

# Assessment of port environmental protection in Taiwan

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Received 2 April 2020  
Revised 16 July 2020  
10 September 2020  
30 September 2020  
6 October 2020  
Accepted 7 October 2020

## Abstract

**Purpose** – There are many different pollution reduction strategies even within different ports in the same country. Every port can learn from these environmental protection strategies. What remains universally key, though, is to select the optimum strategy to reduce pollution. This paper aims to use a fuzzy analytic hierarchy process (FAHP) to prioritize the relative weights of key criteria assessing the port environmental protection and select the best port in Taiwan.

**Design/methodology/approach** – Four criteria and eleven sub-criteria of the FAHP model are developed through expert interviews and relevant literature review. Three alternative ports considered are Kaohsiung, Keelung and Taichung. The expert questionnaire samples (23) include four groups: shipping operators, port operators, governmental officials and academics.

**Findings** – Results indicate that finance is the most important evaluation criteria, followed by port environmental policy, technology and stakeholders. Among the three ports compared, Kaohsiung Port is selected as the best port, followed by Keelung and Taichung Port.

**Originality/value** – The result of this paper can help fill the gap in the existing literature regarding decision analysis techniques for port pollution regulation and expect to present a holistic picture of the important evaluation criteria related to port environmental protection as well as raise issues of public awareness concern and consequently improve green port sustainability.

**Keywords** Fuzzy analytic hierarchy process, Environment, Pollution, Port

**Paper type** Research paper

## 1. Introduction

Growing shipping and ports traffic activities play a key role in global economic development, however, they bring pollution and adverse public health impacts to the surrounding port area, and pose social and environmental challenges during construction and operation periods (Wang *et al.*, 2018; Wang *et al.*, 2019). These negative externalities and social costs can occur in building, repair, breaking and recycling of ships, loading/unloading operations, storing and warehousing, dredging, accidents (e.g. oil spills and ship scrapping), anti-fouling pollution, waste disposal and so on.

Past studies have analyzed the pollution issues of port-related operations (Liu *et al.*, 2014; Barnes-Dabban *et al.*, 2017; Casazza *et al.*, 2019; Luna *et al.*, 2019). For example, Zhou *et al.* (2020) investigated port-related emissions, environmental impact and their implication on green traffic policy in Shanghai and found the emission of container trucks are much higher



than that of cargo-handling equipment. [Munim et al. \(2020\)](#) explored the green port management in the Indian Ocean Rim (including Bangladesh, Sri Lanka and Tanzania) based on Analytic Network Process and Best-Worst methods. Results found increasing privatization in port governance would improve green port management. [Moeis et al. \(2020\)](#) studied sustainability assessment of the Tanjung priok port cluster. The findings indicated that free trade policy and shore power system program policies can maximize the economy and reduce environmental damage. Also, several studies have evaluated the green port policies in Taiwan ([Tseng and Pilcher, 2015](#); [Tseng and Pilcher, 2016](#); [Chang and Jhang, 2016](#); [Tsai et al., 2018](#)). Most of these studies have focused on energy saving or emission reducing strategies, such as reducing speed, fuel transfer, emission tax and shore power system adoption ([Innes and Monios, 2018](#)). In Taiwan, different port authorities have implemented various environmental protection strategies [1]. It is important to identify what kinds of environmental protection work best so that others can follow similar approaches. In addition, a total of three ports are studied, thus providing a more complete picture of how a country as a whole approaches the achievement of minimum port pollution and green port implementation ([Rossi et al., 2013](#)). To develop an effective decision evaluation model, the purpose of this paper adopts a fuzzy analytic hierarchy process (FAHP) to survey this issue in a novel way for the field. The findings of this paper can help construct the establishment of implementation port environmental protection policies and help effectively re-organize resource allocation and environmental programs among private, public and stakeholder divisions.

## 2. Literature review

### 2.1 Main Port pollution sources

Pollutions from port activities might have many complex sources. In this paper, three main sources (air pollution, water pollution and soil and sediment) are described [2].

**2.1.1 Air pollution.** For air pollution, emissions (e.g. SO<sub>2</sub>) might be emitted from trucks and ships around the port area ([Cullinane and Cullinane, 2013](#); [Miluse and Beatriz, 2015](#)). These can affect people's health (e.g. lung cancer) and air quality around the port due to their urbanized character. To reduce this pollution, some regulation policies (e.g. emission control areas (ECA), LNG or bio fuels, shore power (also called cold ironing) technologies, sulphur content regulation of marine fuel are widely implemented in various ports in the world ([Olcer and Ballini, 2015](#)).

**2.1.2 Water pollution.** Water pollution of port (e.g. oil pollution) is a complex challenge since a cocktail of pollutants exist and have a variety of pollutive characteristics ([Liu et al., 2014](#); [Cheniti et al., 2018](#); [Cabrini et al., 2019](#); [Chen et al., 2020](#)). Yet, such pollution is often highly dangerous and can affect ecological, socioeconomic, and human health problem if it is not treated appropriately. Also, water pollution results from the expulsion of fuel oil residue, ballast water, cargo residue, waste disposal and other harmful substances being emitted from ports and ships ([Lam and Notteboom, 2014](#)). These pollution sources come from docking ships, ship building activities as well as industry activities surrounding the port area. The accumulation of harmful substances may have serious impacts on the potential spread of toxic substances, resulting in severe damage to marine ecosystems. In addition, in Port Klang (Malaysia), [Sany et al. \(2013\)](#) indicated heavy metal contamination might bring negative impacts due to industrial wastewater and port activities.

**2.1.3 Soil and sediment.** It is argued that dust might bring serious air-borne particle pollution due to the handling of substances (e.g. coal, sand, grain, and land and sediments pollution) ([Erdas et al., 2015](#)). In addition, dredging operations and disposal of dredging material can create potential soil and sediment pollution, especially in navigation channel

deepening and widening works. In Iran, [Rastmanesh et al. \(2017\)](#) indicated ecological risk assessment should be conducted in the industrial port cities.

### 2.2 Overview of pollution reduction in the three main ports of Taiwan

In Taiwan, in terms of TEU (20-ft Equivalent Unit), Kaohsiung is the largest port, followed by Keelung and Taichung ([Table 1](#)) [[3](#)]. Based on official data [[4](#)], in 2019, the above three ports served 75,717 ship calls and handled 15,298,291 TEU.

To improve port environmental problems, Environmental Protection authorities and Taiwan International Ports Corporation (TIPC) have adopted various strategies (e.g. Taiwan Greening the Ports Action Plan [[5](#)]) in the operation district of the port to control and reduce negative impacts, such as shore power system, dust prevention nets, high water pressure car wash land, automatic spraying system, automatic gates, dredging management, vessel speed reduction, energy consumption management, port waste management, education training for pollution awareness, etc.

### 2.3 Key criteria for evaluating port environmental protection

**2.3.1 Port environment policy criteria.** Port environment policy is understood to mean the pollution regulation rules from international maritime conventions (e.g. MARPOL)/central competent authority/local law enforcement agency [[6](#)]. Some key international maritime conventions are International Convention for the Prevention of Pollution from Ships (MARPOL) or The Clean Air Action Plan (CAAP) or low-sulphur limits of the Emission Control Areas (ECA) ([Cullinane and Cullinane, 2013](#); [Liu et al., 2014](#); [Zhen et al., 2018](#); [Tseng and Pilcher, 2019](#)). To supplement the regulatory scope of international maritime conventions, each country's ports have themselves established strict local rules of pollution prevention and have specified environment standards based on the various characteristics of specific port areas ([Cullinane and Cullinane, 2013](#)). Further, some researchers suggested a cap-and-trade mechanism can be implemented to control air pollution around the port ([Mellin and Rydhed, 2011](#); [Cullinane and Cullinane, 2013](#)). In such schemes, a cap is set on total emissions and divided into permits which are given for free, or auctioned out to participants in the market. The participants could trade their permits. However, it is argued that pollution producers with high abatement costs could exchange permits from pollution producers with low abatement cost. [Lam and Notteboom \(2014\)](#) indicated that minimum environmental standards for port environment regulations require incentives mechanism and technical assistance. It is believed that International Maritime Organization (IMO) should provide greater guidelines from key bodies ([Lam and Notteboom, 2014](#)). Indeed, research shows that some countries have allocated human and other resources to gain environmental certification and such efforts were thought to be excessive [e.g. Poland ([Klopott, 2013](#))]. Furthermore, integrative coordination in a country can help improve implementation and ultimately improve marine water quality, and research shows this has happened in Taiwan when coordination between ports is integrated ([Ko and Chang, 2010](#)). In Taichung (Taiwan), [Tsai et al. \(2018\)](#) adopted self-management approach to estimate the

**Table 1.** Number of ship calls and TEU handled in three main ports in 2019

Port	No. of ship calls	(%)	No. of TEU	(%)
Keelung	22,606	30.0	3,075,685	20.1
Taichung	17,492	23.0	1,793,966	11.7
Kaohsiung	35,619	47.0	10,428,634	68.2
Total	75,717	100.0	15,298,291	100.0

potential reduction of air pollution emission. Linder (2018) indicated policy incentive might affect the shipping company to participate voluntary vessel emission reduction project.

*2.3.2 Technology criteria.* Technology means the various solutions or techniques to regulate and mitigate against the negative impacts on port development. Here, technology can be separated into anti-pollution equipment and facilities, environmental sensors and green energy research (Liu *et al.*, 2019). First, some anti-pollution clean energy equipment and facilities are used to reduce port's various pollutions and expect to fit the requirement of energy regulation rule (e.g. Energy Efficiency Design Index), such as seawater scrubbers and filters, cold ironing, automatic gate systems, low emission trucks, high water pressure car wash lane, dust prevention net, automatic spraying system, covered warehouse facility and sealed storage, (Innes and Monios, 2018). Further, it is believed that adopting efficient and fuel-saving cargo-handling equipment can result in reduced environmental damage used in green ports in many countries (Subasi and Dogan-Saglamtimur, 2013). Subasi and Dogan-Saglamtimur (2013) found that adequate waste reception facilities can effectively reduce and eliminate ship-generated pollution in the port area. In addition, Satir (2014) stated ballast water treatment systems (BWTs) is a useful method to reduce water pollution and proposed an effective management mechanism. Second, environmental sensors have been used to monitor ships' operation activities to reduce environmental impact (e.g. air quality and noise). For example, it is well known that reducing a ship's speed can reduce fuel consumption and emissions. Thus, it has been suggested that establishing effective environmental sensors (e.g. vessel traffic system and automatic identification system) to monitor and control air pollution, noise pollution, sludge, ecology, water quality (Wang *et al.*, 2019) would be effective. Finally, green energy research has involved technical development for fuel oil residue, waste disposal and ballast water (Lam and Notteboom, 2014). Port data collection and analysis (including ships and cargoes) is necessary since it helps identify potential solutions to environmental issues (Darbra *et al.*, 2009). For example, Liu and Tsai (2011) suggested that ballast water and traffic pattern analysis of ships can be well implemented to control and reduce the risk of introducing non-indigenous aquatic species. Thus, here a key need for technical sources assistance should be supported.

*2.3.3 Finance criteria.* Financial is defined as using a "carrot and stick" method to regulate and maintain the port environment (Lam and Notteboom, 2014). Here, financial areas can be categorized into port pricing, supporting incentives and voluntary incentives. In Taiwan, TIPC issues NT 8,000 bonus a ship every time the ship meets the vessel speed reduction criteria both entering and exiting the port. For example, port pricing can be used to encourage port users to reduce pollution based on user pay principles (Tseng and Pilcher, 2019). Bergqvist and Egels-Zandén (2012) suggested that introduction of a hinterland port dues system could reduce port pollution from shipping operations. In addition, supporting incentives mean port authorities could provide financial and technical support to help port users use energy saving equipment or facilities in the port area (Blinge, 2014). Understandably, many solutions have been suggested to help mitigate against such pollutive activities and to improve port sustainability (Tseng and Pilcher, 2015). Therefore, for port authorities, it is arguably effective to conduct voluntary incentives and encourage port users to use environment friendly methods and then obtain port concession.

In general, both "carrot"-type incentives and "stick"-type punitive pricing can be adopted simultaneously (Tseng and Pilcher, 2019). In addition, it is often the case that economic and financial implications are connected to the fact that Labor Unions will be involved in any introduction of green port policies and this in turn will, it has been argued, increase the cost burden for shipping operators. In a case study of Kaohsiung Port, Liu *et al.* (2014) suggested the port authorities should use cold ironing alongside 'carrot and stick' approaches to reduce

SO<sub>2</sub> emissions. Greiner (2014) has also suggested market-based instruments are useful tools to regulate water quality in coastal waterways.

*2.3.4 Stakeholder criteria.* The term stakeholder is understood to denote people who are closely related to port activities and includes governmental officials, port operators, shipping operators and community residents (Hall *et al.*, 2013). In Taiwan, governmental officials are port policymakers and can establish environmental criteria and concession agreements in the port and alter terminal operators/shipping operators' behaviour, such as Maritime and Port Bureau (MPB). Other stakeholders, such as community groups, shipping agents, fishers, ocean resource researchers, legislators, environmental group (Environmental Protection Administration, Environmental Protection Bureau, academia, ship construction operators, could provide suggestions to improve port pollution problems (Ghashat and Cullinane, 2013). Le *et al.* (2014) noted that all stakeholders must be involved to achieve engagement in any policy.

*2.4 Summary*

Based on the above literature reviews, four key criteria and eleven sub-criteria affecting port environmental protection are summarized in Table 2.

**3. Methodology**

*3.1 Research design of fuzzy analytic hierarchy process*

Saaty (1980) initially developed the analytic hierarchy process (AHP) to solve decision-making analysis problems. Based on the assumption that criteria and independent, it provided a systematic hierarchy structure and its ratio scales can be utilized to make reciprocal comparisons for each element and layer. However, traditional AHP exists some limitations due to it cannot fully represent the decision makers' ideas. For example, expert's judgment might entail subjectivity and ambiguity and unavoidably exist uncertainty. According to Zadeh (1965), this paper adopts fuzzy linguistic variables with corresponding fuzzy triangular numbers to conduct comparison analysis among the many elements included. Such a method can help to solve uncertain or vague problems when implementing criteria assessment and decision-making analysis (Ferdous *et al.*, 2012; Goyal *et al.*, 2018; Liu *et al.*, 2019) and is better than traditional AHP method.

A triangular fuzzy number with the member function is shown in Figure 1. [7] Based on Zadeh (1965), the membership function is described by the triplet (l, m, u) as in equation (1):

$$U\tilde{M}(x) = \begin{cases} \frac{(x-l)}{(m-l)}, & l \leq x \leq m \\ \frac{(u-x)}{(u-m)}, & m \leq x \leq u \\ 0, & \text{others} \end{cases} \quad (1)$$

where *m* is the most possible value of the fuzzy number  $U\tilde{M}(x)$ ,  $\tilde{M}(x)$  is a triangular fuzzy number., *l* and *u* represent the minimum and maximum values, respectively:

$$M1 = (l_1, m_1, u_1) \text{ and } M2 = (l_2, m_2, u_2) \text{ are}$$

$$M1 + M2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (2)$$

Criteria	Sub-criteria	Description	Sources
Port environmental policies	International maritime convention (F11)	Maritime pollution regulation convention e.g. MARPOL, Emission Control Areas (ECA)	Cullinane and Cullinane (2013), Lam and Notteboom (2014); Liu <i>et al.</i> (2014), Zhen <i>et al.</i> (2018); Zhu <i>et al.</i> (2018), Tseng and Pilcher (2019)
	Local rules of pollution prevention (F12)	Local port authorities set minimum pollution standard for port operator	Cullinane and Cullinane (2013), Lam and Notteboom (2014)
	Voluntarily-monitoring mechanism (F13)	Port authorities and operators regularly conduct pollution check and monitoring works	Linder (2018), Tsai <i>et al.</i> (2018)
Technology	Anti-pollution equipment and facilities (F21)	Adopting anti-pollution equipment and facilities to reduce environmental pollution, such as modernized equipment of cargo handling, sulphur scrubber, air lubrication, hull coating, etc.	Subasi and Dogan-Saglamtimur (2013), Olcer and Ballini (2015); Innes and Monios (2018), Chen <i>et al.</i> (2019); Peng <i>et al.</i> (2019)
	Environmental sensors (F22)	Using monitoring technologies to regulate port pollution producers, such as vessel traffic system	Bjerkkan and Seter (2019), Tseng and Pilcher (2019)
	Green energy research (F23)	Investment in green energy research and development, such as biofuels, nuclear power, hydrogen, wind and solar technologies	Cullinane and Cullinane (2013), Erdas <i>et al.</i> (2015); Liu <i>et al.</i> (2019)
Finance	Port pricing (F31)	Using port pricing strategies to shorten terminal operation time and then reduce pollution.	Cullinane and Cullinane (2013), Lam and Notteboom (2014); Tseng and Pilcher (2019)
	Supporting incentives (F32)	Investments in port infrastructure to increase operation efficiency, such as support for anti-pollution facilities.	Bergqvist and Egels-Zandén (2012); Lam and Notteboom (2014), Blinge (2014); Innes and Monios (2018), Lam and Li (2020)
	Voluntary incentives (F33)	Agreements to use environment friendly method ) to reduce pollution and then obtain port concession	Lam and Notteboom (2014), Blinge (2014); Tseng and Pilcher (2015), Tsai <i>et al.</i> (2018); Hua <i>et al.</i> (2020)
Stakeholder	Governmental officials (F41)	Governmental officials in port authorities	Ghashat and Cullinane (2013), Le <i>et al.</i> (2014)
	Port operators (F42)	Cargo-handling equipment conductor, stevedore operators, terminal manager, truck driver	Ghashat and Cullinane (2013), Le <i>et al.</i> (2014)
	Shipping operators(F43)	Liner and tramp shipping companies	Mellin and Rydhed (2011), Le <i>et al.</i> (2014); Tseng and Pilcher (2019)

**Notes:** There are many stakeholders (e.g. government, employee, clients, community groups, legislators, environmental group, academia, etc.) that involve port pollution policies. We summarize three key roles (including governmental officials, port operators, shipping operators) based on main past studies

**Table 2.**  
Key criteria for port  
environmental  
protection

$$M1 \times M2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{3}$$

$$\beta \times M_1 = (\beta_{l1}, \beta_{m1}, \beta_{u1}), \beta > 0, \beta \in R \tag{4}$$

$$M^{-1} = (l, m, u)^{-1} = \left(\frac{1}{u}, \frac{1}{m}, \frac{1}{l}\right) \tag{5}$$

Thence, based on fuzzy pairwise comparison matrices (Chang, 1996), fuzzy logic is introduced to solve the uncertainty of AHP analysis.

In this paper, 28 expert samples were chosen by convenience sampling and these experts separately contacted by email or telephone and asked if they were able to take part in the questionnaire survey. The background of these experts were reviewed (e.g. 10 related working and research experiences at least) to make sure they are qualified experts and have sufficient port pollution knowledge. Measurement scale/comparison of elements is a nine-point rating. It is designed to measure the experts' perceptions of what was relatively "important" and "unimportant". Also, a consistency index (CI) is used to test any inconsistency within experts' judgments (Saaty, 1980). In addition, a consistency ratio (CR) is further adopted to test how a given matrix compares to a random matrix in terms of the CI, as shown in equations (6) and (7):

$$CI = \frac{\theta_{\max} - n}{n - 1} \tag{6}$$

$$CR = \frac{CI}{RI} \tag{7}$$

where  $CI$  represents the consistency index;  $\theta_{\max}$  presents the maximum eigenvalue of the positive reciprocal matrix.  $RI$  represents a randomized index and  $n$  is the number of criteria in the matrix. All  $CR$  values are  $\leq 0.1$  (Saaty, 1980).

### 3.2 The proposal fuzzy analytic hierarchy process model

In this paper, four criteria include port environmental policy, technology, finance and stakeholders. To validate the measures, during 1–15 December 2017, five experts in the field were invited to pre-test and refine questionnaire to improve its wording and readability [8].

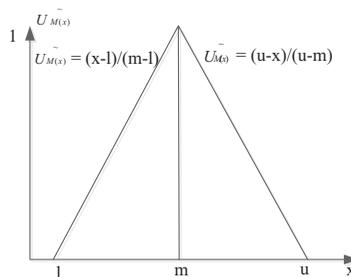


Figure 1.  
Triangular fuzzy  
number

## 4. Results

### 4.1 Data collection

Before sending the questionnaire, we interviewed three senior port experts to conduct content validity of questionnaire [9]. Then we reviewed 28 potential samples' backgrounds (including senior shipping operators (7), senior port operators (7), senior governmental officials (7) and academics (7) to confirm they are qualified candidates to participate the questionnaire survey [10]. On 1 January 2018, 28 questionnaires were sent to samples [11] and 28 questionnaires replies had been received on 21 January 2018. Then the CI was individually checked to confirm the consistency of pairwise comparison matrix. In total, five questionnaires were discarded because they exist highly inconsistent due to  $CI > 0.1$  (Saaty, 1980). Therefore, the effective questionnaire response rate was 82.1% (=23/28).

Table 3 showed 23 samples' characteristics (including six port operators, five shipping operators, six governmental officials and six academics). Regarding shipping/port experts/academics, most of these experts have 16 years' experiences. Their job titles are supervisor or assistant professor (or above).

### 4.2 Fuzzy analytic hierarchy process analysis

Analysis results of fuzzy AHP is shown in Table 4 shows that finance (0.283) is the most important criteria, followed by port environmental policy (0.274), technology (0.226), and stakeholders (0.217). With regard to the sub-criteria, voluntarily monitoring mechanism (0.346), anti-pollution equipment and facilities (0.362), supporting incentives (0.361), and shipping operators (0.379) were the most important sub-criteria in terms of each criteria for port environmental policy, technology, finance, and stakeholders, respectively.

Furthermore, the analysis results indicated that supporting incentives (0.102), port pricing (0.098) and local rules of pollution prevention (0.095) are the top three important criteria affecting port environmental protection.

Finally, Table 5 indicated that Kaohsiung Port (0.400) was selected as the best port with the best port environmental protection, followed by Keelung (0.311) and Taichung (0.289), respectively. Kaohsiung Port has the highest score in terms of port environment policy, technology and finance criteria. Overall, Kaohsiung Port is ranked as the best port due to its higher weight score. Keelung and Taichung Ports are ranked as second and third based on their weight scores. In fact, Kaohsiung is ranked as top one international commercial port in Taiwan and consequently can obtain more finance funds [12] from government related units for port pollution improvement works. Therefore, it is believed Kaohsiung Port has enjoyed a better niche market to implement pollution prevention, monitoring, and control mechanisms in and around the port areas compared to Keelung and Taichung Port.

Keelung port, the second best port in our results, has higher stakeholders score due to the reason that maybe its location is near Taipei Metropolis and many headquarters of port authorities and shipping companies can directly/indirectly bring more decision making impacts.

Actually, these three ports have different strategic positions and consequently develop various port environment protection works for their core services. For example, Keelung port has focused on Asia regional container shipping, cross-Taiwan Straits ferry services, and international cruise services. Taichung Port has dominated at free trade zone with valued-added logistics, and cross-Taiwan Strait passenger and goods transportation services. Kaohsiung Port has played a key role in international container transshipment, full-spectrum value-added logistics and international cruise services.

Regarding port regulation related works, diesel truck driver who do not possess qualified A1~A3 level certificate will be fined NT 60,000. Actually, various initiatives towards

**Table 3.**  
Profiles of the  
samples

Samples	Range	Port operators		Shipping operators		Governmental officials		Academics	
		Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
Job title	President/Director	1	16.7	1	20	0	0.0	—	—
	Senior deputy director	2	33.3	2	40	2	33.3	—	—
	Division director	2	33.3	1	20	2	33.3	—	—
	Supervisor	1	16.7	1	20	2	33.3	—	—
Age (years)	Professor	—	—	—	—	—	—	3	50
	Associate professor	—	—	—	—	—	—	3	50
	Assistant Professor	—	—	—	—	—	—	0	0
	Sub-total	6	100	5	100	—	—	6	100
	Under 40	0	0	0	0	0	0.0	0	0.0
	41~50	1	16.7	1	20	0	0.0	2	33.3
	51~60	4	66.7	3	60	5	83.3	3	50.0
	Above 60	1	16.7	1	20	1	16.7	1	16.7
	Sub-total	6	100 [19]	5	100	6	100	6	100
	Ph.D.	2	33.3	1	20	2	33.3	6	100
Educational Level	Master	4	66.7	4	80	4	66.7	0	0.0
	Bachelor	1	16.7	1	20	0	0.0	0	0.0
	Sub-total	6	100 [20]	5	100	6	100	6	100
	10~15	0	0.0	0	0	0	0.0	0	0.0
Seniority	16~20	2	33.3	1	20	0	0.0	3	50
	21~25	3	50.0	2	40	5	83.3	3	50
	Above 26	1	16.7	2	40.7	1	16.7	0	0.0
	Sub-total	6	100	5	100	6	100	6	100

**Notes:** Basically, the number of field experts are not too many in one country. Referring to other Fuzzy AHP studies [e.g. Wang *et al.* (2008) (5 samples), Sahin and Yip (2017) (22 samples) and Tseng and Cullinane (2018) (25 samples)]; the number of our samples (26) is reasonable in this study

Criteria	1 <sup>st</sup> tier Local weights	Consistency ratio (CR)	Sub-criteria	2 <sup>nd</sup> tier Local weights	Global weights	Rank
Port Environmental Policy	0.274	0.070	International maritime convention	0.321	0.088	5
			Local rules of pollution prevention	0.333	0.091	4
			Voluntarily-monitoring mechanism	0.346	0.095	3
Technology	0.226	0.070	Anti-pollution equipment and facilities	0.362	0.082	7
			Environmental sensors	0.321	0.073	10
			Green energy research	0.317	0.072	11
Finance	0.283	0.034	Port pricing	0.347	0.098	2
			Supporting incentives	0.361	0.102	1
			Voluntary incentives	0.292	0.083	6
Stakeholders	0.217	0.052	Governmental officials	0.339	0.074	9
			Port operators	0.282	0.061	12
			Shipping operators	0.379	0.082	7

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**Notes:** \*Local weight is derived from judgment with respect to a single indicator; \*\*Global weight is derived from multiplication by the weight of each group of the 1st tier and 2nd tier local weights

**Table 4.** FAHP results

Port	Port environmental policy	Technology	Finance	Stakeholders	Weight	Ranking
Keelung	0.263	0.306	0.289	0.409	0.311	2
Taichung	0.367	0.343	0.237	0.196	0.289	3
Kaohsiung	0.370	0.351	0.375	0.395	0.400	1

**Table 5.** Summary of best port comparison

pollution prevention, monitoring and control mechanisms are continuously constructed to enhance the environment quality in and around port areas (e.g. waste management, and electricity/fuel/water/paper consumption management and renewable energy). Therefore, their efforts on pollution improvement should not be ignored or dismissed even though there are some weight differences in the analysis results.

## 5. Discussion and conclusion

Results indicated finance is perceived to be the most important criterion, followed by port environmental policy, technology, and stakeholders. Among the three main ports, Kaohsiung Port is selected as being the best port due to its effective performance in environmental policy, technology and finance criteria. For example, Kaohsiung Port is equipped with sufficient container terminal resources and can offer better cargo handling efficiency (34.99 TEU per hour-crane in 2018). Thus, Taichung (30/92 TEU per hour-crane in 2018) and Keelung (24.34 TEU per hour-crane) [13] can both learn from Kaohsiung Port's development experience and improve operation efficiency. Overall, these three ports in Taiwan have successfully received Eco-Port certification (Port of Kaohsiung in October 2014, Keelung and Taichung in November 2015) [14], policy formulation and implementations (including any commercial activities [15] and cargo handling [16]) for pollution reductions. Nevertheless, as the results here show, there are arguably still many

potential barriers even though these pollution reduction effects have been achieved in recent years.

It is suggested that port authorities should adopt automatic and green facilities (e.g. using hybrid or rail mounted gantry to replace rubber tired gantry) and adopt stricter international conventions to reduce fuel consumption and emissions, noise and related port environmental pollution problems. However, the sources of port pollution are complicated and not easily be regulated by current international maritime conventions or port rules. Therefore, some pollution mitigation strategies just can solve part of port pollutions, such as emission problem (via energy-saving facilities, fuel transfer, vessel speed reducing, etc.) (Chang and Jhang, 2016), water quality (via ballast management) (Cullinane and Cullinane, 2013). Therefore, an integrated decision analysis is needed to investigate potential problems and solutions. For example, port authorities need to balance a wide range of complex decision problems and consider stakeholders' opinions [17]. Also, finance is selected as important criteria since port environment improvement and facilities upgrade (e.g. electronic gantry cranes and clean trucks) always need significant funds, and major polluters should be levied for pollution external cost (or pollution tax) based on a Pigouvian tax [18] principle (Bergqvist and Egels-Zandén, 2012). Pollution tax must be fair for port users in a sustainable manner from the perspective of environment, society and business. However, these policy formulations and legislations are always long-term negotiation processes and require much time since they must achieve the mutual recognition from various stakeholders. In addition, as shown by the findings above, supporting incentive is selected as most important sub-criteria for pollution reduction policies. Such a result can be interpreted to imply that many port environmental policies must adopt 'carrot and stick' method to encourage port users (polluters) adopt greener facilities, renewable or environmental energy (e.g. low-sulphur fuel) and automatic operation processes to reduce port pollution sources. In addition, reducing upstream pollution sources is also key. For example, port authorities (e.g. TIPC and MPB) should continuously cooperate with local governments (e.g. Environment Protection Bureau and Water Resource Management Bureau, Marine Bureau, etc.) to provide funds for constructing sustainable operation areas and waterfront spaces. It is believed the analysis model of this paper can be effectively shifted to other countries (especially in maritime-based or island-based countries, such as UK, Japan, Philippines, etc.) and develop pollution reduction approaches in similar ways. There are two research limitations and researchers can further extend other potential research topics in the future. The first is that all (sub)-criteria are independent in the AHP model. Future researchers can adopt advanced quantitative analysis (e.g. fuzzy analytic network process, decision-making trial and evaluation laboratory [DEMATEL]) to resolve independences problems in similar topics, such as port of call location for liner/tramp shipping/cruise operators, port safety, port governance, etc. Second, this paper adopted a mail-based survey to collect the questionnaires and consequently might lack qualitative analysis content. Future researchers can adopt in-depth interview methods based on grounded theory with content analysis to validate and extend potential areas (e.g. argument of experts' agreement and disagreement opinions) for future research from this paper's findings.

#### Notes

1. There are seven international commercial ports (Keelung, Taichung, Kaohsiung, Hualien, Taipei, Suao, Anping) in Taiwan. Taipei and Suao Port are auxiliary ports of Keelung. Anping Port is an auxiliary Port of Kaohsiung. Hualien Port does not have container traffic. Therefore, only Keelung, Taichung and Kaohsiung port are selected as alternatives in this paper.

2. Port pollutions (e.g. air pollution, water and soil pollution, sediment, port waste, dangerous material, light pollution, noise pollution, brownfield remediation due to heavy industry, etc.) come from various sources and complex. In order to focus on our research targets (scopes) which link with environmental protection strategies, these first three items (air, water and soil and sediment) were discussed. Other pollution sources can be further explored in future research topics.
3. Figures of Keelung include Taipei Port and Suan Port. Figures of Kaohsiung includes Anping Port.
4. Taiwan International Ports Corporation, Ltd. [www.twport.com.tw/en/](http://www.twport.com.tw/en/)
5. [www.twport.com.tw/en/cp.aspx?n=3C08FE6E60F9553F](http://www.twport.com.tw/en/cp.aspx?n=3C08FE6E60F9553F)
6. These laws include Basic Environment Act, Marine Pollution Control Act, Environment Education Act, Air Pollution Control Act, Noise Control Act, Water Pollution Control Act, Environmental Impact Assessment Act, Waste Disposal Act, .
7. Triangular fuzzy number is more popular than the trapezoid number and widely used in port selection and maritime related studies (Chen, 2016).
8. Any related port policies which were implemented or revised must be consulted by various field experts. To our best knowledge, our paper was first study to assess port pollution reduction policies in Taiwan. Even the empirical survey data were conducted in January 2018, it is believed that our research findings can offer useful information and managerial implications for decision makers of port stakeholders.
9. Regarding shipping companies, we interviewed three directors who work for Yang Mine Marine Transport, Evergreen Marine Corp., and Wan Hai Lines in Taiwan. In terms of port authorities, we interviewed two directors who work for Taiwan International Ports Corporation Ltd. and Maritime and Port Bureau in Taiwan. These three interviewees have more than 32 years' practical working experiences. We further revised questionnaire content based on interviewees' comments and suggestions. Each interview averaged 30-60 minutes in length.
10. These potential samples had to have practical port operation or research experience (above 10 years at least) and have a good reputation in the field.
11. We have confirmed the expert can understand how to fill the questionnaire via Fuzzy Analytic Process via phone call before we sent the questionnaire.
12. These funds include dedicated financial budget from the governmental units (e.g. Environmental Protection Bureau, Kaohsiung City Government), anti-air pollution subsidies from the Ministry of Transportation and Communication, Environmental Protection Administration, Executive Yuan, Taiwan. <https://www.epa.gov.tw/Page/7CF1232C5F0B0463>
13. Annual Statistics Report, Taiwan International Ports Corporation, 2018. The figure of Keelung Port has included the Taipei Port.
14. Ministry of Transportation and Communication [www.motc.gov.tw/en/](http://www.motc.gov.tw/en/) [www.motc.gov.tw/en/home.jsp?id=158&parentpath=0,151&mcustomize=news\\_view.jsp&dataserno=201512100006&aplistdn=ou=data,ou=news,ou=english,ou=ap\\_root,o=motc,c=tw&toolsflag=Y&imgfolder=#](http://www.motc.gov.tw/en/home.jsp?id=158&parentpath=0,151&mcustomize=news_view.jsp&dataserno=201512100006&aplistdn=ou=data,ou=news,ou=english,ou=ap_root,o=motc,c=tw&toolsflag=Y&imgfolder=#)
15. Including marinas/leisure, ship building and repair, petroleum product processing, general manufacturing, refrigerated cargo, storage and packaging, chemical industry.
16. Including dry bulk, petroleum/ oil products, general cargo, liquid bulk (non-oil) and ro-ro.
17. Governmental authorities include Ministry of Transportation and Communication, Ministry of the Interior, Council of Agriculture, Environmental Protection Administration, etc. Private operators include shipping operators, terminal operators, cargo handling operators, trucker, tugboat operators, shippers, freight forwarders, shipping agents, etc.

18. It is a tax on any market activity that generates negative externalities (costs not included in the market price).
19. Round up figures to an approximate.
20. Round up figures to an approximate.

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### Further reading

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