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The Methodology to Evaluate Food Waste Generation with Existing Data in Thailand

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Abstract

According to the Sustainable Development Goal 12.3, there is a target to reduce global food loss and waste by 50 percent, by 2030. Currently, Thailand does not have a food waste database or food waste index reports that employ highly accurate methods of measurement. So, tackling the amount of food waste generation is a top priority and challenge in achieving the SDG target. This research aims to present a method that can be adapted to report the amounts of food waste based on available data constraints and a systematic review of the literature, in comparison with the UNEP food waste index report. Due to the limited availability of food waste data in Thailand, especially at household, food service, and retail levels, this study uses level 1 modeling to estimate food waste generation occurring at the national level. These data are based on municipal solid waste (MSW) volumes and organic waste composition. As reported by the Pollution Control Department, organic waste, accounting for 63.57 percent total of garbage, was collected by municipalities across the country. The result showed that the level 1 food waste index of Thailand was 167 kg/capita/year, a value lower than that reported by UNEP. The UNEP Food Waste Index Report 2021 provides a household food waste measure in Thailand of 79 kg/capita/year. The limitation of the estimated calculation of the level 1 food waste index is that the total amount of food waste cannot be classified by sector (households, food service, and retail), material type including edible part (human consumption), and inedible parts (bones, rinds, etc.), and the destinations. The level 2 and level 3 food waste indices both consist of the quantification and qualification of waste by sector, material type, and destinations. On the other hand, the quantification methodology of measurement should be combined with methods that gather more comprehensive information, up to the level of accuracy that includes access to the physical food waste being quantified. The results from this study led to a recommendation to define and select the appropriate methodology of measurement for food waste quantification and disaggregation depending on the main purpose, specific conditions, the technology available. These existing resources are key to tracking and monitoring progress towards the achievement of the food waste reduction targets.

Keywords : Food waste; Methodology; Quantification; Sustainable Development Goal 12.3

Introduction

Almost one-third of the food produced for human consumption around the world is lost or wasted along the food supply chain [1]. More than 931 million tons of food waste were created globally in 2019 representing one of the main sources of greenhouse gas emissions from human activities [2]. Global food loss and food waste (FLW) contribute approximately 4.4 $GtCO_2eq$ emissions each year, or 8 percent of total human greenhouse gas emissions. South and Southeast Asia, including Thailand, are responsible for a carbon footprint of food wastage of 350 kg CO_2 of GHG emissions per person [3]. The Sustainable Development Goals target 12.3 (SDG 12.3) aims to reduce global food loss and waste along the food supply chain by 50 percent, by 2030. Two indicators are tracked; Indicator 12.3.1(a); the Food Loss Index refers to measures at the production, post-harvest, and processing stages of the food supply chain excluding retail; and Indicator 12.3.1(b) the Food Waste Index, measures food waste that occurs at the retail, food service, and household level. The UNEP Food Waste Index Report 2021 announced Thailand produced an average baseline of 79 kg of food waste per capita per year, compared with the household food waste generation in ASEAN countries, in the range from 76 to 91 kg/capita/year. Vietnam averages 76 kg/capita/year, one of the lowest rates, and the highest level of food waste in South-eastern Asia is Malaysia at 91 kg/capita/year.

To achieve the Sustainable Development Goals target for reducing food waste (FW), data need to be collected that will measure exactly how much baseline food waste there is, along with monitoring that supports the prioritization of recommended actions and policies. Currently, Thailand does not have a food waste database or an accurate method of measurement used in the food waste index reports. Therefore, tackling the amount of food waste generated is a top priority and challenge in achieving the target. In Thailand, the volume of municipal waste is increasing significantly every year. The Pollution Control Department [4] reported that 63.57 percent of the total waste sent to landfills was organic waste. Also, the Bangkok Metropolitan Administration reported that an annual average of 46 percent (2011–2018), or around 4,284 tons in 2020, of total solid waste, is food waste [5], which is not a clear representation of the food waste index for the rest of Thailand. Therefore, tackling food waste generation with appropriate methods that have a high accuracy of measurement is a top priority and challenge in achieving the SDG target.

The limitations of the current qualitative data are the lack of availability of data on the national amount of food waste. The purpose of this paper is to provide a method for the country to report the available data on the quantity of food waste. This will include comparing the calculated results with the Food Waste Index Report 2021 values, from the United Nations Environment Programme (UNEP). In addition, appropriate statistical methods and estimators are suggested for highly accurate and reliable small-scale estimates of direct measurement methods.

Materials and Methods

The FW evaluation of the food loss and waste protocol has been adopted in this study. FLW Protocol Steering Committee published the food loss and waste accounting and reporting standard (FLW Standard) [6] that provided the requirements, steps to guide the preparation of an FLW inventory, and the principles of accounting and reporting for governments, companies, and other entities. The four components of FLW Protocol scope are based on the time frame, material type (classified as food, edible part, inedible parts, or both), the destination once removed from the food supply chain (Animal feed, bio-based materials/biochemical processing, co-digestion/ anaerobic digestion, composting/aerobic processes, controlled combustion, landfill, and wastewater treatment), and finally the external elements of the food category, life cycle stage, geography, and organization.

The definition of Food Waste (FW) is defined as any substance, drink that is intended for human consumption includes edible parts and inedible parts measures at retail, food service, and households while, Food Loss (FL) is defined as along production and supply chains, including post-harvest losses [2, 7]. The composition of municipal solid waste (MSW) is food waste, garden waste, paper, wood, rubber/leather, cloth, plastic, foam, metal and aluminum, glass, hazardous waste from the community, electronic waste, infectious waste, and others. FW is defined as a classification of municipal solid waste composition into 12 categories consisting of vegetable scraps, meat scraps, bones, fruit peels, including scraps of raw materials discarded from cooking and discarded food waste excludes any packaging such as banana leaves, plastic bags, film sheets, foam trays, grilled skewers [8].

In the Guidance on FLW Quantification Methods by FLW Protocol [9], there are 10 quantification methods: direct measurements, counting/scanning, assessing volume, waste composition analysis, records, diaries, surveys, mass balance, modeling, and proxy data. Consequently, selecting the most appropriate method for data collection is very important due to the lack of existing data in the Thailand context. The amount of food waste in the national report can be estimated based on the total mass of the municipal solid waste. This indicator is measured by the total amount of food that is wasted in tons, or in terms of the percentage of what is considered to have no economic value and what is food packaging.

The UNSTATS [10] suggests a flexible three-level approach to presenting a methodology that is consistent and comparable information can be compared at regional levels. For level 1, the global model approach will estimate the proportion of food waste in the total waste stream data and municipal solid waste, and then apply the proportion to the total food waste to the existing information. Level 2-3 should identify the scope of which stages of each food supply chain are generated by retail, food service, and household sector. This will be further also divided by material type (edible part, inedible part) and destinations such as animal feed, anaerobic digestion, and landfill.

This study was collected the existing quantitative data from national statistics national of municipal solid waste (MSW) which generated from households, retail, food service, and office buildings and institutions, also the proportion of organic waste fraction, population statistics, and the proportion of household sector. The food waste estimates at level 1 can be calculated by equation (1).

$$FW = \frac{MSW \times f_{ow}}{pop} \times f_{HH} \qquad (1)$$

Where FW is the food waste estimates in kilograms (kg) per capita per year, MSW is the municipal solid waste of the country in tons per year, f_{ow} is the proportion of organic waste fraction in percentage, pop is the number of populations, and f_{HH} is the proportion of household sector.

Results and Discussion

The FLW quantification methods provide 10 methods for collecting primary data and secondary data. The best way is to consider the appropriate methods is to find a balance between robustness and feasibility [11]. The terms of robustness refer to primary data, time series, representativeness, data validation, and uncertainty; whilst feasibility refers to cost or budget, data availability, time, and personnel. The most important criteria are based on goal collect data and waste management scheme in the destination. For example, if the objective is to reduce the total annual food waste by focusing on the waste management at the destination, then the most accurate way to collect data would require direct measurements that cover all seasons, which would require the investment of money, labor, and time. In contrast, if the objective is to provide policies to solve hot spot problems, then the money and time needed to classifying food waste into many complicated categories will increase greatly.

This study provides a feasibility assessment for food waste accounting through comparing the primary data and secondary data collection methods.

1. Calculation with existing data

Apart from the lack of a food waste database with high accuracy methods of measurement, the estimated food waste from secondary sources can be collected from public information provided by government statistics.

The proxy data can be extrapolated to infer quantities, using a mathematical approach that results in a quick estimate. The resulting estimates will be inaccurate but typically costs less than using actual measurements.

According to UNEP the accepted method for national reporting at Level 1 is based on estimations of the proportion of the total food waste from municipal solid waste (MSW) gathered from the accommodation, food services, manufacturing, and retail trade sources. In 2019, the Pollution Control Department (PCD) [12] reported a total generation of municipal solid waste of 28.71 million tons, of which food waste accounted for 63.5%, while the Environment Department, Bangkok Metropolitan Administration (BMA) reported it as 46% (the average of data during 2011–2018) [5], as shown in Table 1. FW contributes a huge portion in the MSW, makes from 59 to 70% of the MSW depending on the city [12]. However, there are some reports by the local municipalities that showed that FW was estimated lower than that of PCD reported. For example, in Samut Songkram Province [13], food waste accounting for 30.3% of total municipal solid waste, consists of rice and bakery 28%, fruit and vegetable 22%, leaf scraps/banana leaf for wrapping food 18%, meat 25%, and other 7.4%. In Phra Nakhon Si Ayutthaya, reported that an average food waste shared about 29.4% of total MSW in 2021; the highest proportion of FW in MSW was in the Subdistrict Administrative Organization (41.4%), followed by Town Municipality (28.5%), Subdistrict Municipality (26%), and City Municipality (21.7%) [14]. Moreover, Surin Town Municipality showed that the FW contributed 39.2% of total MSW in 2019 [15].

The result showed that the food waste index was calculated by using the PCD data based on the MSW generated and the proportion to the total food waste was 167 kg/capita/year in 2019, but when looking at the proportion to the total food waste calculated by the Environment Department, BMA was 121 kg/capita/year. When compared the result with the UNEP food waste index report 2021, this study reported higher levels than the UNEP reported due to the organic waste proportion in MSW, including both food waste, leaves, weeds, twigs, grass, and shrubs. The UNEP reported that the household food waste in Thailand was 79 kg/capita/year in 2019 and the proportion of global averages of generated food waste classified by sectors was: 61% from households, 26% from food service, and 13% from retail, and 14% is lost from food production [16].

The estimated household food waste of Thailand during 2010-2019 has increased continuously every year, as shown in Table 2 and Figure 1. When comparing the total food waste results of this study with the household food waste in developed countries in Asia: in Korea [17], the result indicated that the food waste of Thailand was higher than that of the household food waste in Korea (95 kg/capita/year). This is due to the Korea case study using the direct measurement method and considering the influent factor of seasonality and housing types while this study uses the organic waste composition to estimate the total food waste. In addition, Elimelech et al. [18] reported that the household food waste in Israel is 96.2 kg/capita/year, which accounts for 45% of the household waste composition. Moreover, Liu [19] shows that household food waste in Japan is 96.2 kg/capita/year using the statistical data and calculation method, which accounts for 29% of the household waste composition. Segrè et al. [20] presented that food waste by household in industrialized Asia countries are 80–90 kg/capita/year, while this figure in South and Southeast Asia is only 10–20 kg/capita/year. On the other hand, comparing the household food waste in developing countries in Asia: in Vietnam and Cambodia [21], the household food waste is 190 and 146 kg/capita/year, respectively as shown in Table 3.

Table 1 Lists national data relating to evaluating household food waste with existing data

Year	Detail	Amount	Reference
2019	Total generation of municipal solid waste	28.71 million tons	The Pollution Control Department (PCD) [4, 12]
	The proportion of the food waste in municipal solid waste	63.57%	
	Total population of Thailand (Excluding non-registered population)	66.5 million	National Statistical Office [22]
	The proportion of global averages of generated food waste classified by sectors: Households	61%	UNEP [2]
	Food waste index in Household level	167 kg/capita/year	Evaluate food waste generation with existing data

Table 2 Household food waste estimation from municipal solid waste of Thailand in 2010-2019

Detail	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Population (Million people)	65.98	64.08	64.46	64.79	65.12	65.73	65.93	66.19	66.41	66.56
Amount of MSW (Million tons)	24.22	25.35	24.73	26.77	26.19	26.85	27.06	27.37	27.93	28.71
Amount of Food Waste (Million tons)	15.40	16.11	15.72	17.02	16.65	17.07	17.20	17.40	17.75	18.25
Household Food Waste (63.5%) (kg/capita/year) [4]	142	153	149	160	156	158	159	160	163	167
Household Food Waste (46%) (kg/capita/year) [5]	103	111	108	116	113	115	115	116	118	121

Remark: [4] The Pollution Control Department (PCD); [5] Bangkok Metropolitan Administration

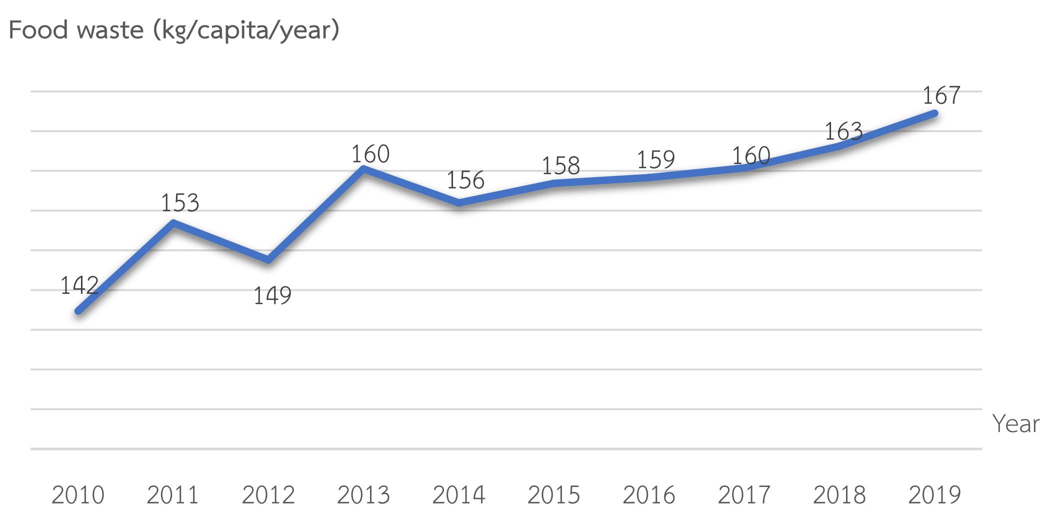

Figure 1 Household food waste estimation of Thailand in 2010-2019

Table 3 The comparing the household food waste in Asia

Country	Amount (kg/capita/year)	Year	Method
Thailand (this study) based on FW 63.57% of total MSW	167	2019	Estimation with existing data.
Thailand (Bangkok) based on FW 46% of total MSW	121	2019	Estimation with existing data.
Thailand reported by UNEP	79	2019	Extrapolating data from other countries [2]
South Korea	95	2019	Direct measurement [17]
Israel	96.2	2016	Weighing method [18]
Japan	48.9	2014	Calculated from the statistical data [19]
Vietnam (Da Nang)	190	2018	Literature data [21]
Cambodia (Phnom Penh)	146	2015	Literature data [21]
Industrialized Asia	85	2012	Literature data [20]
South & Southeast Asia	10-20	2012	Literature data [20]

2. Case studies

The conception of a global measurement method and report in levels 2-3 have been applied in a few studies in Thailand. A small study based on the urban community in Pathum Thani province focused on food waste generated at the consumer stage of the food supply chain. The data collection process from households, such as types of wasted food and the amount of food disposed of, were collected through voluntary participants weighing and recording food waste that they disposed of in a bin separate from other general municipal waste in order to separate the waste into animal feed (fish and dog feed) or landfill. Direct measurements are highly accurate if calibrated and proper measurements are used, but the disadvantages of weighing are the amount of effort and costs involved. Weighing total food waste and measuring the amount (weight) per food category requires separation from the packaging, non-catering waste, liquid waste, and moisture content of FW. This more detailed attempt will classify different types of food waste according to food categories.

This result showed that the direct measurement and sorting analysis of the household food wastage (direct weighing, waste composition analysis, and recording) were feasible in the testing of the methodology for a small sample in an urban community. It should be noted that food waste can be separated from MSW for the small communities. However, our study showed that the classification the food waste based on the universal standard, as the edible part and inedible part, was impossible. This was due to the limited funding, the time-consuming nature of it, the diverse mix of food items resulting in difficulty to classify, and the concept of avoiding food waste due to distinction in food customs. Moreover, the categorization of food waste into five food categories groups of cereals, fruits and vegetables, meat, tuber crop, and others can be unclear and the classification scheme difficult to understanding. Uncertainty in data is very important and thus the study should select an appropriate representative sample size to collect the data whilst dealing with nonresponse biases.

3. Discussion

Our findings showed data collection at the destination is more complex than at the source because separating many sources from large piles of waste brings problems for staff due to the fact that high temperatures and humidity throughout the year in Thailand rots food quickly. The advantage of household food waste sorting at the source is the most effortless management of food waste in the community. For example, we can divide food waste directly into animal feed such as utilizing fruit and vegetable waste to fish feed, or recooking rice, meat, and inedible meat (bones) into dog feed. In addition, the classification of food at collecting points can be useful for saving costs and time. In this study, staff estimations show similar results to the direct weight measurement. From this, we concluded that the initiative method of food waste evaluation should be practical and not unnecessarily complicated. In addition, it is challenging to balance between the representative of primary data and the feasibility of data access, the cost, and time make it paramount to develop clear standard guidelines on how to select a representative sample of national statistics for forecasting the national food waste index.

Future studies should investigate the association between cause and reason for food waste generation and suggest proper options to reduce and prevent wasted food. Consumption and wasted food depend on consumer behavior and involve multiple factors. A recent study on food waste was carried out in Malaysia [23], where a survey was used to examine Malaysian wasted food awareness, knowledge, attitudes, and behaviors. In addition, the influence factors of the season and household types on food waste generation rate should be considered. In the summer season and a single-family home was the highest rate of food waste generation [16]. Moreover, WRAP [24] identifies the reason why consumers throw away food that 33 reasons such as buying and making too much food which understanding of food waste in terms of the amount and types of food waste to reduce food and packaging in the household garbage bins. The implemented project in Australia [25] that a paper-based color coding in refrigerators in households, assigning colors to food types (e.g., green to fruit and vegetables, red to meat, etc.) for raising awareness and communication lead to reduce the quantify of available food items in the fridge. In Thailand, the average temperature is high all the year that most affecting wasted food, so improving technology for cooling storage and packaging help to reduce spoil of food.

Conclusions

Overall, in this study, we propose a food waste evaluation method with existing data that is feasible to report the level 1 UNEP food waste index and is more useful for filling data gaps in an inventory than in actual data. In general, official information or Statistics Database sources held by the government is based on reliable research. For this reason, an evaluation method with existing data should be the beginning before moving into more specific measurement methods that establish more reliable monitoring and reporting of national. Nevertheless, this method cannot be used to track progress over time and cannot be used to identify hotspots or causes.

However, direct weighing of waste could give significantly more accurate data to possibly compare at national levels. Estimation of food waste at 2-3 levels allows the total amount of food waste to be classified by sector (households, food service, and retail), material type including edible part (human consumption), and inedible parts (bones, rinds, etc.), and to record the destinations of that food waste. Furthermore, FW accounting by direct measurement should be based on a broad understanding of the context in which the FW is generated, with a constant focus on the aim of the accounting and the classification scheme, must be reasonably easy to understand, for those staff members conducting the analyses. On the other hand, the quantification methodology of measurement should be a combination of methods that gather more comprehensive detailed information in terms of relevance, reliability, level of accuracy, traceability, and comparable to access the physical food waste being quantified. It is important to perform an initial uncertainty analysis to determine the most appropriate representative sample size.

Food waste reduction requires a cooperative effort from all parties across the supply chain, whether it is in raising awareness, policies, and laws, or in the support of operations, or in the management of technological developments. The participation of the public sector has greatly helped to reduce the amount of wastage at the source and tracking and monitoring this progress will aid in the achievement of halving food waste worldwide.

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Application of Data Envelopment Analysis for Assessment of Eco-Efficiency of Food Shops at Phuket Island, Thailand

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Abstract

Located in the southeast of Thailand, Phuket is an eminent tourist destination not only for its natural splendor but also for its culinary development. In 2015, the island was recognized as a "City of gastronomy" by the United Nations Educational, Scientific and Cultural Organization (UNESCO) proving the undeniable influence of food services on the prosperity of the tourism industry at this island. Together with the aim to increase revenue from the gastronomy, Phuket has also committed to developing responsible and sustainable production and consumption of local food resources. As a contribution to a more balanced development of food services, this study aims to investigate the performance efficiency of food service at Phuket Island in terms of environmental and economic aspects. Data Envelopment Analysis (DEA) had been adopted to study the comparative efficiency performances of 298 food shops at Phuket Island, based on the input and output of the food shops during the operational process. The results being interpreted for different aspects with different comparisons showed the relationship between input (i.e. utility consumption), undesirable output variables (i.e., greenhouse gas (GHG) emissions, and waste disposal), and desirable output (i.e., net profit) in the studied food shops. It was revealed that the electricity consumption accounted for the major share in terms of utility consumption and GHG emission, resulting in the most notable impact on the efficiency score, which was evaluated based on the input and output of the food shops during the operational process. Food shops with lower electricity consumption are clarified as the majority of food shops having a high efficiency score. The surrounding area also played an important role in the efficiency score of the food shops. Food shops in the areas with well-known tourist destinations, such as central Thalang District, southeastern Mueang District, and southwestern Kathu District were more efficient than the food shop in more remote locations such as eastern Thalang District and the northeastern part of Kathu District which are rural areas covered by a variety of mountains and forests with low population.

Keywords : Data Envelopment Analysis; Eco-efficiency; Food service; Phuket Island; Tourism; Food shop

Introduction

As a tourist hub of the region, Phuket - a popular island in Thailand - is one of the fastest developing provinces in Thailand in terms of economy and society, mainly due to the development of tourism [1]. It is the second most visited destination in Thailand after Bangkok, accounting for nearly one-third of all visitors to Thailand. According to statistics from the Tourism Authority of Thailand (TAT), Phuket received about 8.4 million international tourists in 2013, contributing over USD 6.99 billion to the province's revenue [2]. In 2016, the number of international tourists coming to Phuket increased considerably to over 9.6 million people, resulting in an economic contribution of over 10 billion USD [3]. Tourism was expected to be a promising industry in Phuket in the coming years.

Within the tourism industry, expenditure on food has long been one of the largest shares, accounting for about one third of tourists' spending [4]. In the case of Phuket, the food shop business also has a major impact on the economy. On average, a tourist in Phuket spends approximately 43 USD per day on food and drink, accounting for almost a fifth of a tourist's total expenditure per day. This proportion is even higher for travelers (who do not spend on accommodation); they spend about 30% of their budget on food and drinks. Furthermore, Phuket is also a particular representative of Thai cuisine. In 2015, the local government of Phuket joined the Creative Cities Network of the United Nations Educational, Scientific and Cultural Organization (UNESCO), and Phuket was the first city in ASEAN to be awarded the title of Creative City of Gastronomy [5]. This could be beneficial for Phuket to attract more tourists and develop the city's tourism business. The development of tourism, especially gastronomy, could be an advantage, but it also has some harmful effects on the island's environment. The demand for natural resources in Phuket has increased in response to the increase in tourist arrivals, the number of people eating out, and the number of food shops. Therefore, food shops also have an important link to environmental responsibility as they can be considered one of the largest consumers of resources (e.g., energy and water) and disposers of waste, especially food waste. Due to the significant impact of the hospitality industry on the environment, sustainable tourism research should be extended to food-related areas. Examining the inputs, outputs, and practical benefits of the enterprise gives us a more comprehensive view of sustainability.

The main idea of the eco-efficiency (EE) concept is to create more value with fewer impacts on the environment and less consumption of natural resources, thus bringing together environmental improvements that yield parallel economic benefits [6]. The effectiveness of the approaches is assessing the environmental performance of industrial systems and products using single performance factors, such as energy efficiency or fuel efficiency. However, multiple performance factors are often needed for a comprehensive holistic measurement as efficiency evaluation has become more complex and multidisciplinary [7]. Thanawong et al. [8] studied the EE of rice crops in Thailand. While their study offers a reasonable proxy for sustainability analysis, it has an issue of multiple EE ratios (the same number of environmental impacts included). To solve this problem, a weighted totality of the numerous environmental impacts is usually employed to construct an incorporating environmental impact score. The crucial question is how the weights should be selected or determined. DEA combined with EE was considered to be a solution for aggregating different environmental pressures to construct an encompassing of EE indicators.

DEA is a well-known mathematical procedure that uses a nonparametric linear programming technique to evaluate the relative efficiency of a set of similar entities named decision making units (DMUs) such as public organizations and the private sector, or even regions and countries [9]. This method is employed to determine the weights of each environmental impact when building an incorporating environmental impact score. In the traditional DEA (T-DEA), a DMU can attain its maximum efficiency score using its most promising multiplier weights. It has been applied to recognize the efficient DMUs performing best practices and to assist the improvement of the inefficient units by providing optional targets to increase outputs or lessen inputs [10]. In the case of having more than one DMU assessed as efficient, Shannon's entropy DEA (S-DEA), a method developed to calculate optimal weights with the importance degree, can help offer further discrimination among them [11]. Therefore, using both T-DEA and S-DEA models can help to enhance the benefit of using DEA approach.

Despite an increase in DEA applications for efficiency measurement, there is a shortage of research employing this method in the food shops. Most of the research using DEA are in the context of airline industry, other few research focus on restaurants in the USA, European and other countries in Asia [12] such as Iran [13] and Taiwan [14]. However, the results from international studies using DEA for evaluating restaurant efficiency might not be applicable to the Phuket food shops due to a different geographical and economic context [15]. Because of the significance of food shops in tourism industry, studies in this setting were conceptualized. The hypothetical influence relates to driving factors affecting food shop efficiency from a study, where such findings could reflect similarities and differences that could be supportive for operational and management endeavors [12]. Hence, the aim of this study is to evaluate the performance efficiency of food shops in Phuket in terms of environmental and economic aspects using T-DEA and S-TEA.

Materials and Methods

1. Study area

Phuket is located at 7°53'24" N and 98°23'54" E in the south of Thailand. It is the largest island province in Thailand, consisting of 39 smaller islands. It lies off the west coast of Thailand in the Andaman Sea and stretches 49 km from north to south and 19 km from east to west with a total area of 570 km^2 including the province's other islands. Phuket is divided into three districts, which are further subdivided into 17 sub-districts, and 103 villages.

2. Methods

This study uses primary data obtained from questionnaire surveys from different food shops in Phuket for the efficiency assessment. The data collection was conducted in 2017 to early 2018. T-DEA and S-DEA methods are employed to determine the efficiency performances of food service. The research process is presented in Figure 1.

2.1 Questionnaire

A total of 925 questionnaires were filled out. However, the dataset was screened and trimmed to produce the minimum relative error. Finally, data from 298 sampled food shops were analyzed. The distribution of surveyed objects is shown in Figure 2. The distribution of the samples is not widely ranged around Phuket based on food shops' locations. Also, it depends on the food shops' consent to complete the survey.

The survey used both open-ended and close-ended questions both in English and Thai. Participants in the study group were chosen by stratified random sampling into three districts of Phuket Province. The questionnaire provided the information on types of the food shop (i.e., Air conditioning (AC), non air conditioning (Non-AC), and hawker), type of cuisine (Thai/Phuket food, international food, dessert/beverage, and others), costs of operation (electricity fee, tap water fee, and cooking gas), and average profit.

2.2 Eco-efficiency calculation

Considering environmental influence, the WBCSD [16] states the following types of consumption as applicable indicators: energy, materials, water, and GHG emissions. In this research, resource consumption (including electricity, LPG, fuel, and water) and GHG emissions from the utility consumption were focused on.

For the economic value part, Seppälä et al. [17] suggested three economic indicators to represent the value of products and services in regional EE analysis, that is, GDP, value added of industries and output at basic prices. In consideration that our research focuses on the efficiency of small-to-medium enterprises, the net profit margin of food shops was selected to represent value of products and services.

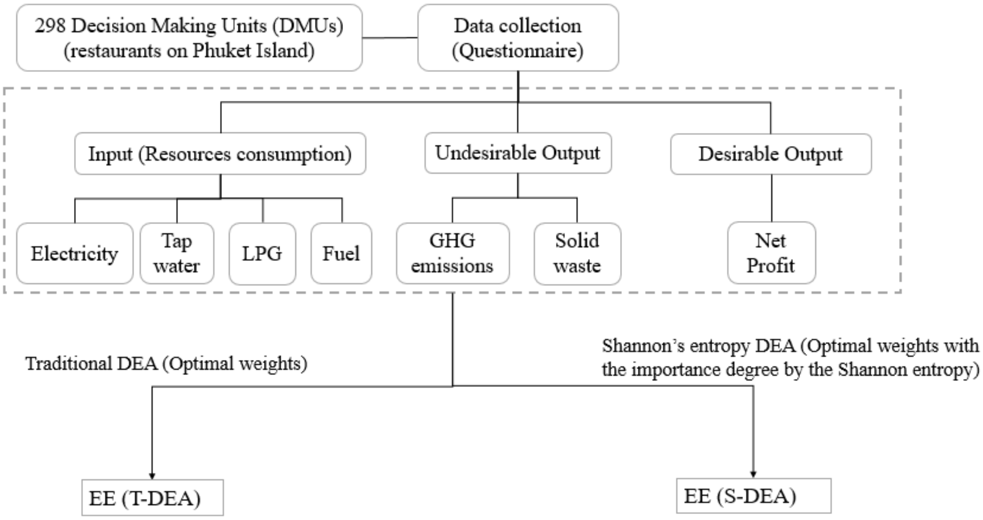

Figure 1 Flowchart of research process

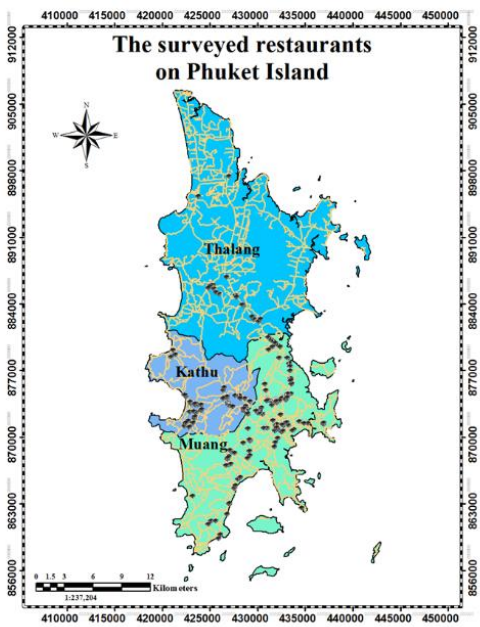

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Figure 2 Location of 298 surveyed food shops on Phuket Island

Treating the undesirable outputs like classic inputs to be minimized in DEA model was already valued as an intuitive approach [18]. In this study, the undesirable outputs were envisioned as inputs in the DEA model for EE analysis.

The EE, which is the efficiency score (θ), is calculated as the ratio of weighted sum of outputs to its weighted sum of inputs as [9]:

$$\theta = \frac{weighted\ sum\ of\ outputs}{weighted\ sum\ of\ inputs} \tag{1}$$

A DMU is considered as efficient if its efficiency score is 1. DEA method is applied to determine weights of input and output of each DMU. It is supposed that in a DEA problem, there are n DMUs with m inputs and s outputs. The vectors $x_j = [x_{1j}, x_{2j}, \dots, + x_{mj}]$ and $y_j = [y_{1j}, y_{2j}, \dots, + y_{sj}]$ are used to denote the inputs and outputs of DMU_j respectively, in which $j = 1, 2, \ldots, n$. Then the efficiency of certain DMU_{j0} ($j_0 = 1, 2, \ldots, n$) is defined as follows [9]:

$$\theta = \frac{u_1 y_{1j_0} + u_2 y_{2j_0} + \ldots + u_s y_{sj_0}}{v_1 x_{1j_0} + v_2 x_{2j_0} + \ldots + v_m x_{mj_0}} = \frac{\sum_{r=1}^{s} u_{rj_0} y_{rj_0}}{\sum_{t=1}^{m} v_{tj_0} x_{tj_0}}$$

$$\text{Maximize } \theta = \frac{\sum_{r=1}^{s} u_{rj_0} y_{rj_0}}{\sum_{t=1}^{m} v_{tj_0} x_{tj_0}} \qquad (2)$$

$$\text{s.t.} \quad \frac{\sum_{r=1}^{s} u_{rj_0} y_{rj_0}}{\sum_{t=1}^{m} v_{tj_0} x_{tj_0}} \leq 1 \qquad j = 1,2, \ldots, n$$

$$u_r, v_t \geq 0$$

in which $v_{j_0} = [v_{1j_0}, v_{2j_0}, \ldots, + v_{mj_0}]$ and $u_{j_0} = [u_{1j_0}, u_{2j_0}, \ldots, + u_{sj_0}]$ are the multiplier weights of inputs and outputs, respectively; θ is the efficiency of the DMU_{j0} under consideration; s is the number of outputs ($r = 1,2, \ldots, s$); m is the number of inputs ($t = 1,2, \ldots, m$) and j denotes *jth* DMUs ($j = 1,2, \ldots, n$).

In this study, the units of assessment chosen are food shops. There are two efficiency scores for each DMU. The EE (T-DEA) is an efficiency score calculated based on a set of optimal weights computed by traditional DEA, while EE (S-DEA) is an efficiency score calculated based on a set of weights with the importance degree computed by Shannon's entropy DEA.

2.2.1 Traditional DEA

Envisioning the undesirable outputs as inputs, this idea leads to the following approach, which is called equation 3:

$$\text{Maximize } \frac{\sum_{r=1}^{k} u_{rj_0} y_{rj0}}{\sum_{t}^{m} v_{tj_0} x_{tj_0} + \sum_{r=k+1}^{s} u_{rj_0} y_{rj0}}$$

s.t.

$$\frac{\sum_{r=1}^{k} u_{rj_0} y_{rj}}{\sum_{t}^{m} v_{tj_0} x_{tj} + \sum_{r=k+1}^{s} u_{rj_0} y_{rj}} \leq 1 \qquad (3)$$

$$j = 1,2, \ldots, n; \; u, v \geq 0$$

$$t = 1,2, \ldots, m; \; r = 1,2, \ldots, s$$

The model assigns an efficiency score between 0 and 1 for each DMU after evaluation, with "1" being the efficiency frontier.

2.2.2 Shannon's entropy DEA

In this study, the estimation of food shops' efficiency performances follows the proposed methodology that comes from Qi and Guo [11]. In order to improve the discriminating power of the DEA method, they proposed a methodology using Shannon's entropy to aggregate different sets of optimal weights into a 'common set of weights' (CSW). Then DMUs could be evaluated with this CSW. The proposed methodology can be formulated as the six steps presented below.

Step 1: Data normalization.

In this study, there is no outlier data in inputs and outputs after the data screening process. For convenience of comparison, the input $x_{tj_0}(t = 1,2, \ldots, m)$ and output $y_{rj_0}(r = 1,2, \ldots, s)$ of $DMU_{j_0}(j_0 = 1,2, \ldots, n)$ are normalized as follows:

$$\begin{cases} x_{tj_0} = x_{tj_0} / \, max_{j \in \{1,2,\ldots,n\}}\{x_{tj}\} \\ y_{rj_0} = y_{rj_0} / \, max_{j \in \{1,2,\ldots,n\}}\{y_{rj}\} \end{cases} \qquad (4)$$

Normalizing residuals by transforming all input and output variables in the data to a common scale of [0;1].

Step 2: Non-zero optimal weights calculation.

In this step, a modified weight restriction model was proposed for calculating non-zero optimal weighs as follows. At the end of this step, a set of non-zero optimal weights for every DMU can be attained. The optimal weights of inputs and outputs are denoted by *V* and *U* respectively, as follows:

$$V = \begin{bmatrix} v_{11} & v_{21} & \cdots & v_{m1} \\ v_{12} & v_{22} & \cdots & v_{m2} \\ \vdots & \vdots & \ddots & \vdots \\ v_{1n} & v_{2n} & \cdots & v_{mn} \end{bmatrix} \begin{array}{l} \leftarrow \; DMU_1 \\ \leftarrow \; DMU_2 \\ \leftarrow \; \vdots \\ \leftarrow \; DMU_n \end{array} \qquad (5)$$

$$U = \begin{bmatrix} u_{11} & u_{21} & \cdots & u_{s1} \\ u_{12} & u_{22} & \cdots & u_{s2} \\ \vdots & \vdots & \ddots & \vdots \\ u_{1n} & u_{2n} & \cdots & u_{sn} \end{bmatrix} \begin{array}{l} \leftarrow \; DMU_1 \\ \leftarrow \; DMU_2 \\ \leftarrow \; \vdots \\ \leftarrow \; DMU_n \end{array} \qquad (6)$$

Step 3: Weights normalization.

The normalization of the non-zero optimal weighs is prepared for the calculation of Shannon's entropy. The optimal weights

$v_{t_0 j_0}(t_0 = 1,2,\dots,m)$ and $u_{r_0 j_0}(r_0 = 1,2,\dots,s)$ of $DMU_{j_0}(j_0 = 1,2,\dots,n)$ are normalized as follows:

$$\begin{cases} \alpha_{t_0 j_0} = v_{t_0 j_0} / \sum_{t=1}^{m} v_{t j_0} \\ \beta_{r_0 j_0} = u_{r_0 j_0} / \sum_{r=1}^{s} u_{r j_0} \end{cases} \quad (7)$$

In this step, the non-zero input weights and output weights are normalized separately.

Step 4: Shannon's entropy calculation.

The Shannon entropy of $DMU_{j_0}(j_0 = 1,2,\dots,n)$ for inputs and outputs are calculated as follows:

$$\begin{cases} e_{j_0}^{input} = -e_0 \sum_{t=1}^{m} \alpha_{t j_0} \ln(\alpha_{t j_0}) \\ e_{j_0}^{output} = -e_1 \sum_{r=1}^{s} \beta_{r j_0} \ln(\beta_{r j_0}) \end{cases} \quad (8)$$

in which e_0 and e_1 are the entropy constants and defined as $e_0 = (ln\, m)^{-1}$ and $e_1 = (ln\, s)^{-1}$. $\alpha_{t j_0}$ and $\beta_{r j_0}$ are probabilities of occurance of outcome.

It is supposes that there are always more than one inputs or more than one outputs which implies that $m > 1$ or $s > 1$. Especially, the entropy of single input or single output is defined as 0.

Step 5: The importance degree of optimal weights determination.

The importance degree of $DMU_{j_0}(j_0 = 1,2,\dots,n)$ is defined as follows:

$$w_{j_0} = (e_{j_0}^{input} + e_{j_0}^{output}) / (\sum_{j=1}^{n} e_j^{input} + \sum_{j=1}^{n} e_j^{output}) \quad (9)$$

The degree of importance is accordance with maximizing the Shannon entropy. In fact, the importance degree determined by the Shannon entropy is based on the difference of both inputs weights and outputs weights. It means that both inputs weights and outputs weights are combined to identify the importance degree of every DMU.

Step 6: The common weights determination.

The common weights $v = [v_1, v_2, \dots, v_m]^T$ and $u = [u_1, u_2, \dots, u_s]^T$ are the aggregation of the optimal weights from every DMU with the importance degree by the Shannon entropy. After this step, all DMUs have only one set of common weights for each input/output variable. It should be noted that the optimal weights used here are the optimal weights before the weights normalization as follows:

$$\begin{cases} v_t = \sum_{j=1}^{n} (w_j v_{tj}) \\ u_r = \sum_{j=1}^{n} (w_j u_{rj}) \end{cases} \quad (10)$$

in which $t = 1,2, \dots, m$ and $r = 1,2, \dots, s$

After these six steps, DMUs can be evaluated with the common weights v and u. The DEA models with Shannon's entropy were run using Premium Solver Platform 2019 software.

Results and Discussion

This section shows the assessment results of 298 food shops' performance and some factors that significantly affects their efficiency scores such as type of food shops (AC, Non-AC or hawker) or the food shops' locations.

1. Relationship between EE and resources consumption

This part shows the result of performance efficiency assessment based on the utility consumptions (electricity, tap water, LPG, fuel), GHG emissions, and solid waste as inputs, and the net profit margin of food shops as an output. It is evident that in every subgroup, surveyed DMUs spent most of their money on LPG and electricity (Figure 3).

It can be seen that the food shop AC type had a significant electricity consumption of 2,289 USD per year, accounting for 61% of the total expenditure and seven times higher than that of the hawker type, which consumed the least electricity. This is due to the cooling and ventilation systems, especially the use of AC which is a high energy-consuming machine. According to Energy Star [19], ventilation, and AC systems account for 28% of the total energy consumption in food shops. Another study also found that ventilation and AC systems, together with water and cooking accounted for more than 90% of total energy demand [20]. As a result, this type of food shop was the most inefficient compared to the Non-AC type and hawker type with an average efficiency score of only 0.505. In contrast, since hawker is a mobile business, the use of electricity in this type of food shop is not essential. Therefore, hawker had the highest efficiency score of 0.896 for T-DEA and 0.595 for S-DEA. Its small operational size, low resource consumption, and low maintenance requirement are the reasons for the relatively high efficiency score.

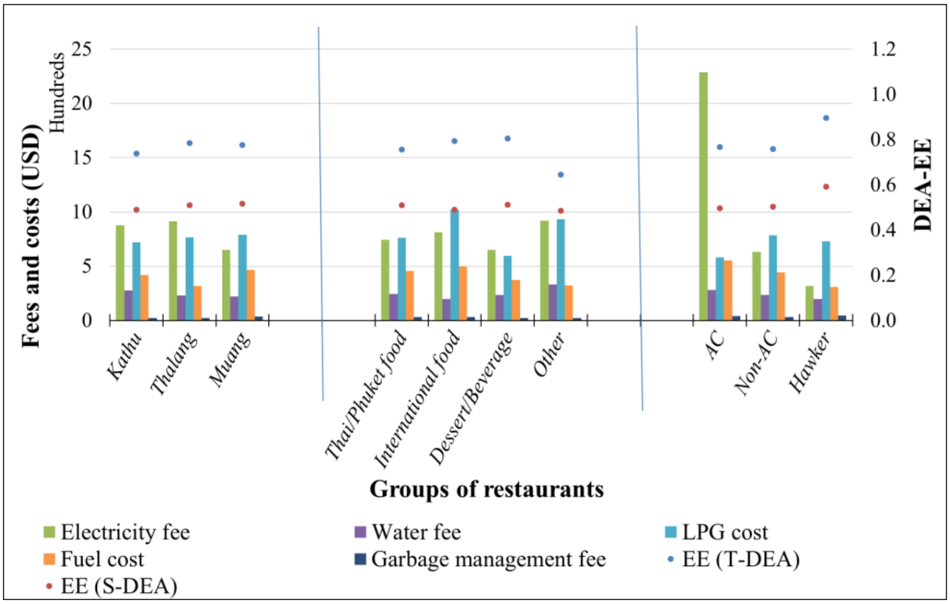

Figure 3 Utility and waste fees/costs and EE performances in different groups of food shop

2. EE performances of different food shop groups

Figure 4 indicates that the studied food shops generated a total of 1,643,973 kg of CO_2-equivalents (CO_2-eq), of which the largest share of 991,388 kg of CO_2-eq (slightly more than 60% of the total) was electricity consumption required for the use of equipment such as lighting, cooking, cooling, refrigeration, and ventilation. Interestingly, solid waste generation was the second largest source of the total GHG emissions from food shops at 416,244 kg CO_2-eq (more than 25% of the total), as food waste is one of the largest contributors to increased GHG generation [21]. The amount of CO_2-eq emissions from tap water use was slightly lower at 72,151 kg CO_2-eq (about 5% of the total). The reason for the high GHG emissions from electricity use but the low number from tap water use was because many food shops used electricity to pump groundwater instead of purchasing fresh water from Provincial Waterworks Authority.

For LPG and fuels, GHG emissions came from LPG consumption, which accounted for 116,167 kg CO_2-eq due to cooking needs. Fuel for transportation is not used to any extent by the food shops; therefore, GHG emissions from fuel consumption were minimal (about 48,023 kg CO_2-eq or about 3% of the total).

Among the three districts of Phuket (e.g., Kathu, Thalang, Mueang), the result shows that the mean efficiency score of Kathu district is the lowest compared to all other districts, with 0.739 under T-DEA and 0.490 under S-DEA. This could be due to the GHG emissions of the DMUs of this district as their average value was the highest at 1,250 kg CO_2-eq. compared to the other districts. However, there was a change in rank between Thalang district and Mueang district in the two models. Under T-DEA, Thalang was relatively the most efficient district with a mean of 0.786, but fell to second place under S-DEA (EE = 0.509). In contrast, although Mueang was rated as more inefficient than Thalang at T-DEA (EE = 0.777), S-DEA of Mueang (EE= 0.516) was higher than that of Thalang.

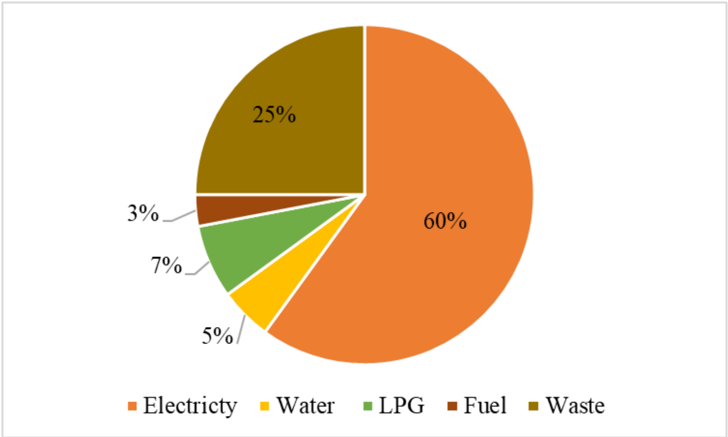

Figure 4 Contributions of each factors to total GHG emissions

The highest efficiency scores belong to the center of Thalang, the southeast of Mueang, and the southwest of Kathu. It should be noted that the mentioned zones are the most famous and busy places in the districts, such as central Thalang with Phuket International Airport, southeastern Mueang with Phuket City – the capital of Phuket Province, and southwestern Kathu with Patong Town Municipality – the center of Phuket's nightlife and shopping, which is located in the coastal area of Kathu district. On the other hand, the east of Thalang and the northeast part of Kathu had lowest efficiency score. These areas are considered as rural areas where mainly local people are engaged in livestock or cultivation of rice, fruits and perennial plants, vegetables and ornamental plants. In addition, these areas are surrounded by mountains and forests. Therefore, there are limited tourists and food services in these areas.

Out of the 298 DMUs, 42 were evaluated as the most efficient by both methods, namely T-DEA and S-DEA. Figure 5 shows that 62% of these 42 most efficient DMUs were located in Mueang district, especially around Phuket City - the capital of Phuket Province, which is an attraction in itself. The district has retained its provincial charm and has a historic old town with many food shops, cafes and night markets that attract thousands of visitors. In addition, Kathu district has a significant number of efficient DMUs, accounting for just over 26% of the total. Most of the efficient food shops in this district came from the populated area (Patong Town Municipality). As mentioned earlier, Patong is one of the most attractive tourist destinations in Phuket and therefore is mainly visited by tourists. Thus, the food shops in this area received a significant contribution from this typical group of customers, which in a way has a positive impact on their profit and efficiency. This result is in accordance with the findings by Mhlanga [11], who found that food shop locations have a statistically substantial relationship with their efficiency. This author also proved that food shops positioned in, or nearby, well-known destinations had higher efficiency scores than those in distant locations [11], due to the convenience of traveling. Hence, several food shops' facilities such as air conditioners or lighting systems served more customers at the same time. It helps increase food shops' income.

In the end, both T-DEA and S-DEA could reveal different issues. For S-DEA, electricity consumption had the highest value of weight, indicating that this parameter was the most demanded by all DMUs. In fact, an enormous amount of electricity is consumed in Phuket, especially for tourism activities. Electricity consumption is also the factor that has the largest contribution to the total GHG emissions in this study. For T-DEA, water had the least slacks, implying that the least reduction of water consumption (compared to other resources) can help most DMUs to reach their maximum efficiency.

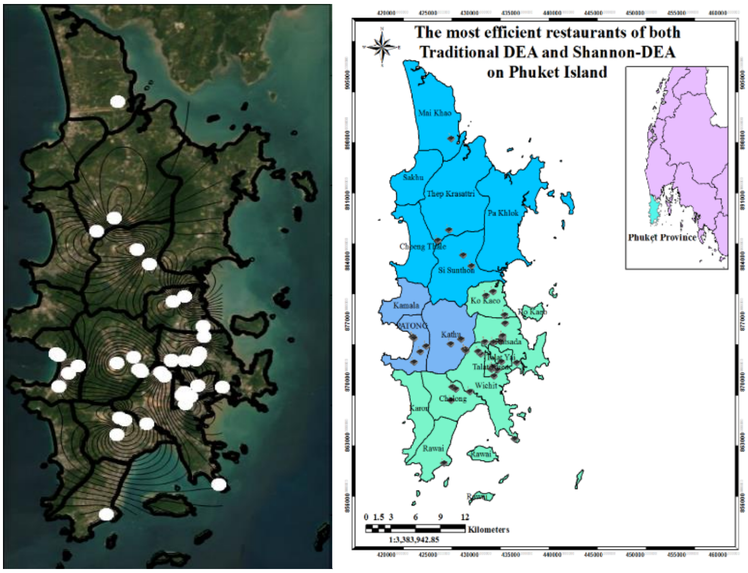

Figure 5 Distribution of the most efficient DMUs

Conclusions

The performance assessment of 298 food shops in Phuket Island was conducted using EE combined with DEA. Many conclusions can be drawn from this study as follows.

The studied food shops studied generated a total of 1,643,973 kg CO_2-eq, of which electricity consumption accounted for the largest share at 991,388 kg CO_2-eq (just over 60% of the total). Solid waste was the second largest source of total GHG emissions from food shops at 416,244 kg CO_2-eq (more than 25% of the total). Tap water, LPG, and fuel consumption accounted for 236,341 kg CO_2-eq (about 15% of the total).

Among the three food shop types considered, hawker had the highest efficiency score. However, the performance of food shops with and without AC depended on the indicator used for the assessment. Electricity consumption might have the greatest impact on the efficiency of the food shops as suggested by the common set of weights' values of S-DEA. Food shops with air conditioners had significant electricity consumption due to the cooling and ventilation systems.

The analysis using T-DEA showed Mueang district was the most efficient area, followed by Thalang and Kathu. The result was slightly different when using S-DEA, where Thalang district was the most efficient area, followed by Mueang and Kathu. The most efficient zones in Phuket Islands were the center of Thalang, the southeast of Mueang, and the southwest of Kathu because they are the most famous and visited places on the island. In contrast, the east of Thalang and the northeast part of Kathu were the most inefficient zones as they are considered more rural areas covered by a wide range of mountains and forests with limited population. Therefore, food shops in or near cities with more prevalent destinations were more efficient than food shops in distant areas.

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Life Cycle Assessment of Southeast Asian Diets

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Abstract

Population growth has increased demand for food globally. Food production has negative impacts on the environment. Previous research has shown that dietary choices significantly influenced environmental impacts. Studies on the environmental impacts of Southeast Asian diets are still limited and needed. The objectives of this study are to assess and compare the life cycle environmental impacts of diets in 9 Southeast Asian countries (Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Thailand, Timor-Leste, and Vietnam), to identify the dietary choices causing the environmental impacts and to provide recommendations on environmental impact reduction. The functional unit of this assessment is food consumption in kilograms per capita per year. The assessment scope is from cradle to gate. Foreground data were obtained from Food and Agriculture Organization (FAO) food balance sheets with the representative year as of 2018 and International Coffee Organization (ICO). Background data were obtained from ecoinvent and Agri-footprint databases. Four environmental impact categories (human health damage, ecosystem damage, resource scarcity, and global warming potential) were assessed using the ReCiPe 2016 method (v1.04). Healthy diet scenarios with the diet and energy intake adjustments to achieve the recommended standard healthy diets were also analyzed. The dietary choices with higher amount and more high-impact food groups would cause higher environmental impacts. Vietnam, Myanmar, and Laos had higher impacts for all impact categories, while Timor-Leste had the lowest impacts among Southeast Asian countries. Meats/meat products and cereals were significant contributors to all impact categories, followed by fish and seafood. Based on the healthy diet scenario analysis, overall reduction and meats & cereals reduction were recommended for environmental impact reduction because meats, fish and seafood, cereals were the major contributors to all impacts categories in Southeast Asia. As meats/meat products lead as a critical food group causing environmental impacts, it is recommended that governments should take specific measures to reduce the consumption of animals and animal products and to support meat substitutes (e.g., tofu, tempeh, beans, etc.).

Keywords : LCA; Southeast Asian diets; Human health; Ecosystem; Natural resources; Global warming potential

Introduction

Due to the rapid growth in world population, global food production and consumption increase and affect human health, the environment, and ecosystems. Global agricultural and food production released more than 25% of all greenhouse gases (GHGs). Fresh and marine water quality was affected by agrochemicals from agricultural and food production [1]. The non-vegetarian diets required more energy and resources than vegetarian diets, specifically more than 2.9 times of water, 2.5 times of primary energy, 13 times of fertilizer, and 1.4 times of pesticides. A higher environmental cost occurred in a non-vegetarian diet than a vegetarian diet. This showed that dietary choices could make environmental changes [2].

On the other hand, there would be a significant effect on land use when meat consumption was reduced or switched entirely to plant-based protein food. Regrowing vegetation in abandoned land (up to 2,700 Mha of pasture and 100 Mha of cropland) could absorb a large amount of carbon. Furthermore, methane and nitrous oxide emissions could be substantially reduced, and it could achieve a 450 ppm CO_2-eq (targeted 50% reduction by 2050) from changing to a low meat diet, which was also recommended for health reasons. Hence, diet changes would benefit human health and global land use; and play a vital role in future climate change policies [3].

Increasing the awareness of the importance of environmental protection and the interest in the possible impacts of the products has led to developing methods to assess, understand, and address these impacts [4]. Life cycle assessment (LCA) is a well-known and widely used tool to evaluate the environmental burdens of a product, process, or service through its entire life cycle. LCA has been a suitable tool to analyze the environmental performance of a food product or industry [5]. Hence, LCA was chosen as part of the methodology to conduct this study. Lucas et al. [6] conducted a study on global environmental and nutritional assessment of national food supply patterns of countries around the globe by applying Data Envelopment Analysis. The study was conducted based on the existing studies, applied FAO food balance sheets of the year 2017 and assessed the environmental impacts including land use, GHG emissions, acidification potential, eutrophication potential, and freshwater withdrawals from each nation's average per capita food supply [6]. However, the results only highlighted the country groups regarding their income levels (high-income, upper-middle-income, middle-income, lower-middle-income, and low-income levels). It did not indicate environmental impacts of specific countries. Furthermore, a study related to the environmental sustainability of food consumption in Asia was done by Adhikari and Prapaspongsa [7]. Nevertheless, only one Southeast Asian country – Thailand - was considered in the study. Regarding the existing studies, the assessment of the diet's impacts in Southeast Asian countries is still limited. Therefore, this study aims to assess and compare the life cycle environmental impacts of diets in 9 Southeast Asian countries (Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Thailand, Timor-Leste, and Vietnam); to determine the diet systems highly contributing to the environmental impacts, and to provide recommendations about ways to reduce the impacts on the environment.

Material and Methods

This study uses LCA to assess the environmental impacts of a process's inputs and outputs according to ISO 14040 [8]. The LCA framework - the research framework in this study - which includes four phases: goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation, can be seen in Figure 1. This study analyzes and quantifies the impacts affecting the environment and determines the significant contributors in the diet systems with the "cradle-to-farm gate" perspective. The functional unit of this study is defined as "food consumption in kilogram per capita per year" in Southeast Asian countries. Table 1 shows the parameters of Southeast Asian countries. There are eleven countries in Southeast Asia; nevertheless, only nine countries can be assessed in the study due to the lack of data availability.

Food consumption is derived from the food availability in Southeast Asian countries, including importing and exporting food in the country. Data from the FAO food balance sheets with the representative year of 2018 and data from international coffee organizations [9] are utilized as foreground data. The background data of each food item are acquired from the ecoinvent and Agri-footprint databases. The food items are categorized into thirteen groups based on the FAO classification and Adhikari and Prapaspongsa [7]. The categorized food groups can be seen in Table 2, which shows the food supply of Southeast Asian countries in kg per capita per year. The food items considered under each food group can be observed in Adhikari and Prapaspongsa [7], categorized twelve food groups. Spices are considered as an additional food group in this study.

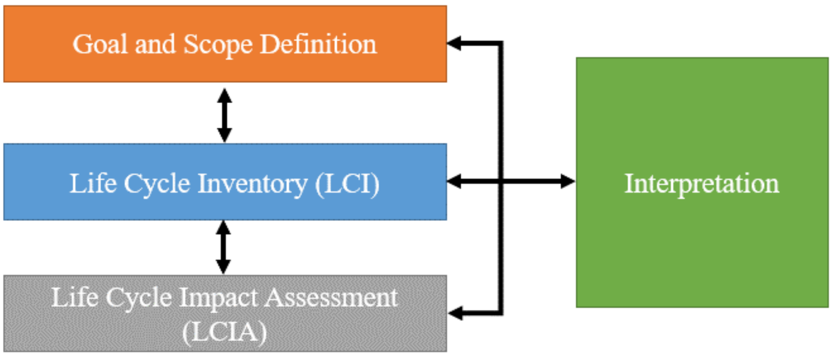

Figure 1 Life Cycle Assessment Framework (ISO 14040; [8])

Table 1 Characteristics and energy intakes per person in Southeast Asian countries

No	Countries [10]	Population (2020) [11]	Population Density (people per sq.km) [11]	Urbanized Population (% of total) [11]	Energy Intake (kcal/capita/day) [12]
1	Cambodia	16,718,971	95	24%	2884
2	Indonesia	273,523,621	151	56%	2492
3	Laos	7,275,556	32	36%	2758
4	Malaysia	32,365,998	99	78%	2845
5	Myanmar	54,409,794	83	31%	2673
6	Timor-Leste	1,318,442	89	33%	2287
7	Philippines	109,581,085	368	47%	2662
8	Thailand	69,799,978	137	51%	2804
9	Vietnam	97,338,583	314	38%	3025

Table 2 Thirteen food groups consumed per person in Southeast Asian countries in 2018

No.	Food Categories (2018) (kg/capita/year) [12]	Cambodia	Indonesia	Laos	Malaysia	Myanmar	Timor-Leste	Philippines	Thailand	Vietnam
1	Cereals	254	260	264	175	213	210	230	195	234
2	Root Vegetables	19	69	57	19	14	44	17	10	17
3	Sugar and Confectionary	33	20	51	45	28	26	25	103	22
4	Legumes, nuts, and oilseeds	14	23	8	12	31	11	9	15	43
5	Oils	3	12	3	17	21	7	6	9	3
6	Vegetables	38	45	220	69	84	27	63	42	173
7	Fruits	19	66	148	42	43	15	98	88	80
8	Coffee [9] and Tea	0	1	2	1	2	0	2	2	3
9	Meats and meat products	14	13	28	54	51	34	43	31	74
10	Fish and Seafood	42	44	25	57	46	8	26	29	37
11	Animal Products	5	11	6	24	32	9	9	29	15
12	Spices	1	2	2	5	2	0	0	6	3
13	Alcohol and Beverages	29	1	12	9	2	4	16	44	20
	Total	**471**	**567**	**826**	**529**	**569**	**395**	**544**	**603**	**724**

Various life cycle impact assessment (LCIA) methods are available; however, ReCiPe 2016 is selected as the LCIA method in this study, with a large set of midpoint indicators (18) and three endpoint indicators. Harmonized characterization factors at the mid-point and the endpoint levels are provided in the ReCiPe 2016 method. The characterization factors in ReCiPe 2016 represent the global scale instead of the European scale. The midpoint and endpoint methods have factors according to the three cultural perspectives: individualist, hierarchist, and egalitarian. These perspectives can be chosen according to time duration or expectations to avoid future damages. Hierarchist perspective is selected in this study, which is based on scientific consensus with regard to the time frame and acceptability of impact mechanisms. Four environmental impact categories (human health damage, ecosystem damage, resource scarcity, and global warming potential) were assessed by conducting the ReCiPe 2016 (V1.04) in Simapro 9.1.1.7. Damage impact categories show the area of protection affected by the 18 midpoint categories, namely climate change potential (GWP), ozone depletion, ionizing radiation, fine particulate matter formation, photochemical oxidant formation: ecosystems quality, photochemical oxidant formation: human health, terrestrial acidification, freshwater eutrophication, human toxicity: cancer, human toxicity: non-cancer, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, marine eutrophication, land use, water use, mineral resource scarcity, fossil resource scarcity [13]. Targeting specific impacts could improve in the selected impact categories; however, some crucial points could be overlooked. Therefore, this work is determined to analyze the environmental impacts at the endpoint level. It should be mentioned that although all LCIA methods have aimed to model possible environmental impacts, it is not possible to include all possible impact pathways. Different methods have different modelling choices and limitations. The detailed methodology and limitations of the ReCiPe method can be seen in Huijibregts et al. [13]. Figure 2 shows the overview of the impact categories covered in the ReCiPe 2016 method and its relation to the area of protection at the endpoint level. In the figure, the impact categories considered in this study are highlighted in red boxes.

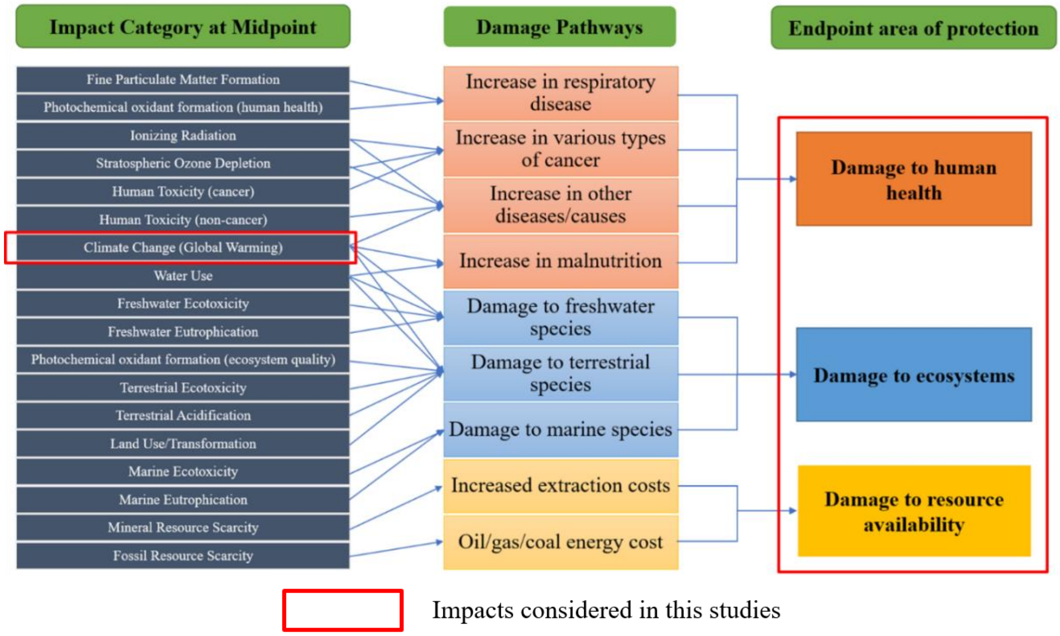

Figure 2 Overview of the impact categories that are covered in the ReCiPe 2016 method and their relation to the areas of protection (endpoint) [13]

Human health damage shows years of life lost and disabled related to respiratory disease, various types of cancer, malnutrition, and other diseases caused by climate change, stratospheric ozone depletion, ionizing radiation, particulate matter formation, photochemical ozone formation, toxicity, and water consumption. Its unit is described as disability-adjusted life years (DALYs). Ecosystems damage describes species losses affected by climate change, photochemical ozone formation, acidification, eutrophication, toxicity, water consumption, and land use in freshwater, marine, and terrestrial species. It is shown in the unit of species-year. The resource scarcity shown in the unit of dollar (USD) refers to the additional extraction costs for mineral and fossil fuel (oil/gas/coal) resources in the future. Additionally, the climate change at the midpoint is used as global warming potential (GWP), in which the integrated infrared radiative forcing increase of greenhouse gas (GHGs) is quantified and expressed in kg CO_2 equivalent [13]. The global warming potential (kg CO_2 equivalent) is considered to be assessed in the study because agriculture and food production contributed more than 25% of greenhouse gas (GHGs) emissions [1]. Hence, assessing the global warming potential of Southeast Asian countries could not be neglected.

Healthy Diet Scenario Development

Healthy Diet Scenarios (HDS) were developed by reducing or increasing the calorie intake of diets in order to reach the healthy level. Calorie intakes differ according to age and gender. Typically, men consume more calories than women; likewise, elders require fewer calories than adults. However, this study does not consider specific age, weight, and gender variants groups. According to FAO, the benchmark intake is 2300 kcal per day [14]. Hence, 2300 kcal per capita per day is determined as the healthy diet intake for adults.

Regarding 2300 kcal per day as a targeted diet intake to clarify the food groups' impacts on the environment and health in Southeast Asian countries, the scenarios are considered three fragments, reduction in overall consumption (HDS_1), cereals only (HDS_2), and HDS_3 meats and, cereals consumption. The reduction in daily energy intake can lead to healthy lifestyles and increase in daily intake in lower kcal consumption would also have a healthy diet style. This LCA identifies the HDS scenarios based on the impact assessment results. Regarding meats (meats, fish and seafood, and animal products) which had significant impacts on the environment, the reduction of the impact in the consumption of indicated food groups alone is not feasible to be considered as a standalone scenario as the intake of animal and animal products was not high in Southeast Asian countries. Hence, reduction in cereals consumption is taken into account along with meats under scenario 3 (HDS_3) to achieve healthy diets. Table 3 describes HDS scenarios reducing/increasing calorie intakes in Southeast Asian countries.

Results and Discussion

Environmental impacts of Southeast Asian diets

Figure 3 presents the life cycle environmental impacts of Southeast Asian diets. Results indicated that Vietnam, Myanmar, and Laos had significant impacts on all impact categories from their dietary choices, while Timor-Leste had minor impacts. Fish and seafood (27%), cereals (26%), meats, and meat products (23%) highly contributed to human health damage. For resource scarcity, cereals contributed the most (25%), followed by meats and meat products (23%) and fish and seafood (20%). On the other hand, ecosystem damages were caused by meats and meat products (26%), cereals (18%), coffee and tea (15%), and spices (14%). Finally, only cereals (39%) and meats and meat products (28%) were the main contributors to global warming potential.

Table 3 Description of HDS Scenarios reducing/increasing calorie intakes in Southeast Asian countries

Countries	HDS1_Overall	HDS2_Cereals	HDS3_Meats* & Cereals	Description
Cambodia	8%	12%	10%	reduction in food items to achieve calorie intake 2300 kcal/capita/day from 2492 kcal/capita/day
Indonesia	20%	33%	30%	reduction in food items to achieve calorie intake 2300 kcal/capita/day from 2882 kcal/capita/day
Laos	17%	28%	24%	reduction in food items to achieve calorie intake 2300 kcal/capita/day from 2756 kcal/capita/day
Malaysia	19%	46%	32%	reduction in food items to achieve calorie intake 2300 kcal/capita/day from 2843 kcal/capita/day
Myanmar	14%	27%	20%	reduction in food items to achieve calorie intake 2300 kcal/capita/day from 2671 kcal/capita/day
Philippines	13%	23%	18%	reduction in food items to achieve calorie intake 2300 kcal/capita/day from 2657 kcal/capita/day
Thailand	18%	38%	29%	reduction in food items to achieve calorie intake 2300 kcal/capita/day from 2801 kcal/capita/day
Timor-Leste	-1%	-1%	-1%	increase in food items to achieve calorie intake 2300 kcal/capita/day from 2286 kcal/capita/day
Vietnam	24%	47%	32%	reduction in food items to achieve calorie intake 2300 kcal/capita/day from 3023 kcal/capita/day

*meats, fish, and seafood (which will be called as a group of meats)

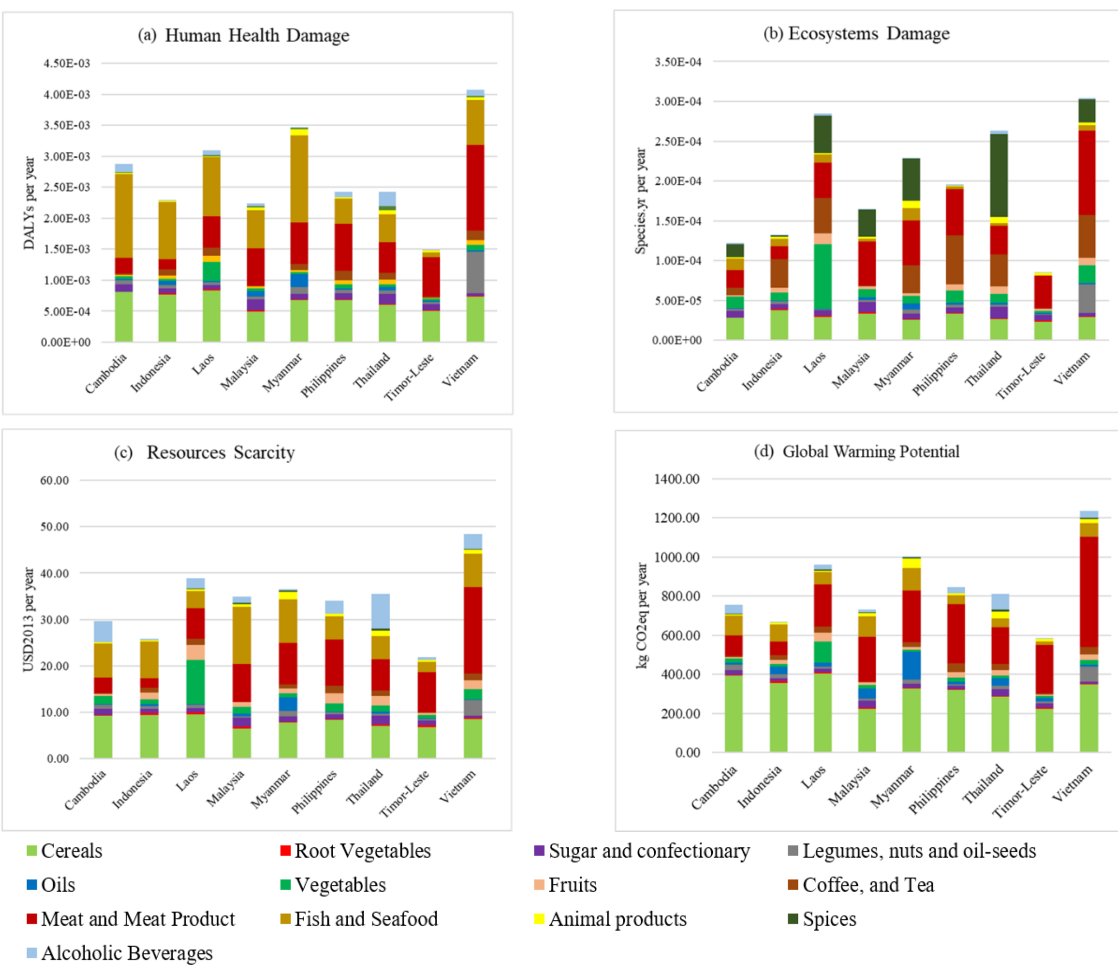

Figure 3 Comparison of life cycle environmental impacts of Southeast Asian diets under the impact categories of (a) human health damage, (b) ecosystems damage, (c) resources scarcity, and (d) global warming potential

The environmental impact intensity shown in relative percentages is illustrated to determine each impact category's contributors (13 food groups) as can be seen in Figure 4. One kg of each food group was assessed, summed up and presented as relative percentages. Per kg, coffee and tea had the most significant impacts in all impact categories. In human health damage, coffee and tea contributed to 45% of total impacts, followed by meats (14%) and fish and seafood (11%). In ecosystem damage, coffee and tea contributed to 49% of total impacts, and followed by spices 31% of total impacts. Moreover, resource scarcity was highly affected by coffee and tea (27%), fish and seafood (14%), meats (13%), and alcoholic beverages (13% of total impacts). Almost 50% of total global warming potential was caused by 1 kg of coffee and tea consumption followed by 1 kg of the meat consumption (17%).

In human health damage, the intensity of damage ranged from 1.50E-03 to 4.07E-03 DALYs in Southeast Asian countries. Vietnam had significant impacts on human health damage with 4.07E-03 DALYs per capita per year. In which, meats consumption was the primary contributor that caused more severe damage to human health (34% of total impacts) and followed by fish and seafood, cereals consumption with (18% of total impacts, respectively). The human health damage impacts in Myanmar (3.47E-04 DALYs per capita per year) and Laos (3.10E-03 DALYs per capita per year) were not much different. Fish and seafood was the major contributor in Myanmar (40%), and meats and meat products (34%) consumption contributed a lot to human health damage in Timor-Leste. In contrast, Timor-Leste had the minimum amount of impact (1.50E-03 DALYs per capita per year) on human health damage among Southeast Asian countries.

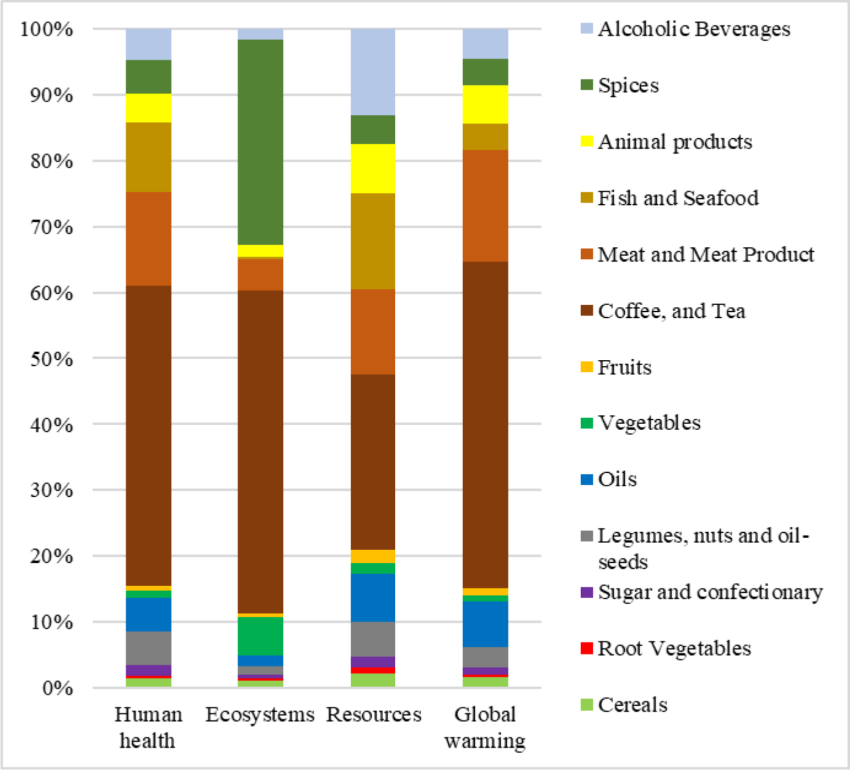

Figure 4 Environmental impact intensity per kg of each food group illustrated in relative percentages

Regarding ecosystems damage, it ranged from 8.50E-05 to 3.04E-04 species-year per capita per year. Meats and meat products (35%) were the primary reason causing intense damage to ecosystems in Vietnam (3.04E-04 species-year) among the Southeast Asian countries. Laos (28.40E-04 species-year) ranked as the second country with a high impact on ecosystems damage from vegetables (42%). The ecosystem damage in Thailand, Myanmar, and the Philippines ranged from 1.96E-04 to 2.64E-04 species-year. Spices (40% of total impact) were also a part of Thailand's major contributors to ecosystems damage. In comparison, coffee and tea (31%), meats and meat products (30%) were principal contributors in the Philippines; furthermore, meat/meat products (25%) and spices (23%) performed as higher contributors in Myanmar. Timor-Leste had the least impact on its ecosystems damage (8.50E-05 species year), where meats/meat products (48%) contributed to its impact.

For resources scarcity, extraction fuel/energy costs from dietary choices ranged from 22 to 48 USD per capita per year in the Southeast Asian countries. A vast amount was found in Vietnam, with 48 USD per person in a year. Meats/meat products (39% of total impacts) contributed more severe resources scarcity in Vietnam, followed by Laos, with 39 USD contributed by cereals and vegetables (24%, respectively). Resources scarcity per capita per year in Myanmar, Malaysia, Thailand, and the Philippines were more or less similar. Fish and seafood food group was a significant contributor to resource scarcity damage in Myanmar (26%) and Malaysia (35%). Meats/meat products (20%) contributed to resources scarcity in the Philippines. At the same time, 21% alcoholic beverage, 20% cereal consumption, and 19% meats/meat products contributed to Thailand. Simultaneously, a person's cereals consumption for a year significantly contributed to resource scarcity damage in Cambodia (31%) and Indonesia (36%). Timor-Leste had the lowest impact cost (22 USD) in resources scarcity by meat and meat products (40% of total impacts).

Emissions caused to global warming in Southeast Asia fluctuated depending on dietary choices (ranging from 586 to 1234 kg CO_2 eq). Generally, cereals, meats, and meat products were the key contributors to GWP. Vietnam had significant emissions to the environment (1234 kg CO_2 eq), primarily by meats and meat products (46%), followed by Myanmar, which had 1001 kg CO_2 eq contributed by cereals (33%), meats/meat products (26%). Cereals (42%) contributed a lot to global warming in Laos, which had 959 kg CO_2 eq. Furthermore, emissions in the Philippines, Thailand, Cambodia, and Malaysia ranged 755 ~ 845 kg CO_2 eq per person and, majorly caused by cereals (>35%) in the Philippines, Thailand, Cambodia, while meat and meat products (32%) contributed to the global warming potential in Malaysia. Besides, cereals (54%) played as a leading contributor to climate change in Indonesia. In comparison, Timor-Leste (586 kg CO_2 eq) had the minimum impact on global warming per person in 2018.

Vietnam had the highest impact in Southeast Asia, contributing 17% of the damage to human health and ecosystems, 16% of the damage from resources scarcity, and the global warming potential. Majorly, cereals, fish and seafood, meats, and meat products were the significant contributors to all impact categories. However, legumes, nuts, and oils were an important food group that had the most significant impact on human health, ecosystems, resources scarcity, and global warming potential in Vietnam compared to the other Southeast Asian countries. Meats contributed 44% to GWP in Vietnam in 2011, and pork and bovine meat were the significant contributors to the meat impacts on the GWP (220 kg CO_2 eq per capita per year, respectively) (Heller et al., 2020). In 2018, meats contributed 46% to the global warming potential in Vietnam, in which pork (200 kg CO_2 eq per capita per year) was highly contributing to the meat's impact on the GWP than bovine meat (324 kg CO_2 eq per capita per year).

Healthy Diet Scenario Analysis

Figure 5 revealed the environmental impacts of HDS. Overall reduction (HDS_1) is favorable to reducing the environmental effects in all impact categories, followed by meats reduction (HDS 3). Vietnam had a high decrease in all impact categories for HDS_1 consideration, followed by Indonesia,

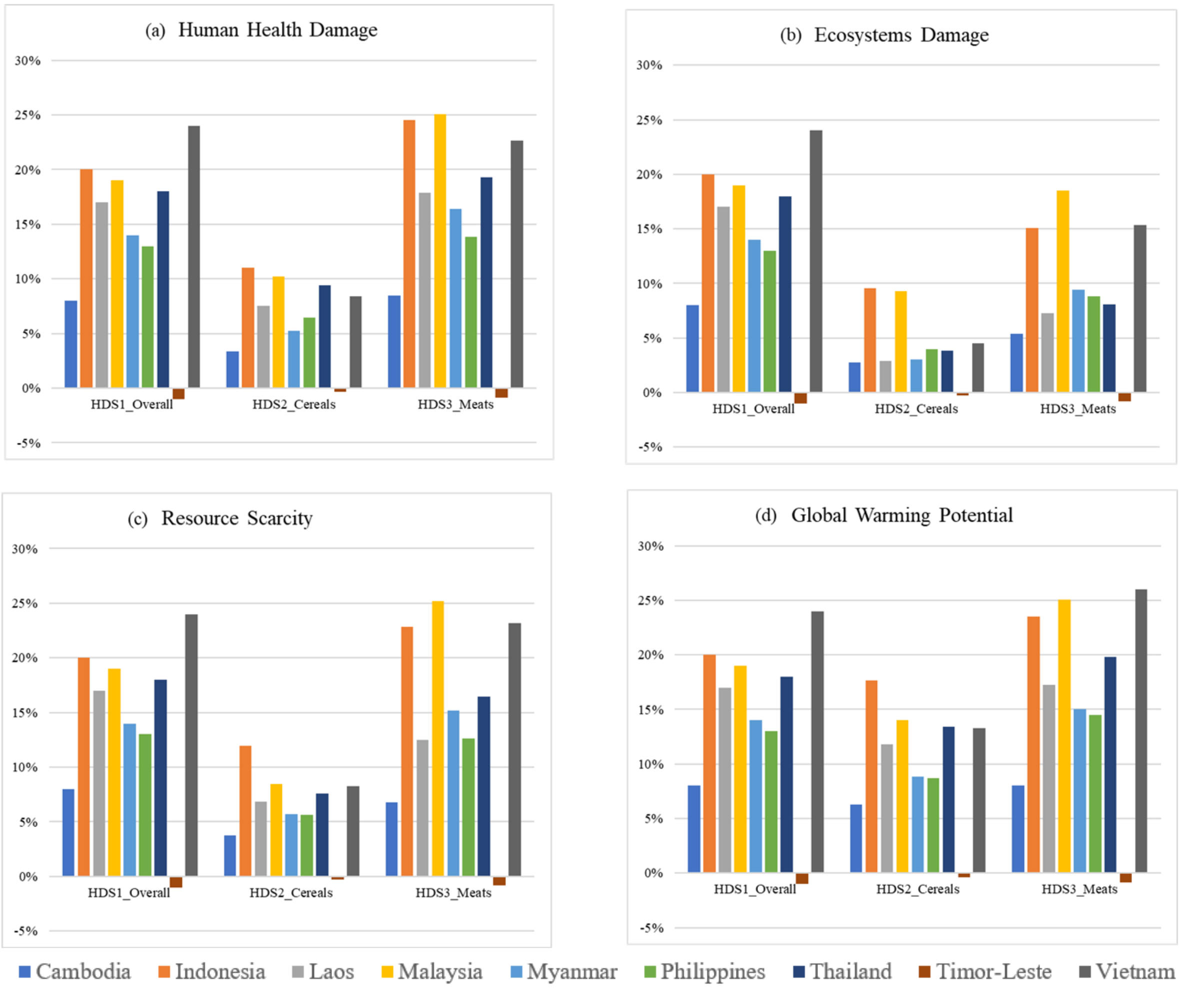

Figure 5 Percentage differences of damage impacts and the global warming potential resulted by applying Healthy Diet Scenarios (HDS)

Malaysia, Thailand, respectively. In order to achieve the benchmark intake of 2300 kcal per capita per day, the consumption was required to be reduced >8% for all countries in all impact categories except Timor-Leste. Timor-Leste, with the lowest diet intakes, 2286 kcal/capita/day, is demanded to be raised in its consumption. However, there was no significant impact increase (1%) after increasing its intake (1%) to hit the benchmarked intakes in all impact categories. Vietnam would require to be reduced 24% of its overall consumption (HDS_1), which had 24% decline in all impact categories. Indonesia (20%), Malaysia (19%), and Thailand (18%) made decreases in their impacts with directly proportional to its percent decreases of their consumption. Furthermore, 17% overall consumption reduction is required to reduce the impacts in Laos (17% of total impacts decrease). Meanwhile, 14%, 13%, and 8% of total impacts in human health damage, ecosystems damage, resources scarcity, and the global warming potential are dropped by the decrease of overall consumption in Myanmar (14%), Philippines (13%) and Cambodia (8%).

Under HDS_2 analysis, global warming potential is affected by the reduced cereal consumption in Indonesia (18%), 14% in Malaysia, 13% in Vietnam and Thailand, 12% in Laos, 9% in Myanmar, and the Philippines of total impacts, and 6% in Cambodia. Indonesia had 11% reduction, 10% of total impacts reduction in Malaysia and Thailand, 9% reduction in Vietnam, 6% decline in the

Philippines, 8% reduction in Laos and 5% in Myanmar, 3% reduction in Cambodia occurred in human health damage. There is a slight decrease in impact percentage (<10%) for all countries in ecosystems damage by cereal consumption reduction because meats, coffee and tea, spices were the significant contributors to the ecosystems. Similarly, in resources scarcity, besides cereal consumption, as meats, fish and seafood largely contributed to the resources scarcity, a minor impact reduction occurred (<12%). However, the intakes in all countries were considered to reduce above 12% of their consumption. As for Timor-Leste, there was no impact increase (0%) due to raising its intake to achieve the healthy diet by FAO.

Animals, animal products, and cereals consumption reduction is considered as one scenario, HDS_3. Malaysia has the higher impact decrease in all impact categories after applying HDS_3, followed by Vietnam, Indonesia, and Thailand. Since cereals, meats, fish and seafood were primary contributors to human health damage, resources scarcity, and global warming potential, the impacts are more prominent than ecosystems damage. 25% decrease in human health, resources scarcity, and global warming potential, 19% decrease in the ecosystems are discovered when Malaysia's energy intake is reduced by 32%. After Vietnam is considered to be reduced by 32% of its consumption under HDS_3, a 15% impact decrease occurred in ecosystems damage, 23% in human health damage, resources scarcity, and 26% in global warming potential. Meanwhile, although the percent reduction of consumption in Indonesia (30%) and Thailand (29%) are almost the same, the differences in impacts decrease in those countries are more or less significant. While there are 25%, 15%, 23%, and 24% of total impact decrease occurred in Indonesia for human health damage, ecosystems damage, resources scarcity, and global warming potential, 19%, 8%, 16%, and 20% in Thailand. The impacts declination in Myanmar and the Philippines are only 1~3% different, similar to the percent reduction of their consumption (20% of Myanmar, 18% of Philippines). In Cambodia, 8% reduction in human health damage, 7% reduction in resources scarcity, 8% reduction in global warming potential, and 5% reduction in the ecosystems damage occurred if the consumptions of animals, animal products, and grains in Cambodia are reduced by 10% in order to reach the benchmark of 2300 kcal/capita/day from 2492 kcal/capita/day. A non-significant decrease (7%) occurred in ecosystems damage in Laos. Furthermore, 12% impact declination is occurred in resource scarcity, 12% in global warming potential in Laos after its consumption was reduced by 18% to achieve healthy diets. Like HDS_1, Timor-Leste had no severe impact increase after raising its intake from 2286 to 2300 kcal per day. Vietnam had the highest energy intake (3023 kcal per day) among Southeast Asian countries. Therefore, there is a significant reduction in impact in all impact categories (HDS_1 and HDS_3) when the healthy diet scenario analysis is applied and 2300 kcal per day is taken as a benchmark for a healthy diet. As meat consumption in Malaysia is the highest in Southeast Asia, significant percentage decreases in all impact categories are found in all scenarios. Only Indonesia and Malaysia have significantly lower ecosystems impacts under HDS_2, as meat/meat products and spices are major contributors to ecosystems damage in the other countries. Timor-Leste, which had lower consumption than the reference value, is assumed to have increased its consumption. However, no significant increase in impacts was found.

Conclusions

This study has shown that differences in dietary habits across Southeast Asian countries have significant implications on human health, ecosystems, resources, and global warming. Vietnam, Myanmar, and Laos had the largest impacts, while Timor-Leste had the lowest impacts in all categories. In all countries, the consumption of fish and seafood, meat/meat products, and cereals caused high levels of harm to human health, while meat and meat products, coffee and tea, and spices damaged ecosystems. In terms of resource scarcity and global warming potential, grains, meat, and meat products topped the list of contributors to damage. On average, seafood consumption, grains, meat, and meat products contributed the most to impacts in all categories. Based on the healthy diet scenario analysis, total consumption and reduction in meat consumption are the most favorable scenarios in terms of reducing the impact of meat, fish, and seafood, with cereal consumption contributing the most to all impact categories in Southeast Asian countries. After applying the three scenarios, Vietnam had a large reduction in impacts in all categories, followed by Indonesia and Malaysia. However, Timor-Leste found no significant impact decrease after applying the scenario analysis.

Although the consumption of meat, fish, and seafood contributes significantly to the impacts, the intake (2018) in the Southeast Asian countries was not high enough to reduce the consumption and develop the scenarios to achieve a healthy diet of 2300 kcal per capita per day from the consumption of these products alone. However, if the consumption of animals and animal products were reduced along with the consumption of cereals, this would lead to a significant reduction in impact in Southeast Asian countries. Therefore, future studies should consider only reducing the consumption of animals and animal products to determine the reduction in impact. [15] showed that meat contributed to 44% of GHG emissions in Vietnam in 2011, with pork and beef accounting for the largest share of meat GHG emissions impacts (both 220 kg CO_2 eq per capita per year). In this study, meat contributed to 46% of the global warming potential in Vietnam, with pork (200 kg CO_2 eq per capita per year) contributing more to the GWP impact of meat than beef (324 kg CO_2 eq per capita per year). It is recommended that governments take specific measures to reduce the consumption of animals and animal products and support meat substitutes (e.g., tofu, tempeh, beans, etc.). It is also recommended that, in collaboration with the public health and education sectors, a project be launched to educate and encourage citizens to adopt a balanced diet.

Besides cereals, meats, fish and seafood, coffee, and spices, alcoholic beverages also contributed to the environmental impacts, especially on resource scarcity and human health damage. Nevertheless, as the contribution of alcoholic beverages was not much significant among food groups, the influential food groups were only highlighted. However, from a health perspective, alcoholic beverages have risks in health. Excessive alcoholic consumption would lead to chronic diseases and other severe problems, including high blood pressure, heart disease, stroke, liver disease and various cancers (breast, mouth and throat, liver, colon and rectum, esophagus, voice box), learning and memory problems, mental health (depression and anxiety), and social problems [16]. Moreover, other food items such as sugar, oil, salt, etc., also have health risks. Consuming too much sugar has heart disease risk factors such as obesity, high blood pressure, and inflammation. Moreover, diabetes and the increase in the risk of dying from heart disease have been linked to high-sugar diets [17]. Conclusively, choosing vegetables over meats have benefits to the environment. Moreover, if it looks up from the health perspective, meats also play a non-negligible role that gives required protein to have healthy diets. Certain nutrients like iron can be dropped when meats are taken off from the diets. Iron plays as an importan nutrient which function to convey oxygen in the whole body for producing energy and chronic fatigue, hair loss, dizziness, weakness, headaches, pale skin and fast heartbeat symptoms can be found when the taken iron are not suffient [18]. Moreover, omega-3 fatty acids can primarily be achieved from fish such as mackerel, herring, sardines and salmon. Omega-3s are crucial for cardiovascular health, eye and brain function. Omega-3s from plant-based versions cannot efficiently give what humans required [19]. However, this study only highlighted related to environmental problems. Hence, future studies should consider the health perspective with the sustainable diet systems.

Acknowledgment

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Health Impacts and Cost Assessment of Fine Particulate Matter Formation from Rice Straw Utilization in Thailand

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Abstract

Air pollution problems attributed to open burning of agricultural wastes have constantly affected the air quality and subsequently the human health in Thailand. To take advantage of the resource potential in rice straw, several alternative management practices have been carried out in Thailand. Hence, it is imperative to evaluate the potential health impacts of fine particulate matter emitted from the different rice straw utilization techniques. Thai spatially differentiated characterization factors were determined and applied to characterize the damage on human health related with $PM_{2.5}$ emission from the selected rice straw utilization scenarios. The results of the study depicted that open burning of the total rice straw generated increases health impact by 81.1% compared to Business-As-Usual (BAU) scenario, which supports the effectiveness of the different agricultural residue management methods integrated in the BAU scenario instead of open burning 100% of the rice straw generated. Furthermore, assessing the impact of alternative scenarios demonstrated that adopting rice straw management techniques such as fertilizer, animal feed and electricity production individually also can reduce health damage efficiently as compared to open burning. The BAU scenario extended vast economic benefit of 242 billion THB, compared to 100% open burning of rice straw. In addition, each of the alternative scenarios (except open burning) also provided large economic benefit in comparison with BAU scenario. Hence, both the health impact and economic benefit assessments were able to corroborate the efficiency of alternative rice straw utilization techniques in comparison to open burning, both when integrated or carried out individually. Due to the use of Thai spatially differentiated characterization factors, the study was able to project results specific to the context of Thailand.

Keywords : Fine Particulate Matter; Rice Straw Utilization; Health Impact; Economic Benefit; Thai Spatially Differentiated Characterization Factors

Introduction

Ambient fine particulate matter pollution is an important health risk factor that significantly contributes to increasing global mortality. In 2019, Global Burden of Disease (GBD) study ranked $PM_{2.5}$ exposure as the 6^{th} global mortality risk factor and the 7^{th} leading risk factor in Thailand [1]. Amongst the major sources resulting in high levels of $PM_{2.5}$ emission (including industries, transportation, biomass burning and transboundary haze [2]), the extent of agricultural waste burning and its adverse implication on air quality is pronounced in Thailand [3, 4]. Thailand is an agricultural-based economy and agriculture accounts for about 47% of the total land cover of Thailand [21]. Rice is one of the major crops of Thailand that is planted throughout the country [5]. In 2017-2018, about 32.24 million tonnes of rice was produced ranking Thailand as the sixth largest global producer of rice [7]. Thailand is also among the leading countries that export rice, holding about 24% of global rice export market share [6]. Along with the production statistics, rice also has a high crop to residue ratio such that rice residue is the highest-ranking crop residue that is openly burned in Thailand annually (70% of total residues of Thailand) [3]. Moreover, Thailand had the 10^{th} highest amount of biomass burned globally in 2016 [3]. The detrimental impacts of $PM_{2.5}$ emission attributed to open burning of agricultural waste on ambient air quality [8, 9, 12] and human health [2, 10, 11] is evident. Ongoing efforts by the government of Thailand have focused on addressing the problems of open burning agricultural wastes by providing control measures and promoting alternative measures to manage the crop residue generated [9, 13]. Several practices for alternative management of rice residue are carried out such as bio-energy generation, incorporation as fertilizer, utilization as animal feed, mushroom plantation, etc., to advantage of its resource potential [3, 5, 14, 16-20]. Life cycle impact assessment (LCIA) can be adopted to efficiently analyze the health impacts associated with $PM_{2.5}$ emission [32]. Studies specific to the context of Thailand that have evaluated the environmental impacts of different rice straw management techniques have either not focused on $PM_{2.5}$ formation impact category, applied global LCIA methods or have limited study area [16-20]. Thus, the aims of the study were: 1) to determine spatially differentiated characterization factors of $PM_{2.5}$ formation specific to 77 provinces of Thailand; 2) to assess the health impacts of $PM_{2.5}$ formation from different rice straw utilization techniques at provincial and country level; and 3) to determine the economic benefit of each of the alternative rice straw utilization techniques.

Methodology

The methodology focuses on determination of human heath impact and cost of fine particulate matter formation from rice residue utilization in 77 provinces of Thailand. The assessment was carried out as per the ISO 14040:2006 standardized framework for LCA [15].

Goal and Scope Definition

Evaluation of the human health impacts and costs of different rice residue utilization scenarios at the provincial and country levels of Thailand was the goal of the study and the unit of analysis was rice straw generated from annual production of rice in 2019. The air pollutants under scrutiny were primary $PM_{2.5}$ and secondary $PM_{2.5}$ precursors i.e., nitrogen oxides (NO_x), sulphur dioxide (SO_2) and ammonia (NH_3). The primary focus of this study was on agricultural waste management, so the system boundary of the analysis does not cover rice cultivation process and only the residue management part. The health impacts and economic benefits of each rice straw management scenarios considered have been determined for 77 provinces of Thailand following the framework shown in Figure 1, and the results of the study were represented at provincial and country-levels.

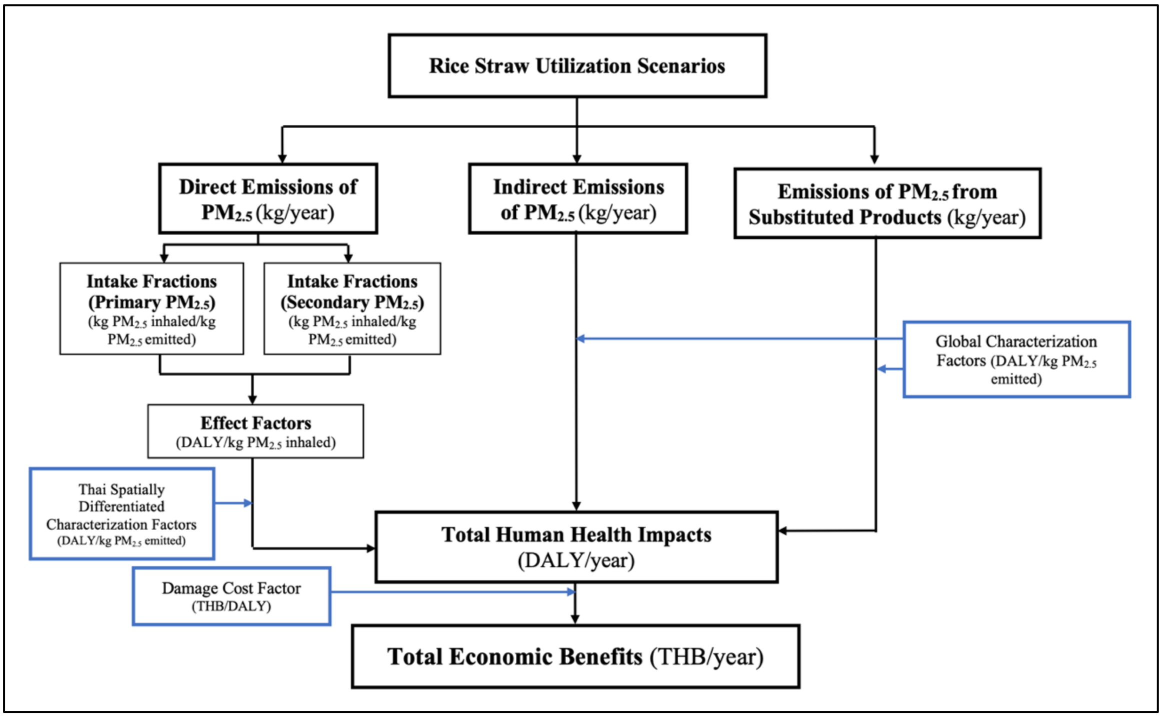

Figure 1 Overall Research Framework

Scenario Description

The study first involves determining the impacts of Business-As-Usual (BAU) scenario, followed by comparing it with alternative scenarios. In the BAU scenario, the total share of rice straw has been apportioned between 5 pathways (Table 1). While 100% of rice straw generated was utilized in the 4 alternative scenarios considered (Table 2). The percentage share of major (harvested in wet season i.e., September-April) and minor (harvested in dry season i.e., October-December) rice straw utilized in the BAU scenario (Table 1) has been adapted and modified from a study that conducted questionnaire survey to examine rice cultivation and residue management behavior during 2014/2015 crop season of Thailand [5]. Each scenario involves processes that lead to direct (that occur in Thailand) or indirect (that occur outside Thailand) emissions. The products obtained by utilization of rice straw in the considered scenarios lead to avoiding emissions that would have otherwise occurred from production of the substituted products. The substituted products as a result of each of the defined scenarios have been considered in the study and are provided in Table 2.

Table 1 Rice Straw Share (%) for Business-As-Usual (BAU) Scenario [5]

Rice Straw Utilization Pathways	Share of Rice Straw Utilization (%)									
	North		Northeast		Central		South		Thailand	
	Major	Minor	Major	Minor	Major	Minor	Major	Minor	Major	Minor
Fertilizer	0.28	0.23	0.07	0.14	0.25	0.15	0.31	0.14	0.24	0.18
Animal Feed	0.32	0.24	0.38	0.36	0.11	0.36	0.32	0.32	0.18	0.31
Mushroom Plantation	0.08	0.05	0.06	0.11	0.01	0.05	0.17	0.07	0.05	0.07
Open burning	0.20	0.26	0.01	0.21	0.36	0.18	0	0.02	0.30	0.21
Left in the field	0.11	0.22	0.48	0.18	0.26	0.26	0.19	0.45	0.23	0.23

Table 2 Overall Scenario Description

Scenario		Process	Emission	Substituted Product
Business-As-Usual (BAU) Scenario	BAU 1: Fertilizer (21%)*	Incorporation into the field**	Direct Emission	Nitrogen-Phosphorous-Potassium Fertilizer (Global Market)
		Straw Chopping**		
		Diesel Production	Indirect Emission	
	BAU 2: Animal Feed (24%)*	Straw Chopping**	Direct Emission	Animal Feed (Global Market)
		Baling Operation**		
		Transportation**		
		Diesel Production	Indirect Emission	
	BAU 3: Mushroom production (6%)*	Straw Chopping**	Direct Emission	-
		Baling Operation**		
		Transportation**		
		Diesel Production	Indirect Emission	
	BAU 4: Open Burning (26%)*	Open Burning	Direct Emission	-
	BAU 5: Left in Field (23%)*	Left in field	Direct Emission	-
Scenario 1: Open Burning (100%)*		Open Burning	Direct Emission	-
Scenario 2: Fertilizer (100%)*		Incorporation into the field**	Direct Emission	Nitrogen-Phosphorous-Potassium Fertilizer (Global Market)
		Straw Chopping**		
		Diesel Production	Indirect Emission	
Scenario 3: Animal Feed (100%)*		Straw Chopping**	Direct Emission	Animal Feed (Global Market)
		Baling Operation**		
		Transportation**		
		Diesel Production	Indirect Emission	
Scenario 4: Electricity Generation (100%)*		Straw Chopping**	Direct Emission	Grid Electricity (High Voltage) (Local Market)
		Baling Operation**		
		Transportation**		
		Electricity Generation		
		Diesel Production	Indirect Emission	

*Percentage share of rice straw utilized; **Emission from diesel combustion

Emission Inventory Development

Emission inventories for the different scenarios of this study were developed for: direct emission, indirect emission and substituted product emission (Table 2). The emission inventory data were obtained from secondary sources. The rice production yield (tonnes/ha) and harvested area (ha) data were gathered from the year book "Agricultural Statistics of Thailand – 2019" [21]. The ratio for residue to crop and dry matter to crop were taken as 1.19 of 0.85 respectively, to obtain the rice residue generated (dry weight) [22]. The rice straw percentage shares provided in Table 1 and Table 2 are adopted for calculation of the equivalent share of residue for all considered scenarios.

Direct Emission: The direct emission was determined by combining emission factor with activity data. The input data adopted for calculating the direct emissions from the different processes considered have been provided in Table 3. Round trip transportation distance of 10 km by 7-tonne diesel vehicle (from field to collection center) was assumed for utilization as animal feed and mushroom plantation [20]. Whereas round-trip transportation distance of 90 km by 15-tonne diesel vehicle (from field to electricity generation plant) was assumed for rice straw-based electricity generation, with 10% transportation loss [20, 19]. The emission factors in case of diesel combustion from transportation and diesel required per tkm were obtained from the ecoinvent database v3.7.1, for 7.5-16 tonne, EURO 3 lorry (freight transport) [25].

Indirect Emission: To compute the indirect emission from diesel production, total diesel (kg) required for all processes involved in each scenario were determined (such as straw chopping, incorporation into the field, baling operation and transportation). The density of diesel i.e., 0.85 kg/L has been adopted [29]. The $PM_{2.5}$ emissions from diesel production (global market) were directly calculated from the ecoinvent database v3.7.1 available from SimaPro v9.2.0.1 [25].

Table 3 Input data for direct emissions

Process	Parameter	Value	Unit	Reference
Incorporating residue into the field	Nitrogen (N) content	6	kg/tonne of rice straw (dry weight)	[23]
	Phosphorous (P) content	1	kg/tonne of rice straw (dry weight)	[23]
	Potassium (K) content	19	kg/tonne of rice straw (dry weight)	[23]
	Emission Factor (NH_3)	0.12	kg NH_3/ kg of N	[24]
	Emission Factor (NO_X)	0.04	NO_X/kg of N	[38]
Diesel combustion (agricultural machinery)	Energy content (diesel)	38.42	MJ/L	[40]
	Diesel requirement (straw chopping)	78	L/ha	[19]
	Diesel requirement (incorporation into the field)	16	L/ha	[19]
	Diesel requirement (baling operation)	1.2	L/ha	[19]
	Emission Factor (NOx)	866	g/GJ	[25]
	Emission Factor (SO_2)	22.4	g/GJ	[25]
	Emission Factor ($PM_{2.5}$)	109	g/GJ	[25]
Diesel combustion (transportation)	Diesel requirement	0.04	kg/tkm	[25]
Open burning	Combustion Factor	0.87		[22]
	Emission Factor ($PM_{2.5}$)	8.3	g/kg rice straw	[26]
	Emission Factor (NOx)	3.34	g/kg rice straw	[26]
	Emission Factor (SO_2)	0.48	g/kg rice straw	[26]
	Emission Factor (NH_3)	4.1	g/kg rice straw	[26]
Electricity Generation	Energy content (rice straw)	14.2	MJ/kg	[5]
	Plant Efficiency	23	%	[27]
	Emission Factor ($PM_{2.5}$)	133	g/GJ	[28]
	Emission Factor (NOx)	81	g/GJ	[28]
	Emission Factor (SO_2)	10.8	g/GJ	[28]

Substituted Product Emission: The products that utilization of rice straw as fertilizer substituted are N, P and K fertilizers (global market). The data on nutrient content per tonne for rice straw generated was used. Rice straw utilization as animal feed substitutes feed energy (global market). The feed energy per kilogram of rice straw (dry weight) is 8.45 MJ [30]. Rice straw-based electricity generation substitutes grid electricity generation in Thailand (high voltage). The $PM_{2.5}$ emissions from all substituted products were calculated directly using the ecoinvent database v3.7.1 available from SimaPro v9.2.0.1 [25].

Health Impact Assessment

The health impact assessment follows an impact pathway that characterizes the emission of $PM_{2.5}$ and health impact associated with subsequent inhalation by exposed population [31]. Characterization Factor (CF) for fine particulate matter formation is the parameter that translates the chain of effects in the impact pathway from emission to human health damage. The CF represents impacts on human health from exposure to $PM_{2.5}$ and is indicated as disability-adjusted life year (DALY) per kilograms $PM_{2.5}$ emitted. CF calculation comprises integrating intake fraction (iF) with effect factor (EF) [32]. The iF represents ratio of $PM_{2.5}$ that the exposed population inhales to total $PM_{2.5}$ emitted at source. While EF relates population exposure to $PM_{2.5}$ with health effects. The spatially differentiated iF and EF for 77 provinces of Thailand have been calculated by adapting and updating input parameters in existing iF and EF models [33, 34]. The determination of the province specific CF involves considering the effect of $PM_{2.5}$ emission in an urban area (i.e., specific province in Thailand) and the surrounding rural area (i.e., Thailand and Indochina) [32-34, 39]. The iF model also considers city-specific outdoor emission on both indoor and outdoor compartments.

$$CF_i^{urban} = iF_{i\leftarrow i}^{urban} \times EF_i^{urban} + iF_{k\leftarrow i}^{urban} \times EF'^{total}_k \quad (1)$$

where, $CF_i^{\text{urban}} =$ Characterization Factor (DALY/kg $PM_{2.5}$ emitted) for province (*i*)

$iF_{i\leftarrow i}^{\text{urban}}$ =Total urban inhalation iF (kg $PM_{2.5}$ inhaled/ kg $PM_{2.5}$ emitted) for province (*i*)

$iF_{k\leftarrow i}^{\text{urban}} =$ Total rural inhalation iF (kg $PM_{2.5}$ inhaled / kg $PM_{2.5}$ emitted) for rural area excluding province (*i*) (denoted as *k*)

EF_i^{urban} = Effect factor (average slope) for province (*i*) (DALY/kg $PM_{2.5}$ inhaled)

EF'^{total}_k Effect factor (average slope) for rural area excluding province (*i*) (DALY/ kg $PM_{2.5}$ inhaled)

The input parameters revised in the iF model to determine spatially differentiated values were province-specific population, urban area, linear population density (LPD), ambient $PM_{2.5}$ concentration, mixing height, wind velocity and dilution rate. Similarly, the input parameters revised in EF model to obtain province-specific factors were mortality data, severity factors, population and $PM_{2.5}$ concentration. Since the current framework of iF does not involve secondary $PM_{2.5}$, global average iF values of secondary $PM_{2.5}$ precursors have been used [35]. Since the global intake fractions were not differentiated for urban and rural areas, effect factor covering a larger area, i.e., Thailand has been used. The total health impact (HI) scores for direct emissions from each scenario were calculated as a summation of the product of spatially differentiated CF_i for $PM_{2.5}$, NO_X, SO_2 and NH_3 with their respective province specific emissions.

$$HI = \sum HI_i = \sum(Emission_i \times CF_i) \quad (2)$$

In case of indirect and substituted product emissions, health impacts (DALY) were calculated directly in SimaPro v9.2.0.1 using Impact World+ Endpoint [36] which is a method for life cycle impact assessment. Total health impacts were calculated by subtracting health impacts of substituted products from sum of health impacts of direct and indirect emissions.

Economic Benefit Valuation

The human health impact score was monetized using damage cost factor that translates value of 1 DALY into Thai Baht (THB) [37]. The factor has been calculated based on budget constraint approach which considers 1 DALY equivalent to an individual's annual income earned at the state of full-wellbeing and is the maximum amount an individual is willing to pay for additional year of full-wellbeing [37]. The value of 1 DALY in 2011 was equivalent to 512,000 THB. Future valuation of 1 DALY considered the time value of money applying inflation rate of Thailand averaged over period of 2011-2019 (reference year) [39]. Hence, the future value of DALY in 2019 was determined as 572,736 THB. The economic benefit provided by each of the alternative scenarios were determined by relating it with the total health impacts reduction as compared to BAU scenario.

$$Economic\ Benefit = Damage\ Cost\ Factor \times (HI_{BAU} - HI_{scenario}) \quad (3)$$

The summarized information on overall work process of the study has been presented in Figure 2.

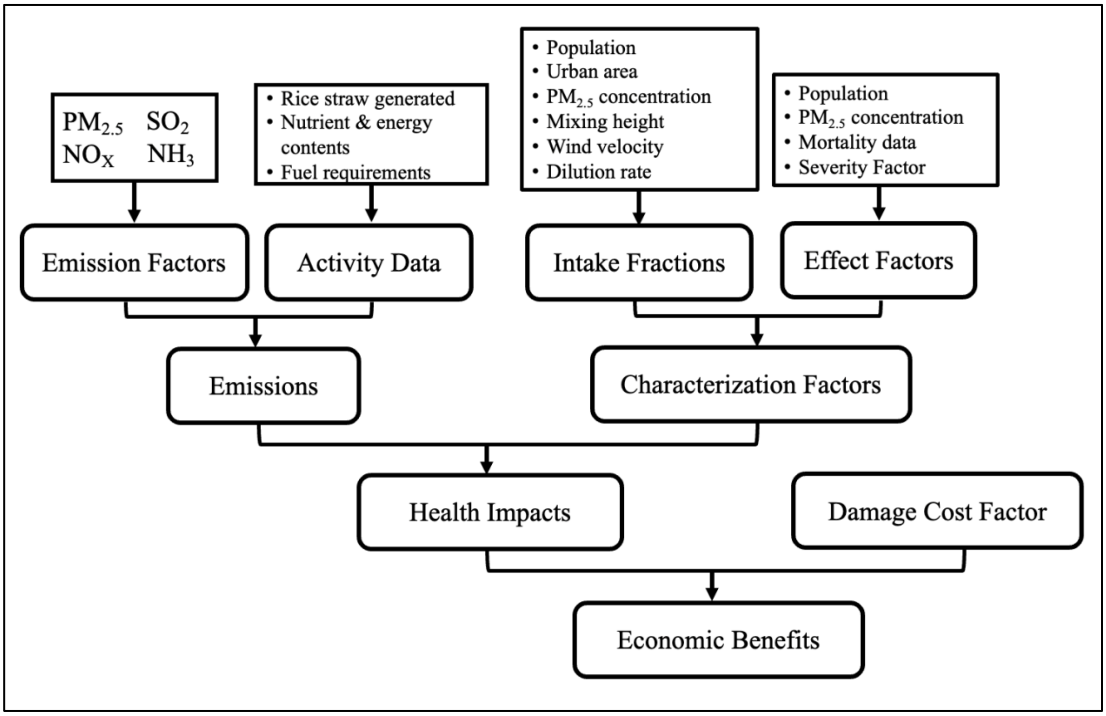

Figure 2 Summarized workflow diagram

Results and Discussion

Spatially differentiated characterization factors

The spatially differentiated CFs were determined for $PM_{2.5}$ by combining iF and EF, at provincial-level of Thailand. The determined CF for primary $PM_{2.5}$ of 77 provinces have been presented in Figure 3. The provinces having population density and ambient $PM_{2.5}$ concentration at higher range were found to have higher iF values. While provinces having atmospheric dilution rate at lower range were found to have higher iF values [39]. The provinces having ambient $PM_{2.5}$ concentration at higher range were found to have lower EF values. This is because the relative risk of $PM_{2.5}$ exposure is characterized by an exposure-response model that is non-linear, such that with increment in the $PM_{2.5}$ exposure concentration the slope of health effects decreases gradually [34]. In case of secondary $PM_{2.5}$ precursors gases, global iF and country-specific EF was used such that the obtained CF is spatially differentiated at country-level. The determined CFs for NO_X, SO_2 and NH_3 are 1.90E-05, 9.40E-05 and 1.61E-04 DALY/kg $PM_{2.5}$ emitted respectively. Hence, the health damage resulting from primary $PM_{2.5}$ have greater impact as range of CF for primary $PM_{2.5}$ (Figure 3) is higher compared to secondary $PM_{2.5}$ precursors. Nonetheless, the obtained CF was widely varying between provinces which shows that the health impact assessment using global CF would not be able to adequately reflect the variable effect emission sources have on health impact.

Health impacts of BAU scenario at provincial level

The health impacts imposed by rice straw utilization in BAU scenario for all 77 provinces of Thailand has been depicted in Figure 4. The top five provinces with highest health impacts were Nakhon Sawan (12,837 DALYs), Suphan Buri (10,138 DALYs), Phetchabun (8,229 DALYs), Kamphaeng Phet (5508 DALYs) and Phichit (4,816 DALYs). While the lowest health impact was observed in Phuket (0.006 DALY). In general, the province with rice straw generation (tonnes) and CF (DALY/kg $PM_{2.5}$ emitted) in the higher range were found to have higher health impact.

Phichit had the 3rd largest rice straw available however, it ranked as 5th highest health impact because its CF was in the lower range. This depicted the importance of applying the spatially differentiated CF because if global CF were used then the results would only be proportional to rice straw generation data and the effect of regionalized health impact would not have been revealed in the results. Amongst all the underlying pathways of BAU, open burning consistently contributed to the highest health impact in all the 77 provinces (95% of total BAU health impact). The health impact imposed by BAU1 (Fertilizer), BAU2(Animal Feed), BAU3 (Mushroom Plantation), and BAU5 (Left in Field) were 2.5%, 0.8%, 0.4% and 1.2% respectively, which were diminutive compared to BAU4 (Open Burning). Furthermore, the percentage share of rice straw utilization varies regionally, as shown in Table 1. For instance, open burning has the highest share of rice straw in central region of Thailand (27%), while lowest share of rice straw undergoes open burning in the southern region (1%). This also explains why the top 5 provinces of Thailand with highest health impact were located in central region while the province with lowest health impact was located in the southern region of Thailand.

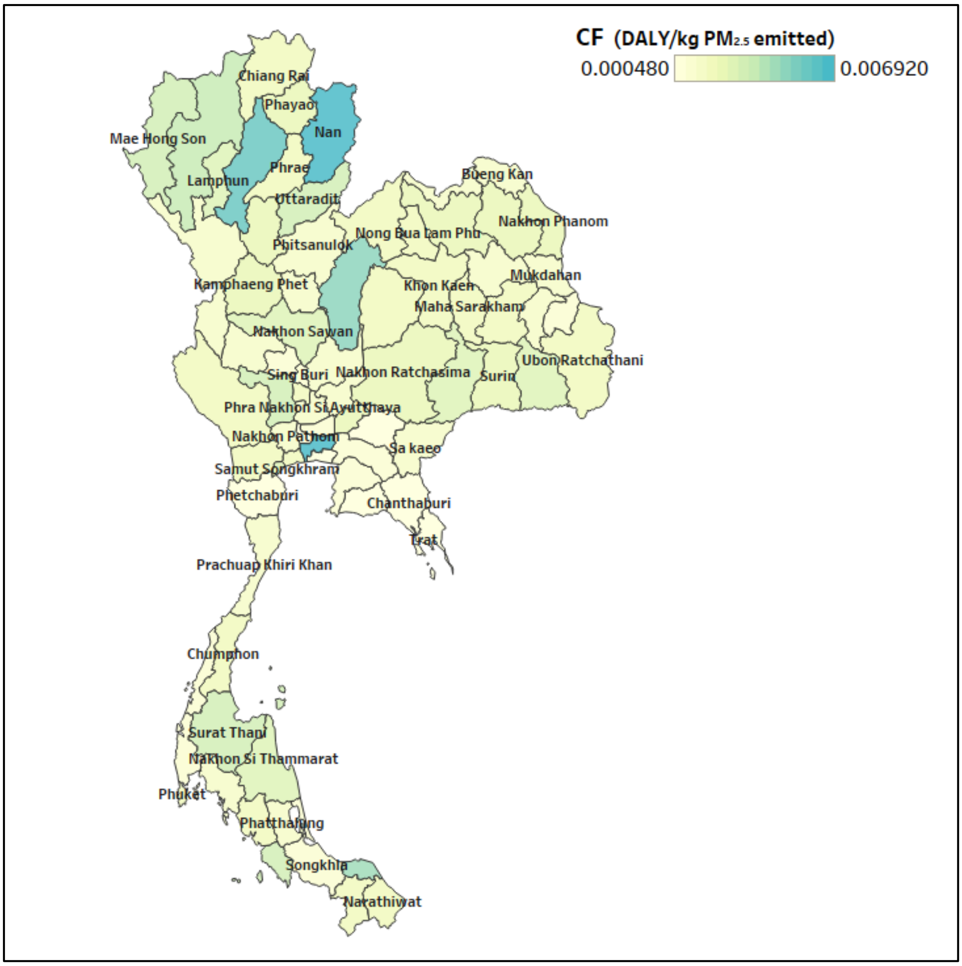

Figure 3 Spatially differentiated CF for primary $PM_{2.5}$

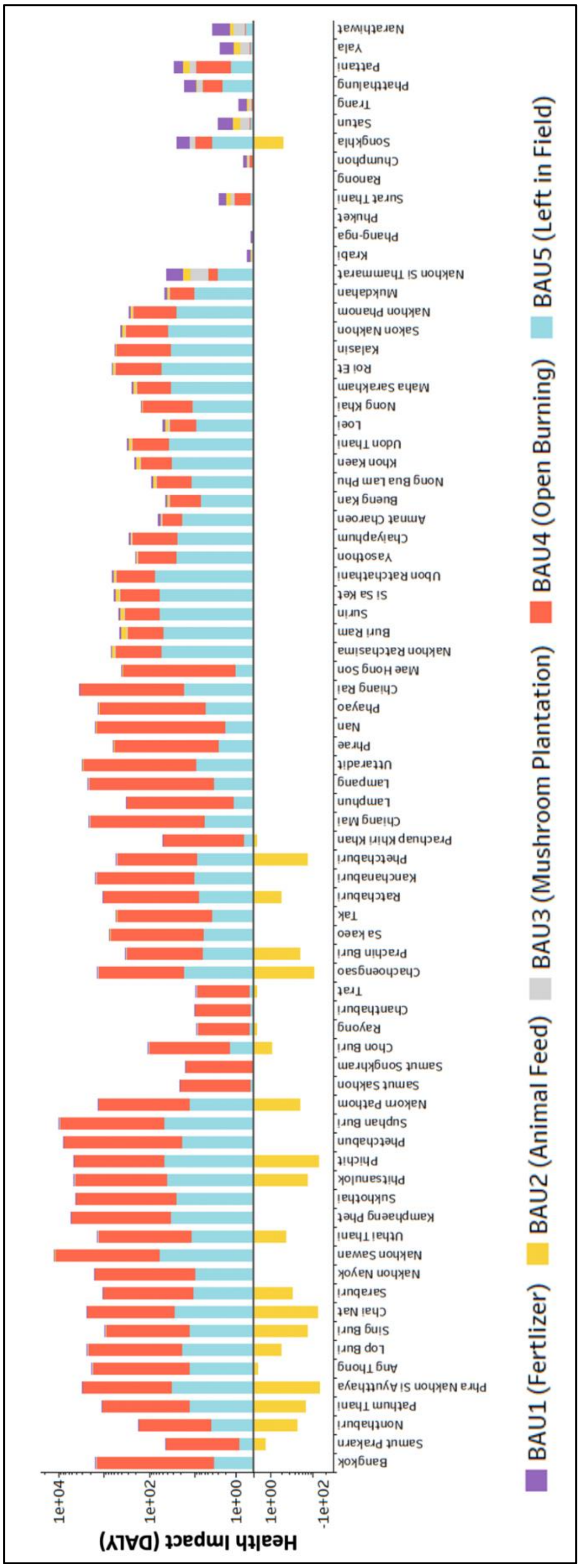

Figure 4 Health impacts of BAU scenario at provincial level (Logarithmic scale)

Total health impacts of alternative scenarios

The total health impacts have been determined by combining the effects of direct, indirect and substituted product emission of all 77 provinces of Thailand. Total health impacts of the four alternative scenarios have been compared with the BAU scenario in Figure 5. The scenario having the highest total health impact was Scenario 1 (Open Burning) and it was also the only scenario having higher impact than BAU i.e., 423,193 DALYs more than BAU. The remaining 3 alternative scenarios (i.e., electricity production, fertilizer and animal feed) have lower health impact than BAU scenario i.e., health benefits. Scenario 3 (Animal Feed) was the alternative scenario that contributed the lowest health impact i.e., health benefit of 96,526 DALYs. Scenario 1 involves only direct emission by open burning 100% of rice straw generated. In Scenario 2, direct emission predominantly leads to about 16,222 DALYs, while indirect emission leads to only 412 DALYs and substituted product emission reduces 1,576 DALYs. While in Scenario 3, direct emission leads to about 7,985 DALYs, indirect emission leads to only 265 DALYs and substituted product emission reduces 5,876 DALYs. Similarly in Scenario 4, direct emission leads to about 35,334 DALYs, while indirect emission causes 264 DALYs and substituted product emission reduces only about 3 DALYs. Hence, direct emission caused highest health impact in all the four alternative scenarios but avoided emission from substituted product significantly helps in reducing the impact only for Scenario 3 (Animal Feed). Diesel combustion due to agricultural machinery and transportation cause direct emission of $PM_{2.5}$ in Scenarios 2, 3 and 4. Additionally, $PM_{2.5}$ was also emitted in electricity generation plant for Scenario 4, which was still very less compared to emission of $PM_{2.5}$ by open burning of rice straw in the field.

Furthermore, the results showed that Scenario 1 increases the health impacts by 423,193 DALYs compared to BAU scenario which extends the effectiveness of incorporating different agricultural residue management methods instead of open burning all the rice straw that was generated. But, BAU still has higher health impact than Scenarios 2, 3 and 4 as open burning was one of the integrated pathways of BAU. As 5 pathways were combined in BAU, the alternative Scenarios 1, 2 and 3 helped to understand the health effect each scenario has individually. Moreover, Scenario 4 has been formulated because rice straw has potential of electricity generation [5] but it was not included in BAU. Through the results we can see the adverse effect open burning has on human health and the capability of alternative scenarios to counteract the negative impact of open burning, both when integrated (in BAU scenario) or carried out individually (in alternative scenarios 2, 3 and 4).

Total economic benefits of alternative scenarios

To better comprehend the total cost/benefit of the alternative scenarios, the health impacts increment/reduction with respect to BAU have been translated into monetary terms combining the results of all 77 provinces. From Figure 6, Scenario 3 (Animal Feed) has the highest total economic benefit of 55 billion THB as large amount of $PM_{2.5}$ emission was avoided because of substitution of animal feed with rice straw. It was followed by Scenario 2 (Fertilizer) whose economic benefit was slightly less, i.e., 48 billion THB. Scenario 4 (Electricity Production) ranks 3rd with an economic benefit of 36 billion THB. While Scenario 1 (Open Burning) rendered health cost of 242 billion THB rather than benefit in comparison with BAU, which is in line with the results obtained in total health impact analysis (i.e., direct emission from open burning has highest impact). Although BAU scenario consisted of approximately 26% of rice straw open burning, it still has economic benefit of 242 billion THB compared to 100% open burning of rice straw. Moreover, Scenarios 2, 3 and 4 were subjected to higher economic benefits as the BAU scenario has open burning integrated as agricultural residue management technique. Scenarios 2, 3 and 4 extend economic benefit of 120%, 123% and 115% respectively in comparison with Scenario 1 (Open Burning). Hence, the results show that replacing open burning with other alternative scenarios can efficiently increase economic benefits.

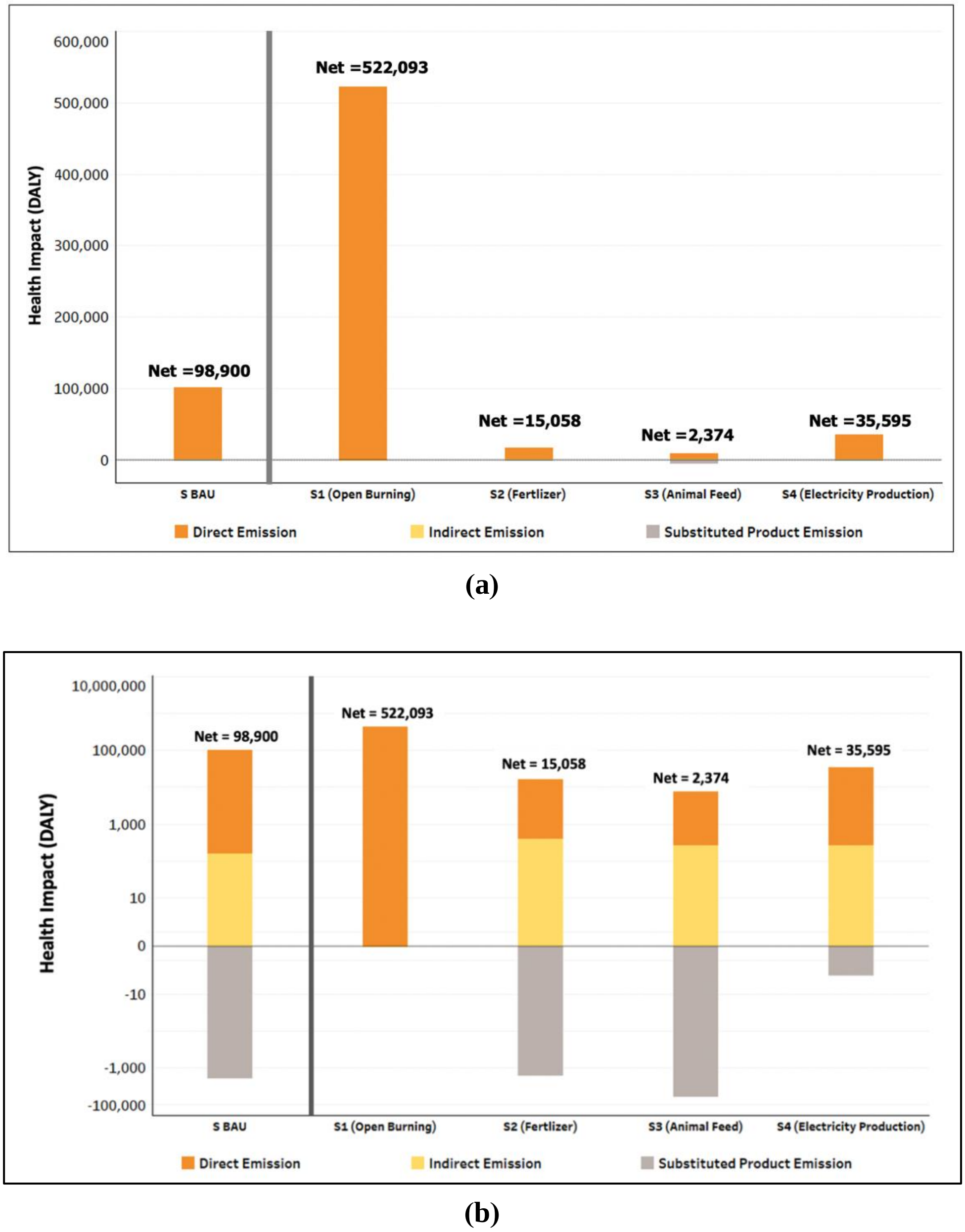

Figure 5 Total health impacts of alternative scenarios (a) normal scale and (b) logarithmic scale

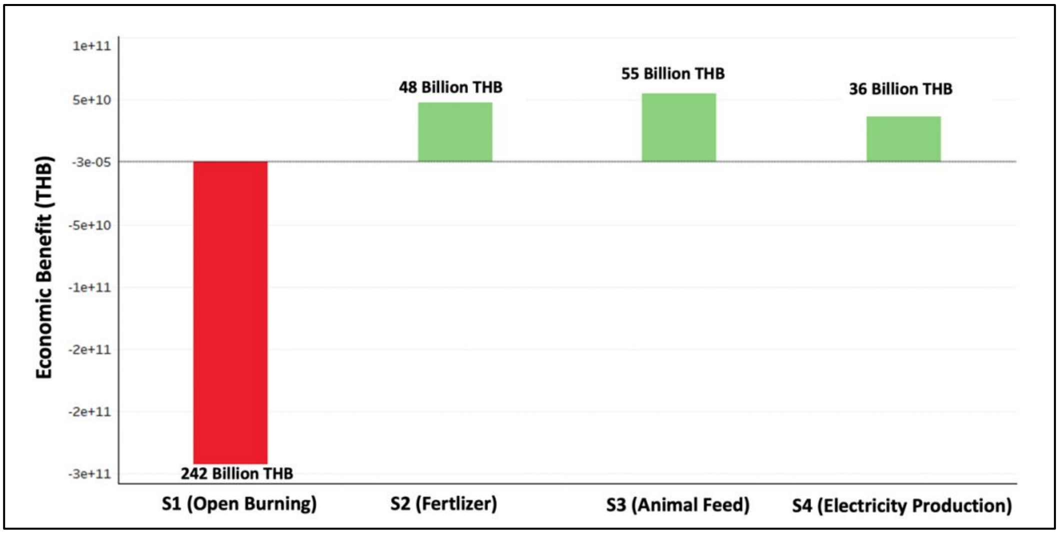

Figure 6 Total economic benefits of alternative scenarios

Conclusions

The health impact and economic benefits of fine particulate matter formation was determined for different rice straw utilization practices of Thailand. To calculate the health impact, spatially differentiated characterization factors (CFs) of $PM_{2.5}$ were determined for the 77 provinces of Thailand. The calculated CFs varied extensively between provinces which demonstrated that the health impact assessment using global CFs would not be able to capture the contribution of region specific $PM_{2.5}$ exposure-response relationship. Province-specific health impact was evaluated for Business-As-Usual (BAU) scenario which had 5 different rice straw utilization methods integrated together. Provinces with the highest and lowest health impact attributed to BAU scenario were Nakhon Sawan and Phuket respectively. Open burning pathway in BAU scenario contributed the highest health impact i.e., 95% of total BAU health impact in all the 77 provinces. Total health impacts of the four alternative scenarios (i.e., open burning, fertilizer, animal feed and electricity production) were compared with the BAU scenario to analyze the individual effects of each residue management method. The results show that the BAU scenario was capable of decreasing health impact by 81.1% compared to the open burning scenario, which supports the effectiveness of combining agricultural residue management methods instead of open burning of the entire rice straw generated. In comparison with alternative scenarios such as fertilizer, animal feed and electricity production, the BAU scenario contributes to higher health impact as open burning is one of the integrated management methods. Hence, individually assessing the impact of each alternative scenarios with respect to the BAU scenario demonstrated the higher efficiency of these alternative rice straw management techniques. Furthermore, the economic benefit assessment helped in providing a better perspective by translating the health impact assessment results into monetary terms. The results depicted that the BAU scenario extended vast economic benefit compared to 100% open burning of rice straw (i.e., 242 billion THB). In addition, the alternative scenarios (fertilizer, animal feed and electricity production) also provided large economic benefit individually as compared to BAU. Hence, both the health impact and economic benefit assessments were able to corroborate the efficiency of alternative rice straw utilization techniques in comparison to open burning, both when integrated or carried out individually. Moreover, due to the use of Thai spatially differentiated CFs, the study was able to obtain outcomes that were particularly for the case of Thailand. As alternative residue management methods like fertilizer, animal feed and electricity production demonstrated positive results, future studies can be carried out to develop scenarios by integrating diverse residue management techniques and allocating different proportions of crop residue to each of the considered techniques which will help in recommending the best scenario for effective agricultural residue management in Thailand. Finally, the overall outcomes are subjected to uncertainties because of the methodology adopted, assumptions made, and data utilized in calculation of the $PM_{2.5}$ emissions for the processes considered and the spatially differentiated $PM_{2.5}$ characterization factors.

Acknowledgements

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Mask and ATK Wastes Management in Urban Community By People Participatory Process under COVID-19 Pandemic Crisis of Bangkok, Thailand

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Abstract

Under the situation of Coronavirus 2019 (COVID-19) pandemic for the past 2 years, people had used the facial masks (masks) for protection of COVID 19 and antigen test kit (ATK) waste and left its mixing with the general wastes without segregation at source. Rationally, It should conduct the study on such masks waste collection management as qualitative research, of which the objectives were 1) to develop the collection system of the used masks and ATK in the community by people participatory process, 2) to raise awareness for the importance of the hygienic collection of the used masks and ATK management and get familiarize with participatory process, 3) to survey the management of used masks and ATK management at the communities, construction worker camp sites, and industrial dormitories in Bangkok Metropolitan Administration (BMA) area. The study area covered 11 communities in Dusit District (Inner Bangkok), 5 construction worker camp sites in Laksi District, and 5 industrial plants in Bangkhen District. The study of 11 communities resulted that the used masks and ATK waste were averagely collected as for 19.25 kg/week or 2.75 kg/day with the trend of weekly increasing. The appropriate model for the communities on used masks and ATK management was the means of participation process. People participatory process was performed through the community leaders and committee for the provision of collection containers, location and number of containers, appointing date/time and frequency. The effective mean of participation process was not only public relation together with requesting for people participation but also monitoring the hygienic segregation and collection of the used masks and ATK wastes. The appropriate model for the construction worker camp sites was creating awareness for an importance on hygienic segregation and collection of the used masks and ATK wastes together with issuing the regulations for safe living in the camp for such hygienic segregation and collection of wastes. The communication to the workers should use simple and understandable language for hygienic mitigation measures. The appropriate model for industrial dormitories was creating the awareness on an importance of the hygienic collection management of the used masks and ATK wastes. The strong protection measures were issuing the regulation with strict enforcement on segregation and collection management of the used masks and ATK wastes under the intensive monitoring by the workers' chief. The hygienic equipment and accessories had to be provided adequately for both number and locations of wastes drop-off point. Communication to the Thai and foreign workers by simple and understandable language.

Keywords : People Participatory; Used Mask; COVID 19 Pandemic

Introduction

The situation of pandemic of Coronavirus disease or COVID-19 has generated the management problem of used masks mixed with general wastes left by household. That has caused increasing the health risk on COVID-19. Pollution Control Department, Thailand, has forecasted that if using the mask as 1 piece/person/day, the used masks would be 1,800 million pieces/month. The used masks might have been contaminated with COVID-19 virus caused by secretions such as saliva, mucous, phlegm, etc. Such used masks were considered as infectious wastes which enable spreading of the diseases like COVID-19. Thus, it required the hygienic collection management of the used masks. One of the efficacious means of the used masks collection was the people participatory process. For the fiscal budget 2019, Bangkok Metropolitan Administration generated infectious wastes of 42.53 ton/day collected from 3,378 public health service stations by Krungthep Thanakom Co., Ltd, and disposed at the infectious wastes incinerator plants at On Nuch and Nong Khaem. (Figure 1) [1]. Regarding the fiscal year 2020 under the normal condition prior the pandemic of COVID-19, the infectious wastes generated in Bangkok Metropolitan area was averagely 43.94 ton/day which was not different compared to the generation rate in the past year. During the pandemic period of COVID-19 particularly at the heavy pandemic during January-June 2021, the infectious wastes had increased as high as 74.07 ton/day, which was generated from the medical treatment and diagnosis units in the hospitals, disease surveillance and laboratory analysis of severe viral including the temporary health care stations and the quarantine stations [2, 3]. In addition, the generation rate of infectious wastes as COVID-19 of the medical treatment of COVID-19 in hospitals was averagely 7.5 kg/capita/day. Whereas, the quarantine area, the generation rate of infectious wastes as COVID-19 was averagely 1.32 kg/capita/day [4].

a) Courtyard for Infectious Wastes Containers at On Nuch Solid Wastes Disposal Center

b) Infectious Wastes Vertical Rotary Kiln at On Nuch Solid Wastes Disposal Center

c) Infectious Wastes Rotary Kiln at Nong Khaem Solid Wastes Disposal Center

Figure 1 Infectious Wastes Incinerator of Bangkok Metropolitan Administration (BMA)

Regarding the good practice on infectious wastes management under the situation of COVID-19 Pandemic, the recommendations of the United Nations Environment Program (UNEP) are to categorize the hierarchy of wastes basing on the concept of 3 R (reduce, reuse, recycle) together with the holistically integrated management by the responsible agency. It is necessary for the government to establish the emergency plan under the criteria and conditions of each local organization as well as management strategy, of which the government and local authority organizations have to play an important role for such situation [5-7]. The infectious wastes contaminated with COVID-19 virus were generated from the health service rooms, laboratories, and any things related with COVID-19 patients including wastes from cleaning in the health stations and centers. Such infectious wastes have to be collected in the separated bags and disposed of according to the existing law [8]. Management of infectious wastes as COVID-19 in various countries was variety. Wuhan county, Republic of China where the COVID-19 firstly occurred, the infectious wastes as COVID-19 generated in the heavy period of pandemic was almost 247 ton/day, which was almost 6 times of the amount of infectious wastes generated under the normal condition. Wuhan County had hired 4 additional companies for medical waste disposal and constructed the emergency treatment stations as well as mobile incinerators for burning the high increasing amount of PPE wastes such as masks, gloves, and single use of protection equipment [9]. At Japan, management of infectious wastes as COVID-19 generated from hospitals had employed incineration, autoclave followed by destruction; dry disinfection and destruction; and disposal by specific sanitary landfill. Regarding the management of COVID-19 wastes generated from household, it would be mixed with other flammable wastes and burnt by incineration [10]. At South Korea, the used masks and PPE had to be brought out of the places for hygienic disposal on the same day that wastes generated [11]. For Thailand, the infectious wastes as COVID-19 generated during the pandemic of COVID-19 was over the disposal capacity of incinerator, which could be indicated by the complaint news on red bag of infectious wastes leaving in the community as well as the problem of solid wastes collection on time of the local administration organization. Basing on such problems, all agencies had collaborated to find the solution for COVID-19 waste problems by issuing the announcement on bringing infectious wastes to be the fuel for incinerator of some industries in order to burn wastes as for temporary management. BMA has hired Krungtep Thanakom Co., Ltd. for disposal of infectious wastes generated in Bangkok area with the capacity of 70 ton/day and forecasted to increase the disposal capacity of 79.99 ton/day in August 2021, that would have residual infectious wastes of 9.99 ton/day [1]. BMA had provided specific containers (red color) for collection of used masks distributing in the public area. The problem was that the used masks was still left mixing with general wastes. This was due to no segregation of the used masks and general wastes of household. [12, 13]. Thus, it is the rational to conduct this research, of which the objectives were 1) to develop the collection system of the used masks and ATK in communities by people participatory process 2) to raise awareness of people on the importance of hygienic collection of the used masks and ATK management and get familiarize with participation process, and 3) to survey the management of used masks and ATK at the construction worker camp sites and industrial dormitories in Bangkok Metropolitan Administration area.

Study Area

The study area consisted of 11 communities in Dusit District (Inner Bangkok Metropolitan area) comprising of 2,496 households and population of 6,614 peoples; 5 construction worker camp sites in Laksi District located in the north of Bangkok Metropolitan comprising of 1,136 workers; and 5 industries in Bangken District located in the north of Bangkok Metropolitan comprising of 691 workers (Figure 2).

Material and Method

1) Studying the guideline of mask and ATK wastes collection of the study area as mentioned above.

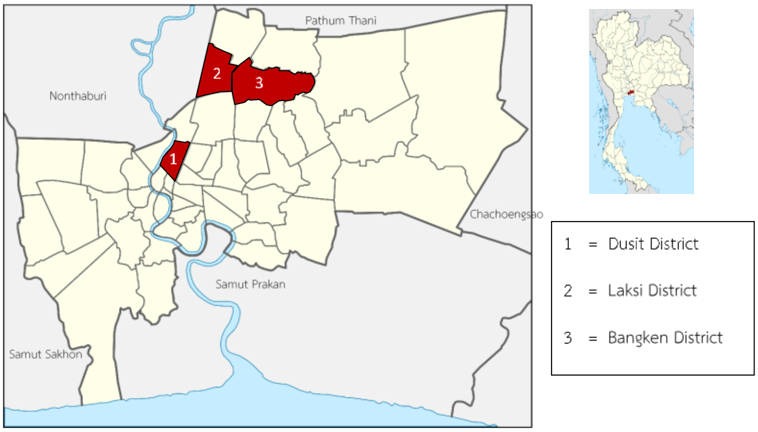


Figure 2 Study Area in Bangkok Metropolitan Administration

2) Investigating the appropriate mask and ATK wastes collection of the mentioned study areas by the participation process.

- For community study, focus group discussion with community leaders or representatives, BMA staffs and researchers had been performed in order to scrutinize the mean for the highest decision of people for such waste collection. In addition, the survey of the used masks and ATK waste had been undertaken for 4 weeks parallel with public participation on correct segregation and littering of used mask and ATK, collection of them and follow up on the waste separation of the target communities.
- Construction worker camp sites and industrial dormitories study. Similarly to the community study, the study had been performed by workers participatory process so as to consider the practical segregate and leave the used masks and ATK wastes. The problems and solutions of such practical collection also were investigated in order to assemble for the appropriate collection management guideline of the used mask and ATK waste for the construction worker camp sites and industrial dormitories.

3) Summarizing the guidelines of the used masks and ATK wastes collection from the studies of communities and construction worker camp sites / industrial dormitories.

4) Developing the appropriate model for the used masks and ATK wastes by following steps;

- presenting the summarized guidelines to the stakeholder including community representatives, managers of construction worker camp sites, managers of industries, officers of Dusit District, Officers of BMA, Experts as the adviser of the Research Project in order to get the comments of all stakeholders;
- compiling all relevant comments to summarize the mutual practical guideline for the appropriate model waste management of the used masks and ATK wastes.

Results and Discussion

1. Community participation on used mask and ATK waste collection model

Participation of people on the collection of the used mask and ATK waste was firstly started with the meeting with 11 community leaders, staffs of District Officers who are responsible for collection and transportation, staffs of BMA who are responsible for policy and action plan. The content of meeting proposed to the participants was rationale and importance of the management of the used masks and ATK wastes collection, awareness of the dangerous of non-hygienic/no segregation of such wastes, guideline for community on hygienic separation and collection of such wastes. The significant content was finding out the appropriate model and agreement such as number of participatory households; collection containers including number, location, appointment time and frequency of collection, output of collection; and community representative. Summary and recommendation are as follows.

1) Convincing all household in each participatory community to participate group meeting and activities for such wastes collection. In the meantime, raising awareness of people by presenting the important content of the used mask and ATK waste management on the public relation board sized 120x50 cm. installed for each participatory community.

2) Providing the collection containers and red plastic bags. The community leaders/ representatives provided the red handy bags sized 8x16 inch for each household to segregate and collect the used masks/ATK wastes and left at the red containers provided along 4 weeks survey.

3) The District Officer provided the red containers sized 80 liters placing at the suitable locations suggested by the participatory communities. Total of 24 red containers were provided together with the announcement to the people for drop-off points as shown in Figure 3.

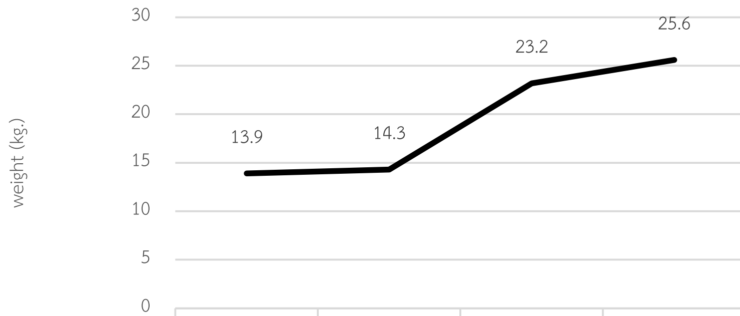
4) Set Out time for collection of such waste by BMA District Office. Result from consulting/survey the leader opinion, the collecting time was Sunday starting at 08.30 since the public announcement would be easier.

5) Frequency of collection was once a week on the designated day as the number of waste collection containers, placing points, and volume of wastes had capacity for once-a-week collection.

Figure 3 Collection Containers Placing at Various Points

Regarding the study results, it revealed that communities had participated for not only recommendations such as provision of red bags for the used masks and ATK wastes collection from household, public relation board, but also drop-off points for collection containers, frequency of wastes collection, etc. In addition, the memorandum of agreement had been made to assign the community representatives for public communication on segregation and collection of the used masks and ATK wastes by red bags and red containers, respectively at the collection points together with the weight measurement. It was found that the used masks and ATK wastes had been increased weekly, representing the people had strong participation on this segregation and collection activities. The used masks and ATK wastes were averagely 19.25 kg/week or 2.75 kg./day (Figure 4). It is estimated that collection of the used mask less than 1 piece/person-day, basing on the assumption that the used masks was partially left and mixed with general wastes, and some peoples used cloth masks being reused after washing. Accordingly, public relation had to be intensively undertaken for leaving and collection the used masks/ATK wastes as hygienically designated, which could be effectively performed through the community leaders. Besides, it was found that there was other general wastes mixed in the red containers provided only for the used masks and ATK wastes at the large communities with crowded transportation. Such mistakes of wastes leaving and collection was due to lack of awareness for segregation, non-suitable drop-off points of red containers as well as inadequate public relation.

Base on the study results, the appropriate model for the used masks and ATK wastes collection in the communities on the basis of the people participatory process should have 5 levels of participation approach including informing, consulting, involving, collaborating and empowering [14] through the community leader and committee. The information providing to the study community people consisted of segregation/collection at home with the red bags, leave to the red containers at the drop-off points, appointing time and frequency



	25/10/64	01/11/64	08/11/64	15/11/64
Weight (kg.)	13.9	14.3	23.2	25.6

*One piece of mask weights is about 2.8 – 3.0 grams

Figure 4 Used Masks/ATK Wastes Collected during October-November 2021

for collecting by the District Officer together with the informative announcement on the public relation board, as well as monitoring the performance of such hygienic waste collection. The community leaders and committee resided in the area who are very close to and have high capability to communicate with the community members. In accordance with the research results, any communities leaded by the strong leaders/committee who were very intensive on public relation and monitoring the segregation/leaving and collection directed to the hygienically method as designated, the used masks and ATK wastes collection was accordingly successful. In addition, the District Officer have to effectively pay attention to collect such wastes at the appointed time and frequency as well as cleaning the red container with disinfectant solution presenting in front of people for acceptance and participation of people (Figure 5)

2. **Construction worker camp site participation on used masks and ATK wastes collection model**

The used masks and ATK wastes collection were not hygienically as expected. Mostly, the specific wastes containers (red color) provided for the used masks and ATK wastes) at the drop-off points (Figure 6) , but there was an error on mixing with general wastes at drop-off point prior further collection by the District Officer. In addition, no coordination between the construction worker camp site and the district officer, it causing no waste separation. Most workers at the construction camps are willing to participate for segregation of the used masks and ATK wastes and further disposal by the District Office. However, some construction camps were worried about service fee for collection and disposal in the future, particularly if use the service of private company for collection and disposal because of the problems learnt from the past period of COVID-19.

Consequently, the appropriate model for waste collection of the used masks and ATK wastes for the construction worker camp site was awareness raising and knowledge management on the importance of hygienic collection of such wastes. The workers would very well participate on this model application as used to experiencing the past pandemic problem of COVID -19 as well as the strict regulation for segregation/leaving and collection of such wastes. In addition, the manager of construction camp site had to intensively monitor the model application by the workers and further hygienic segregation and collection to disposal by the District Officer. Therefore, the significant guideline is to firstly issue strong and strict regulation for the construction worker camp site and the use the understandable language for communication to the workers especially the foreign workers in order to make an apparent perception and action.

1

Operational Planning

Cooperation of the District Officer cooperate and Community Leader for carrying the activity on segregation of the used masks and ATK wastes from the general wastes of household.

Provision of the District Offices for adequate number of containers to collect such segregated wastes distributing to the suitable points, and making appointment time and frequency collection of such wastes for further collection.

2

Creation of perception and understanding

Cooperation of the community leader and the District Officer for the routine public relation to create perception and understanding of the people on the importance and human safety of such wastes management by segregation/leaving and collection of such wastes.

3

Action to operational plan

- Placing containers for collect such segregated wastes as the points in the community as mutual agreement.
- Appointing time and frequency for leaving such wastes.
- Collecting such wastes for further disposal by the District Officer following by cleaning the container with disinfectant solution in front of people so as to acceptance and participation.

4

Monitoring and Evaluation

- Monitoring the operation of community on the waste collection model by Community leader/committee; segregation /leaving and collection to the container as hygienic manner.
- Making perception and understanding if no-hygienic manner was found.
- Regularly collect the segregated wastes of the community by the District Officer and monitoring with evaluation of the operational plan as well as the quantity of the used masks and ATK wastes weekly.

Figure 5 Operational of Used Masks and ATK Wastes Collection in the Community by Participatory Process

Figure 6 Used Masks and ATK Wastes Litters at Worker Camp Sites

3. Industrial dormitories participation on the used masks and ATK wastes collection model

Waste collection of the used masks and ATK wastes among the industries were different. The large industry had segregation/collection and disposal system in the correct process (Figure 7). Some small industries consisting of less than 50 workers did not have such wastes segregation. The problem found for the small industries consisting of foreign workers.

Figure 7 Used Masks and ATK Wastes Litters at Industrial Dormitories

Accordingly, the appropriate model for collection of the used masks and ATK wastes for the industrial dormitories was awareness raising and knowledge on the importance of hygienic collection of such wastes together with suggestion and collection of such wastes to the workers due to the close living causing risk to diseases by COVID-19, particularly the industrial dormitories. Mostly, industry would pay more important to the production process area. Additionally, the industrial owners/ managers have to issue the strict regulation for living in the dormitory and housing area for segregation/leaving and collection under the close monitoring of the worker head as well as facilitating the adequate number of containers with apparent location. Public relation and communication to the workers with understandable language particularly to the foreign workers to encourage cooperation.

By the reason of characteristic of similar construction worker camp sites and industrial dormitories, the collection management of such wastes are as follows (Figure 8)

Analysis of the Research Result

Base on the survey, the success factors for segregation of the used masks and ATK wastes were awareness raising and knowledge management to the people. Such success factors are in conformance with the study of Lubna Salsabila et al [15]; but in different viewpoint as the existing payment for solid wastes collection and disposal fee had already made, thus it was not necessary to participate in any solid wastes activities. In other viewpoints, if people have understood the correlation of their behaviour and environmental deterioration, they will have higher trend of participation. It has to realize that not only to dispose the unwanted materials but to value the resources and conserve it as stated by O'Connell, Elizabeth J. [16]. Particularly the study of success factors by Mejjad, N. indicated that the change of behaviour on segregation, disposal as well as installation of facilities for effective and practicable solid wastes disposal management in the city [17] together with the involvement of private sector that would enable higher effective management of solid wastes disposal. [18].

1

Operational planning

-Cooperation of the District Officers and manager of the construction worker camp site or manager of the industry for planning on segregation of the used masks and ATK wastes from the general wastes.
-Providing an adequate number of containers for collection of such wastes along with the collection time and placing the containers as designated points.
-Issuing the regulation for workers on segregation of the used masks and ATK wastes so as to safety of workers in the construction camp sites or industrial dormitories.

2

Creation of perception and understanding

- Mangers of the construction worker camp site or industry create public relation the guideline of such waste segregation, leaving and collection.
- Build the knowledge and awareness of the adverse impact of the pandemic of COVID-19.

3

Action to operational plan

-Manager of the construction worker camp site or industry provide an adequate number of containers for collection of such segregated wastes at the drop-off point in the area as mutually designate.
-Workers of the construction worker camp site or industry have to strongly and strictly segregate such wastes and leave to the specific containers following the designated regulation.
-Installing the public relation board with the understandable language especially for communication to the foreign workers
-Announcing the hygienic collection of such wastes through mass media (radio) to all workers at lunch time daily
-Collecting and disposal following by disinfection cleaning the container by the District Officer.

4

Monitoring and Evaluation

-Manager of the construction worker camp site or industry assign the staff to monitor for monitoring the performance on segregation of such wastes by workers
-Manager of the construction worker camp site or industry monitor and evaluate the action performance and quantity of such segregated wastes as mutual agreement.
-If it found the mixing waste in the collection container, they will need to be corrected and further understanding of the workers.

Figure 8 Operational of Used Masks and ATK Wastes Collection in the Construction Worker Camp Site and Industrial Dormitory by Participatory Process

Conclusion

Segregation of the used masks and ATK wastes of communities or construction worker camp sites or industrial dormitories or housing area located in the industry would be successful by participatory process of people resided in the communities, workers in the construction worker camp sites or industrial dormitories. Firstly, it had to begin with the public relation and communication to those people and workers on the benefit of segregation of such wastes in order to be safety of themselves and other people/workers. The community leaders/committee or mangers of the construction worker camp sites or industrial dormitories were the principal ones who play very important role on raising awareness and knowledge with regularly emphasis for the productive segregation of the used masks and ATK wastes as designated tasks without mixing with general wastes. Secondly, there is an adequate number of collection containers for the segregate wastes provided and placed at the suitable locations as mutual agreement with the community people or workers. Thirdly, the District Officer have to collect the segregated wastes according with the appointed time and frequency, then clean the containers with disinfectant solution to make sure that the containers are well taken care. Fourthly, the important factor is the community leader or mangers of the construction worker camp sites or the industrial dormitories have to regularly monitor the mission on segregation of the used masks and ATK wastes. If it is found that wastes leave to the wrong container, the explanation and communication have to be made for more understanding on segregation of the used masks and ATK wastes for the stakeholders to make a success for human safety and living under the crisis of COVID-19 pandemic.

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A Bench Scale Study on Polluted Canal Water Purification in Comparison between with and without Addition of Fermented Products

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Abstract

This study aimed to investigate the possibility of using five types of fermented product (FP) to improve the removal efficiency of basic pollutants (under aerobic condition via strong agitation), i.e., non-filtered COD_T, BOD_T and SS presenting in two polluted canals in Bangkok area, namely, San Saeb and Kaja canals. The results were compared with the 'Control' experiment, which was without the addition of any fermented products (FPs). Obviously, it was found that the addition of FPs (containing high VFA) increased the COD_T concentration of the raw polluted water from 52 to the range of 87 – 107 mg/L. However, there was no clear-cut conclusion on the benefit of the FP addition in this study. Also, it was apparent that all five designated FPs gave similar treatment results. The only advantage of the FP supplement was to increase the MLSS or bacteria mass in less time, which is good for a startup process. However, bacterial mass (MLSS) can be enhanced through an ordinary startup without necessity of FP addition if there is no any particular problem. In conclusion, BOD and COD removals in the reactors with FP addition were not significantly different from the 'Controls', which eventually determined that EM and FPs addition cannot effectively treat polluted water.

Keywords : Effective Microorganism (EM); fermented products (FPs); polluted water; canal water; PNSB

Introduction

According to the severe flood situation in Thailand during the year 2011 that covering large area in central part of Thailand, polluted floodwater became a national issue at that moment. Enormous amounts of floodwater could not be easily dried out and subsequently became stagnant. Dark color, debris and strong odor of stagnant water caused a nuisance to residences among the flood. Without sufficient scientific evidences, fermented products (FPs) were claimed to help relief polluted water problems. Some government expenditures were even planned for FP application with this purpose of polluted water treatment.

Fermented Products (FPs) here refer to the products, both chemical and biological, obtained from the fermentation of glucose and lactose in plants, fruits or meats with the assistant of molasses (or other sugar-containing substances). The fermentation results in different readily degradable volatile fatty acids (VFAs) such as acetic and propionic acids as well as anaerobic lactic acid bacteria (LAB), yeast and actinomyces. Whereas photosynthetic bacteria (PB) such as purple non-sulfur bacteria (PNSB) are exaggerated by some to be abundant in these

FPs [1]. The PNSB under anaerobic condition are claimed to be able to, through the photosynthesis process, reduce bad odor by oxidizing sulfide to element sulfur, as shown in Eq. 1.

$$CO_2 + H_2S \rightarrow (CH_2O) + H_2O + S \quad (1)$$

EM or Effective Microorganism is the trade name of a main FP available in some parts of the world [2]. It was firstly developed by Teruo Higa in 1970s. Several EM-like products claimed during the flood situation (year 2011) had usually been made by composting food, vegetable or fruit wastes and natural microbial inoculums from the fertile soil from various sources. These are mixed with molasses to form EM liquid, while some are mixed with appropriate ratio of rice chaff, bran, sand, and mold to compress the size of a tennis ball to form EM ball. It has been reported that the solution contained over 80 microbial species from 10 genera, including lactic acid bacteria (LAB), phototrophic bacteria, and yeast [3, 4]. Some EM applications were suggested include agricultural activities, household cleaning, probiotic for pets and animals, wastewater treatment and purification, and waste management [5-11].

For agricultural activities, EM has been claimed to be used as a soil conditioner [5], increasing plant health, yield and nutrition. For environmental management, EM has been used in some communities for waste or wastewater treatment [12-13], and also used for treating sludge from wastewater treatment plant [14]. Some researchers using EM in wastewater treatment plant claimed that EM could reduce odor, COD, BOD and suspended solids (SS) [3, 15-16]. However, these researchers mostly conducted their experiments without the Control system, thus**, it has been unclear that the COD, BOD and SS reduction was achieved due to the self-purification of the river/canal or the capability of the EM**.

Therefore, this study aimed to scientifically evaluate the possibility of using five different FPs to improve water purification under aerobic condition. Two canals from different locations in Bangkok area were designated to for comparison. In addition, the Control system (without addition of any FPs) were identically setup in order to obtain self-purification characteristics of polluted canals.

Methodology

Polluted water

Due to this study was setup after the severe flood in 2011, polluted water from the flood was not existed anymore. Hence, the authors chose polluted canals in Bangkok area to imitate polluted floodwater. In this article, polluted waters were taken from two canals, i.e., San Saeb and Kaja canals, Bangkok, Thailand with enough amount for all experiments in this study. The average characteristics of two polluted waters were shown in Table 1.

Table 1 Characteristics of polluted waters

Parameters	**San Saeb canal**	**Kaja canal**
Temp (^oC)	30.5	31.5
pH	7.31	7.21
DO (mg/L)	1.67	2.07
Turbidity (NTU)	0.73	1.93
BOD (mg/L)	23.2	48.3
COD (mg/L)	72.3	98.9
SS (mg/L)	38	24

Fermented Product (FP)

Five different types of Fermented Products (FPs) used in this study were commercially sold in the market. These five FPs were sampled and determined for their existing expected heterotrophs, results of which were shown in Table 2 [17]. The application ratios of FPs to water for general purposes recommended by their suppliers were mostly 1:10,000. However, the ratios of FP to polluted water applied in this study (Table 3) were selected from the optimum ratios resulted from previous work [18].

Table 2 Amount of heterotroph microorganisms in each fermented products [17]

Type of FPs	Total bacteria as SPC (CFU/ml)	Lactic acid bacteria (CFU/ml)	Purple non-sulfur bacteria(CFU/ml)
FP 1*	201,000±1,732	8,733±58	127±4.6
FP 2*	34,667±577	3,033±153	101±7.8
FP 3**	56,333±1,528	6,067±208	600±43.6
FP 4**	54,000±1,732	290±10	176±1.0
FP 5*	1,340,000±10,000	187,000±10,000	156±3.5

*Company's product
**Produced by local people; FP 4 was produced from fermented mushroom

Table 3 Ratios of each FP used in this study*

Type of FPs	Ratio (v/v)
FP 1	1:5,000
FP 2	1:5,000
FP 3	1:5,000
FP 4	1:5,000
FP 5	1:10,000

*pre-selected from previous study [18].

Experimental setup

As mentioned above, the purpose of this study was to obtained scientific data of treating polluted water by FPs. If there was any improvement of polluted water after application of FPs, this study expected to clarify whether it was due to self-purification of polluted water or activity of FPs. Therefore, six reactors with the effective volume of 20 liters were set up for each polluted canal experiment. Besides the 'Control' reactor (without FP addition), five reactors were set up with addition of five different types of FPs (FP1 to FP5). The addition of FPs was done only once at the beginning of the experiment. The experimental setup is shown in Figure 1.

The mixed water (FP + polluted water) was agitated continuously for three days of operation with air diffusers. Unfiltered water samples were taken from the 20–L reactors on Days 0, 1 and 3 for subsequent parameters, i.e., pH, DO, non-filtered COD (COD_T), non-filtered BOD (BOD_T) and SS analysis. All parameters were analyzed according to the Standard Methods procedure [19] as tabulated in Table 4. Due to the published page limitation, the analytical results were described and discussed only by mean. Standard deviation (SD) values (or error bars) could not be clearly shown here because of several graphical lines.

Table 4 Analytical method

Parameters	Analytical Methods
SS	Gravimetric method
DO	DO meter
pH	pH meter
COD	Closed reflux
BOD	Modified Azide method

Results and Discussions

Experiment with polluted water from San Saeb canal

Figure 2 illustrated the treated water quality during three days of aeration. The initial pH values of all test units including the Control unit were in the narrow range of 7.2–7.4 as shown in Figure 2a, which could be said that the FPs addition did not affect pH quality of polluted water from San Saeb canal. After three days of operation, the final pH values were in the range of 6.9–7.1, which was not evident enough to conclude their decrease.

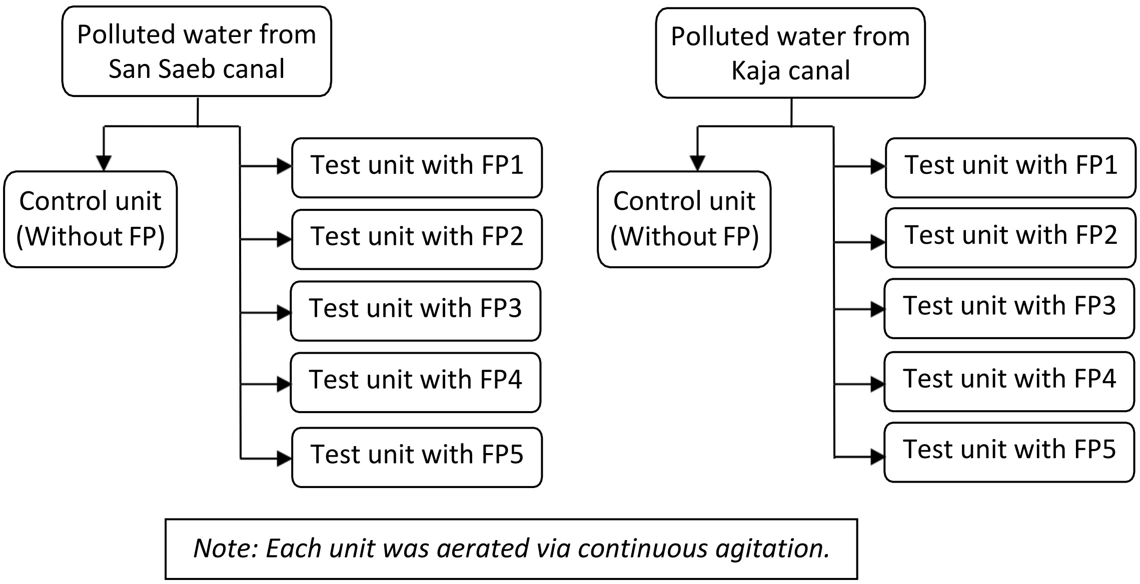


Figure 1 The experimental setup

In case of DO, Figure 2b showed that the initial DO of polluted canal water (both of test units and Control unit) was about 2.2 mg/L. After FP addition, DO levels of the mixed solutions instantly decreased to the range of 1.6–1.8 mg/L, then increased to the higher range of their initial values throughout the three days of operation. The instant decline of DO at Day 0 could be due to the increase of organic loading from the addition of FPs. Moreover, DO increase in this study should be due to the aeration and possibly low BOD loading in polluted water. Interestingly, the highest DO throughout the operation was observed in the Control unit.

For COD_T, as illustrated in Figure 2c, it is apparent that with FP addition, the COD_T concentrations increased from 52 mg/L to the range of 87–107 mg/L on Day 0 due to high organic content in FPs. This is generally known that high concentration of organic carbon in FPs was from the fermentation of molasses in which their COD was normally in the range of 80,000–100,000 mg/L [20]. On the last day of operation, COD_T in every test unit, including the Control unit, were decreased to the range of 25–42 mg/L. The lowest COD_T was observed in the test unit with FP5 addition.

Figure 2d showed BOD_T results from all test units, the BOD_T reduction patterns were consistent to COD_T reduction, except the Control unit. Though BOD_T of the polluted water mixed with FPs, which were in the range of 21–25 mg/L, did not show obvious difference from BOD_T of the Control unit (22 mg/L), all test units with FPs addition still observed BOD_T reduction after three days of operation. The BOD_T concentrations on Day 3 of all test units with FPs addition were in the range of 9–15 mg/L. However, the BOD_T pattern of the Control unit were different, that is, they increased to 36 mg/L on Day 3. Though this analytical BOD_T result was double-checked and could not found any reasonable flaw, this BOD_T (36 mg/L) was quite abnormal as its corresponding COD_T were almost identical (41 mg/L). Anyway, other experiments with the same polluted canal water in the same project was not observed this kind of abnormality.

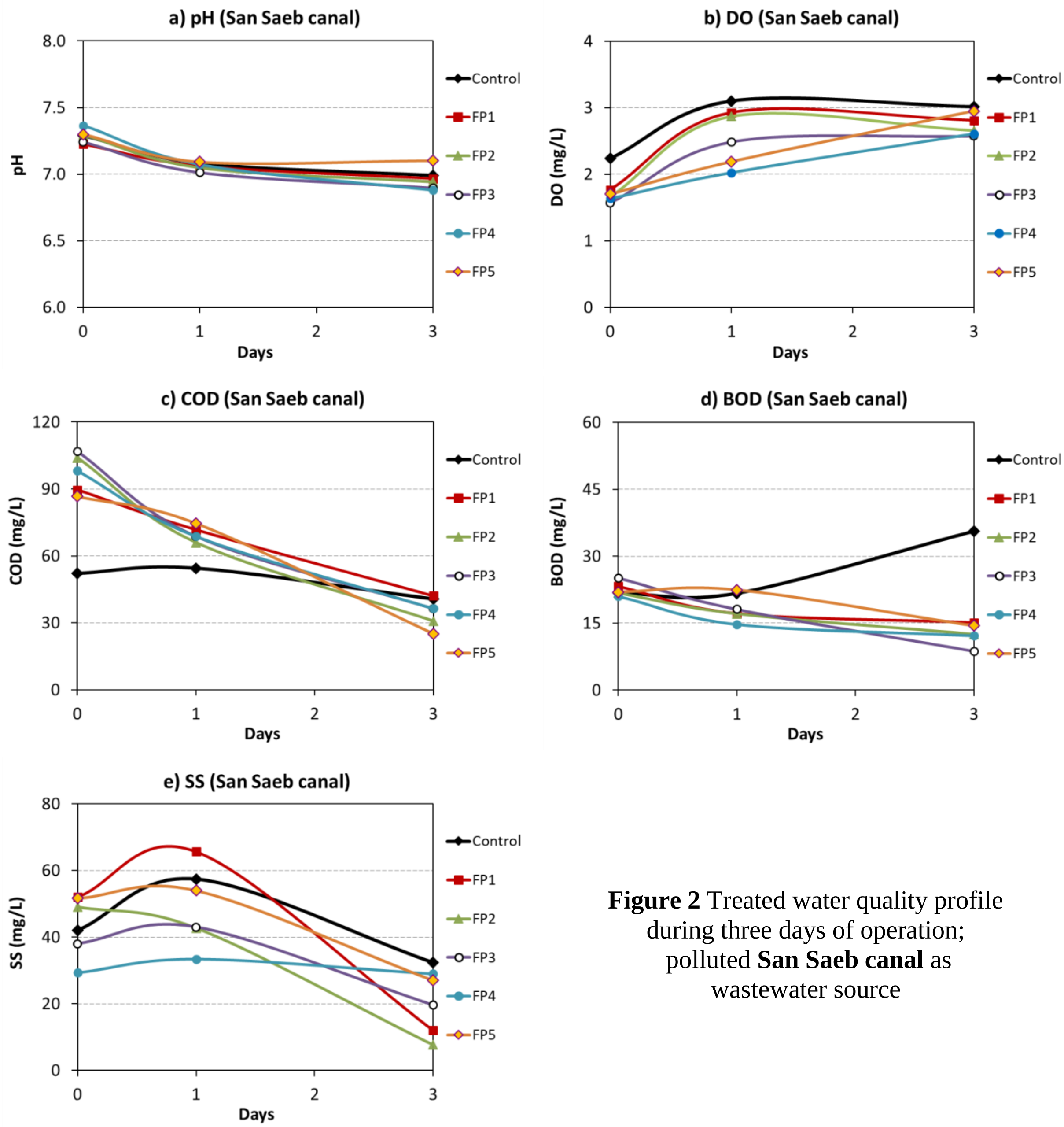


Figure 2 Treated water quality profile during three days of operation; polluted **San Saeb canal** as wastewater source

For suspended solids (SS), in this case was not totally related to the treated effluent quality, but rather bacterial mass. After FPs addition (Day 0), SS concentrations (29–52 mg/L) were observed both higher or less than those of the Control unit (42 mg/L) as shown in Figure 2e. On Day 1, all test units including the Control unit showed the increase of SS, which should be the result of the increased bacterial mass from the utilization of available carbon source in both the canal water itself and FPs. Nevertheless, the SS reduction was also observed after three days of operation in all test units. The final SS concentrations in the range of 8–29 mg/L were found in those test units with FPs addition, while that of the Control unit was 32 mg/L. Obviously, the addition of five different FPs did not perform a distinguished advantage over the no-FP case.

Experiment with polluted water from Kaja canal

In this experiment, the polluted water sample was taken from Kaja canal and divided into six test units, one of which were a Control unit and other five units were with FPs addition. The treated water quality of the polluted Kaja canal after three days of aeration was demonstrated in Figure 3. The initial pH values with FPs addition were mostly identical to the Control unit (of about 7.2). After three days of operation, some test units were almost the same as their initials while some showed little increase to the range of 7.3–7.4 as shown in Figure 3a.

For DO characteristic, Figure 3b illustrated that the DO level of the Control unit clearly increased from its initial concentration of 2.1 to 3.5 mg/L on Day 3. Also, DO levels in all test units with FP addition increased from its initial range of 2.0–2.1 mg/L to the final range of 2.7–3.0 mg/L. This could be explained that oxygen supply from aeration should be more than enough for bacterial respiration in all test units. However, FPs addition brought more organic content into the units, therefore, more oxygen consumption would be expected.

Figure 3c showed that the initial COD_T in all test units were in the range of 81–117 mg/L and tended to decrease to the range of 46–60 mg/L on Day 3 of operation. Among all test units, these final COD_T levels were almost similar to each other, which should be implied that this leftover COD_T would not be further easily biodegradable. In addition, these test units with FP addition did not perform better COD_T reduction than that of the Control unit.

The BOD_T reduction patterns for all test units including the Control unit in Figure 3d showed that the initial BOD_T in the range of 35–45 mg/L decreased to the range of 14–19 mg/L on Day 3. In comparison with the Control unit (without FP addition), there was no apparently better efficiency of BOD removal in test units with FPs addition.

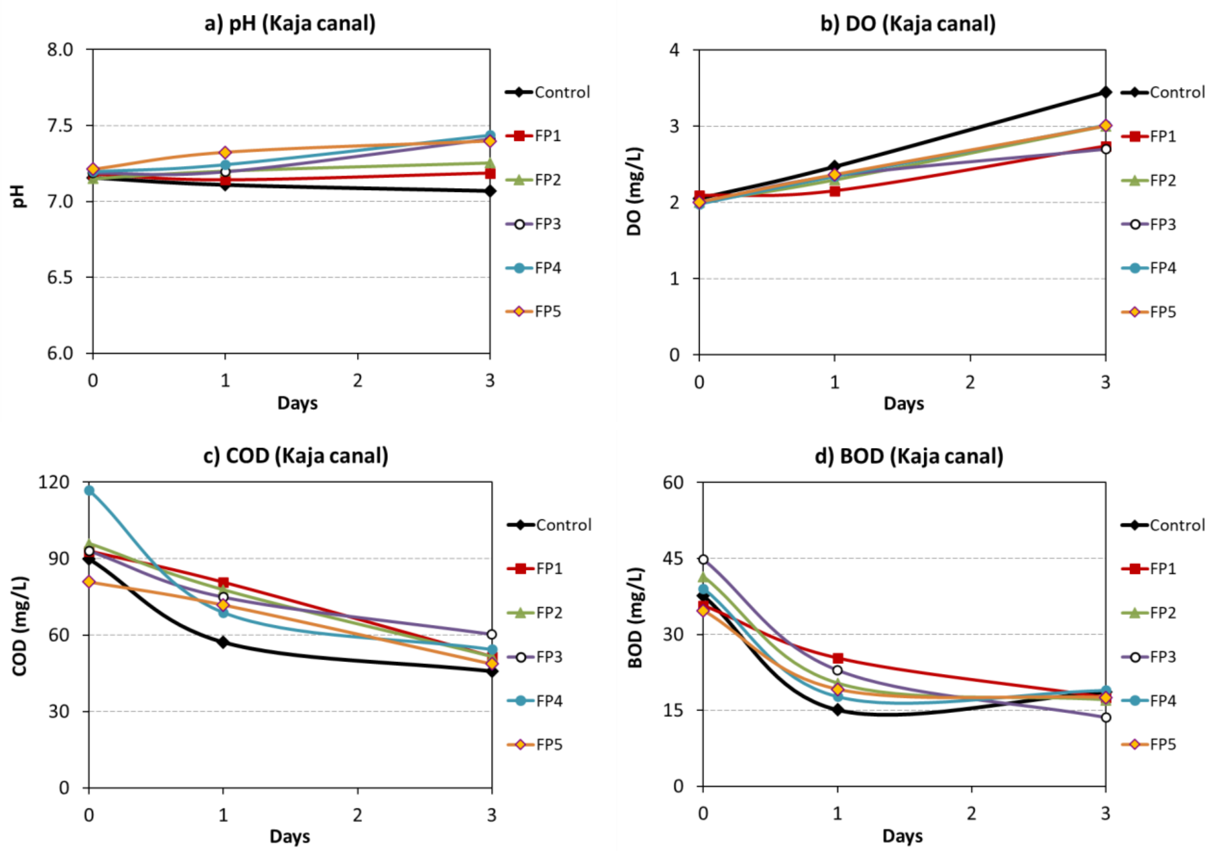
In case of SS, the results shown in Figure 3e were similar to those experiment with polluted water from San Saeb canal (in previous section). SS levels in all test units with polluted water from Kaja canal increased from the range of 21–30mg/L to 20–36 mg/L on Day 1, and then decreased to the range of 8–24 mg/L on Day 3.

Effects of fermented products addition

From the results as shown in Figures 2 and 3, it was quite clear to mention that the addition of FPs gave no different performance in both the Control (without FP) and all five test units (with PFs addition). The results also illustrated the increase of final DO from their initials in every unit as the organic concentrations (BOD_T) decreased. Despite the “high dilution ratio” of FP addition (1:5,000 or 1:10,000), the initial organic concentrations (both BOD_T and COD_T) were still raised up a little in comparison to the ‘Control’ due to most fermented products contained high organic component from their fermentation process.

Both BOD_T and COD_T reduction patterns for polluted waters (San Saeb and Kaja canals) in this study did not clearly show distinguished treatability between FP addition (five FP types) and no-FP case. For an instance, the COD_T on Day 3 of the Control unit in Kaja canal experiment was even better than those with FPs supplement (Figure 3c). Though the actual mechanism of water purification occurrence in these reactors (with FPs addition) could not be evidently explained, these results scientifically confirmed that indigenous microorganisms also performed similarly or even better. The researchers from Wageningen University attempted to study the effectiveness of EM and concluded that EM is not effective, at least under their study conditions [21].

Moreover, adding FPs could increase the SS on Day 1, which was the result of the increased bacterial mass from the consumption of carbon source available in FPs themselves and polluted waters. These results were inconsistent with some researchers, which reported their success in using certain FPs in wastewater treatment [12, 22].



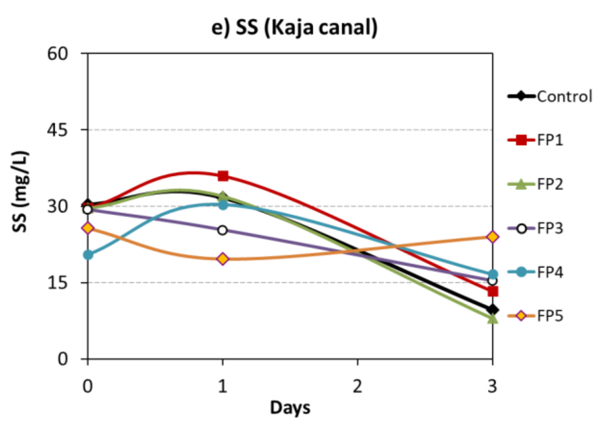


Figure 3 Treated water quality profile during three days of operation; polluted Kaja canal as wastewater source

The indistinctive advantage of the FP supplement may be to increase bacterial mass (represented by SS values) in less time, which would be useful for startup process. However, this is at additional cost (or expense) while the bacterial mass (MLSS) can be enhanced through a conventional startup procedure if one knows how to do the job. Besides, if most of bacteria contained in FPs were produced from the anaerobic fermentation process, the benefit for startup process in aerobic treatment would still be doubtful.

Several FP manufacturers and EM supporter used to claim their products were enriched with PNSB, resulting in high photosynthesis. In contradiction, low PNSB was found in these FPs applied in this study [17] (as shown in Table 2). It is also noteworthy that polluted canals are septic and if the high COD removal has to be anticipated, huge investment through the aeration for whole canal to get complete aerobic condition will have to be encountered. Therefore, this is not consistent with the claim from FP manufacturers and their believers that their products can increase the oxygen level in any polluted canals due to the photosynthesis. Moreover, this illusion of photosynthesis emitting oxygen to the atmosphere needs to be clarified, especially photosynthesis by bacteria. Unlike vegetational photosynthesis, this bacterial photosynthesis did not produce oxygen. There are about five groups of bacteria doing photosynthesis; green sulfur bacteria (GSB), green non-sulfur bacteria (GNSB), purple sulfur bacteria (PSB), purple non-sulfur bacteria (PNSB) and cyanobacteria [23].

Conclusions

The addition of five fermented products (FPs) into raw polluted water from two designated canals in Bangkok could increase the initial COD_T organic concentration from 52 mg/L to the range of 87–107 mg/L. There was no clear-cut conclusion on the benefit of the FP addition in terms of COD_T and BOD_T reduction. It was apparent that the five FPs gave similar treatment results, as well as, all performance of the test units (five FPs) were similar to the Control one (some were even worse). This could be said that water purification of polluted canals did not require FP addition actually. The only advantage of the FP supplement was the increase of SS or bacterial mass in less time, which was preferable for startup process. It was postulated that not much odor reduction was to be achieved, due to very low PNSB found in the FPs. The claim that the FPs can increase the oxygen-level in any polluted canals should be therefore misleading information.

Acknowledgement

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Adjusting Ventilation for Heat Control in an Industrial Building Using Computational Fluid Dynamics: Case Study of a Heat Treatment Plant in Automobile Industry

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Abstract

Heat strain is a serious health issue in many manufacturing industries, including steel plants, foundries, and automobile industries. This research attempts to control the high temperatures in a heat treatment plant of automobile industry whose existing ventilation methods were insufficient to address the heat-related problems. Preliminary studies were carried out to determine the existing temperatures and air velocities, the effectiveness of the ventilation measures and the problems associated with the heat processes. The obtained data were fed into a computational fluid dynamic (CFD) model with initial and boundary conditions, used to predict the temperature and airflow inside the building. Five additional building models were created, each adding different thermal control and ventilation measures to the initial configuration. Based on the simulations from CFD, a model with windows, ventilators, enclosures, and jet fans was selected as the best case. This ventilation system was then physically installed in the building. The performance of the real system was measured and compared to the predicted values. A good correlation was found between the numerical simulation and the experimental results; the temperature differences between the values at 1.5 m, 3 m and 4.5 m above the ground were 1.8%, 2.7% and 3.3%, respectively. The final ventilation solution was able to decrease the average temperature by 5.3°C and increase the average air velocity by 1.5 m/s. This study demonstrates how numerical modeling and building ventilation solutions can be effectively used to solve the problem of high temperatures in an indoor industrial environment.

Keywords : Computational fluid dynamic; Heat stress; Heat ventilation; Industrial heat control; Jet fan ventilation

Introduction

Heat treatment is a principal manufacturing process that plays an important role in the production of automotive components and regulates the properties of the final product [1-3]. Automotive production generally uses steel, iron, aluminum, plastics, rubber, and glasses as raw materials. Assembling a product from these raw materials requires different types of heat treatments, such as annealing, normalizing, quenching, and tempering. Heat treatment improves the properties of metallic components to achieve the required strength, hardness and durability [4-6]. This makes heat treatment essential for the automotive industry. Heat treatment also generates considerable heat causing a hot and unhealthy industrial environment. Workers working near process-related heat in manufactures such as steel mills, foundries, and automotive plants are at high risk of heat stress [7, 8]. Acute exposure to extreme heat over short periods of time leads to heat stroke, exhaustion, collapse, heat rash, fatigue, and can even lead to death. Long-term exposure leads to cardiovascular disease, mental health problems, and kidney disease [9-11]. It is necessary to protect workers from heat exposure, which can be achieved through engineered safety measures such as insulation, baffles, partitions, personal protective equipment, and ventilation [12].

Recently, jet fans have been widely used to extract polluted air in parking garages and tunnels [13, 14]. In a jet ventilation system, a fan draws in a small amount of air and discharges it at a very high velocity, pushing the polluted air in front of it while drawing in air from the surrounding area. This moves the air long distances without the need to use ducts and requires less installation space due to the high speed of air movement [15]. There is an abundance of research on the use of jet fans in tunnels [16, 17] and parking garages [18-20], but almost none on industrial applications. CFD is a useful tool for predicting air movement in ventilated spaces to determine spatial temperature variations [21], and has been used in engineering for ventilation system design [22]. CFD has been successfully used for a wide range of building applications in the design and evaluation of indoor air flow, thermal comfort, smoke conditions, etc. [23-25]. CFD models have been used for indoor air quality analysis of various building environments including offices, residential buildings, stadiums, historical settlements, etc. [26-29]. Nevertheless, there is still a lack of application in the analysis of heat reduction ventilation in industrial buildings.

The purpose of this study is to adjust the ventilation of an existing building used for heat treatment of automotive parts to reduce the temperature to a comfortable range. The ventilation adjustments are first simulated using CFD and the most favorable case is selected for implementation in the real building. The study focuses on measuring the indoor temperature and velocity, validating CFD model for the existing conditions, CFD simulation of the upgraded building with different ventilation adjustments, and finally comparing the indoor temperature between the best suitable case from the CFD simulation and the implementation in the existing building.

Methods

Description of the Building

The building has dimensions of L **x** W **x** H = 120 m **x** 84 m **x** 12 m and consists of heat sources composed of 5 heat processes. Heat processes 1, 2 and 3 consist of a drying oven, an input chamber, a preheating chamber, a brazing chamber, a cooling chamber and an output. The car parts are transported from each process starting from the drying oven through the exit. Each unit has an individual local exhaust system to extract and remove smoke generated during the heat treatment process [30]. Heat process 4 is a heating oven and heat process 5 is used as a high temperature process to remove oil products. Currently, the building has 6 doors (D1-D6) for access to the interior of the building that also provide natural ventilation, 2 roof monitors for stack ventilation, 10 vents and 28 roof fans that also contribute to the ventilation of the building. The schematic diagram of the external and internal features of the building can be seen in Figure 1.

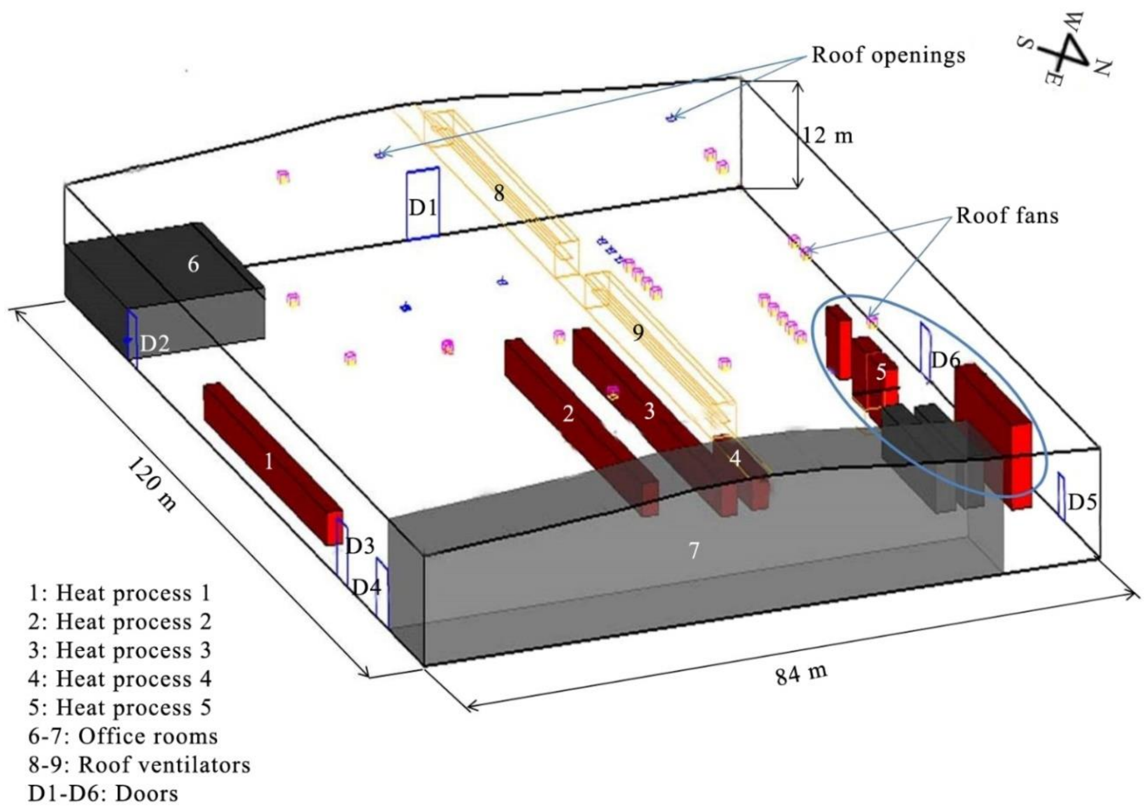


Figure 1 Diagram of the case study building.

Measurements

Temperature

The external surface temperature of the heat treatment equipment was measured using a thermal imaging camera [31, 32]. Ambient temperature was measured using Raygner 3i handheld laser pyrometer at three different heights of 1.5 m, 3 m and 4.5 m above the ground. At each height, the temperature was measured at 64 points. For this purpose, rectangular aluminum plates (300 mm **x** 300 mm) were attached to a metal bar at each height. The laser beam of the pyrometer was directed to each point and the temperature was recorded.

Velocity

Air velocity was measured at the same points as described above using a hot-wire anemometer [33]. In addition, air velocity through roof ventilators, doors, windows, and roof monitors was measured to calculate ventilation flow rates, which were then used as boundary conditions for CFD modeling.

Computational Fluid Dynamics (CFD)

In this study, the commercial CFD code Airpak 3.0 (Fluent Inc., Lebanon, NH, USA) was used for the simulations. Airpak uses FLUENT to solve the Navier-Stokes equations for the transport of mass, momentum, species, and energy when calculating laminar and turbulent flows [34, 35]. Turbulence of air flow in space is modeled using a number of turbulence models, of which the most commonly used models are the zero-equation turbulence model, the k-ε turbulence model, and the Reynolds stress model [36]. Among these models, the k-ε turbulence model is the most widely used and popular turbulence model for simulating airflow in a space [37, 38]. The k-ε turbulence model is based on a transport equation for the turbulent kinetic energy k and a transport equation for the dissipation of the turbulent kinetic energy ε [39]. The standard k-ε turbulence model provides stable results and is suitable for general flow calculations, so, it was used for the simulations in this study. The CFD model was used to simulate the steady-state internal temperature and velocity during the application of different heat reduction strategies [40]. The convective heat transfer modeling in the k-ε models using the concept of Reynolds' analogy to turbulent momentum transfer is given by the following equation.

$$\frac{\partial}{\partial t}(\rho E) + \frac{\partial}{\partial x_i}[u_i(\rho E + p)] = \frac{\partial}{\partial x_i}\left(k_{eff}\frac{\partial T}{\partial x_i}\right) + S_h \quad (1)$$

Where ρ is the density, E is the total energy, t is the time, u_i is the summation of the mean and instantaneous velocity components (i = 1,2,3…), p is the pressure, k_{eff} is the effective conductivity, T is the temperature, and S_h is the volumetric heat source.

For the standard k-ε model, k_{eff} is given by

$$k_{eff} = k + \frac{c_p u_t}{Pr_t} \quad (2)$$

Where k is the conductivity of the material, C_p is the specific heat, U_t is the turbulent viscosity, and the default value of the turbulent Prandtl number (Pr_t) set to 0.85 [41].

In Airpak, the computational domain is first divided into discrete control volumes, followed by integration of the equations for each control volume to establish algebraic equations, which are later converted to linear equations and solved. Since Airpak is a commercial CFD code, its ability to simulate the temperature variations in the building had to be verified. To verify the CFD code, a grid dependence study was performed to ensure the convergence, consistency and stability of the CFD code [42]. An automatic hexa-unstructured grid from existing settings in Airpak was employed, which provided an accurate representation of the boundaries. An unstructured grid was used because it minimizes numerical error and provides a consistent solution across the modeling domain [43, 44]. Initially, a coarse grid was used, which was refined until the temperature values inside the building did not change significantly. In this study, the grid density was considered sufficient if the difference in average temperature at each elevation between successive denser grids was less than 5%.

Initial and boundary conditions

The geometry of the building and internal components used in the calculations of CFD is approximately the same as the original geometry of the building. The internal temperature during the measurement was approximately 33°C, which was used as the initial internal temperature during the simulation. The values of heat generated by each heat process were equated to the measured surface temperatures of each heat process. Air intake was through the southwest and south doors and air exhaust was through the north doors and other ventilation measures. The measured capacity of the exhaust air was about 3500 CMM and that of the supply air was about 2500 CMM at the same time. Hence, the air velocities at the inlet and outlet doors and ventilation measures were set to match the resulting airflow of 3500 CMM and 2500 CMM, respectively. The dimensions of the ventilation measures, the initial conditions and boundary conditions of the heat sources and the building are given in Table 1, Table 2 and Table 3, respectively.

Validation of the CFD model

The average measured and simulated temperature at 1.5 m, 3 m and 4.5 m above the ground, when all ventilation devices were open, was used to validate the CFD model. Three of the six criteria recommended by ASTM D 5157-96 were used for validation. The criteria used were: (1) correlation coefficient of 0.9 or higher, (2) regression slope between 0.75 and 1.25, and (3) regression intercept 25% or less of measured average temperature.

Table 1 Number and specification of existing ventilation measures

Serial Number	Description	Dimensions (in meter) (L x W x H)	Quantity
1	Door	4 **x** 0 **x** 3.5	1
2	Door	3.5 **x** 0 **x** 3.5	1
3	Door	3 **x** 0 **x** 3	1
4	Door	4 **x** 0 **x** 4	1
5	Door	3 **x** 0 **x** 3	1
6	Door	2 **x** 0 **x** 2.5	1
7	Roof ventilation monitor	32 **x** 2 **x** 2	1
8	Roof ventilation monitor	32 **x** 2 **x** 2	1
9	Opening	1 **x** 0 **x** 1	10
10	Roof fan	1 **x** 0 **x** 1	28

Table 2 Initial conditions for numerical modeling

Parameter	Values
Plant size	120 m **x** 84 m **x** 12 m
Ambient temperature	33° C
Exhaust ventilation volume	3550 m^3/min
Inlet volume	2500 m^3/min
Gravity vector	-9.8 m/s^2
Turbulent model	k-ε model
Time variation	Steady state
Variables solved	Temperature, Flow
Door status	Open

Table 3 Dimensions and properties of all heat sources in the building

Heat sources	Dimensions (in meter) (L x W x H)	Heat values		
		Front (°C)	Center (°C)	Back (°C)
HP 1	46 **x** 2 **x** 2	70	45	33
HP 2	49.5 **x** 2 **x** 2	70	45	33
HP 3	41 **x** 2 **x** 2	70	45	33
HP 4	13 **x** 2 **x** 2	40	50	50
HP 5a	4.5 **x** 2 **x** 3.5	54	52	48
HP 5b	4.5 **x** 2 **x** 3.5	58	56	53
HP 5c	4.5 **x** 2 **x** 3.5	58	58	53
HP 5d	19 **x** 2.5 **x** 5	80	75	70

Adjustments to the existing building

In order to reduce the existing temperature, several adjustments were made to the existing building by adding thermal control measures. The added components were:

Insulated Enclosures

The inspection of the heat sources revealed that the high temperatures inside the building were mainly due to the heat transfer from the heat sources and the inability of the insulation to control the existing heat transfer from the source to the room. To control the heat from the source, insulated partitions were installed at each of the heat sources [45]. Because frequent access to the heat source elements was required, the insulated partitions were installed 2 m above the floor and 1 m outside the surface of the heat sources. Most of the heated air would be trapped in the enclosure, as large amounts of heat would be released from the top of the heat source and hot air would be naturally forced up from the sides. The diagram of the insulated enclosure is shown in Figure 2.

Gravity Ventilators

The existing ventilators were installed along the length of the building, parallel to the wind direction. They were inefficient in removing the indoor air as they were not able to pull the hot air out of the building [46]. To solve this problem, a pair of ventilators with dimensions 40 m (L) **x** 2 m (W) **x** 2 m (H) were installed on both sides of the existing ventilators and placed directly above the insulated enclosures. The diagram of installed gravity ventilators is shown in Figure 2.

Windows

There were too few windows in the existing building, which was one of the major causes of the low airflow velocity inside the building and the lack of air pressure to direct the hot air through the exiting exits. More importantly, there were no windows on the southwest side of the building, the prevailing wind direction. These deficiencies were addressed by installing windows on the downwind side of the building along the entire length of the wall. The windows were installed in the upper part of the building, as this was where most of the hot air accumulated. Similarly, a total of 5 sets of windows were installed on the right and left sides of the building. The location and dimensions of the windows are shown in Figure 3.

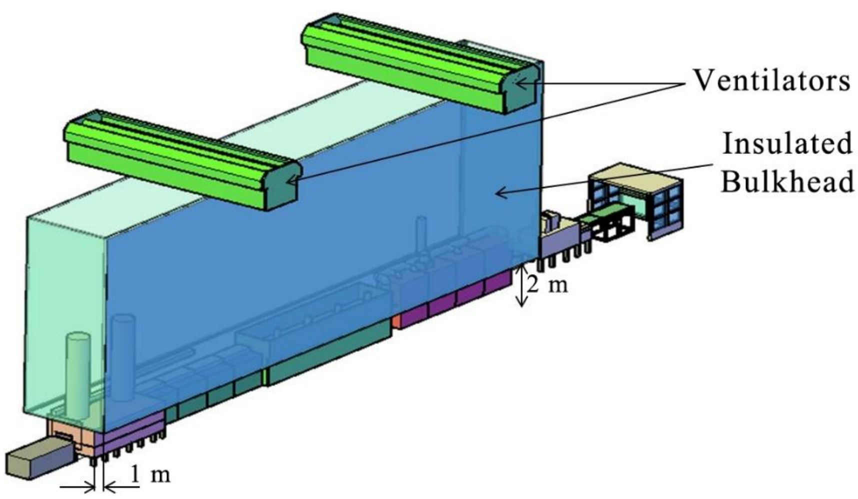


Figure 2 Diagram of insulated enclosures and gravity ventilators installed above heat sources 1-3

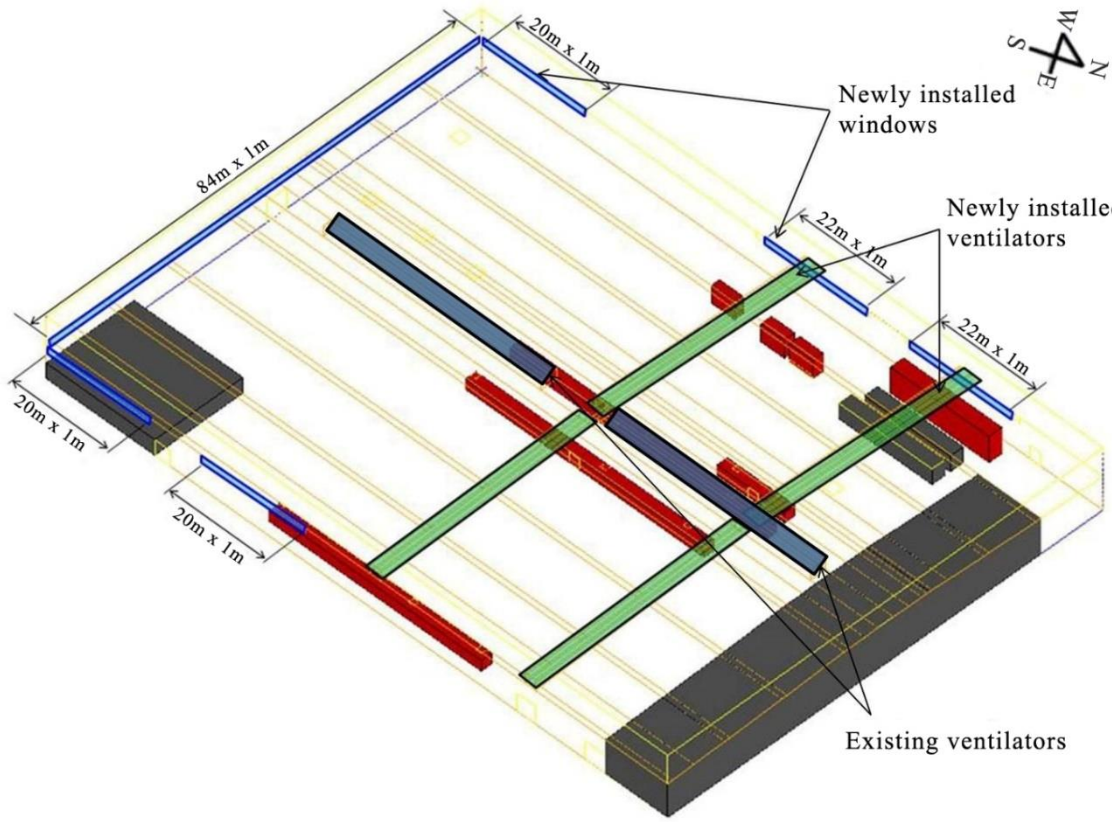


Figure 3 Diagram of building with newly installed gravity ventilators and windows

Jet Fans

Since the existing ventilation system was not able to generate the required air velocity, jet fans were considered as a possible solution [47]. Jet fans would improve the situation by maintaining a constant supply of air at high velocity, which was not the case with the existing ventilation. Jet fans could be placed in key areas where workers spend longer periods of time. The placement of jet fans took into consideration the obstructions created by various heat processes, some equipment in the building, and the position of the workers. Two types of jet fans (single jet fans and power jet fans) were used (their specifications are given in Table 4). The power jet fans were installed in the main aisles as shown in Figure 4. Single jet fans were used in conjunction with air conditioners to move cold air from the air conditioners at high velocity.

Table 4 Specifications of jet fans

Species	Specifications	
	Single jet fan	Power jet fan
Airflow (CMH)	600-2280	15000
Air speed (m/s)	10-25	33
Entrainment ratio	More than 25 times	More than 25 times
Power	0.38 kW/1 ϕ 220 V	5.5 kW/3 ϕ 440 V
Range	30 m/0.4 ms^{-1}	80 m/0.4 ms^{-1}

Installation of Air Conditioning Systems

In addition to the ventilation measures, air conditioning was installed to further reduce the temperature. The air-conditioning ducts were distributed along the areas of high heat generation and the outlets of the ducts were connected to single jet fans. The locations of the combination of air conditioning ducts and single jet fans are shown in Figure 4.

These components were used either individually or in combination to form six different cases as described in Table 5. Highest priority was given to natural ventilation and natural heat removal from the building, such as windows, enclosures, and ventilators. Case 1 was a model of existing conditions in the building. Windows and ventilators were added to Case 1 to create Case 2. Enclosing all heat sources in Case 2 resulted in Case 3. Power jet fans were added to Case 2 and Case 3 to develop Case 4 and Case 5, respectively. Similarly, air conditioners in conjunction with single jet fans were added to Case 5 to compose Case 6. A total of six cases were prepared and a CFD simulation was performed for each case. Temperature and velocity were predicted at a height of 1.5 m, 3 m and 4.5 m from the ground.

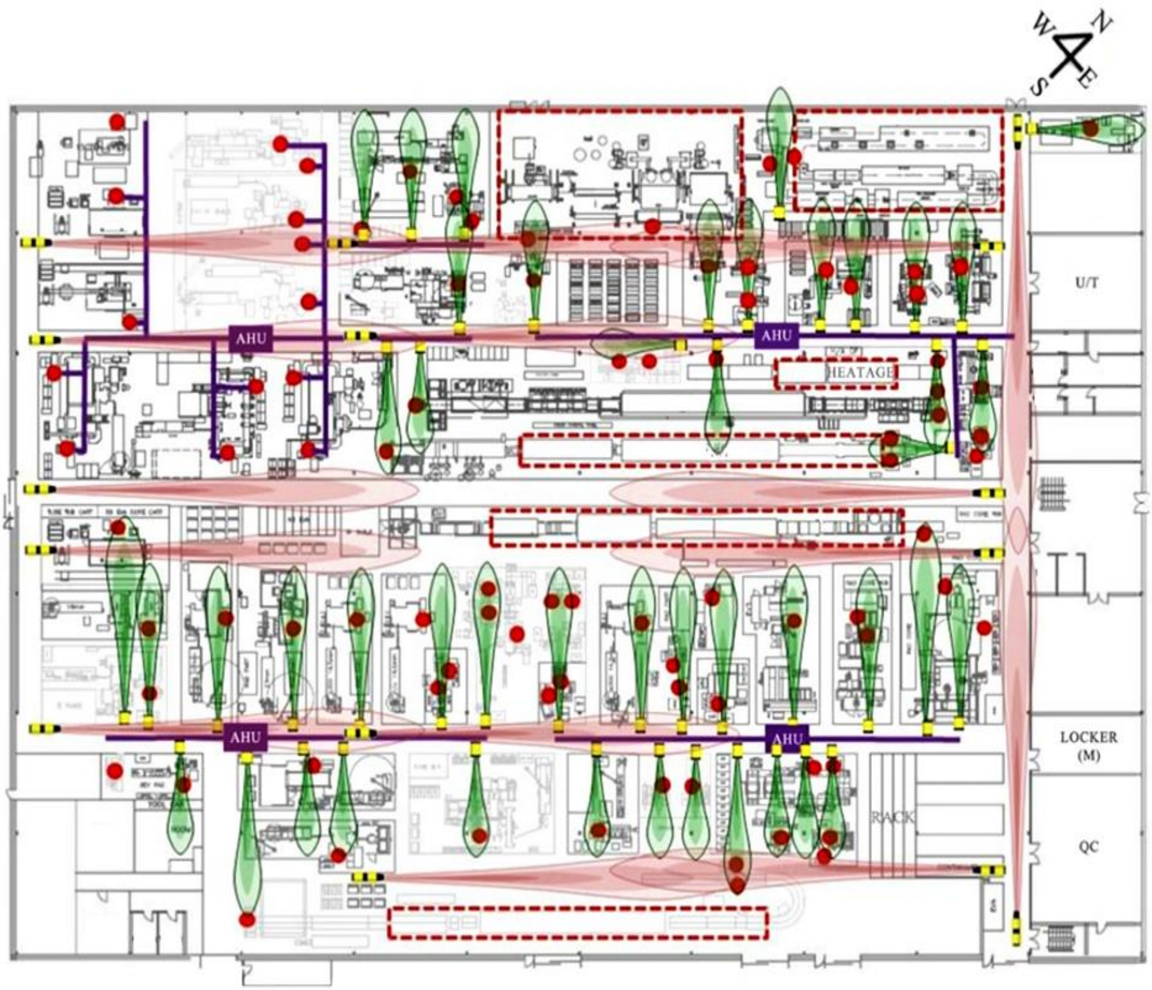


Figure 4 Position of workers (red dots) and planned installation positions of single jet fans (yellow blocks connected to green contours representing wind direction), power jet fans (double yellow blocks connected to red contours representing wind direction), and air conditioning (purple lines)

Table 5 Cases formed for CFD simulation

Cases	Installation of					Remarks	Number of grids in million (approx.)
	Windows	Ventilator	Enclosure in HP 1-5	Jet Fans	Air conditioners		
1	-	-	-	-	-	Original status	0.8
2	√	√	-	-	-	-	0.9
3	√	√	√	-	-	-	0.9
4	√	√	-	√	-	Power jet fans only	1.2
5	√	√	√	√	-	Power jet fans only	1.2
6	√	√	√	√	√	Power + single jet fans	1.2

Results and Discussion

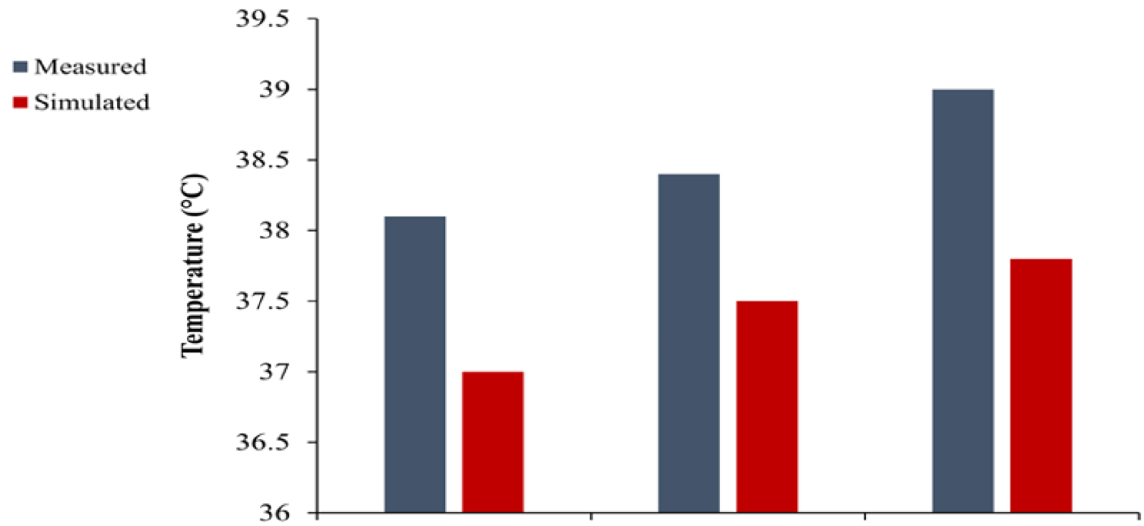
Validation results of the CFD model

The average measured and simulated temperature as the preliminary test is shown in Figure 5. The regression curve and regression equation obtained by comparing the simulated and measured average temperature are shown in Figure 6. It shows that the correlation coefficient is 0.89 which is almost equal to the recommended criterion of 0.9, the slope of the regression is 0.83 which is between the recommended criteria of 0.75 and 1.25, and the intercept of the regression is 5.35 which is less than 25% of the measured average temperature. Therefore, it was considered that the CFD model is sufficiently able to model the temperature inside the building.

Case-based simulation results

The temperatures and air velocities predicted by CFC are listed in Table 6. Together with the predicted values, the distribution of temperature and air velocity at 1.5 m height is shown in Figure 7. The average ambient temperature during all experiments was 33°C. In case 1, representing the current condition of the building, the average temperature was 37.4°C, which was 4.4°C higher than the ambient temperature. The average air velocity was 0.12 m/s. The temperature was evenly distributed in the building and there was difficulty in removing the heat through the existing ventilation and ensuring adequate air velocity. The result is a lot of heat inside the building, which has a negative impact on the health of the workers and the productivity of the industry [7, 8].

As a first step towards improvement, windows and ventilators were installed in the CFD model (Case 2). This improvement had a direct effect on temperature as the average temperature dropped to 33.8°C, a decrease of 3.6°C. However, the air velocity did not increase significantly. The installation of enclosures on all heat sources (Case 3) resulted in a further 1.0°C decrease in temperatures, but the enclosure walls obstructed air flow and thus decreased air velocity. In Case 4, the enclosures were removed and power jet fans were installed in all aisles, near the heat sources. Compared to Case 2, this did not reduce the temperature as much, although the air velocity increased significantly. Moreover, the temperature in the areas near the heat sources where workers stay for long periods of time was 37.0°C, which is not desirable. As a result, both enclosures and power jet fans were added to Case 5. This helped to both lower the temperature and increase the air velocity; the resulting average temperature and air velocity were 33.2°C and 0.49 m/s, respectively. This is a significant decrease in temperature (5.2°C) and increase in air velocity (0.37 m/s) compared to Case 1. The final improvement involved air conditioning combined with single jet fans (Case 6). This configuration lowered the temperature to 32.0°C and increased the velocity to 0.82 m/s.



Height		1.5 m	3.0 m	4.5 m
Measured	Mean	38.1	38.4	39.0
	S.D.	3.02	2.93	3.34
Simulated	Mean	37.0	37.5	37.8
	S.D.	3.23	2.87	2.99

Figure 5 Comparison of average measured and simulated temperature at different heights

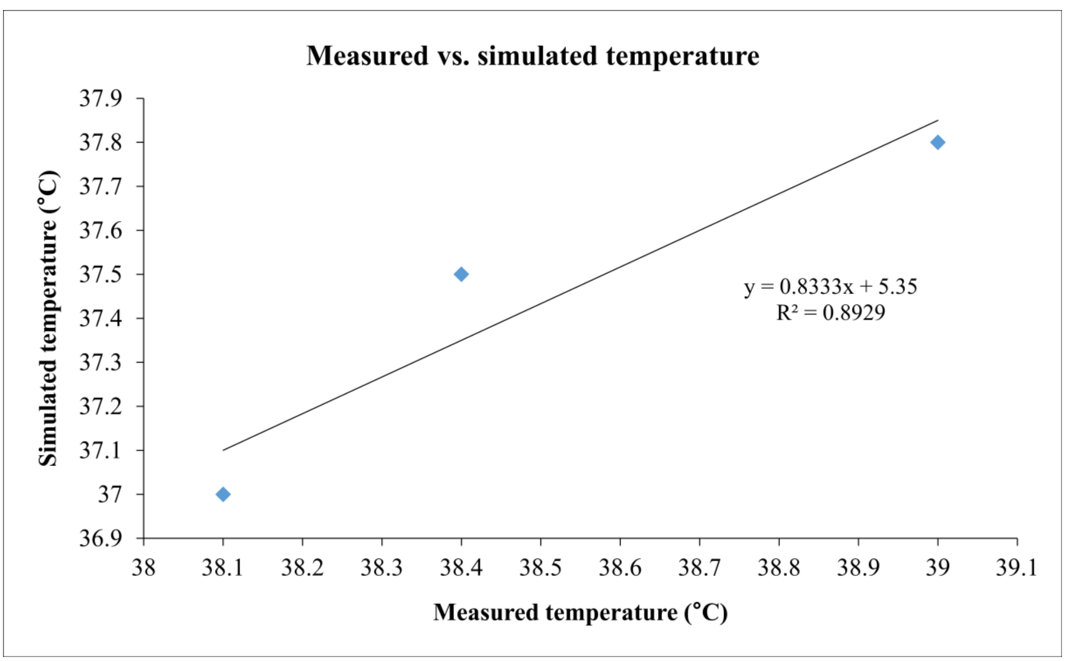


Figure 6 Simulated vs. measured temperature at all measurement heights

Table 6 CFD results of temperature and velocity

Cases	Temperature (°C)				Velocity (m/s)			
	1.5 m	3 m	4.5 m	Average	1.5 m	3 m	4.5 m	Average
1	37.0	37.5	37.8	37.4	0.14	0.11	0.10	0.12
2	33.6	33.8	34.1	33.8	0.18	0.12	0.09	0.13
3	33.2	33.3	33.4	33.3	0.09	0.07	0.06	0.07
4	33.5	33.5	33.6	33.5	0.40	0.45	0.77	0.54
5	33.2	33.2	33.3	33.2	0.34	0.40	0.72	0.49
6	31.9	32.0	32.0	32.0	0.73	0.74	0.99	0.82

Air conditioners are often the top energy-consuming parts in industrial plants [48]. Although the ventilation performance of Case 6 was the best; the cost of installation, operation and maintenance of the air conditioning system was expensive and the improvement in indoor conditions achieved in Case 6 was not much higher than that of Case 5. In Case 5, the temperature of 33.2°C was in the defined comfort zone of many studies [49-51] and a wind speed of 0.49 m/s was at a modest level that can help to provide better comfort. In Case 6, wind speeds in many areas of the work area were also above the appropriate level (< 1 m/s approximately) [52, 53]. Too high wind speed can cause adverse health effect to workers such as higher dust concentration in the air [54], higher noise level [55], dry eyes [56], and so on. Thus, Case 5 was adopted as the optimal case for application in the existing industry.

Application to the Real Site

The solution selected from the simulation results of CFD, Case 5, was applied to the existing building to measure its effectiveness and performance in the real world. All the components i.e. windows, ventilators, enclosures, and jet fans were installed in the building. Extra care was taken to ensure that the real installations matched the CFD model as faithfully as possible. The real temperature and velocity measurements are shown in Table 7. There is a good correlation between the Case 5 results predicted by CFD and the experimental results; the difference between the results at 1.5 m, 3 m, and 4.5 m was 1.8%, 2.7%, and 3.3%, respectively. The temperatures and air velocities of the original and improved building setups are compared in Figures 8 and 9. The provided ventilation solution was able to reduce the average temperature by 5.3° C and increase the average air velocity by 1.5 m/s.

However, aforementioned discussion is only a matter of success in lowering the temperature, but it is the initial fundamental factor that must be considered [48]. Although the operators were satisfied with the current conditions in the work area after the improvement, another point that should be further observed in the long term is the comfort of each operator due to the different wind speeds in locations which is subjective [57]. Maintaining air flow uniformity is always not easy when a jet fan is the chosen option for industrial ventilation [58].

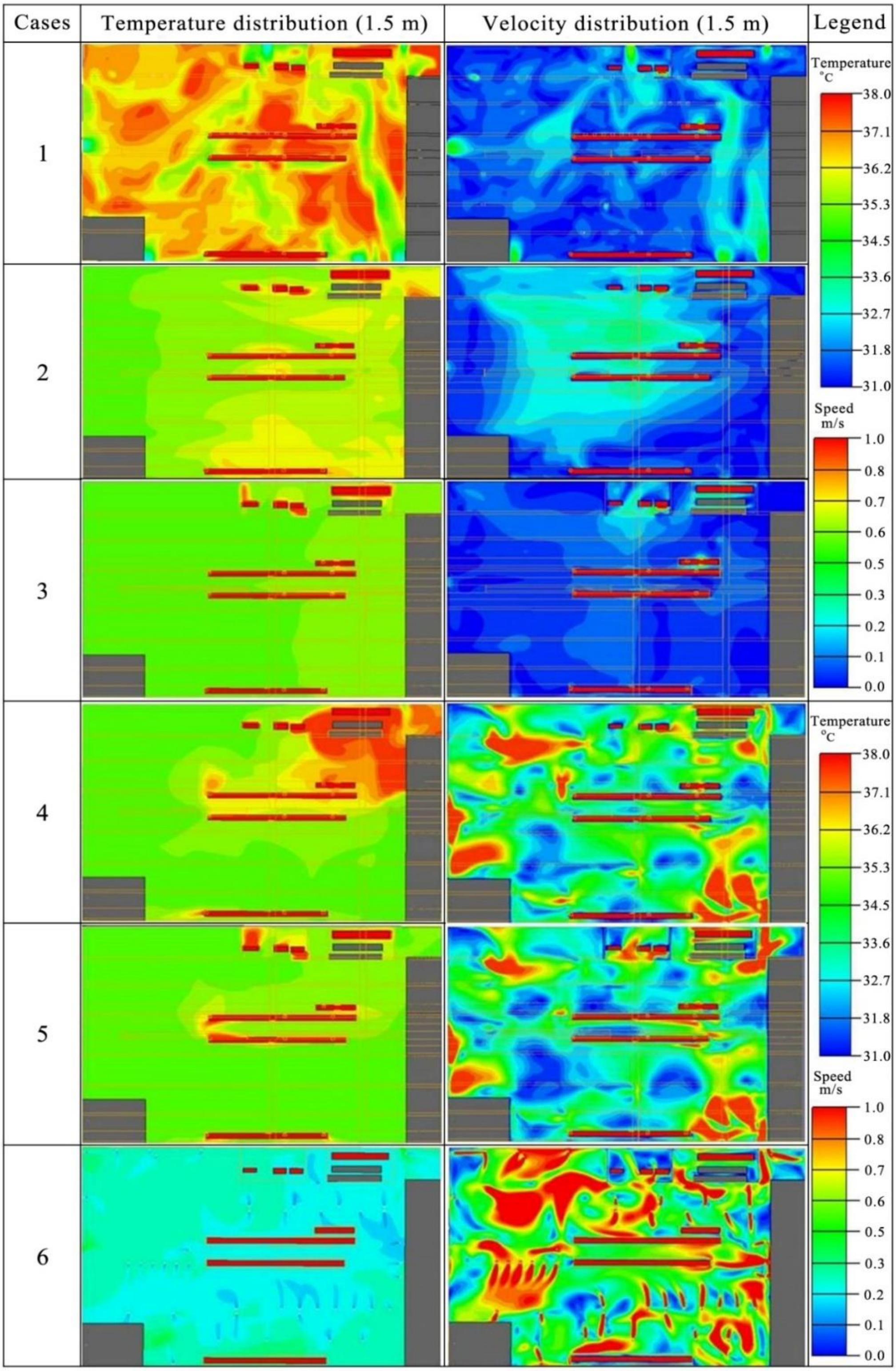


Figure 7 CFD-predicted results of temperature and air velocity distribution

Table 7 Comparison of CFD simulated and measured temperature for improved condition (Case 5)

Height (m)	CFD simulated temperature (°C)	Measured temperature (°C)	Difference (%)
1.5	33.2	33.8	1.80
3	33.2	34.1	2.70
4.5	33.3	34.4	3.33

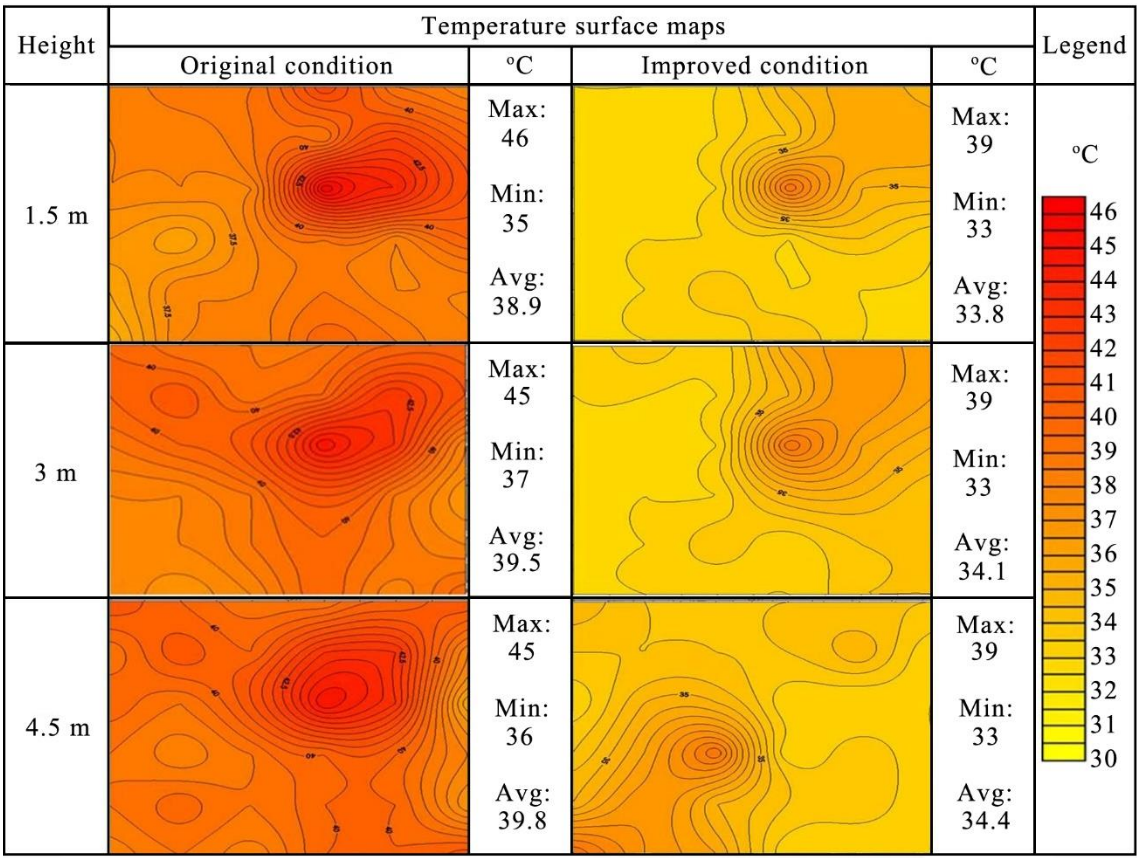


Figure 8 Comparison of temperature between original and improved conditions

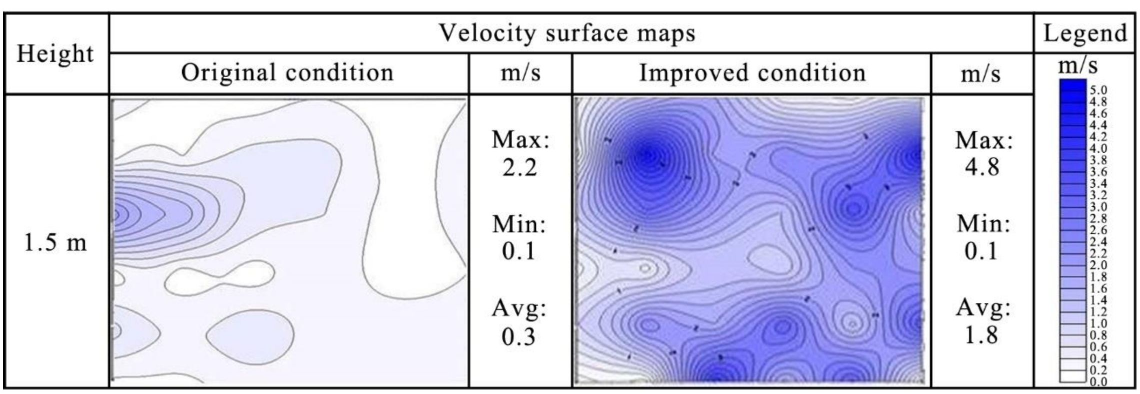


Figure 9 Comparison of air velocity between original and improved conditions

Conclusions

This research is an attempt to solve the problem of high temperatures in an existing industrial workshop environment. Although general and local exhaust ventilations have been a topic of extensive research on the elimination of gases and pollutants in the workplace, these methods may not be effective for heat-related problems. This paper provides some insight into the application of various techniques. In addition to the obvious heat control options, jet fans have been used as a potential solution because they can supply a constant flow of air at high velocity.

The research is accomplished through the successive use of experimental and numerical methods. Firstly, the problem was identified by measuring the related factors and then understanding the possible solutions that could be implemented. The effectiveness of the possible solutions is examined by using CFD simulations. The optimal option (reaching maximum temperature for acceptability with an appropriate level of wind movement) identified by CFD is implemented in the real site. Ventilation designs presented in this study can be an example that helps inspire the factory manager to consider other innovative options apart from air conditioners usually installed against high workplace temperatures (with a high cost of energy consumption). From the results of the final application in the real site, it is found that the installed system was able to dissipate sufficient amounts of heat and make the workplace comfortable for the workers with no complaints.

Although this study still leaves some questions unanswered, such as the comparison of the final conditions in the building with the available standards and limits, the use of air conditioning in the real application, these limitations are mainly due to a lack of resources. This presents a good opportunity for further investigation into different ventilation options for workplace heat control and comparison with standard limits. Nevertheless, the analysis of ventilation and the methods provided by this research should help to make the workplace more comfortable and safer.

Acknowledgements

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Bacterial Growth Patterns and COD Reduction in Agitated Vessels Treating Polluted Canal Water with Fermented Products Addition

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Abstract

Fermented Products (FPs) are mostly solution form compounds produced by the microorganism fermentation of sugar and/or lactose as carbon and energy sources. In this study, polluted water was taken from Kaja canal in Bangkok City. The experiment with this polluted water were divided in to two parts, that is, the one with sterilized polluted water and another one with non-sterilized polluted water. Both sterilized and non-sterilized polluted waters were experimented with five different types of commercial FPs. The FPs were added into polluted water (either sterilized or non-sterilized) with the ratio of 1:10,000 by volume as suggested by FP manufacturers. Whereas, the vessels without addition of FP were set up as the controls to receive scientific data to prove the benefit of FPs application, especially in treating polluted water. The mixtures (polluted water and FP) were then aerated through moderate agitation continuously for seven days of operation. Then, samples were taken on Days 0, 1, 3, 5 and 7 for bacterial count, while non-filtered COD (COD_T) analysis were monitored only in samples on Day 0 and 7. The growth patterns of total heterotrophs showed the enhancement of growth especially in sterilized pollute water in comparison to non-sterilized one. This was postulated to be the effect of autoclaving (high temperature and pressure) which made the organic matters be more easily degradable. Besides, the SPC, LAB and PNSB growth patterns were similar between no FP addition or different FPs addition, denoting no positive effect from the FP addition. For COD_T removals, the reduction of COD_T after seven-day operation did not show the substantial difference between FPs addition and the 'Control'. In brief, when both the bacterial count and COD_T reduction were considered, there was no clear benefit of the FP addition to the polluted canal water, regarding its water quality improvement.

Keywords : Effective Microorganism (EM); fermented products (FPs); purple non-sulfur bacteria (PNSB); lactic acid bacteria (LAB); wastewater treatment

Introduction

Fermented product (FP) or Effective Microorganisms (EM) is the technology developed by Professor Dr Teruo Higa, the University of the Ryukyu, Okinawa, Japan since 1970's. They have usually been made by composting food, vegetable or fruit wastes and natural microbial inoculums from the fertile soil from various sources. These are usually mixed with molasses to form FP liquid, while some are mixed with appropriate ratio of rice chaff, bran, sand, mold and clay and compressed to form a ball shape, known as EM balls. These fermented products are claimed to help improve polluted water quality [1-3]. The FP believers always explained that their FP solutions consisted of four important microorganisms which are lactic acid bacteria (LAB), photosynthetic bacteria (PB), yeast and actinomyces [4-7].

These microorganisms have been claimed to well treat wastewater especially those physical characteristics, e.g., color, turbidity, odor and debris, because of their acidic by-product. For instance, lactic acid is said to help eliminating odor by neutralization reaction [4]. EM or Effective Microorganism is the trade name of a main FP available in some parts of the world [8, 9]. There are many reasons of FP (or EM) solutions popularization in agriculture, livestock, fisheries and environmental management; e.g., their easy production, friendly operating and wide range applications.

For agricultural management, FP has been used for increasing crop yield, improving agricultural product and soil quality, and preventing the insect infestation [10-20]. For environmental management, FP has been applied for odor elimination of kitchen garbage, waste treatment plant, livestock farm, and also used for treating sludge from wastewater treatment plant and oily sludge from petroleum refinery plant in certain communities [1, 5, 21-25].

Some FPs, which were believed by some to be applicable to reduce organic matter in polluted water, were widely promoted due to its lower cost as well as ease of production and application. These FPs were exaggerated to improve polluted canal water quality during the Thailand severe flood situation in 2011 without reasonably scientific information. Although some researchers claimed that the microorganisms in FP had the ability to reduce the BOD, COD and eliminate odor [24-28], there still had been solid arguments against these claims by others. Moreover, the ability of the effective microorganism (EM) in inhibiting the growth of pathogenic bacteria was mentioned elsewhere [29].

Therefore, this study aimed to investigate the bacterial abundance in five fermented products (FPs) commercially sold in Thai market and their growth patterns. In addition, the treatability of five different FPs in polluted water were determined via the reduction of non-filtered COD (COD_T). Sterilized and non-sterilized polluted water were compared to distinguish the activities of indigenous microorganisms from the effects of FPs addition.

Methodology

Polluted water

This study was setup due to some certain FPs (EM liquid and EM ball) were claimed to reduce odor and turbidity of stagnant flood water during the severe flood in 2011. Some were even exaggerated that FPs can treat polluted water or any wastewater. However, such a polluted water in 2011 was not existed anymore. Hence, the authors chose a polluted canal in Bangkok area to imitate polluted floodwater. Kaja canal is selected to be a source of polluted water in this study because of its deteriorated water quality (like conventional polluted waters in Bangkok) and accessibility. Enough amount of polluted water was taken at once for all experiments to avoid different polluted water characteristics. Their characteristics (Temp, pH, DO, BOD, COD and SS) were analyzed before storage and application in the experiments.

This polluted water was divided into two portions, one of them was sterilized by autoclaving at 121˚C and 15 psi pressure for 15 minutes to destroy microorganisms in polluted water before it was experimented. The rest was directly used in the experiments as non-sterilized polluted water. Both sterilized and non-sterilized polluted water will be investigated to compare the effects of local microorganism in treating polluted water.

Fermented Product (FP)

Usually, the treatability of fermented products (FPs) has been explained that these FPs contain some important microorganisms capable to improve pollute water quality. Although the manufacturing of these FPs has never been standardized, any FPs suppliers always claim their similar effectiveness. Therefore, the authors selected five different brands of FPs from those commercially sold in Thai market for this study, namely FP1 to FP5. Each FP was added into polluted water both cases of sterilized and non-sterilized with the ratio of 1:10,000 by volume (as suggested by FP manufacturers). As previously mentioned, this study was attempted to find any scientific data to clearly discuss the treatability of FPs as their believers has been claimed. The authors tried to keep any application steps of FPs as similar as those instructed by their manufacturers/suppliers.

Experimental setup

Twenty-liter plastic tank equipped with mixer and sampling tube was used as an agitated vessel used in this study as shown in Figure 1. Slow speed mixing was applied to prevent settling during the experiment. For each portion of polluted water (sterilized and non-sterilized), six 20-L tanks were set up for the experiments with five FPs addition and the 'Control' (no FP addition). The addition of each FP was done only once at the beginning of the experiment. The mixture (polluted water and FP) were then gradually agitated to imitate natural aeration. The agitation was maintained for seven days of operation.

In order to obtain scientific data about the transition of microorganisms before and after applying FPs, water samples (about 500 mL) were taken from the vessels on day 0, 1, 3, 5 and 7 for bacterial count by standard plate count (SPC) [30]. Plate counting was focused on heterotrophic microorganisms (total microorganisms), anaerobic lactic acid bacteria (LAB) and photosynthetic bacteria (purple non-sulfur bacteria, PNSB). The media used for them were Tryptic soy medium, De Man-Rogosa-Sharoe medium (MRS) and Basal Agar medium, respectively. For treatability discussion, non-filtered BOD (BOD_T), non-filtered COD (COD_T) and SS were analyzed only on days 0 and 7. DO was also monitored to observe the degree of aeration. All parameters were analyzed according to the Standard Methods procedure [31]. Figure 2 showed the experimental setup for this study.

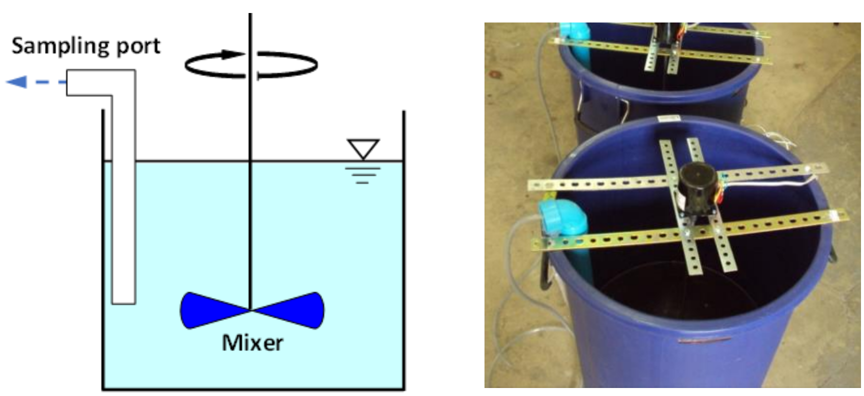

Figure 1 Agitated vessels

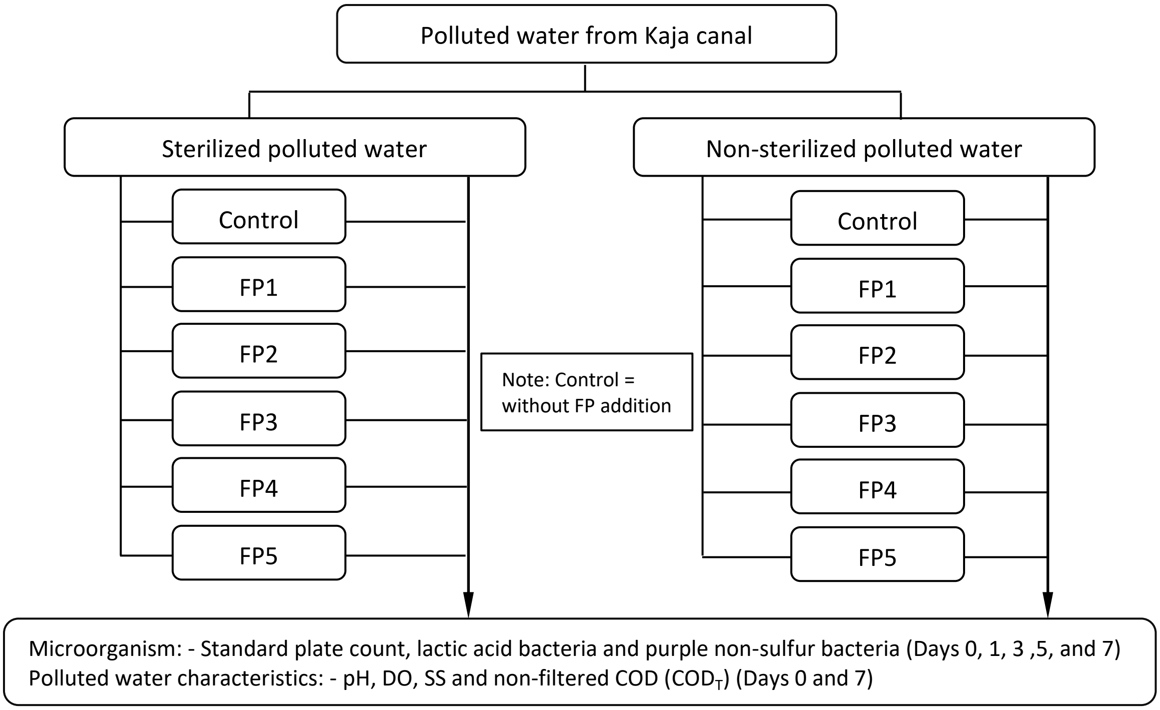

Figure 2 The experimental setup

Results and Discussions

Polluted water taken from Kaja canal were determined for their characteristics as shown in Table 1. Their low DO (0.61 mg/L) and substantial BOD value (22 mg/L) illustrated their 'polluted' situation. All five fermented products (FPs) used in this study were identified and bacterial counted for heterotrophic microorganisms before applied to the experiments.

Table 1 Characteristics of Kaja canal water

Parameters	Kaja canal
Temp (^oC)	30.2
pH	7.42
DO (mg/L)	0.61
Turbidity (NTU)	0.85
BOD (mg/L)	22.1
COD (mg/L)	80
SS (mg/L)	17

The result of bacterial counts as shown in Table 2 exhibited that each FP had different amount of total heterotrophic bacteria, especially FP5 that showed the significantly higher number of SPC and LAB than the others. In case of PNSB, similar amounts of PNSB (101–176 CFU/mL) were observed in four FPs, but the one as high as 600 CFU/mL was found in FP3. However, the number of heterotrophic microorganisms in each FP were not considerably high, the addition of FPs into polluted water with the ratio of 1:10,000 (the instructed ratio by manufacturers) should not help increase the initial amount of the microorganisms in the mixtures on Day 0 substantially.

Owing to the turbulence created by the agitation, the polluted water in a vessel became under aerobic condition. For sterilized polluted water vessels, DO levels were ranging from 3.0–3.8 mg/L on Day 0 to 4.0–4.9 mg/L on Day 7. For non-sterilized polluted water vessels, DO levels were in the ranges of 0.6–0.8 mg/L on Day 0 to 1.2–1.5 mg/L on Day 7 as shown in Figure 3. Admittedly, the higher

DO levels in sterilized polluted water would be due to any turbulence caused by water preparation (container transfer, autoclaving, etc.). Moreover, any DO consumption in non-sterilized polluted water could occur all the time due to the existing microorganisms were not destroyed. Obviously, increase of DO on Day 7 should be the result of continuous DO supply from agitation and slower DO consumption due to less organic matters.

Table 2 Amount of heterotroph microorganisms in each fermented product

Type of FPs	Total bacteria as SPC (CFU/mL)	Lactic acid bacteria (CFU/mL)	Purple non-sulfur bacteria(CFU/mL)
FP 1*	201,000±1,732	8,733±58	127±4.6
FP 2*	34,667±577	3,033±153	101±7.8
FP 3**	56,333±1,528	6,067±208	600±43.6
FP 4**	54,000±1,732	290±10	176±1.0
FP 5*	1,340,000±10,000	187,000±10,000	156±3.5

Note: *Company's product **Produced by local people; FP 4 was produced from fermented mushroo

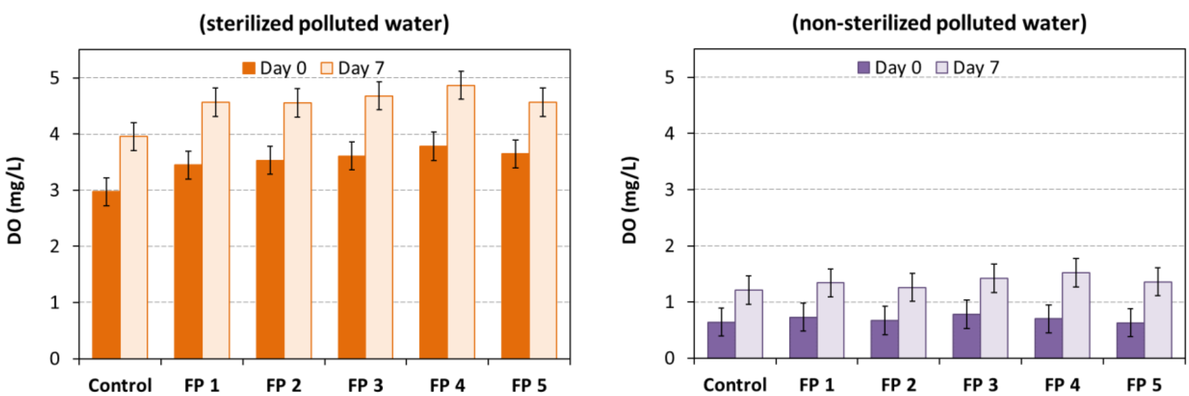

Figure 3 DO in agitated reactors with and without FPs addition

Heterotrophic microorganisms

From Figure 4a, it illustrated the growth patterns of heterotrophs, as counted by SPC method, in the experiment with sterilized polluted water. It is noteworthy that no colony of heterotrophs was found in the Control while the others (with FPs addition) were observed very small amount within the range of 6–680 CFU/mL. This assured that polluted water was all sterilized. When the operation went on, increases of heterotrophic microorganisms were observed in every vessel until Day 3. It can be seen that the Control (no FP) and five different FPs vessels with the sterilized polluted water, could produce similar increase patterns but different magnitudes, with FP5 giving the highest count of 63×10^6 CFU/mL on Day 3. This was probably due to its higher SPC content in the FP5 in the first place (see Table 2). Interestingly, the Control vessel ranked the second high count of 53×10^6 CFU/mL. Therefore, this evidently showed no beneficial result of the FP addition to the system, in terms of the SPC results.

In case of non-sterilized polluted water (Figure 4b), the initial counts of heterotrophic microorganisms (Day 0) were much higher than those of sterilized polluted water. That is, the Control (no FP) was observed the count of around 0.6×10^6 CFU/mL, while the others (with FPs addition) were in the range of 0.7×10^6–0.9×10^6 CFU/mL. However, the sterilized polluted water vessels (Figure 4a) could apparently induce the bacterial growth significantly despite local microorganisms in polluted water were all destroyed (by sterilization). The increase of bacterial count in case of sterilized polluted water could rise up to higher than 60×10^6 CFU/mL while those of non-sterilized pollute water was merely less than 5×10^6 CFU/mL (for FP5 scenario) as shown in Figure 4b.

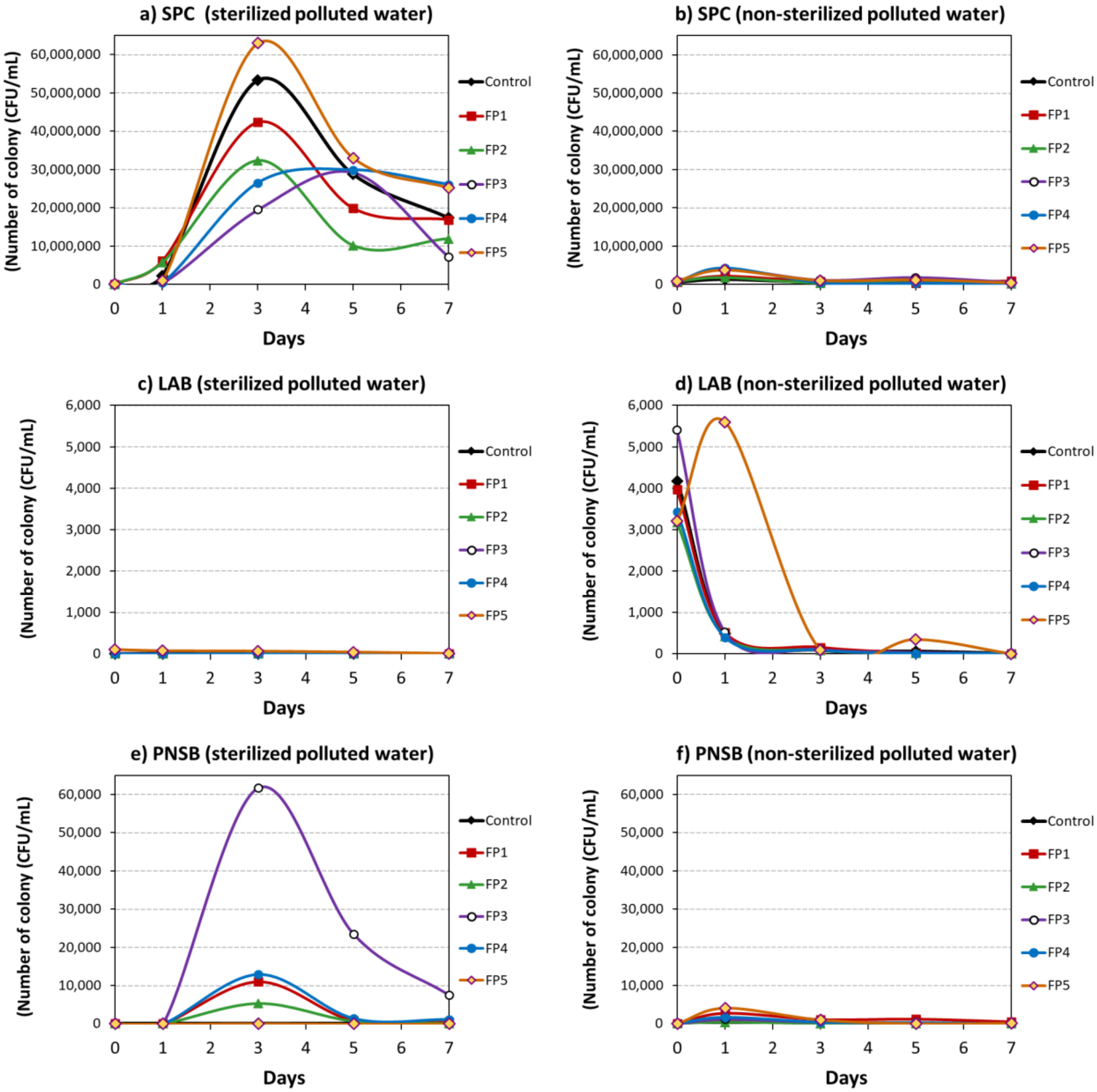

Figure 4 Growth patterns of total heterotrophs (expressed as SPC), lactic acid bacteria (LAB) and purple non-sulfur bacteria (PNSB)

Moreover, in comparison between sterilized and non-sterilized cases, the peak of bacterial count appeared different day. That is, the heterotrophic microorganisms grew and generally peaked on around Day 3 (or 5) in the sterilized vessels, while those in non-sterilized vessels increased to their peak on around Day 1. After their peaks, the number of heterotrophs declined. Two probable assumptions were 1) some organic matters were partly degraded under autoclaving, resulting in smaller and more easily biodegradable organics, as well as higher yield of bacterial growth; 2) certain growth inhibitors were present in the raw non-sterilized polluted water.

Lactic acid bacteria (LAB)

Figure 4c shows the increase patterns and counts of the lactic acid bacteria (LAB) in the sterilized case comprised of the Control and the test units with FP addition (FP1 to FP5). It is clear that they were very much alike, illustrating no clear benefit of the FPs addition. Especially, the initial numbers of LAB (Day 0) were extremely low, that is, no colony of LAB were found in the Control, FP2 and FP4 vessels. The others, namely FP1, FP3 and FP5, were observed the LABs counts of only 1, 13 and 99 CFU/mL, respectively. Nevertheless, LAB count did not show any increase during the 7-day operation. The presence of substantial DO in the sterilized vessels could possibly inhibit anaerobic growth of LAB.

In comparison, the non-sterilized case showed the higher initial number of LAB (Day 0) than sterilized case. That is, the number of LAB in the ‘Control’ (no FP) vessel was about 42×10^2 CFU/mL while those in the test units with FPs addition were in the range of 32×10^2–54×10^2 CFU/mL (Figure 4d). Obviously, the initial amount of LAB on (Day 0) in non-sterilized polluted water vessels were similar to each other. This could be said that LABs from FPs addition were insignificant, and most of them were local microorganisms in polluted water. But, after only two or three days of operation, the rapid decline of LAB occurred. This could be possibly due to some inhibition by the presence of DO (from agitation). Therefore, this such a decline of LAB did not support the exaggerated benefit in wastewater treatment, especially aerobic treatment.

Purple non-sulfur bacteria (PNSB)

Considering the results shown in Table 2, the amounts of PNSB originally available in FPs were in the range of 101–600 CFU/mL. This amount should have no considerable impact on the initial amount of PNSB in the mixtures on Day 0 due to the high dilution ratio of 1:10,000 (v/v). For sterilized polluted water vessels, negligible amount of PNSB (0 CFU/mL) was observed in all vessels on Day 0 as shown in Figure 4e. Surprisingly, PNSB in the sterilized system showed their increase to a certain number and declined after three days of operation (Figure 4e), especially with the addition of FP3 that contained the highest PNSB itself. The peak of PNSB count in FP3 vessel was up to 62×10^3 CFU/mL. However, this increased PNSB were then declined after Day 5.

For non-sterilized polluted water vessels, little amount of PNSB were detected in the range of 58–84 CFU/mL as shown in Figure 4f. Obviously, FPs addition did not increase the number of PNSB in comparison to the Control (no FP). This illustrated that PNSB was a kind of indigenous microorganisms and already existed in this polluted water. The addition of FPs (with the ratio of 10:10,000 v/v) could not noticeably increase the amount of PNSB in the mixtures (of polluted water and FP). On the contrary to sterilized polluted water, PNSB in non-sterilized condition did not show any substantial growth during the experimental course. Slight increase of PNSB count was observed on Day 1, but this higher amount of PNSB did not last long throughout the seven days of operation. They eventually became less and undetectable at the end of the period. Probably, non-sterilized polluted water might contain some local microorganisms that competed against or hindered growth of PNSB.

Treatability of FP in polluted water

Batchwise experiments were further done to determine the reduction ability of non-filtered COD (COD_T) and non-filtered BOD (BOD_T) in the 'Control' (without FP) and the test units (FP 1 to FP 5). The non-filtered COD (COD_T) of the polluted water itself was about 83 mg/L and became 54 mg/L after being autoclaved. In the sterilized condition, addition of FP increased the initial COD_T concentration of the test units to the range of 67–79 mg/L. After seven days of operation, the COD_T of the vessels with FPs addition were in the range of 50–63 mg/L which were not much different from the 'Control' unit (60 mg/L) (Figure 5a). The 'Control' unit did not show any reduction of COD_T while there were some small COD_T reduction observed in the vessels with FP addition. However, this small COD_T reduction could not be said that the FP addition did help improve the COD_T reduction capability of the system.

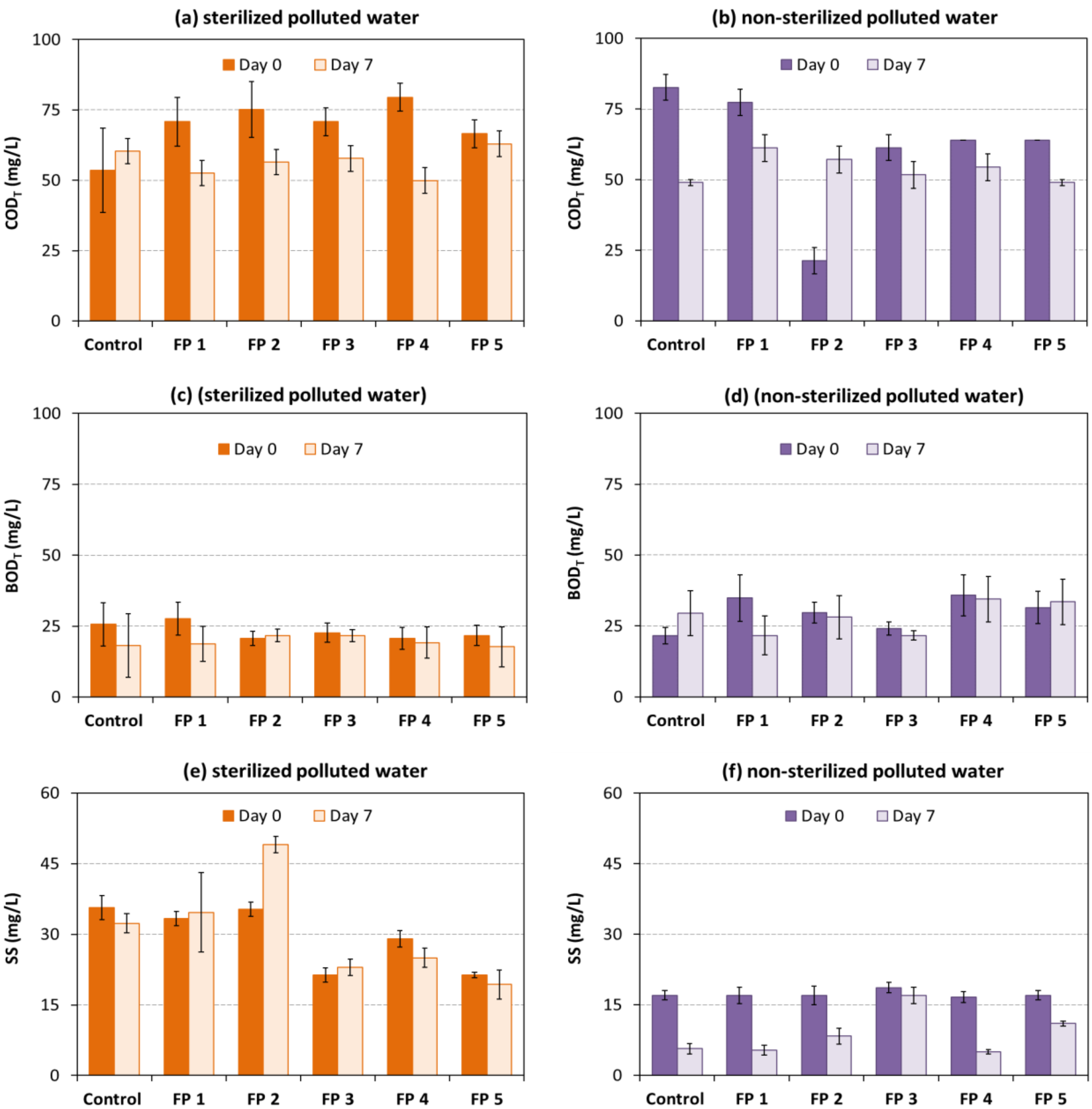

Figure 5 COD_T, BOD_T and SS reductions of agitated reactors with and without FPs addition

For the non-sterilized condition (Figure 5b), some minor change in the initial COD_T after FP addition was apparent, except the vessel with FP2 that very low COD_T (21 mg/L) was observed without reasonable explanation. However, at the end of seven-day operation, the COD_T of test units were in the range of 49–61 mg/L which were very similar to that of the 'Control' unit (49 mg/L). Therefore, it could be again concluded that FP addition in both sterilized and non-sterilized cases did not provide a positive effect on the COD_T reduction.

Figure 5c showed BOD_T change in sterilized polluted water vessels. The BOD_T values on Day 0 were in the range of 21–28 mg/L, while they were in the range of 18–22 mg/L after seven days of operation. Some slight reduction of BOD_T could be perceived, but difference between with and without FPs addition was again unclear. Similarly, BOD_T concentrations on Day 0 in non-sterilized polluted water vessels were in the range of 22–36 mg/L. But, BOD_T reduction after operation were indecisive as they were in the range of 22–34 mg/L (Figure 5d).

It is noted that these COD_T and BOD_T was the non-filtered type, then, the organic SS (or biomass) was counted as a part of analyzed COD_T or BOD_T. Likewise, SS did not show significant difference between the 'Control' and the ones with FPs addition (Figures 5e and 5f). The results from this study were inconsistent to some studies that concluded their achievement in wastewater treatment with FP addition [31–34].

Conclusions

For the sterilized samples, different FPs gave different heterotroph growth levels, with FP5 seemed to be the best growth promoter. Surprisingly, the 'Control' (no FP addition) ranked second in terms of SPC growth. This illustrated that there was no affirmative advantage of addition FPs to the system. Regarding the non-sterilized system, practically very low heterotroph growth (measured as SPC) was perceived. No obvious difference of SPC growth between with and without addition of FPs was scientifically noticed. This finding suggests that the FP addition did not enhance the treatment efficiency.

Considering the LAB and PNSB growth patterns and magnitudes, it was also apparent that FP addition did not increase their density in both sterilized and non-sterilized conditions, resulting in no advantage of adding the FPs to the system. Agitation should affect DO concentrations in the vessels, they were in the rages of 3.95–4.87 mg/L and 1.21–1.52 mg/L for sterilized and non-sterilized polluted water, respectively. Both LAB and PNSB microorganisms eventually decline to undetectable range after operation possibly due to the presence of DO.

In terms of treatability, FPs addition did not enhance the reduction of COD_T or BOD_T in comparison to the Control (no FP addition). Even suspended solid (SS) did not showed significant improvement by FPs addition. Therefore, it was concluded that no obvious benefit from FPs addition on canal polluted water treatment.

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