible in terms of the national strategy of the world's major economies and the development direction of the world's leading enterprises in various industries.

In South East Asia, what are the opportunities for countries to grow in green and low-carbon industry? How to apply some sustainable strategies into the countries and companies to reach the great ESG standards? We will discuss more about them from the company aspects, which is related to their company strategy shifting impact in the green area.

Keyword: Global warming/ Green industry/ Low carbon/ Sustainability/ Climate legislation

1. INTRODUCTION

Country	Carbon Emissions (tons/person)	GDP per Capita (current US$)	Year
Indonesia	6.8	4,150	2023
Philippines	2.1	3,900	2023
Vietnam	4.5	3,500	2023
Thailand	3.2	7,200	2023
Malaysia	7.1	12,500	2023
Myanmar	0.9	1,300	2023

References: Global Carbon Atlas. (2023). Carbon emissions by country. Retrieved from Global Carbon Atlas World Bank. (2023). GDP per capita (current US$). Retrieved from World Bank Data

This table summarizes the relationship between carbon emissions and GDP per capita for various ASEAN countries, providing a clear view of the need for further development and carbon management strategies.

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1.1 Adapting carbon reduction strategies: Lessons for ASEAN countries from western practices

In considering carbon reduction strategies, ASEAN countries should be cautious about adopting the immediate restrictions on high-energy-consuming industries, such as coal-fired power plants and steel manufacturing, as seen in Western nations. This is because financial institutions may withdraw loans from such industries, potentially leading to job losses and economic setbacks. For instance, Germany's energy transition, known as the Energiewende, involved a phased closure of coal-fired power plants and a significant push towards renewable energy sources. While this strategy has contributed to substantial reductions in carbon emissions, it has also resulted in short-term increases in energy costs and economic fluctuations (Wettengel, 2021).

Moreover, the impact of financial institutions' lending practices on high-energy industries underscores the need for careful consideration. In the UK, for example, banks imposed loan restrictions on high-pollution enterprises in 2019, which led to reduced production and job losses, highlighting the economic disruptions such measures can cause (Smith, 2020). ASEAN countries, if they were to implement similar policies without adequate preparation, could face analogous challenges, impacting economic stability and social welfare.

The structure of energy consumption also plays a crucial role. In India, despite a gradual increase in renewable energy sources, coal-fired power remains a dominant and stable energy source due to its reliability and cost-effectiveness. A sudden restriction on coal power could destabilize electricity supply and increase overall energy costs, as renewable energy infrastructure involves higher initial costs (Kumar, 2019). This suggests that a sudden shift could adversely affect both the economy and the public.

Furthermore, the rapid growth of ESG (Environmental, Social, and Governance) assets without corresponding support from the real economy can pose systemic financial risks. An example can be seen in China, where accelerated green finance initiatives led to asset bubbles and challenges in project selection and risk management (Li, 2022). This indicates that ASEAN countries must align ESG investment growth with real economic development to avoid similar financial risks.

In conclusion, while ASEAN countries can learn from Western experiences in carbon reduction, it is crucial to tailor strategies to their own energy consumption structures and economic conditions. Immediate adoption of restrictive measures similar to those in Western countries could lead to significant economic and social issues. Thus, a balanced approach that ensures economic stability and maintains public trust while pursuing carbon reduction goals is essential.

2. METHODOLOGY

2.1 Geographical advantages and renewable energy potential in Southeast Asia

Southeast Asia possesses significant geographical advantages, particularly in the area of natural resource management, making it a key player in global carbon sequestration efforts. Forests, in particular, play a crucial role as one of the most effective methods of carbon sequestration in the region. Forest ecosystems in countries such as Malaysia and Indonesia serve as critical carbon sinks, absorbing substantial amounts of atmospheric carbon dioxide, thus contributing to global climate mitigation strategies (Brown and Zarin, 2019).

To reduce the costs of clean energy production and storage, it is essential to maximize the use of coal resources through effective sorting and optimization. Although coal is a non-renewable resource, by employing advanced sorting technologies, its extraction and usage can be optimized to minimize waste and increase efficiency (International Energy Agency, 2021).

Additionally, Southeast Asia's unique topographical features offer opportunities for energy storage using gravitational energy. By taking advantage of geographical altitude differences, it is possible to store energy during low-demand periods (e.g., at night) and release it during peak periods of electricity demand. Pumped hydroelectric storage systems, which store energy by moving water between reservoirs at different elevations, exemplify this method and are particularly promising in countries like Laos and Vietnam (Kaunda, 2020).

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Singapore, recognizing the need for sustainable energy sources, has been importing hydrogen from Australia as a cleaner alternative to fossil fuels. Hydrogen has the potential to provide a stable energy supply for the region, especially as technological advancements reduce its production costs (Ng et al., 2022).

Furthermore, Malaysia and Indonesia, with their extensive coastlines, have significant tidal energy resources. Tidal energy, which harnesses the movement of ocean water to generate electricity, is another underexplored yet promising renewable energy source in the region (Lewis et al., 2019). These countries are well-positioned to exploit their tidal resources to meet increasing energy demands while contributing to global sustainability goals.

In conclusion, Southeast Asia's geographical advantages, from its forests to its coastal waters, provide immense potential for both carbon sequestration and renewable energy development. Leveraging these natural resources while adopting innovative energy storage and production techniques can drive the region's transition towards a cleaner and more sustainable energy future.

2.2 Project cost estimations

The capital expenditures (CAPEX) required for these projects are substantial, varying based on technology, scale, and location. Below are the estimated costs for each type of project:

Forest Carbon Sequestration (Malaysia and Indonesia)

Estimated Costs: Forest conservation and restoration projects can cost between $1,000 and $5,000 per hectare, depending on the scope, technology used, and long-term maintenance requirements (Brown and Zarin, 2019). Given the significant land areas involved, the total project cost could range from tens to hundreds of millions of dollars.

Coal Resource Optimization

Estimated Costs: Utilizing advanced sorting technologies to maximize coal resource efficiency typically incurs costs ranging from $5 million to $50 million per project. These technologies help improve the efficiency of coal extraction and utilization, which could reduce waste and lower operational costs over time (International Energy Agency, 2021).

Pumped Hydroelectric Storage (Laos and Vietnam)

Estimated Costs: Building a pumped hydroelectric storage system involves civil engineering, reservoir construction, and installation of turbines and pumps. The total cost can range between $500 million and $1 billion per project, depending on the capacity and terrain challenges (Kaunda, 2020).

Hydrogen Import and Storage (Singapore)

Estimated Costs: Singapore's hydrogen import and storage infrastructure could cost between $200 million and $1 billion, depending on the technology used for hydrogen production and the scale of the infrastructure built to handle the imports from countries like Australia (Ng et al., 2022).

Tidal Energy Development (Malaysia and Indonesia)

Estimated Costs: Tidal energy projects, which harness the movement of ocean water, are still in their early stages. The estimated cost per megawatt of installed capacity is approximately $5 million to $10 million. A mid-sized tidal power plant could cost between $100 million and $500 million, depending on the scale and location (Lewis et al., 2019).

2.3 Financial returns and benefits

After the construction phase, these projects are expected to generate significant financial, environmental, and social returns:

1. Forest Carbon Sequestration (Malaysia and Indonesia)

Economic Benefits: Forest carbon sequestration projects offer the potential for revenue generation through carbon credits, which can be traded in international markets. With carbon credits priced between $20 and $50 per ton of CO_2, forest projects could yield substantial income depending on the scale of carbon absorption (Brown & Zarin, 2019).

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Environmental Benefits: Forests play a vital role in mitigating climate change by absorbing CO_2, thereby contributing to global efforts in carbon reduction. Additionally, they help conserve biodiversity and prevent soil erosion.

Social Benefits: These projects create local employment opportunities in forest management and restoration, and support sustainable land use practices.

2. Coal Resource Optimization

Economic Benefits: By enhancing coal extraction and usage efficiency, these technologies can reduce overall operational costs, potentially improving energy production efficiency by 5-15%. This reduces the cost of coal per unit of energy produced and prolongs the life of existing coal reserves (International Energy Agency, 2021).

Environmental Benefits: Improved coal efficiency leads to lower carbon emissions per unit of electricity generated, helping reduce pollution and greenhouse gas emissions associated with traditional coal power plants.

3. Pumped Hydroelectric Storage (Laos and Vietnam)

Economic Benefits: Pumped hydroelectric storage can capitalize on electricity price differentials by storing energy during periods of low demand and selling it during peak demand. This can yield annual revenues of tens to hundreds of millions of dollars, depending on the electricity market (Kaunda, 2020).

Environmental Benefits: By providing energy storage, pumped hydro enables greater integration of renewable energy sources like wind and solar, reducing reliance on fossil fuels.

4. Hydrogen Import and Storage (Singapore)

Economic Benefits: Hydrogen is considered a high-density energy carrier with the potential to replace fossil fuels in industries and transport. As Singapore imports hydrogen and builds up its infrastructure, it could reduce fossil fuel dependency, stabilize energy costs, and enhance energy security (Ng et al., 2022).

Environmental Benefits: Hydrogen is a clean energy source that produces zero direct CO_2 emissions, significantly lowering the carbon footprint of industries that shift towards hydrogen-based energy.

5. Tidal Energy Development (Malaysia and Indonesia)

Economic Benefits: Tidal energy provides a predictable and stable source of electricity, with fewer fluctuations compared to wind and solar power. A mid-sized tidal power plant could supply power to millions of households, reducing fuel costs and stabilizing electricity prices in the long term (Lewis et al., 2019).

Environmental Benefits: Tidal energy produces no direct greenhouse gas emissions, making it an environmentally friendly alternative to fossil fuel-based power generation.

2.4 Methodology of

This section outlines the research design and methods employed in the study, focusing on a mixed-methods approach to examine Southeast Asia's (SEA) green industry prospects, corporate strategy shifts, and the region's policy frameworks in the context of achieving net-zero GHG emissions. Both qualitative and quantitative methods are used to ensure comprehensive analysis.

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1. Research Design

The study employs a mixed-methods design combining qualitative case studies and quantitative data analysis to provide a well-rounded understanding of how SEA countries can achieve their green industry goals and address gaps in policy and corporate strategies. This design allows the study to:

Examine policies and corporate strategies through qualitative interviews and document analysis.

Assess the potential of renewable energy technologies using quantitative data and financial modeling.

The overall goal is to analyze how SEA can meet the challenges posed by global carbon markets and the Paris Agreement while also leveraging digital and technological advancements in green industries.

2. Data Collection

The data collection process is broken down into several key components:

2.1 Policy and Market Data Collection

To analyze the renewable energy adoption, policy frameworks, and carbon reduction strategies of SEA countries, the following sources were utilized:

Government Reports: National energy strategies, climate change mitigation plans, and country-specific policies related to GHG reduction were collected from government websites and publications. For example, Thailand's **Energy Policy and Planning Office (EPPO)** provided detailed data on the country's renewable energy targets and progress.

International Databases: Data from organizations such as the **International Energy Agency (IEA), World Bank, and GlobalData** were used to understand the renewable energy capacity, carbon emissions, and economic indicators of SEA countries.

Secondary Literature: Academic papers and industry reports were reviewed to gain insights into the effectiveness of current policies, the challenges SEA countries face, and the impact of Western carbon markets.

2.2 Corporate Strategy Data Collection

To investigate corporate strategy shifts toward green initiatives, data was collected through:

Company Reports: Sustainability and ESG reports from key companies operating in SEA, such as **Samsung Electronics** (Vietnam), **PTT Group** (Thailand), and **Pertamina** (Indonesia). These reports provided detailed insights into how these firms are adjusting their operations to align with green policies and net-zero goals.

Qualitative Interviews: Semi-structured interviews were conducted with corporate executives and industry experts in the energy, manufacturing, and technology sectors to gather their views on green transitions, challenges, and opportunities within SEA. This qualitative data helps fill gaps in publicly available information and offers real-time perspectives on green strategies.

2.3 Renewable Energy Project Cost Estimations

Quantitative data was collected to estimate the costs of renewable energy projects in SEA, focusing on:

Technology Cost Data: Using data from the **International Renewable Energy Agency (IRENA) and IEA**, estimates for solar, biomass, and hydroelectric energy costs were obtained. These figures were adjusted for regional variables such as labor costs, infrastructure, and resource availability.

Financial Models: Levelized Cost of Energy (LCOE) models were applied to estimate the long-term costs and benefits of renewable energy projects. For example, LCOE was used to evaluate Thailand's solar energy potential, considering both the initial capital expenditures and the operating costs over the project lifespan.

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3. Analytical Framework

The analysis is divided into two main components: **qualitative policy analysis and quantitative energy and financial modeling**.

3.1 Qualitative Policy and Corporate Strategy Analysis

Content Analysis: A systematic content analysis of government reports, corporate sustainability reports, and interviews was conducted to identify recurring themes, such as policy gaps, regulatory challenges, and corporate responses to global carbon markets.

Comparative Policy Analysis: Policies from SEA countries were compared with those of Western economies, particularly the EU and US, to assess the alignment with global trends like the Carbon Border Adjustment Mechanism (CBAM).

Case Studies: Detailed case studies were conducted for Thailand, Vietnam, and Indonesia to highlight country-specific strategies, technological adoption, and the role of corporations in achieving net-zero goals.

3.2 Quantitative Energy and Cost-Benefit Analysis

Cost Estimation Models: Financial modeling, particularly using the Levelized Cost of Energy (LCOE) approach, was applied to evaluate the feasibility of renewable energy projects. This method accounts for all costs associated with energy generation, including construction, operation, and maintenance over the project's life cycle.

Scenario Analysis: Several scenarios were modeled to estimate the potential outcomes of different policy and corporate strategies. For example, one scenario modeled the impact of accelerated renewable energy adoption in Thailand and its potential to reduce GHG emissions by 2035, while another looked at the cost implications of scaling up biomass projects in rural areas of Vietnam.

Sensitivity Analysis: Sensitivity analyses were conducted to test the robustness of the cost models, particularly around variables like carbon pricing, government subsidies, and technology costs. This helped ensure that the results are applicable even if external conditions, such as international carbon prices, fluctuate.

4. Assumptions and limitations

4.1 Assumptions

The study makes several key assumptions based on available data:

Policy Stability: It is assumed that the current policy frameworks in SEA countries will remain stable over the next decade, allowing for the continuation of renewable energy incentives and regulations.

Technology Costs: The cost of renewable energy technologies, particularly solar and biomass, is expected to decline over time due to advancements in technology and economies of scale. This assumption is based on historical trends observed by IRENA and IEA.

4.2 Limitations

Data Availability: While the study uses the most up-to-date data available, some countries in SEA may lack detailed or reliable energy and policy data. This could affect the accuracy of certain projections.

Regional Variations: The results may not fully account for the differences in regional infrastructure and resource availability within SEA countries. For instance, rural areas may face higher logistical costs for renewable energy project implementation.

Corporate Data Confidentiality: Some corporate strategies, especially in the private sector, may not be fully disclosed in public reports, potentially limiting the scope of the corporate strategy analysis.

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2.1 Current Renewable Energy Adoption and GHG Targets in SEA

The renewable energy landscape across SEA varies widely between countries, with some making significant strides toward green energy, while others lag behind. The following is a summary of the current status of renewable energy adoption and GHG emission reduction targets for key countries in the region:

Indonesia: Indonesia has pledged to reduce GHG emissions by 29% by 2030 compared to a business-as-usual (BAU) scenario, with plans to expand its renewable energy share to 23% by 2025. However, heavy reliance on coal remains a challenge (International Energy Agency, 2021).

Vietnam: Vietnam has become a leader in solar power adoption, with its installed capacity reaching 16.6 GW by 2020. The country aims to increase its renewable energy share to 32% by 2030 (World Bank, 2022).

Thailand: Thailand's renewable energy goals include increasing the share of renewables to 30% by 2037. The country also sees significant potential in solar energy, biomass, and carbon sinks, with plans to enhance forest conservation and increase carbon sequestration projects (Energy Policy and Planning Office, 2023).

Malaysia: Malaysia has set a target to reduce its GHG emissions by 45% by 2030. It is investing heavily in solar power, aiming to increase its capacity to 18 GW by 2035 (GlobalData, 2022).

2.2 Technological Adoption and Assumptions (with improved methodology)

For each SEA country, assumptions about technology adoption must be clearly stated and backed by reliable data. The estimated costs and potential benefits of renewable energy projects in SEA are as follows:

Solar Energy in Thailand: Thailand's solar energy potential is significant due to its geographical location. Advanced photovoltaic (PV) technology is being adopted, with costs expected to decrease by 10-15% over the next decade due to economies of scale and government incentives (Renewable Energy Report, 2023).

Biomass in Thailand: Biomass projects, particularly in rural areas, have the potential to provide both electricity and employment opportunities. Estimated project costs range from $1,200 to $3,000 per kW, with a projected annual growth rate of 7% (International Renewable Energy Agency, 2022).

Hydropower in Laos and Vietnam: Hydropower remains a key energy source in Laos and Vietnam, with pumped hydroelectric storage providing a stable energy supply. These projects have capital costs ranging from $500 million to $1 billion depending on the scale and geographical factors (Kaunda, 2020).

3. CORPORATE STRATEGY SHIFTS AND GREEN TRANSITIONS

3.1 Corporate Perspectives on Green Transition (new data and cases)

Corporate engagement in green initiatives is essential for SEA’s progress toward carbon neutrality. Through interviews and data collection from regional firms, this paper highlights several key corporate strategies:

Samsung Electronics (Vietnam): Samsung has committed to reducing its carbon emissions across its global supply chain, including its factories in Vietnam. It plans to transition 100% of its energy use to renewable sources by 2050, starting with solar and wind installations (Samsung Sustainability Report, 2022).

PTT Group (Thailand): Thailand’s largest state-owned oil and gas company, PTT, has announced its intention to diversify into renewable energy, with a $7 billion investment in solar and wind projects over the next five years. This marks a major shift in corporate strategy as the company aims for net-zero emissions by 2050 (PTT Annual Report, 2023).

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Pertamina (Indonesia): Indonesia's state-owned oil company, Pertamina, is shifting towards cleaner energy by investing in geothermal and biofuel projects. The company has set a target to achieve carbon neutrality by 2060 (Pertamina Sustainability Report, 2022).

4. POLICY GAPS AND RECOMMENDATIONS FOR SEA (ADDRESSING RESEARCH GAPS)

While SEA countries have made progress, several gaps remain in their policy frameworks compared to Western carbon markets:

Carbon Pricing: Unlike the EU's CBAM, SEA lacks a unified carbon pricing mechanism. Countries should consider implementing cap-and-trade systems or carbon taxes to create market-based incentives for reducing emissions.

Technology Financing: Although many SEA countries have ambitious renewable energy targets, the financing required for large-scale projects remains a challenge. Innovative financial instruments, such as green bonds and public-private partnerships, are needed to attract investment.

Corporate Accountability: While some firms are making strides in sustainability, many companies in SEA still lack clear strategies for reducing emissions. Stronger regulatory frameworks and incentives for corporate sustainability initiatives are necessary.

5. CONCLUSION

The implementation of these renewable energy and carbon sequestration projects in Southeast Asia represents a significant financial commitment, with initial capital expenditures running into billions of dollars. However, the long-term economic benefits, particularly from carbon credit trading, energy market arbitrage, and the reduction in fuel costs, promise to generate substantial returns on investment. Additionally, these projects offer considerable environmental benefits, helping Southeast Asia reduce its carbon footprint and transition towards a more sustainable energy future. Through innovative technologies and strategic use of natural resources, Southeast Asia is poised to become a leader in the global clean energy movement, driving economic growth and environmental sustainability.

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Social Resilience of Communities Around Industrial Areas in Facing Environmental Changes and Preserving Ecosystems in Gresik Regency, Indonesia

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ABSTRACT

The development of the Java Integrated Industrial Port Estate (JIIPE) in Gresik Regency, East Java, Indonesia, has created a dilemma for the surrounding communities. On one hand, it promotes regional development and stimulates the local economy through job creation and economic multiplier effects. On the other hand, the industrial area has caused social changes and environmental problems. These issues include air pollution, river and groundwater contamination, ecosystem and marine life damage, changes in occupation and income of the local population, coastal sedimentation, erosion, weak environmental management, climate change, and extreme temperatures. The degree of social resilience in facing these environmental changes, marine ecosystem shifts, temperature variations, and climate change remains suboptimal. This study aims to analyze the social resilience of communities in facing the environmental and climate change impacts, as well as their efforts in environmental and marine ecosystem management. Conducted in Gresik Regency, the study focuses on two sub-districts, Manyar and Bungah, covering nine villages. Data collection was carried out using mixed methods, combining survey techniques and in-depth interviews with government officials, community leaders, NGOs, CBOs, youth and women's groups, industrial representatives, and vulnerable groups. The data were analyzed to explain the level of social resilience in responding to environmental changes and the strategies for environmental and marine ecosystem management. The study found that the community's adaptive capacity to environmental changes remains suboptimal due to economic, social, and cultural conditions. The transformation of the area from fishponds to an industrial center has led to changes in the ecosystem and the work rhythm and occupation of the local population. Efforts to maintain environmental balance can be achieved through the provision of air quality monitoring and water purification facilities, flood prevention, greening of the area, sustainable housing and eco-friendly lifestyles, the use of renewable energy sources, socialization of coastal and marine ecosystem maintenance and management, and the development of environmentally friendly behaviors. Collective and participative activities need to be developed to enhance adaptive capacity to environmental and climate changes, ensuring that industrial growth aligns with environmental sustainability and community welfare. Pentahelix collaboration (academia, industry, community, government, media) should be continuously developed to maintain environmental sustainability based on the principle “industry yes, environmental damage no”.

Keywords: Social resilience/ Environment/ Industrial area/ Marine ecosystem

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Social Capital and Waste Management Practices in Jembrana and Banyuwangi, Indonesia

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ABSTRACT

This study examines the role of social capital in shaping a variety of waste management practices in Jembrana and Banyuwangi, Indonesia, including recycling, burning, and communal clean-up efforts. Using thematic analysis based on qualitative data from focus group discussions (FGDs) with local community leaders across 14 villages, five key categories of social capital influencing waste management behavior were identified: collective responsibility, social pressure, cultural and religious influences, leadership and influential groups, and collective health and environmental awareness. In Jembrana, collective responsibility manifests through community-driven maintenance of public spaces and neighborhood cleanliness, while social pressure is enforced through social sanctions. Cultural values play a role in practices such as river cleanliness and discouraging the burning of baby diaper waste. Local leaders and women's groups significantly influence waste management initiatives, with health concerns like mosquito prevention being key motivators. In Banyuwangi, similar patterns emerge, with neighborhood cleanliness and communal activities being central. Social pressure arises from the fear of neighbors' complaints and direct confrontations over littering. Although cultural influences are less pronounced, leadership roles held by women and youth groups are critical, and some environmental awareness stems from the need to curb mosquito-borne diseases. These findings highlight the nuanced role of social capital in promoting sustainable waste management behaviors. Tailored approaches that consider local social dynamics are crucial for effective waste management strategies.

Keywords: Social capital/ Waste management practices/ Waste management/ Waste management behavior

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A Study on Island Ecotourism Development Models Based on System Dynamics: A Case Study of Amami-Oshima Island

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ABSTRACT

Sustainable island tourism development refers to tailoring tourism to the specific conditions of an island, ensuring that tourism activities remain within reasonable environmental capacity while promoting coordinated development economic, environmental, and social benefits. However, the fragility of the ecological environment, and the uniqueness of economic and social development conditions limit the sustainable development of island tourism. Research topics on the sustainable development of island tourism have gradually shifted towards the direction of ecotourism. Firstly, this study establishes a comprehensive evaluation index system for island ecotourism, using Amami-Oshima Island as a case study, encompassing the environmental, economic, social, and other-sector tourism aspects. The Coupling Coordination Degree Model is applied, utilizing data from Amami-Oshima Island from 2010 to 2021, to conduct quantitative analysis of the current status of island ecotourism coupling coordination development. The findings reveal: (1) From 2010 to 2021, Amami-Oshima Island exhibited an overall growth in the comprehensive development of ecotourism, with the environment-tourism subsystem showing the most significant development, the social-tourism subsystem displaying fluctuating growth, and the economic and other tourism sectors consistently progressing. (2) The coupling degree and coordination level of Amami-Oshima Island ecotourism showed an overall upward trend, evolving from minimal to intermediate coordination. Secondly, this study introduces a System Dynamics model to analyze the causal feedback relationships and construct system flow diagrams for the ecotourism operation mechanism on Amami-Oshima Island. Aiming to provide robust support for formulating scientifically sound development strategies. Finally, the research outcomes have profound implications for assessing the current state and future directions of ecotourism on Amami-Oshima Island, and provide insightful policy suggestions for promoting ecotourism on other islands.

Keyword: Island-destination development/ Ecotourism/ Coupling coordination degree/ System dynamics

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Diversity of Urban Spontaneous Vegetation on Roadsides in Chaing Mai, Thailand

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ABSTRACT

Green spaces with trees are crucial in urban environments because they increase biodiversity, improve air quality, and lower temperature in dense urban areas. However, urban development often results in fragmented patches and narrow pavements that are unsuitable for tree growth. Consequently, there is a pressing need for alternative vegetation in urban landscapes to sustain biodiversity in areas where tree planting is impractical. Urban spontaneous vegetation (USV) refers to plants that establish naturally without cultivation. It holds promise for urban landscaping due to its low maintenance and potential to provide ecosystem services. The objectives of this study are to determine the plant species richness and abundance of USV in eight locations within Chiang Mai city and adjacent districts. At each location, a 1×1 m sample quadrat was placed every 20 meters on both sides of the main roads. All non-tree vascular plant species were recorded and identified. The survey covered 2,927 quadrats along 26 sidewalk routes, spanning a total length of 58 km. USV predominantly thrived in pavement gaps, curbside cracks and cracked pavement along urban roads. A total of 63 USV plant species from 24 families were identified. The Poaceae family had the highest diversity with 15 species, followed by the Asteraceae family with 8 species. Among the 63 species recorded, 32 species (53%) were identified as non-native. The built urban environment serves as a reservoir for non-native plant species. Three species—*Euphorbia thymifolia* L., *Phyllanthus amarus* Schumach. & Thonn., and *Oldenlandia corymbosa* L.—were found in all surveyed locations, indicating their adaptability to diverse and challenging urban conditions. This study represents the first survey of USV composition along roadsides in Chiang Mai, Thailand, highlighting the diversity and potential role of USV in urban landscapes. Nevertheless, further research is necessary to fully grasp the implications of these spontaneous vegetation species in urban areas.

Keyword: Species richness/ Urban spontaneous plants/ Urban plant survey/ Urban landscape

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Do *Undaria pinnatifida* Seaweed Farms Have Potential to Sequester Carbon?

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ABSTRACT

Recently, seaweed farms have been attracting attention as they are expected to contribute to carbon sequestration. In order to evaluate the carbon sequestration function of seaweed farms, it is necessary to clarify whether the organic matter derived from cultivated seaweed is sequestered in the sediments of these farms. In this study, we focused on the sediments of an *Undaria pinnatifida* farm in Matsushima Bay, Miyagi Prefecture, Japan and evaluated the organic carbon contained in the sediments.Sediments were collected with an acrylic pipe with a diameter of 30 mm and a length of 1 m. Samples were subdivided into 10 cm segments and frozen at -18 °C or below. Total organic carbon (TOC) was analyzed with a TOC analyzer, and a digital PCR was used to identify the presence of *U. pinnatifida* eDNA. The eDNA of *U. pinnatifida* was detected from sediment layers between 0 cm to 28 cm from sites with a history of *U. pinnatifida* farming. However, eDNA was detected only between 0 cm to 8 cm in sediments with no farming history. TOC from farm sediments (mean±standard error) was 2.58±0.063%, whereas TOC taken from sites with no farming history was 0.669±0.023%. We hypothesize that seaweed farming can enhance TOC content in sediments below the farms and contribute to carbon sequestration.

Keywords: Climate change/ eDNA/ Macroalga/ Seaweed farm/ Sediments/ TOC

1. INTRODUCTION

The IPCC Sixth Assessment Report states that climate change is a consequence of greenhouse gas emissions from human activities and that mitigation and adaptation measures to reduce emissions are urgently needed [1]. In this context, one of the measures to mitigate climate change is to Human activities since the Industrial Revolution, including fossil fuel consumption, deforestation, and industrialization, have led to a rapid increase in atmospheric greenhouse gas concentrations from 280 parts per million (ppm) in the 19th century to over 410 ppm today [2,3]. Maintain and expand carbon sinks [4,5].

The ocean is an important carbon pool and is estimated to absorb about one-third of the carbon emitted by human activities [6]. Of this, the carbon sequestered and stored by the marine environment is known as "blue carbon" [7]. Historically, coastal mangroves, salt marshes, and seagrass beds have been considered carbon sinks. However, this view has recently been challenged, and seaweed beds have also been suggested to play an important role as blue carbon [8,9,10], drawing attention to seaweeds.

Persistent organic matter secreted by seaweeds can contribute to long-term carbon sequestration [11], with fucoidan secreted by brown algae being an example [1]. Therefore, seaweed farms are also being promoted worldwide for their potential to effectively capture atmospheric carbon dioxide [13,14,15]. However, our knowledge of the carbon sequestration process and the amount of carbon sequestered by seaweeds is still limited, and although some studies have assessed the amount of carbon sequestered by seaweed farms, these were often estimated from seaweed biomass and primary production [16,17,18]. Therefore, future studies should measure the amount of organic carbon in sediments to determine whether seaweed farms act as blue carbon. In this study, I focused on wakame

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seaweed (*Undaria pinnatifida*), which is cultivated nationwide and has been shown to release fucoidan, a persistent organic matter [19]. I then examined organic carbon in the sediment, hypothesizing that sediments from sites with a history of seaweed farming may sequester more organic carbon, and that genes derived from cultivated seaweed may be more abundant at sites with a history of seaweed farming.

2. METHODOLOGY

2.1 Location

This study was conducted in Matsushima Bay, Miyagi Prefecture (Figure 1). The study area is in the inner part of Sendai Bay, where the water depth is mostly less than 5 m [20]. The study area, Matsushima Bay, is included in the 88 closed marine areas defined by the Ministry of the Environment.

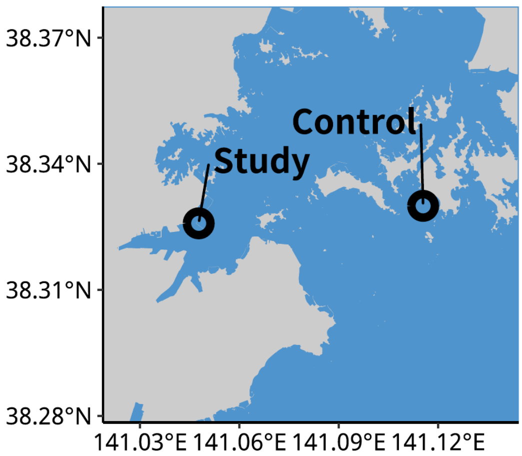

Figure 1. Study sites were in Matsushima Bay, Miyagi, Japan. "Study" refers to sites with a history of seaweed farming, and 'Control' refers to sites with no farming history.

2.2 Sediment Core Survey

Sediment coring was conducted on September 14, 2023. Core collection sites were selected based on visual confirmation of sea conditions on the day of the survey. Cores were collected by divers. An acrylic pipe (1 m in length, 30 mm in diameter) was driven vertically into the seafloor with a rubber hammer to a depth of 60 cm. The acrylic pipe was capped with a silicone stopper, extracted from the sediment, and then a second stopper was placed at the bottom of the core to prevent sediment from spilling out of the pipe. Location information was recorded using a handheld GPS (GPSMAP66i, Garmin). The sediment cores were transported to Yuriage Factory, Riken Foods, Inc. (Natori City, Miyagi Prefecture). Sediment cores were extruded at 10 cm intervals from the bottom and extruded samples were collected in sealable plastic bags. Samples were frozen in a -20°C freezer.

2.3 Sediment Organic Carbon Determination

The organic carbon content of the sediments was analyzed with a total organic carbon analyzer (soilTOC, Elementar Japan). In this study, frozen samples were dried in an oven at 60°C for at least 48 hours and then ground to homogeneity using a mortar and pestle.

2.4 Measurement of the genetic content of wakame seaweed (Undaria pinnatifida) in sediments

Species-specific environmental DNA (eDNA) analysis was conducted using digital PCR to measure the amount of wakame (*Undaria pinnatifida*) genes in the sediments. The analysis was performed on two core samples, one from a sediment sample at a site with a history of wakame farming and one from a sediment sample at a site with no wakame farming history. Samples were taken from

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each extruded sample from one representative core from each site. EDNA analysis was done by a contracted agency (Bioengineering Lab Co. Ltd.).

2.5 Data analysis

Data analysis was performed using R (R version 4.3.2: R Development Core and Team). Data results were expressed as mean ± one standard error. A t-test was performed to test for differences in organic carbon content between the study and control plots. The significance level was set at 0.05. For sediment core data, three core samples for which insufficient sediment samples could be collected were excluded from the data.

3. RESULTS AND DISCUSSION

3.1 Organic carbon content in sediment

13 sediment core samples were collected: 8 core samples from sites with a history of wakame (*U. pinnatifida*) seaweed farming and 5 core samples from sites with no wakame farming history. The organic carbon content of the sediments was 2.58±0.063% for samples from sites with a history of wakame farming and 0.669±0.023% for samples from sites with no wakame farming history. The differences in the organic carbon content among the sites were statistically significant (Welch t-test: $t_{5.0199}$=32.088, p-value<0.0001; Figure 2). Our analysis suggests that sites with a history of seaweed farming may store more organic carbon derived from wakame seaweed in their sediments. We plan to evaluate the export of organic carbon farms into the seafloor by collecting organic matter settling into sediment.

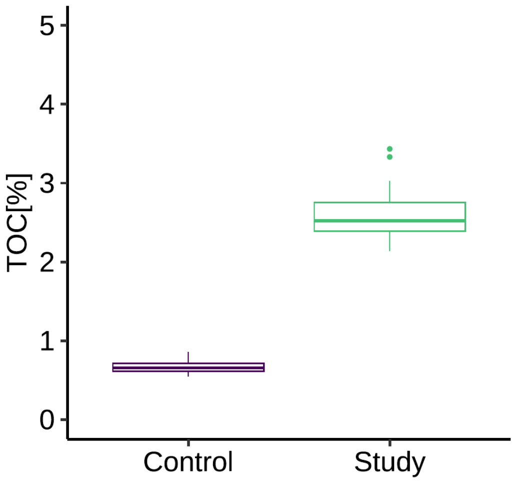

Figure 2. Box-and-whisker plots of organic carbon content in sediments from sites with no history of wakame (*Undaria pinnatifida*) farming (Control) and sites with a history of wakame farming (Study). The dots plotted in this box-and-whisker plot represent values 1.5 times greater than the interquartile range. The minimum, first quartile, second quartile, third quartile, and maximum values for sites with no history of wakame farming were 0.5415 %, 0.6140 %, 0.6575 %, 0.7110 %, and 0.8555 %, respectively. The minimum, first quartile, second quartile, third quartile, and maximum values were 2.140 %, 2.386 %, 2.522 %, 2.759 %, and 3.025 %, respectively, for sites with a history of wakame seaweed farming.

3.2 Genetic content of wakame (Undaria pinnatifida) in sediment

Species-specific eDNA analysis using digital PCR was used to measure the amount of wakame-derived genes in the sediments. EDNA analysis revealed that wakame genes were detected in sediment samples from sites with a history of wakame farming at depths ranging from 0 cm to -28 cm and from -48 cm to -58 cm. Sediment samples from sites with no wakame farming history had wakame genes detected at depths ranging from 0 cm to -8 cm (Figure 3).

These results suggest that some of the persistent dissolved organic carbon (DOC) and runoff biomass released by wakame seaweed was deposited in the sediments within the wakame farming site in large quantities. Another possible cause for the detection of wakame genes in the sediments within

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the wakame farming site at depths of -48 cm to -58 cm could be due to agitation of the sediments by the Great East Japan Earthquake Tsunami [20] or contamination of sediment samples from other layers in the process of collecting the sediment samples.

On the other hand, a few genes were detected in sediments at depths of 0 cm to - 8 cm, even from sediments at sites with no history of wakame farming. These results suggest that some of the persistent DOC released by wakame farming, as well as some of the biomass from runoff, may have been transported away from the farm and deposited in the sediment. In previous studies, genes derived from seaweed have been detected in sediments at sites distant from natural seaweed beds [21].

The number of genes detected in samples from sites with a history of wakame farming decreased with the depth of the sediments. This could be attributed to the fact that wakame farming production in Matsushima Bay began in earnest in 1988, with production increasing as the years passed [22]. However, since sediment agitation was confirmed by Ota et al. (2017) [20], it is necessary to determine the age of the sediments, clarify to which sediment layer agitation occurred, and clarify the relationship between the age of the sediments and the reason why wakame genetic material decreased with the depth of the sediments.

The results of these studies suggest that wakame farming sites have the potential to store a large amount of organic carbon in the sediments within their farms and play an important role in providing organic carbon in the sediments. In order to accurately determine the origin and contribution rate of carbon to carbon sequestration in seaweed farm sediments in the future, it will be necessary to increase the number of survey sites and data, and to compare the results with those of other farm waters.

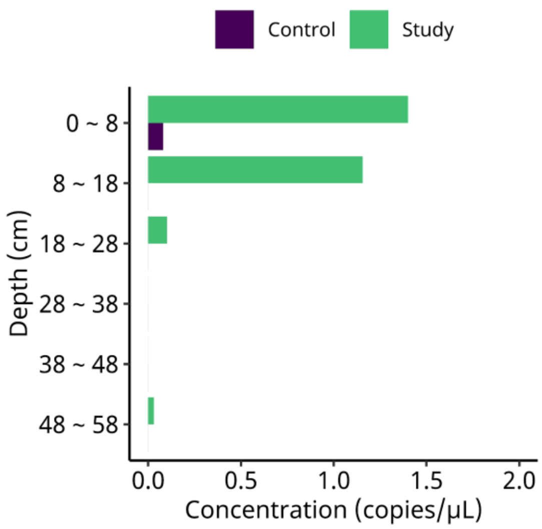

Figure 3. Wakame (*Undaria pinnatifida*) DNA concentrations in sediment per sample from sites with no history of wakame (*Undaria pinnatifida*) farming (Control) and sites with a history of wakame (*Undaria pinnatifida*) farming (Study).

4. CONCLUSIONS

Sediment organic carbon content was found to be higher in sediments from sites with a history of wakame farming than in sediments from sites with no wakame farming history. Wakame genes were also identified in sediments from sites with no wakame farming history, suggesting that some of the wakame-derived carbon produced in wakame farms is leaching out of the farms. The results of this study support the carbon sequestration capacity of wakame farms and provide fundamental knowledge for blue carbon crediting. Future work is needed to determine the amount of organic carbon derived from farmed seaweed species in sediments and to quantify the amount of carbon sequestered by seaweed farms.

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Reproductive Modifications of Marine Rotifer in Relation to Thermal Conditions: Implications for Ecological Adaptations

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ABSTRACT

Temperature significantly affects the physiological performance and metabolic acclimation associated with reproduction, survival, and behavior of aquatic organisms. Marine *Brachionus* rotifers constitutes a live food source during the initial phase of larviculture. Furthermore, they are pivotal in ecological adaptability and evolutionary studies due to the reproductive features of cyclical parthenogenesis: sexual versus asexual. The occurrence of a sexual life cycle with the formation of resting (diapausing) eggs could be an effective strategy to improve species fitness to cope with environmental unpredictability. Specific temperature manipulation following the growth preferences of rotifer species has been shown to induce a transition in reproductive patterns. We previously utilized diverse strains of rotifer, *Brachionus plicatilis*, exhibiting two distinct reproductive patterns at 25°C (control; laboratory stock temperature): cyclical (NH1L strain) and obligatory parthenogenesis (Amami and Obama strains). Using these strains, we determined the efficacy of low-temperature induction (incubation at 15°C for 14 days) on sexual reproduction in rotifers by regulating the transcription levels of key biomarkers of endocrine and energy metabolism, including ecdysone-induced 78C, estrogen receptor, and β-glucosidase, as well as cellular stress tolerance, such as heat shock protein 70. While the reason for the reproductive transition triggered by low temperature exposure remains unclear: a short-term stimulatory effect or an adaptive response? Seasonal species replacement often occurs in natural *Brachionus* rotifers populations. The *B. plicatilis* species predominates in winter period, suggesting the reproductive adaptations to low temperatures following ecological preferences. Therefore, we performed further investigations of the reproductive pattern of the three aforementioned strains after acclimation to low-temperature conditions for one and six months. Results showed that following acclimatization to 15°C for one month, the three strains showed significantly faster population expansion during 14 days of cultivation at 15°C (1.6-2.3 folds, $p<0.05$), in comparison to individuals who were not acclimated. Furthermore, species-specific responses to sexual reproduction were observed. The sexual capacity of NH1L from the acclimated group was diminished, compared with that of individuals without low temperature acclimation. Nevertheless, the similar effects of low temperature on the sexual reproduction of the Amami (enhance) and Obama (no change) strains were identified in both acclimated and non-acclimated groups. It is suspected that the differential responses reflect metabolic modifications associated with rapid or prolonged ecological adaptations.

Keyword: Temperature/ Aquatic resource/ Reproduction/ Adaptative strategy/

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Advanced Analytical Approaches to Dissolved Organic Matter for a Sustainable Future: Innovations for a Net Zero Future

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ABSTRACT

Innovations and technology that improve our understanding and management of natural resources play an important role in achieving net zero emissions. This study aims to investigate the pivotal role of dissolved organic matter (DOM) characteristics in the environment, utilizing advanced analytical techniques such as Pyrolysis-Gas Chromatography-Mass Spectrometry (Py-GCMS) and Orbitrap Mass Spectrometry (Orbitrap MS). DOM is a complex mixture of organic compounds in aquatic environments that plays a significant part in carbon cycling, water quality, and ecosystem dynamics. Understanding its structure and behavior is critical for building long-term environmental management approaches. This study employs molecular composition analysis by Py-GCMS and Orbitrap MS to give a complete analysis of DOM, showing its chemical structure, characteristics, and origins within the ecosystem. Together, these techniques provide a detailed picture of the dynamics of DOM, offering valuable information to develop strategies aimed at reducing environmental impact by identifying specific harmful organic compounds in DOM, so water treatment facilities can tailor their processes to target and remove toxic substances efficiently and supporting sustainability by ensuring safer drinking water along with reducing the need for extensive chemical treatment that support the transition to a net zero world. Monitoring changes in DOM composition over time can also act as an indicator of environmental changes, such as shifts in land use or climate conditions, which helps assess the impacts of climate change on ecosystems. Py-GCMS offers insights into the thermal decomposition products of DOM they focus on breaking down large molecules into smaller fragments which can be detected in mass spectrometry, helping to identify specific organic compounds and their origins. The result divided the substances into 8 categories: Polysaccharide Aromatic, Lignin, Lipid, Tannin, and Siloxane. Among them, it was found that the main compound of every sample analyzed is lignin. Using Orbitrap MS operates at lower temperatures (around 30ºC), even though it may miss larger molecular components, with its high-resolution capabilities, allowing for precise mass measurement of DOM components, enabling the detection of even the most subtle changes in composition and reactivity molecules below 2000 Da, essential for a comprehensive understanding of NOM. The assigned MS sample peaks were described in van Krevelen diagrams employing the CHON formulas. In these regions, lignin-like and tannin-like substances are particularly abundant and were quantified to contain the largest portion of all substances (approximately 20%), indicating that all of the samples originate from a terrestrial source. This result corresponds with the Fluorescence EEM data, which have a FI value of less than 1.4 for all samples, indicating terrestrial origin. This study will enable the broader goal of conserving natural resources and enhancing human activity sustainability by expanding our understanding of DOM and its role in environmental processes.

Keyword: DOM/ Py-GCMS/ Orbitrap MS/ Sustainable development

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Effect of MOF-derived Cu/CeO_2 Catalysts Depending on Calcination Temperature in Water-Gas Shift Reaction

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ABSTRACT

The WGS(Water Gas Shift) reaction is essential for the process of producing high-purity hydrogen from natural gas. The WGS reaction proceeds in two stages with different reaction temperatures due to thermodynamic limitations. For the efficient operation of the power system, a compact reformer with a small size is important. In the case of a compact reformer, a single-stage WGS reaction is applied due to the limitation of the reformer size. In this study, tailored WGS catalysts for small reformers were prepared by varying calcination temperatures that affect the physicochemical properties of the catalysts. That is, tailored Cu/CeO_2 catalysts for WGS in small reformers were prepared using CeO_2 supports derived from metal-organic frameworks (MOFs) at various calcination temperatures. The MOF-derived CeO_2 supports were prepared using various hydrothermal synthesis methods. Cu was added to the MOF-derived CeO_2 support via incipient wetness impregnation method. Various techniques such as Brunauer-Emmett-Teller (BET), Oxygen Storage Capacity (OSC), and X-ray Diffraction (XRD) were performed to understand the relationship between the catalytic performance and physicochemical properties of the Cu/CeO_2 catalysts. Among the prepared catalysts, the Cu/CeO_2 catalyst prepared using MOF-derived CeO_2 support calcined at 400°C exhibited high CO conversion (X_{CO}=74%) at a very high gas hourly space velocity of 50,233 $mL \cdot g^{-1} \cdot h^{-1}$ and high stability for 50 h. This excellent catalytic performance is mainly attributed to its high oxygen storage capacity for enhancing the WGS reaction. In conclusion, the Cu/CeO_2 catalyst using the MOF-derived CeO_2 support calcined at 400°C is expected to be a suitable WGS catalyst for a small reforming reactor to produce hydrogen from natural gas.

Keyword: Water gas shift/ Metal-organic frameworks/ Oxygen storage capacity / Calcination temperature

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Modulating the Co-CoO$_x$ Interface in Co-Nb-CeO$_2$ Catalysts through Controlling Titration Rate for Enhanced Performance in Water-Gas Shift Reaction

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ABSTRACT

Hydrogen is proposed as a promising alternative to address environmental issues from fossil fuels. In the waste gasification process, the Water Gas Shift (WGS) reaction is crucial for producing high-purity hydrogen. The WGS reaction are divided into the two steps as high temperature-water gas shift (HT-WGS) and low temperature-water gas shift (LT-WGS) reaction due to thermodynamic limitation and kinetic. Previously, the Co/Nb-CeO$_2$ catalyst for HT-WGS were designed prepared with co-precipitation method, but the effect of titration rate which is an important parameter relating to catalytic performance was not investigated. In this study, the different titration rates were applied to prepare Co/Nb-CeO$_2$ catalysts by controlling the addition rate of precipitant (KOH) from 1 mL/min to 25 mL/min. To understand the physicochemical properties of the catalysts various characterization techniques were used such as TEM, XPS and H$_2$-TPR analyses. As a Result, among the prepared Co/Nb−CeO$_2$ catalysts, 5-Co/Nb-CeO$_2$ prepared with precipitant addition rate as 5 mL/min exhibited the highest activity, with a CO conversion of 97.8% at a temperature of 450°C and a gas hourly space velocity of 315,282 h^{-1}. Moreover, long-term thermal stability was observed for the 5-Co/Nb-CeO$_2$ catalyst. Carbon formation and sintering, which deactivates the catalyst activity was minimal when 5-Co/Nb-CeO$_2$ catalyst was tested because of the favorable interactions between the CeO$_2$ and Co-CoO$_x$ pairs. In contrast, the other catalysts underwent faster deactivation because of faster carbon deposition and pore blockage, ultimately limiting the H$_2$ production activity.

Keyword: Water-gas shift/ Hydrogen/ Co-Co$_x$ pairs/ Metal-support interactions/ Waste-derived syngas

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Abstract
Poster Presentation

Environmental Impact of Prior Pesticides Occurring in Wetland Ecosystems

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ABSTRACT

The use of pesticides can contaminate surrounding waterbodies and harm non-targeted aquatic organisms. Wetlands are known to rapidly degrade and eliminate organic pollutants. However, there is a lack of research on the fate and impact of pesticides in wetland ecosystems. Therefore, this study aims to explore the occurrence and concentration of pesticides entering wetlands near agricultural fields and evaluate the potential risk of priority pesticides considering their toxic mode of action. To identify pesticides in the wetland, sampling was conducted at 10 representative points for 10 times in per month. Grab samples were collected in 1L amber bottles. After filtration, citrate buffer and internal standards were added to the sample. To enrich the sample, a solid-phase extraction (SPE) was applied. Elution solvents were alkaline and acidic ethyl acetate/methanol solutions. Extracts were concentrated to 0.1 mL, reconstituted with water/methanol (9:1), and filtered through a 0.45 µm filter. The samples were then analyzed using high performance liquid chromatography-high resolution mass spectrometry (HPLC-HRMS). The lowest PNECs values from the NORMAN Ecotoxicology Database were used to calculate the Risk Quotient (RQ) values. For the mode of action (MOA), the MOA data of the Fungicide Resistance Action Committee (FRAC) were used. A total of 76 pesticides were detected out of approximately 300 target substances. The 4 prior pesticides included orysastrobin, metalaxyl, tebuconazole, and carbendazim. The highest detected concentration of orysastrobin was approximately 3,300 ng/L. Pesticide concentrations tended to decrease from wetland inflow to outflow. Orysastrobin's mode of action is associated with group C (respiration), metalaxyl is with group A (nucleic acids metabolism), tebuconazole is with group G (sterol biosynthesis in membranes), and carbendazim is with group B (cytoskeleton and motor protein). Therefore, it is expected that the organisms in the wetland would be strongly affected by group C (respiration), the group corresponding to the highest detected MOA of orysastrobin. To explore the potential risk of the pesticides detected, risk quotient (RQ) values were calculated. The results showed that the RQ value of orysastrobin was up to 17 at the inflow point, but decreased to 4 at the outflow point. The decrease indicates that pesticides are under rapid degradation/break-down within the wetland. Despite the self-purification ability of wetlands, some pesticides require proper management to reduce their impact.

Keyword: Pesticide / Wetland / HPLC-HRMS / Mode of action (MOA) / Risk Quotient (RQ)

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Identification of Water-Soluble Chemicals in Leachate of Plastics and Their Kinetics Enhanced under Photooxidative Conditions

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ABSTRACT

Plastics can be extensively discharged in various environments such as rivers, coastal areas and offshore. When plastics in aquatic environment are subject to photooxidative conditions, various substances (e.g., plasticizers) can be leaching-out. The leaching kinetics would be affected by aging process enhanced by photo-oxidation. However, the release and fate of leachable substances and their leaching kinetics are not well understood. The identification of these chemicals can be achieved through suspect screening and non-target screening methods using high resolution mass spectrometry (HRMS). This study aims to investigate the substances released when plastics are exposed to a xenon lamp and natural sunlight, as well as the leaching kinetics over time under photooxidation condition. five types of plastics (PP, PS, PE, PVC, PLA) were selected based on their global use amount. The leaching experiment was performed using each 350 g of plastics in Boro bottles with 700 mL of DI water. The samples were subjected to a xenon lamp with a light intensity of 600W/m² for 21 days. Samples were collected at 7-day intervals. To enrich the sample, a solid phase extraction (SPE) was used. The sample was adjusted to 100 mL, and citrate buffer with internal standards was added. Elution used alkaline and acidic ethyl acetate/methanol solutions. Extracts were concentrated to 1 mL, reconstituted with water/methanol (9:1), and filtered through a 0.45μm filter. The samples were then analyzed using high performance liquid chromatography-high resolution mass spectrometry (HPLC-HRMS). A suspect list was established using the NORMAN Suspect List Exchange and literature survey. Subsequently, suspect screening was performed based on the peak selection criteria (i.e., peak intensity, isotopology pattern, and MS2 fragments ratio). Acquired MS2 fragments were evaluated with MS2 library (e.g., mzCloud) for qualitatively chemical structure elucidation. A total of 9 substances were tentatively identified. Out of identified suspects, 2 plasticizers: Caprolactam, Melamine and 1 solvent: Isophorone were confirmed using reference standard (confidence level 1). Occurrences of Butyl-methacrylate and 3 compounds (i.e., Heptapropylene-glycol, Hydrogenated-terphenyl, Styrene) were evident with confidence level 3. 1,2,4-Trimethylbenzene and N-Dodecanoyl-N-methylglycine were identified with confidence level 4. The peak area of 4 compounds (i.e., Caprolactam, Hydrogenated-terphenyl, Melamine, N-Dodecanoyl-N-methylglycine) showed the time-independent trends, whereas the other substances continuously increased over time. These results are expected to expend our understanding of the fate of substances released from plastics through photodegradation.

Keyword: Plastics/ Leachate/ HPLC-HRMS/ Suspect and non-target screening/ Photo-oxidation

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Deletion of Glycine Betaine Transporter Gene Confers Increased Ectoine Accumulation in the Moderately Halophilic *Halomonas elongata*

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ABSTRACT

To survive in high-salinity environments, the moderately halophilic *Halomonas elongata* OUT30018 uses several mechanisms, including the biosynthesis and the uptake of compatible solutes, ectoine (Ect) and glycine betaine (GB), to accumulate as osmolytes inside the cell. This study aims to develop an *H. elongata* cell factory that can use a high-salinity medium derived from soy sauce dregs' hydrolysate (SH medium) as a substrate for efficient production of Ect, a high-value chemical used in the cosmetic and medical industries. However, soy sauce dregs and other waste biomass contain GB, and GB uptake and accumulation strongly suppress Ect production. To block the entry of GB into *H. elongata* cell, we deleted the *betH* gene, which encodes the GB transporter, from the genome of *H. elongata* OUT30018. Analysis of intracellular concentrations of Ect and GB in the recombinant *H, elongata* BN1 (Δ*betH*) cultured in SH medium containing 9% w/v NaCl shows that *H. elongata* BN1 accumulated higher level of Ect than the wild-type *H. elongata* OUT30018 cultures under the same conditions. As the *H. elongata* OUT30018 genome contains more than one GB transporter gene, subsequent deletion of more GB transporter genes from the *H. elongata* BN1 genome may further increase Ect accumulation.

Keyword: Ectoine/ Glycine betaine/ Osmolyte/ GB transporter/ High salinity/ *Halomonas elongata*

1. INTRODUCTION

In modern society, large-scale production technologies have improved and made our lives more comfortable. However, these technologies also generate large amounts of industrial waste, which has become a global problem. As a result, the concept of Sustainable Development Goals (SDGs) is gaining international momentum, although the advancement of science and technology to support SDGs is still in its early stages.

In our laboratory, we aim to establish the foundation for a recycling-oriented society by using genetic engineering approaches to develop cell factories for upcycling waste biomass from agricultural and fermentation industries into high-value chemicals.

In the project presented here, we focus on developing cell factories that can effectively produce Ect, which is a compound used in cosmetic, pharmaceutical, and medical industries [1, 2] using media derived from soy sauce dregs, which are the nutrient-rich high-salinity byproducts from the fermentation of soy sauce—an essential ingredient in Japanese food culture.

H. elongata OUT30018, a moderately halophilic bacterium isolated from salty soil in the Northeastern region of Thailand [3], was chosen as a host due to its ability to thrive in high-salinity media derived from biomass waste [4]. Although *H. elongata* OUT30018 can grow under salinity ranging from 0.3% to 21% w/v NaCl, the cell is subject to osmotic stress that causes various inhibitory effects on its biological functions in high-salinity environments. To protect cellular functions, *H. elongata* cell produces or imports compatible solutes such as Ect and GB (Fig. 1), accumulating them inside the cell as osmolytes. When the salinity level of the environment changes, these osmolytes can be released from the cell to maintain osmotic homeostasis with the environment. Interestingly, there is evidence that the uptake and accumulation of GB could decrease the ability of the cell to produce and accumulate Ect [5].

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As soy sauce dregs contain GB, we took a genetic engineering approach to delete a GB transporter gene (*betH* gene) from the genome of *H. elongata* 30018 in an attempt to minimize the negative effect of GB accumulation on Ect accumulation. Here, we report the effect of this deletion on the level of Ect and GB accumulation in the recombinant *H. elongata* BN1 (Δ*betH*) and discuss strategies to further increase Ect accumulation in *H. elongata* cells.

2. MATERIALS AND METHODS

2.1 Triparental mating method for transformation of H. elongata

The strains used in the triparental mating are the recipient *H. elongata* OUT30018 wild type, the helper *Escherichia coli*, and the donor *E. coli* harboring an engineered pk18mobsacB-Δ*betH* plasmid. These three strains were mixed and co-cultured on the PTFE membrane, and the *H. elongata* transformants with successful *betH* gene deletion were selected by culturing on selective media. Confirmation of the *betH* gene deletion was done by genomic PCR using specific primers, which bind to the 5’ and 3’ franking regions of the gene.

2.2 Culturing condition and osmolytes qantification

Pre-cultures were grown in 5 mL of LB medium containing 3% w/v NaCl in a 37^{o}C water-bath shaker until their OD_{600} reached 0.8. The main cultures were grown in a medium derived from soy sauce dregs hydrolysate (SH medium) containing 9% w/v NaCl. Osmolytes were extracted by dissolving cell pellets in MilliQ water for the cell to release osmolytes, including Ect and GB, into the supernatant, and the concentrations of Ect and GB were quantified by HPLC as mentioned previously [6, 7].

3. RESULTS AND DISCUSSION

3.1 Analysis of Intracellular Accumulation of Ect and GB in H. elongata OUT30018 grown in media containing GB

To determine the extent of interference the imported GB has on the cellular accumulation of Ect, we cultured the wild-type *H. elongata* OUT30018 in the LB medium containing 12% w/v NaCl. As shown in Fig. 1A, GB accumulation was much higher than the Ect accumulation in the cells cultured under this condition. These may result from the high GB content in the LB medium, making it easier for the cells to uptake GB and accumulate it as a major osmolyte than using cellular resources and energy in *de novo* biosynthesis of Ect. As the media derived from biomass waste usually contain high concentrations of GB, active GB accumulation would interfere with the ability of the cells to produce and accumulate Ect.

3.2 Generation of the Recombinant H. elongata **BN1** *with Genomic Deletion of GB Transporter Gene*

As shown in Fig. 1, *H. elongata* OUT30018 prefers to use the less energy-demanding GB uptake pathway over the *de novo* biosynthesis of Ect to protect the cells from hyperosmotic stress. Therefore, we hypothesize that suppression of the GB uptake pathway may force the cells to increase the production and accumulation of Ect. To block the entry of GB into *H. elongata* cells, we deleted the *betH* gene, which encodes one of the *H. elongata* OUT30018’s GB transporters, from its genome. The genomic structure of the *betH* locus on the genome of the resulting recombinant *H. elongata* BN1, in which the coding sequence (CDS) of the *betH* gene was deleted, is shown in Figure 2A. The result from genomic PCR with specific primers designed to amplify the DNA fragment between the 5’-upstream and the 3’-downstream regions of the *betH* CDS confirms the lack of the *betH* coding region in the genome of *H. elongata* BN1 (Figure 2B, lane #2).

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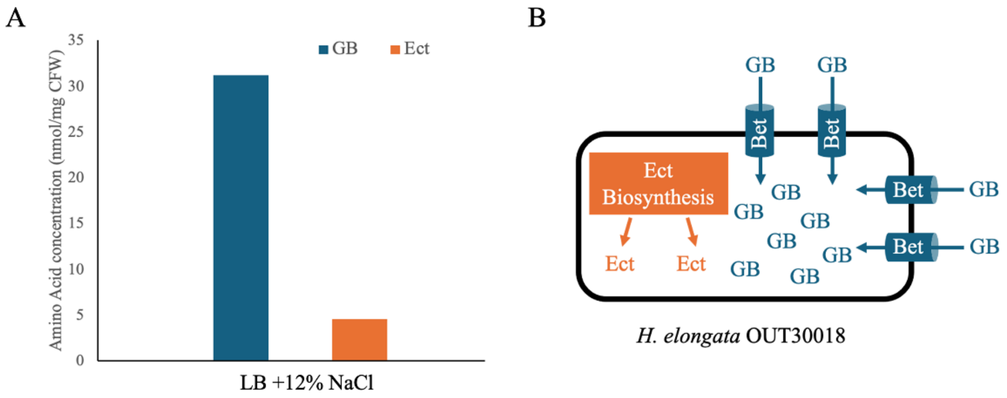

Figure 1. Ect biosynthesis and GB uptake are primary mechanisms for maintaining osmotic homeostasis within the cells of *H. elongata* OUT30018 grown in a high-salinity LB medium. A. The amount of Ect and GB accumulated in *H. elongata* OUT30018 cells cultured in LB medium containing 12% w/v NaCl. As the LB medium also contains GB, it was imported and accumulated in the cells as one of the major osmolytes. B. Schematic diagram showing the mechanisms used by *H. elongata* OUT30018 to maintain osmotic balance with its environment. The high salinity of the medium activates Ect biosynthesis and GB uptake. Ect, ectoine; GB, glycine betaine; Bet, GB transporter.

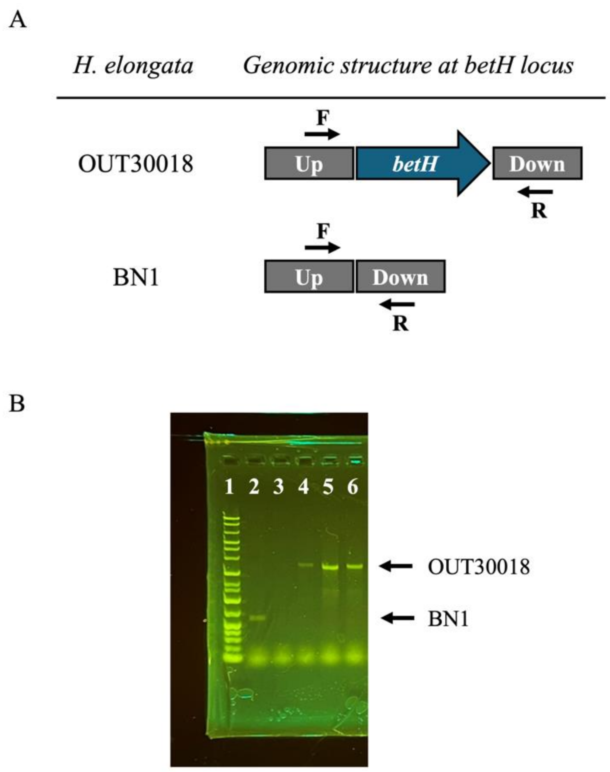

Figure 2. Genomic PCR is used to verify the absence of the *betH* coding region from the *betH* locus in the recombinant *H. elongata* BN1. A. Schematic diagram showing genomic structures of the *betH* loci on the genomes of *H. elongata* OUT30018 and *H. elongata* BN1. Up, 5’ flanking region of *betH* CDS; Down, 3’-franking region of the *betH* CDS; F and R, forward and reverse primers used in the genomic PCR reactions. Arrows indicate the annealing positions and directions of the primers. B. Agarose gel electrophoresis of the products of genomic PCR using specific F and R primers shown in A. Lane 1, Size marker; Lane 2, amplified fragments from PCR reaction using genomic DNA of *H. elongata* BN1 as a template; Lanes 4 to 6, amplified fragments from PCR reaction using genomic DNA of *H. elongata* OUT30018 as a template. Arrows indicate the amplified products with the correct sizes.

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3.2 Analysis of Intracellular Accumulation of Ect and GB in H. elongata OUT30018 and BN1 cultured in high-salinity SH medium

To determine the effect of *betH* gene deletion on the production and accumulation of Ect and GB, *H. elongata* OUT30018 and BN1 strains were cultured in SH medium containing 9% w/v NaCl. When the optical density at 600 nm (OD_{600}) of the cultured reached 0.8, the amounts of Ect and GB accumulated in their cells were analyzed by HPLC. As shown in Figure 3, the recombinant *H. elongata* BN1 accumulated a much higher amount of Ect than GB, which is the opposite of the result obtained for the wild-type *H.* elongata 30018 cultured in the high-salinity LB medium (Fig. 1A). However, the level of GB accumulated in the *H. elongata* BN1 cells was not significantly different from the level accumulated in *H. elongata* OUT30018 cultivated under the same conditions. This result indicates that, although *betH* gene deletion confers enhanced Ect accumulation in *H. elongata* BN1, this deletion alone was insufficient to suppress the GB transporting activity of *H. elongata* BN1 cells. Interestingly, different from the cell cultured in LB medium containing 15% w/v NaCl (Fig. 1A), *H. elongata* OUT30018 cultured in SH medium containing 9% w/v NaCl did not accumulate Ect in the cells (Fig. 3B). This result implies the existence of a strong suppression mechanism on Ect production or accumulation in the cell of *H. elongata* OUT30018 cultured in high-salinity SH medium.

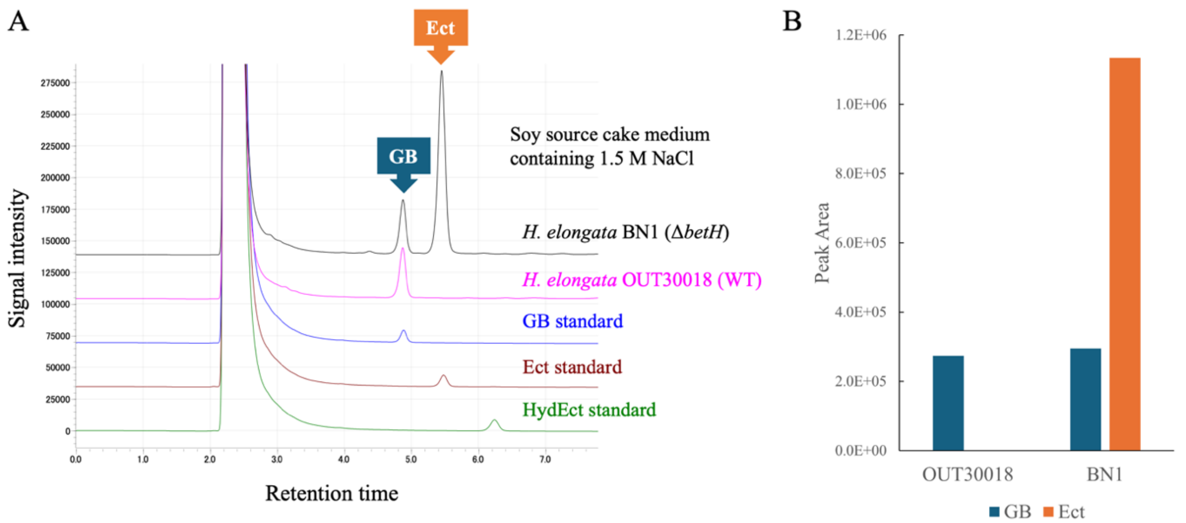

Figure 3. The amount of Ect and GB accumulated in the cells of *H. elongata* OUT30018 and BN1 strains cultured in SH medium containing 9% w/v (1.5 M) NaCl. GB, glycine betaine; Ect, ectoine.

4. CONCLUSIONS AND PROSPECTS

Based on the results obtained in this study, we conclude that the deletion of the *betH* gene positively affected the production and accumulation of Ect *in H.* elongata BN1 grown in high-salinity medium that contains GB. As the concentration of GB was still relatively high in the cells of *H. elongata* BN1, we plan to delete more GB transporter genes from the *H. elongata* BN1 genome to increase Ect accumulation further. To our surprise, *H. elongata* OUT30018 cells cultured in a high-salinity SH medium did not accumulate Ect inside their cells (Fig. 3B). This may be the result of severe suppression of Ect biosynthesis by high concentration of GB as shown in the case of *H. elongata* sp SBS 10 [5]. Other explanations include the influence of unknown amino acids or amino acid derivatives that can be imported from the SH medium and accumulated as intracellular osmolytes. Further experiments to obtain a comprehensive amino acid profile of the *H. elongata* OUT30018 and BN1 strains cultured in the high-salinity SH medium may help explain this result.

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Cell Surface Engineering as a Tool to Transform the Moderately Halophilic *Halomonas elongata* into a Nutritious Single-Cell Eco-Feed

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ABSTRACT

Cell surface engineering is a technology used to generate versatile microbial cell factories for various applications. We previously developed a cell-surface display system for *Halomonas elongata* OUT30018, a moderately halophilic bacterium that can be used as a cell factory to produce valuable amino acids and their derivatives. In this system, Lipoprotein 5 (LP5), an outer membrane protein encoded by *H. elongata* OUT30018's *Helipop5* gene, is used as an anchor to attach peptides of interest to the outer membrane. The attached peptides are, therefore, displayed on the cell surface. This work aims to use this system to generate a recombinant *H. elongata* that displays nutrient-rich peptides on the cell surface. Because Methionine (M), Lysine (K), and Tryptophan (W) serve as essential nutrients for fish, we first screened the genome of *H. elongata* OUT30018 for fragments that encode M-, K-, and W-rich peptides. As a result, a sequence encoding a short M, K, and W-rich peptide was found and was named a nutrient peptide (NP). Subsequently, the DNA sequence that encodes NP was cloned, and plasmids for surface-displaying one to eight repeats of the NP peptide as LP5-NP x1 to x8-HA fusion proteins were constructed. After the correct expression of these fusion proteins were confirmed in *E. coli* by immunoblot of crude protein extracts with anti-HA antibody, further plasmid constructs were prepared for expressing the LP5-NPx1 or LP5-NPx8-HA fusion proteins in *H. elongata* OUT30018. Although the constructs were successfully integrated into the genome of *H. elongata* OUT30018, generating recombinant *H. elongata* SN1 and SN8 strains, HPLC analysis did not detect any increase in the M, K, and W concentrations in their cell extracts. As the expression constructs were placed under the control of the relatively weak *Helipop5* promoter, we are currently working to express this construct under a more potent promoter in the proline-overexpressing *H. elongata* HN10 previously developed in our laboratory. Proline is an essential amino acid that also functions as a feed stimulant for fish. Therefore, Proline-overexpressing *H. elongata* equipped with surface-display NP could be used as a single-cell eco-feed for aquaculture. Successful implementation of this strategy will establish a proof-of-concept for a versatile platform technology for displaying peptides on the cell surface of *H. elongata* for diverse biotechnological applications.

Keyword: Cell surface engineering/ Feed additives/ Essential amino acids/ Self-cloning/ *Halomonas elongata*

1. INTRODUCTION

Fishmeal has been used as the main feed for the aquaculture industry due to its high protein content and well-balanced amino acid composition [1]. Due to a decrease in supply, the cost of fishmeal is increasing, making it essential to find a fishmeal alternative [2]. Plant proteins are considered the alternative [3]. Still, they do not contain sufficient amino acids essential for aquaculture feed, such as M, K, and W. Therefore, there is an urgent need to develop inexpensive and sustainable alternative feeds that contain enough essential amino acids.

Cell surface engineering is a technology used to generate microbial cells that can display various proteins on their outer membrane [4]. Due to the ability of a moderately halophilic bacterium, *H. elongata* OUT30018, to thrive in a medium derived from high-salinity biomass waste [5], here, we use cell surface engineering to transform *H. elongata* OUT30018 into cells that display M, K, and W-rich NP on their surface (Figure 1). While our findings indicate that the initial quantity of the displayed NP was low, we are currently devising a potential strategy to address this issue.

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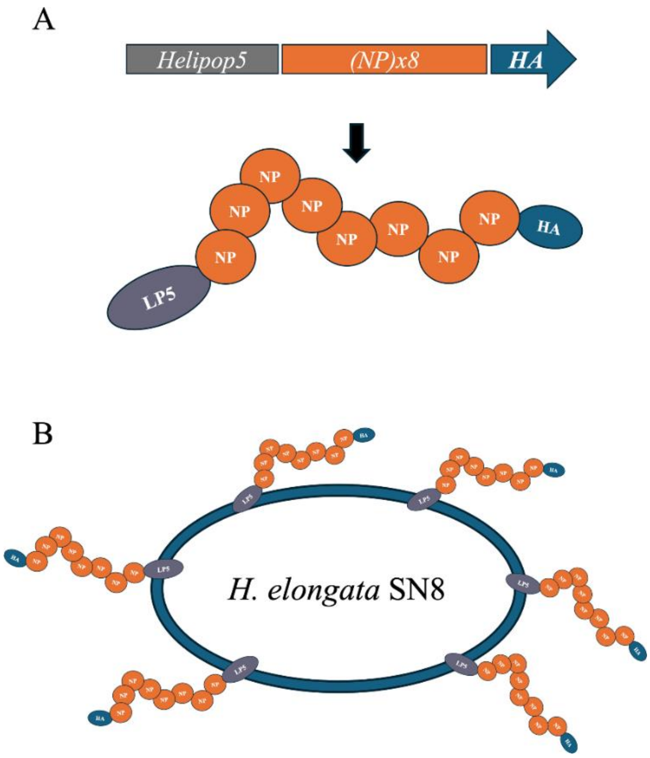

Figure 1. Generation of *H. elongata* displaying nutrient peptide (NP) on the cell surface. A. Structure of synthetic gene (*Helipop5*::*NP*x*8*::*HA*) for expressing eight repeats of NP on the surface of *H. elongata* SN8 cell. B. Schematic diagram of recombinant *H. elongata* SN8 displaying NP peptide on the cell surface. The NP peptides were anchored to the outer membrane through LP5 proteins. *Helipop5*, a gene encoding *H. elongata*'s lipoprotein 5 (LP5); (*NP*)x*8*, a synthetic gene encoding eight repeats of the nutrient peptide (NP); *HA,* a gene encoding the HA (hemagglutinin) tag, which is derived from the human influenza virus HA protein.

2. METHODOLOGY

2.1 Plasmid construction and protein verification

The DNA fragments encoding LP5, one to eight repeats of NP, and an HA tag (LP5-NPx1 to x8-HA) fusion proteins were assembled in pET vectors. The constructs were introduced into *E. coli* BL21-DE3 for protein expression. The correct expressions of the fusion proteins were verified by immunoblot with an anti-HA antibody.

2.2 Generation of recombinant Halomonas elongata

The constructs expressing LP5-NPx1 or x8-HA were assembled in the pK18mobsacB vector that will be used in the transformation of the *H. elongata* OUT30018 via the tri-parental mating method. After double homologous recombination, the expression cassettes encoding LP5-NPx1 or x8-HA would replace the coding region of the *Helipop5* gene, which encodes the native LP5 protein, on the *H. elongata* OUT30018 genome. Correct transgenes integrations in the transformants were confirmed by genomic PCR using specific primers designed to amplify the fragment between the 5' and 3'- flanking regions of the *Helipop5* coding sequence (CDS). The forward primer sequence was 5'-TACAACCAGCGCCTTTCCGAGCGTC-3', and the reverse primer sequence was 5'-CCGGAATGGGCAAGAAAGGGTGGACAAG-3'. Correct expressions of the fusion proteins were also confirmed by immunoblot with an anti-HA antibody.

2.2 Preparation of the microsomal protein fraction

The microsomal fraction was isolated from the crude protein extract by centrifugation at 12,000 × g for 15 min. After the centrifugation, the supernatant was collected as a soluble protein fraction, and

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the pellet was dissolved in phosphate-buffered saline (PBS) to the volume equal to that of the soluble fraction and used as a microsomal protein fraction.

2.3 High-Performance Liquid Chromatography (HPLC) analysis of dabsyl amino acids

Dabsylation of amino acids was performed based on a previously described method [6]. Briefly, the dabsyl amino acids solution of each sample was collected and filtered through a filter vial with 0.2 µm pore-size Polytetrafluoroethylene (PTFE) membrane (SEPARA® Syringeless filter, GVS Japan K.K., Tokyo, Japan) before being used as an HPLC sample. The quantification of dabsyl amino acids was carried out using an HPLC system (Shimadzu, Kyoto, Japan) equipped with a UV/VIS detector (SPD-10 A VP), an autosampler (SIL-10 AD VP), two pumps (LC-10 AD VP), degasser (DGU-14A), system controller (SCL-10A Vp), and column oven (CTO-10AC VP). The LabSolutions LC software (Shimadzu, Kyoto, Japan) was used to control the system and collect data. Dabsyl amino acids were separated through an analytical C18 column (Poroshell 120, 2.7 µm, EC-C18, 4.6 × 75 mm, Agilent Technologies Inc.) equipped with C18 guard column (Poroshell 120, 2.7 µm Fast Guard, EC-C18, 4.6 × 5 mm, Agilent Technologies Inc.) using a mobile phase gradient system consisting of 15% acetonitrile in 20 mM sodium acetate (pH 6.0) (mobile phase A) and 100% acetonitrile (mobile phase B). Dabsyl amino acids were detected by the UV/VIS detector at 468 nm. The injection volume was 10 µL, the flow rate was 0.5 mL/min, and the column temperature was maintained at 25°C. The eluent gradient was set as previously described [6].

3. RESULTS AND DISCUSSION

3.1 Expression of LP5-NPx1 to x8-HA in E. coli

To express the NP peptide on the cell surface, we designed a construct to fuse the NP-coding sequence to the *Helipop5* gene, which encodes Lipoprotein5 (LP5), a native outer-membrane protein of *H. elongata* OUT30018. A sequence encoding HA-tag was also added to the 3' end of these constructs, generating a series of pET plasmids containing *Helipop5*::*NP*x*n*::HA (*n*=1 to 8) expression cassettes. These constructs were introduced into *E. coli* BL21-DE3 for immunoblot verification of correct protein expressions from the constructs. As shown in Figure 2, all constructs were correctly translated. As indicated by the strength of the detection signal, proteins containing lower numbers of repeats (one to three repeats, Lanes 1 to 6) of NP are translated more efficiently, probably because they are smaller in size. Lower signals in Lanes 7 to 16 reflect the lower expression level of the longer peptide sequences (four to eight repeats).

Figure 2. Immunoblot of crude proteins extracted from *E. coli* cells expressing LP5-NPx1 to x8-HA fusion proteins. The HA-tagged proteins were detected by immunoblotting with anti-HA antibody. Lanes 1 and 2, LP5-NPx1-HA; Lanes 3 and 4, LP5-NPx2-HA; Lanes 5 and 6, LP5-NPx3-HA; Lanes 7 and 8, LP5-NPx4-HA; Lanes 9 and 10, LP5-NPx5-HA; Lanes 11 and 12, LP5-NPx6-HA; Lanes 13 and 14, LP5-NPx7-HA; Lanes 15 and 16, LP5-NPx8-HA; M, molecular weight marker; kDa, kilodalton.

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3.2 Expression of LP5-NPx1 and x8-HA in H. elongata

To generate *H. elongata* cells with surface-display NP, we further transferred the *Helipop5*::*NP*x1 or x8::HA constructs to pK18mobsacB *H. elongata* OUT30018 transformations. After confirming the correct integration of the transgenes by genomic PCR, crude proteins extracted from *H. elongata* SN1 and SN8, which contain expression cassettes of LP5-NPx1-HA and LP5-NPx8-HA fusion proteins on their genome, were also subjected to immunoblot analysis using anti-HA antibodies. The result shown in Figure 3 indicates that the strains correctly expressed LP5-NPx1 and LP5-NPx8-HA fusion proteins. The result also shows that most fusion proteins are correctly targeted to the cell membrane, as the detection signals were more substantial in the sample derived from the microsomal fractions. Further *in situ* immunolabelling with anti-HA antibodies would further confirm the presence of NP peptides on *H. elongata* SN1 and SN8's cell surface.

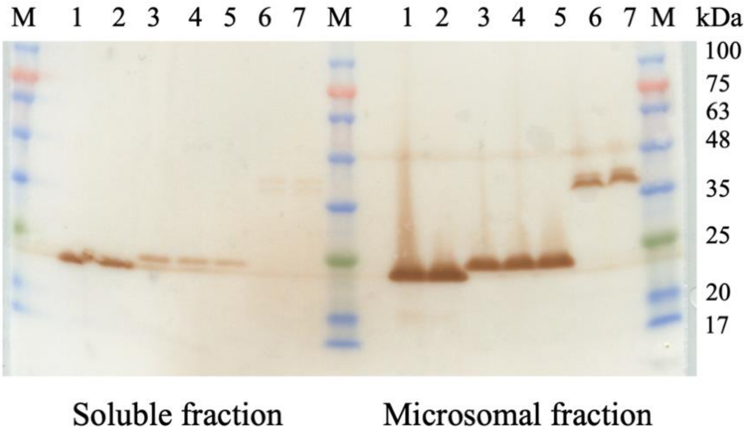

Figure 3. Immunoblot of soluble and microsomal fractions of the proteins extracted from *H. elongata* SN1 and SN8, which express LP5-NPx1-HA or LP5-NPx8-HA fusion proteins, respectively. The HA-tagged fusion proteins were detected by immunoblotting with anti-HA antibody. Lanes 1 and 2, control LP5-HA; Lanes 3, 4, and 5, LP5-NPx1-HA; Lanes 6 and 7, LP5-NPx8-HA; M, molecular weight marker; kDa, kilodalton.

4. CONCLUSIONS

We successfully expressed one to eight repeats of NP fused to the outer membrane LP5 protein in both *E. coli* and *H. elongata* cells. By separating the microsome fraction from crude protein extracted from *H. elongata* SN1 and SN8, we also confirm that the LP5-NPx1 or x8-HA are associated with the microsomal fraction. However, HPLC analysis of the amino acids content of the microsomal fractions found no difference in M, K, and W concentration between the extracts from *H. elongata* SN1, SN8, and the wild-type OUT30018 (data not shown). The weak activity of the *Helipop5* promoter may cause this. Therefore, our next step is to express *Helipop5*::*NP*x8::*HA* construct under a more potent promoter in the proline-overexpressing *H. elongata* HN10 previously developed in our laboratory [6]. Proline is an essential amino acid that also functions as a feed stimulant for fish. Therefore, Proline-overexpressing *H. elongata* equipped with surface-display NP could be used as a single-cell eco-feed for aquaculture. Due to the ability of *H. elongata* OUT30018 to thrive in a medium derived from high-salinity biomass waste, the development of a single-cell eco-feed with the genetic background of *H. elongata* OUT30018 has the potential to enhance the sustainability of the aquaculture industry.

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Hydrochar Production from Lignocellulosic Biomass and Evaluating Its Value Added Utilization

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ABSTRACT

With increase of social consensus for efficient resource using and sustainable energy production, various studies on adding value for waste and resource recovery have been conducted. Especially biochar production from waste by using thermochemical treatment methods (e.g., hydrothermal carbonization, gasification, pyrolysis, plasma, etc.) are receiving great attention in terms of reducing carbon emissions and utilizing abandoned carbon sources. Among the thermochemical treatment methods, the hydrothermal carbonization has energy efficient merit due to unnecessity of additional wet removal step for high moisture containing biomass and relatively low operating temperature comparing with the other thermochemical treatment methods. Spent mushroom medium, mainly consist of recalcitrant lignocellulosic biomass (i.e., lignin, cellulose, hemicellulose), was hydrothermally carbonized under temperature range of 180-300°C and converted into hydrochar. And the physico-chemical characteristics of hydrochar were analyzed by employing FTIR and SEM to evaluate feasibility of value addition for spent mushroom medium. The hydrothermal reaction helped moisture evaporation from inside of raw biomass, and it increased pore space and gave potential as a porous material. Since hydrothermal carbonization is operated under relatively low temperature to the other thermochemical treatment methods, few thermal destruction of surface functional groups was observed and most of functional groups were maintained. The high porosity characteristic of hydrochar and surface functional groups could promote direct interspecies electron transfer (DIET) effect and biogas production when injecting the hydrochar into anaerobic digesting reactor. Furthermore, increase of clean hydrogen energy production also would be expected by promoting biogas production using hydrochar.

Keyword: Direct interspecies electron transfer/ Functional group/ Hydrochar/ Lignocellulosic biomass/ Porosity

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Effects of Hydrothermal Pretreatment Temperature on Product Properties and Biogas Producing Potential using Lignocellulosic Biomass

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ABSTRACT

Coir medium, which widely used for mushroom cultivation, is made of coconut fruit hard shell by adding nutrient supplements. Cultivating mushroom using coir medium lead to involve large amounts of spent coir medium generation, and high lignocellulosic component concentrations in base material of spent medium could lower resource recovery and recycling potential. Various pretreatment methods have been recommended to improve availability of lignocellulosic biomass. Since hydrothermal process does not need to employ additional wet removal step and is operated under mild temperature range, the hydrothermal process is known as an energy efficient pretreatment method for high moisture containing biomass. The solid and liquid phase of products after hydrothermal process could be used for diverse purposes. Especially, liquid phase of hydrothermal process product could be used as substrate for biogas production by linking additional process (e.g., anaerobic digestion) due to presence of solubilized organic material in liquid product. In this study, effects of hydrothermal pretreatment temperature on physico-chemical properties of product (including solubilized organic matter concentration) with the pretreatment temperature range of 180-300°C. After pretreatment, the solid and liquid phases of products were separated by centrifugation and filtration (GFC, 0.45 um) sequentially. Finally, the obtained liquid phase of product was anaerobically digested under mesophilic condition and was converted into biogas. From the results, biogas producing potential from solubilized organic fraction of hydrothermal pretreatment process for spent coir mushroom medium was investigated. And the feasibility of using recovered biogas as source for clean hydrogen energy was also evaluated.

Keyword: Anaerobic digestion/ Biogas/ Hydrothermal pretreatment/ Lignocellulosic biomass/ Treatment

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Electrochemical Water Treatment and Hydrogen Production Using a PEM Electrolysis Cell

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ABSTRACT

Water electrolysis is an electrochemical process that utilizes electrical energy to decompose water into hydrogen and oxygen. Among various electrolysis methods, polymer electrolyte membrane (PEM) electrolysis exhibits high current density and produces high-purity hydrogen. When recalcitrant organic compounds, which are not effectively treated by conventional water treatment processes, are used as influent in a PEM electrolysis system, direct oxidation reaction occurs under the applied electrical energy, leading to the decomposition of these compounds. Additionally, when sodium chloride is added to the organic matter, oxidizing agents such as hypochlorous acid are generated, which induce indirect oxidation reactions of the organic compounds. Therefore, this study aimed to decompose representative reference organic substances, humic acid and bovine serum albumin (BSA), using a PEM electrolysis system and to quantify the amount of hydrogen produced as a by-product. The degradation efficiencies of humic acid and BSA were evaluated by analyzing total organic carbon (TOC) and the average molecular weight distribution using size-exclusion chromatography (SEC).

The minimum voltage required for hydrogen productions determined using deionized (DI) water. The optimal conditions for generating chlorine-based oxidants were derived by adjusting the concentration of sodium chloride and the flow rate of the influent. Subsequently, direct oxidation reaction of humic acid and BSA was confirmed, and the reduction in TOC and average molecular weight of the decomposed organic matter was observed following the addition of sodium chloride, indicating the effects of both direct and indirect oxidation reactions.

Keyword: Water electrolysis/PEM/Electrochemical water treatment/Hydrogen Production

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Evaluation of Ventilation Effectiveness After Kitchen Renovation in Schools of Gyeongsangnam-do Province

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ABSTRACT

In February 2021, the death of a school kitchen worker due to lung cancer was recognized as an industrial accident for the first time in South Korea. Since then, several confirmed and suspected lung cancer cases have been reported in lung cancer medical checkup. To protect the health of school kitchen workers, the Office of Education at Gyeongsangnam-do Province selected Twenty-eight schools and implemented environmental improvement projects focused on the ventilation system in the kitchens. To evaluate the ventilation system in the kitchen, fan flow rate and hood face velocity were measured, and concentrations of CO, CO_2, and $PM_{0.3}$ were measured during cooking operations. The smoke visualization technique was used to evaluate the capability of protecting worker's breathing zone. Mean Fan flow rate increased from $260m^3$/min before renovation to $794m^3$/min after renovation. Hood face velocity was tripled. The concentrations of $PM_{0.3}$ showed a 95% reduction. Concentrations of CO showed more than a 75% reduction. Smoke visualization showed greater protection of worker's breathing zone. The renovations to the ventilation system have resulted in improved ventilation performance, increased capture of cooking pollutants, and a safer and more comfortable working environment in the kitchen.

Keyword: Hood/ Kitchen/ Ventilation/ School

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Analysis of Urban Microclimate Characteristics Using ENVI-Met Modeling

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ABSTRACT

Urbanization leads to changes in land use, which in turn affects the local microclimate and has a direct impact on urban residents. Physical changes like shifts in land use influence micro-scale factors such as temperature and wind patterns in urban areas. These microclimatic changes can significantly affect thermal comfort and the dispersion of air pollutants like particulate matter. National weather data are often insufficient to detect these micro-scale variations, so using microclimate simulation tools is essential for accurate analysis. In this study, the microclimate simulation program ENVI-met was used to examine the microclimatic characteristics in an urban area based on its physical environment. The study focused on Won-i streets in Changwon, South Korea, which features various land use types, including single-family and multi-family residential areas. The area was modeled in the simulation, and the results were analyzed using ArcGIS Pro, dividing the area to extract data on land use ratios, impervious surfaces, sky view factor (SVF), and microclimatic variables. Correlation analysis showed that areas with larger impervious surfaces, such as those categorized as "roads" including parking lots, generally had higher temperatures. In contrast, lower temperatures were found in urban wetlands. When comparing single-family and multi-family residential areas, single-family areas were warmer. This was likely due to their low building height (1-2 floors), which provided less shading, and the surrounding impervious roads that caused heat to accumulate. In contrast, multi-family residential areas had more permeable surfaces, such as grass and trees, and taller buildings providing more shade, resulting in lower temperatures. These findings can help guide the management of urban thermal environments. Additionally, in areas with higher temperatures, the spread of air pollutants like particulate matter may be more active, making this data useful for managing pollutant dispersion.

Keyword: Urban microclimate/ Land use / ENVI-met/ Urban planning

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Analysis of GHG Reductions in Energy Transition Sector Based on National New and Renewable Energy Plan Scenarios in Korea

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ABSTRACT

South Korea has announced 2050 Carbon-Neutrality Scenario and 2030 Nationally Determined Contribution (NDC) to achieve carbon neutrality. According to the 2050 Carbon-Neutrality Scenario, South Korea has proposed energy transition as the primary strategy to reduce greenhouse gas (GHG) emissions. Specifically, the government has finalized the National New and Renewable Energy Plan (NNREP) to achieve the carbon neutrality goal in the section of energy transition. However, 2050 Carbon-Neutrality Scenario and NNREP do not provide specific GHG emission reduction in each year. Therefore, it is essential to quantitatively analyze whether the carbon neutrality goal could be achieved by the national plans. The NNREP consists of renewable energy 3020 implementation plan (plan A), the 5th basic plan for the development and utilization of new and renewable energy technology and supply (plan B), and the 10th basic plan of long-term electricity supply (plan C). In this study, GHG reduction scenarios was constructed for each plans A, B, and C. Then, energy supply capacity was estimated, based on the scenarios by using regression analysis. Finally, GHG reduction was estimated based on the supply capacity of each energy technology. The GHG reductions was analyzed by electricity generation amount of each energy technology. If GHG emissions are reduced to current rates, the year of achieving carbon neutrality was analyzed as 2057 for Plan A, 2061 for Plan B, and 2047 for Plan C. To achieve carbon neutrality, the analysis shows that 14.8% and 23.7% additional GHG reductions are required of Plan A and Plan B, respectively.

Keyword: Carbon neutrality/ Energy transition/ New and renewable energy plan/ Scenarios/ Greenhouse gas (GHG) reduction

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Analyzing the Relationship Between Local Climate Zones (LCZ) and Land Surface Temperature (LST) Focusing on Impervious Surfaces

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ABSTRACT

As urbanization rapidly progresses worldwide, more than 57% of the global population now resides in cities. This shift has resulted in a dramatic transformation of natural environments into built environments, leading to a significant increase in impervious land cover such as concrete, asphalt, and buildings. These changes have intensified urban environmental issues, notably the Urban Heat Island effect and heatwaves, both of which are directly linked to rising temperatures and have severe implications for aspects such as health, energy consumption, and overall urban life quality. Furthermore, the concentration of impervious surfaces in cities alters local climate patterns by reducing natural cooling processes, such as evaporation and shading, intensifying the heat accumulation in urban areas. Given the growing occurrence and severity of extreme heat events driven by climate change, it is becoming ever more crucial to understand thermal vulnerabilities across various physical environments within cities. Comprehensive knowledge of these vulnerabilities can inform the development of effective mitigation and adaptation strategies, which are essential for ensuring sustainable development in the face of growing climate challenges. In this study, we utilized the Local Climate Zones (LCZ) classification, which is based on consistent land cover types and urban spatial structure, to analyze the distribution of Land Surface Temperature (LST) across different types of physical environments. Furthermore, we examined the correlations between LST the share of impervious surfaces, along with building heights, for each LCZ type. This analysis allows us to identify the thermal characteristics and vulnerabilities of each LCZ type, providing foundational data for developing sustainable urban planning strategies that consider thermal environments and adapt to climate change.

Keyword: Local climate zone/ Land surface temperature/ Climate change/ Correlation analysis/ Urban planning

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