USING A MULTI-CRITERIA DECISION MAKING APPROACH IN CONJUNCTION WITH A DELPHI STUDY TO IDENTIFY FACTORS INFLUENCING POLLUTANT EMISSIONS

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KEYWORDS

AHP method, Delphi method, Plastic industry, Pollution emission

ABSTRACT

Pollution is currently a major concern in Thailand and other countries around the world. The Thai government has made environmental degradation a priority, emphasizing the benefits of reducing pollution generated by heavy industries. To be successful, a variety of efforts and authority at all levels are required. This study adds to the existing literature on identifying factors that reduce pollution emissions in the plastic industry using a multi-criteria decision-making (MCDM) approach. Two-phase methodologies were used to identify and rank such factors from a practical standpoint. From the first phase, two rounds of the Delphi method yielded three main criteria and 12 sub-criteria. Regarding that, the Analytical Hierarchy Process (AHP) was used to rank those factors. The findings indicated that the top three sub-criteria for According to the findings, the top three sub-criteria for reducing pollution emissions were "determination of standard improvement of pollution discharge at source clearly" (19.55%), "improvement of production efficiency" (15.32%), and "set up action plans for emergency pollution accidents from industry" (11.04%), respectively. Among the main factors, "Source reduction" has the highest rank (40.4%). Finally, this study discussed recommendations for entrepreneurs and policymakers.

INTRODUCTION

Plastic is a synthetic material that has become widely used in everyday life. The plastics industry is a significant sector of both the Thai and global economies. In 2019, the industry contributed 6.1% of Thai GDP, or USD 36.9 billion, and is expected to grow by 2.0-3.0% year on year from 2020 to 2023 [1]. Thailand's domestic and export volumes of plastic products are expected to increase by USD 8.63 billion at a 4.72% CAGR between 2021 and 2026 [2]. The industry has played an important role in connecting the supply chain from upstream petrochemicals to downstream end-user industries that include automotive components, packaging, medical devices and equipment, electrical and electronic appliances, footwear, and other applications. The plastics industry manufactures both semi-finished and finished goods. Figure 1 depicts the locations of plastic producers in Thailand, with the majority (81.5%) concentrated in the country's center.

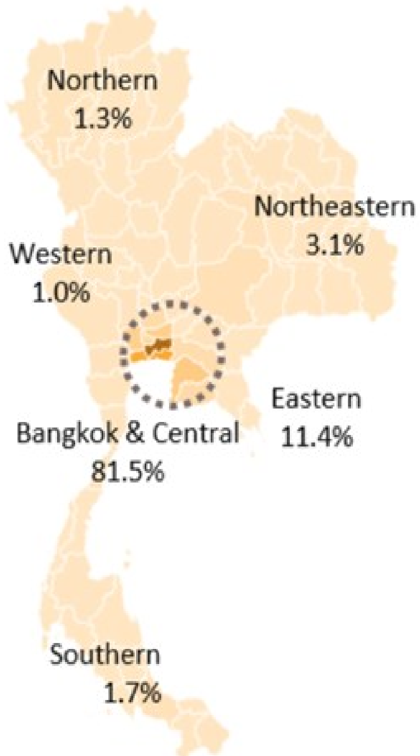

Figure 1: Locations of Plastic Producers in Thailand
Source: [1]

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Plastics are made with a lot of fossil fuels and a lot of additives like plasticizers, sorbents, inhibitors, and pigments that are incorporated during the process of manufacturing. Despite the fact that the sector offers significant opportunities for economic growth, it contributes to high levels of pollutants and carbon emissions in the atmosphere [3]. These inappropriate pollutants have the potential to devastate ecosystems and degrade the environment's air, water, and soil. These emissions would contribute to greenhouse gas emissions and global warming, as well as negatively impact public health. PM, NO_x, SO_2, CO, and CO_2 are a few examples of major emissions from plastic manufacturing. A large portion of the remaining plastic waste ends up in the environment, in local landfills, and in watersheds, widely dispersed throughout natural and man-made scenery all over the world. Regardless of disposal method, all discarded plastic waste poses a threat to both the environment and living things, including humans. To control and develop environmentally friendly alternatives within the factory, reducing pollutants and CO_2 emissions from the production of plastics will necessitate actions, regulations, as well as internal cooperation and employee awareness. Plastic processing can also be harmful to the environment of employees and residents. Serious injuries have resulted in explosions, chemical fires, chemical contamination, and poisonous combustion clouds. These occurrences have resulted in deaths, injuries, evacuations, and significant property damage. A serious example occurred in Thailand in 2021 when a plastic manufacturing factory on the outskirts of Bangkok exploded. Several people were injured, and one person was killed. Massive black clouds were forming in the sky 21 miles away from the city's downtown. Many residents within a 10-kilometer radius of the factory had been evacuated due to toxic smoke [4]. People suffering from respiratory illnesses such as asthma may be affected by the liquid chemical released by the fire.

As a result, it is in our best interests to investigate and assess factors to reduce pollutant emissions, particularly in the plastics industry, as well as regulations and practices related to this issue. Its goal is to prioritize and identify appropriate solutions to meet emission control targets. First, we looked at factors influencing pollutant emission reduction from the perspective of experts using the Delphi method. Following that, Analytical Hierarchy Process (AHP), a multi-criteria decision making approach, was then used to rank the significance of those factors.

The remainder of this manuscript is divided into several parts. The following section goes over the materials and methods. Section 3 displays the findings of the study and discussion. The conclusion is summarized in the concluding section.

MATERIAL AND METHODS

The inquiry was carried out using the Delphi and AHP approaches, with the participation of a panel of ten experts.

Delphi Technique

A Delphi study is a constructed, anonymized, iterative approach that employs controlled feedback to evoke an expert group's consensus on a certain future [8], [9]. In the late 1940s, the Rand Corporation created the technique as a short-term forecasting approach [10], and it has been broadly applied in a variety subject areas to gather clarity of the conclusions. The expert panel should be chosen carefully, with a combination of scholars and professionals involved with the issue being examined. Several suggestions for the number of experts have been made, including 3-5 people [11] and 5-20 people [8]. According to Surowiecki [12], the characteristics of expert groups specializing in a specific topic should be variability and individuality of personal views.

The Delphi method, according to Fowles [13], comprises the steps that follow.

i) Create the questionnaire and select the panel experts;

ii) Conduct the first-round anonymous expert survey;

iii) According to the outcomes of the initial round of surveys, a precise questionnaire is developed and distributed to the same group members, together with a summary of the previous iteration's findings;

iv) Monitor whether new solutions are proposed or new insights are provided;

v) Repeat steps (iii) and (iv) until consensus and precision are achieved.

Analytic Hierarchy Process (AHP)

According to Cinelli et al. [14], various multi-criteria decision-making methods are used for ranking purposes. The Analytic Hierarchy Process (AHP) was claimed to be the most widely used method in practice [15]. Saaty developed AHP with the goal of systematically evaluating quantitative and qualitative factors in pairwise comparisons using an absolute scale ranging from 1 to 9 [6], [7].

In general, AHP consists of four major steps [16], which are as follows:

i) Split the complicated problem into hierarchical levels.

ii) Generate data input comprised of pairwise comparison matrices designed to determine the relative weight among the decision elements' attributes on a scale of 1 to 9. N*(n-1)/2 is the total number of comparisons, where n is the total number of criteria taken into account [17]. Table 1 depicts Saaty's importance scale.

Table 1: AHP Preference Pairwise

The importance scale	Importance
9	Highly recommended
8	Extremely strongly to extremely strongly
7	Extremely preferred
6	Extremely preferred
5	Definitely preferred
4	Moderately to firmly
3	Generally preferred
2	Equally to moderately preferred
1	Equally preferable

Reciprocals: If the ith criterion is compared to the jth criterion, a_{ij}, then $1/a_{ij}$ is the judgement value when the jth criterion is compared to the ith, i.e. $a_{ij} = 1/a_{ji}$.

Source: [7]

iii) Form an opinion and estimate the relative weight of the elements.

iv) Determine the relative weights of the decision elements in order to generate a set of ratings for the decision alternatives/strategies.

When using AHP, it is essential to verify whether the paired matrix results are consistent. The consistency index (CI) and consistency ratio (CR) are described in the following ways:

$$CI = (\lambda_{max} - n)/(n-1) \quad (1)$$

$$CR = CI / RI \quad (2)$$

where λ_{max} the eigenvalue of the matrix, n is the size of the matrix, and RI is the average index of randomly generated weights.

The consistency index is a number that indicates how far the system deviates from the consistent matrix. It is acceptable for a CR value of less than 0.10. If the CR is higher than this threshold, the judgment matrix is incoherent. The judgments should then be examined to reduce incongruence. Table 2 demonstrates the CR established on matrix size.

Table 2: The Average Random Index for Different Values of N

The matrix's size	RI
1	0.0000
2	0.0000
3	0.5799
4	0.8921
5	1.1159
6	1.2358
7	1.3322
8	1.3952
9	1.4537
10	1.4882

Source: [18]

Implementation Steps

The methodology is broken down into four steps, which are as follows:

1) Extensive literature review: Initially, a review of various published literature and technical documentation on driving factors and pollution emissions reduction in manufacturing plants was conducted.

Develop a questionnaire: The second step was to create a questionnaire established on factors and sub factors obtained from a literature review and other related documents. Each question was answered using a five-point Likert scale [5]. Level "1" demonstrated that the factor is of minimal importance in terms of reducing pollutant emissions,whereas level "5" demonstrated that the factor is of maximum in regards to lowering air pollutants.

2) Delphi study: The Delphi method was used to reach expert consensus on factors affecting the reduction of pollution emissions. In this study, two rounds of an email survey were conducted in succession. Ten experts working as production managers, safety managers, directors from plastics manufacturing companies, government officers in environmental fields, and consultants were selected to conduct the assessment. They were all key combinations of an academic or professional group with experience in the environmental and plastics industries. A mean average score equal to or greater than 4.0 (Mean > 4.00) and a standard deviation greater than 1.00 (S.D. > 1.00) was selected as an extremely important factor for this model. The first round's results were summarized and reported back to the same experts, who were asked to re-evaluate their answers, which presented the previous results anonymously. After two rounds of surveying, three main criteria and twelve sub-criteria were obtained.

3) Analytic Hierarchy Process (AHP): In the end, only five experts agreed to continue the comparison process. As a result, a pairwise comparison matrix of criteria and sub-criteria with respect to an upper level was developed. The weights and relative importance of the determining factors within each class were then evaluated by pairing two factors presented by Saaty's [6-7] relative preferences of 1-9. The research framework in this study is depicted in Fig.2.

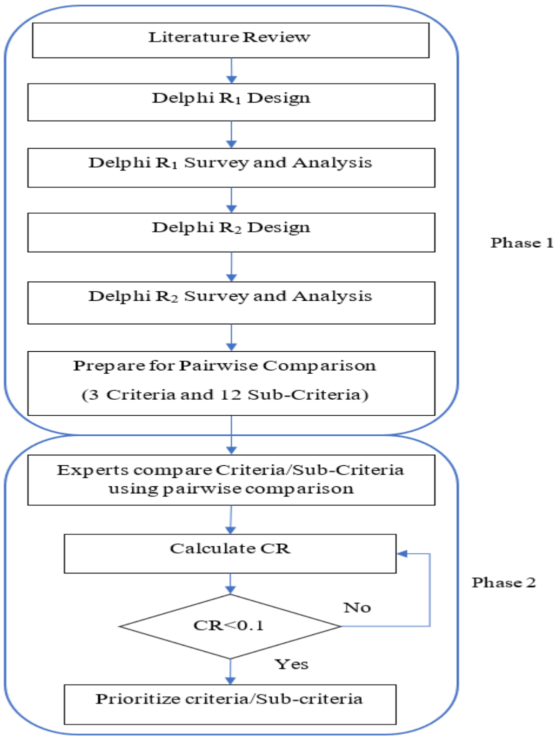

Figure 2: Research Framework

PROBLEM SOLUTION

Delphi Results

The Delphi study was conducted in the initial phase to identify factors to reduce pollutants emissions in the plastics industry. Following two rounds of Delphi results, twelve sub-criteria were obtained under three main criteria: production process (P), source reduction (S), and waste management (W). Table III displays the study's completed round of results, along with their average and standard deviation.

AHP Results

Using the AHP method, the Delphi results from Table 3 were used to rank those criteria and sub-criteria. The computational results of AHP are shown below.

Table 3: Analysis of the Factors to Reduce Pollutants Emission Given by Experts

Criteria	Sub-criteria	Mean	S.D.	Chosen factors
Production process (P)	Quality and age of machines (PQ)	4.50	0.707	✓
	Doing business by following the international standard (PB)	4.50	0.707	✓
	Production efficiency improvement (PP)	4.60	0.516	✓
	Define buffer zone/protection around the industrial estate (PZ)	4.30	0.675	✓
Source reduction (S)	Determination of standard improvement of pollution discharge at source clearly (SS)	4.70	0.483	✓
	Determination of rules and regulations for industry to control and promote the environment seriously (SR)	4.50	0.850	✓
	Considering using less toxic additives in fuel (ST)	4.20	0.789	✓
	Supporting bringing waste and wastewater from the production process to produce renewable energy (SW)	4.00	0.816	✓
	Supporting waste exchange systems from between the same industry (SI)	3.90	0.994	×
	Encouraging reusing and recycling waste and by-products (SE)	4.20	0.789	✓
	Set up continuous emission monitoring systems (SM)	4.10	1.101	×
Waste management (W)	Set up action plans for emergency pollution accidents from industry (WA)	4.50	0.707	✓
	Reduction of hazardous substances in the production process (WH)	4.30	0.949	✓
	Define rules and regulations for recall (WR)	3.90	1.197	×
	Define route and schedule in transferring waste and hazardous systematically (WT)	3.70	0.949	×
	Set up pollution emission report and priority substance list (WP)	4.00	0.943	✓
Acceptable: Mean ≥ 4.00 and S.D. > 1.00				

Table 4 shows pairwise comparisons with average scale and local weights for respective criteria, and Tables 5 to 7 show pairwise comparisons with average scale and local weights for production process, source reduction, and waste management sub-criteria, respectively.

Table 4 : Pairwise Comparison with Average Scale for Main Criteria (CR = 0.0942)

Main criteria	P	S	W	Local weights
P	0.287	0.215	0.481	0.328
S	0.540	0.405	0.266	0.404
W	0.173	0.380	0.253	0.268

Table 5 : Pairwise Comparison with Average Scale for Production Process (CR = 0.0706)

Production process	PQ	PB	PP	PZ	Local weights
PQ	0.178	0.187	0.131	0.202	0.175
PB	0.234	0.218	0.054	0.232	0.184
PP	0.488	0.507	0.376	0.486	0.467
PZ	0.090	0.088	0.439	0.080	0.174

Table 6 : Pairwise Comparison with Average Scale for Source reduction (CR = 0.0742)

Source reduction	SS	SR	ST	SW	SE	Local weights
SS	0.488	0.549	0.509	0.499	0.374	0.484
SR	0.093	0.106	0.251	0.140	0.343	0.187
ST	0.117	0.222	0.121	0.181	0.065	0.141
SW	0.098	0.075	0.068	0.099	0.062	0.080
SE	0.204	0.048	0.051	0.081	0.156	0.108

Table 7 : Pairwise Comparison with Average Scale for Waste Management (CR = 0.0385)

Sub-criteria	WA	WH	WP	Local weights
WA	0.405	0.485	0.346	0.412
WH	0.214	0.258	0.327	0.266
WP	0.381	0.257	0.327	0.322

Based on the results shown in tables 4-7, it can be concluded that the matrices were consistent across the pairwise comparison for further analysis since all of the CR values were less than 0.10 [7]. The global weights of 12 sub-criteria, as well as their rankings, were then calculated and shown in Table 8.

Table 8 : Final Results

Sub- criteria	Global weights	Priority
PQ	0.0574	8
PB	0.0604	7
PP	0.1532	2
PZ	0.0571	9
SS	0.1955	1
SR	0.0755	5
ST	0.0570	10
SW	0.0323	11
SE	0.0436	12
WA	0.1104	3
WH	0.0713	6
WP	0.0863	4

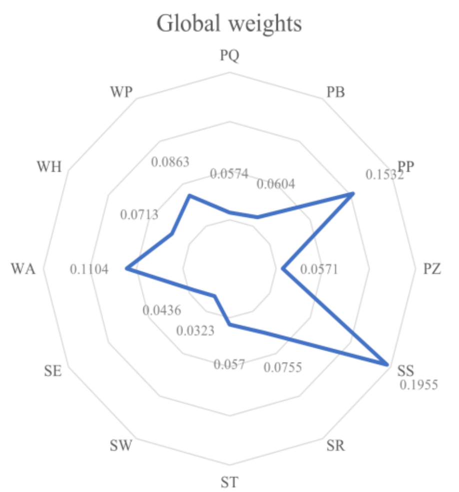

Figure 3: Weight of Sub-criteria

The global weight of sub-criteria results from Table VIII and Fig. 3 revealed that "Determination of standard improvement of pollution discharge at source clearly (SS)" was the most significant sub-factor, with an importance weight of 0.1955. This finding is consistent with the findings of the United States Environmental Protection Agency (EPA), which mentioned that pollution could be diminished by removing or preventing pollution before reprocessing, treatment, or disposal [19].

"Production efficiency improvement (PP)" was the second most important sub-criterion, with a weight of 0.1532. The findings were mostly in line with what had been discussed in the literature. According to King and Lenox's [20] research, lean manufacturing through ISO 9000 adoption and low toxicity stockpiles may help reduce garbage and environmental damage. According to Kovilage [21], lean is a performance improvement approach that distinguishes and removing waste though the ongoing improvement.

The third important sub-criterion, with a weight of 0.1104, was "*Set up action plans for emergency pollution accidents from industry (WA)*". An appropriate emergency response plan, according to Tseng et al. [22], is critical for limiting the consequences of the accident to the smallest possible area around the accident location. Descriptions of personnel roles and responsibilities, infrastructure, response actions, impact mitigation, internal and external communications, training, drills, incident reporting, and review procedures are all included.

The findings will assist manufacturers in making the best decisions when implementing strategies to reduce environmental pollution in their factories. This analysis will produce a superior primary concern set of potential factors to guide the industry in determining which factors have the most influence and must be addressed first. The research was supported by the Environmental Protection Agency (EPA) of the United States [19], which specified that source reduction is more desirable and essential than waste management and pollution control in the production process. As a result, entrepreneurs should focus on changing production processes, operations, and raw materials used, encouraging the use of environmentally benign or less toxic substances, implementing and inspiring relatively clean manufacturing technology, and increasing recycling rather than discarding them [23]. Knowledge and precautions about pollution sources should be communicated, and requirements for improving pollution discharge at the source should be established and clearly defined.

Thai governments should also review and revise laws and regulations, as well as implement effective policies, to encourage the plastic industry to build an innovation ecosystem, establish pollution standard precautions, support innovation sandboxes, and facilitate product life cycle analysis [24]. Furthermore, regional and local governments should disincentive polluting manufacturing plants across national policies such as carbon pricing and emissions tax rates, in addition to other policies such as regulatory measures and public awareness campaigns.

CONCLUSION

One of the most serious environmental problems is environmental degradation. To be successful, a variety of efforts and authority at all levels are required. Due to its manufacturing/transformation activities, the plastics industry is a major contributor to pollutants and carbon emissions in the atmosphere. There are several methods for overcoming and reducing environmental pollution in the industry. From the perspective of practitioners, this paper provides insights into identifying and prioritizing influencing factors to promote pollution emissions in the plastics industry. It can be regarded as a primary policy solution for industry management.

This paper's findings can be summed up as described in the following:

i) The experts agreed on twelve sub-criteria representing three categories: manufacturing process (P), source reduction (S), and waste management (W). The production process has four sub-criteria, the source reduction process has five sub-criteria, and waste management has three sub-criteria.

ii) According to the results of the priority analysis using the AHP method, the top three sub-criteria in reducing pollution emissions were "Determination of standard improvement of pollution discharge at source clearly (SS)," "Production efficiency improvement (PP)," and "Set up action plans for emergency pollution accidents from industry (WA)".

The current study's contribution is that it offers 12 sub-criteria under three dimensions related to reducing pollutant emissions in plastics manufacturing. Furthermore, those sub-factors were prioritized based on the concerns of their practitioners. Records on the number of operating industries are required for more reliable results. This presented model will be applied to other geographical areas in Thailand in future studies to help generalize results. It is also worthwhile to look at other industries to determine which factors are crucial in pollutant-reduction practices.

DATA AVAILABILITY STATEMENT

The authors can provide a Delphi study questionnaire upon request. The questionnaire and data that support the findings of this study are available upon reasonable request from the first author, [Walailak ATTHIRAWONG].

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