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**JTL**


Journal of Transportation and Logistics  
7 (1) 2022



DOI: 10.26650/JTL.2022.1020557

RESEARCH ARTICLE

## A Priority Analysis on Emission Reduction Strategies in Foreland and Hinterland of Ports

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### ABSTRACT

Maritime transportation is responsible for a considerable extent of the world's total air emissions. For this reason, IMO regulations have started to control emissions coming from ships. Especially in the wake of IMO 2020 rules first being applied, ship owners pay much more attention to emissions released. In contrast, the regulations do not involve the other actors within maritime transportation, so for instance, ports have not focused significantly on emissions while operating. However, emissions produced by port operations have directly threatened human health due to the ports' proximity to cities. Recently, various acts were created to mitigate these emissions. Although these acts were beneficial, strategies to alleviate emissions from shipping should be stricter to achieve the United Nations' 2030 and 2050 targets for emission reduction. In this study, strategies to reduce air emissions produced by ports were identified, categorized, and prioritized. Strategies to prevent both in-port and hinterland emissions were evaluated for the first time. The findings of the study (based on expert evaluations) were presented, and implications related to these findings were interpreted. Finally, some suggestions for further studies related to port emissions were proposed.

**Keywords:** Port emissions, Hinterland emissions, Emission Reduction Strategies, Fuzzy AHP

Submitted: 08.11.2021 • Revision Requested: 23.11.2021 • Last Revision Received: 27.12.2021 • Accepted: 18.01.2022

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**Citation:** Bucak, U. (2022). A Priority analysis on emission reduction strategies in foreland and hinterland of ports. *Journal of Transportation and Logistics*, 7(1), 83-94. <https://doi.org/10.26650/JTL.2022.1020557>



## 1. Introduction

Maritime transportation did not previously focus on the environmental impacts of its operations due to it being recognised as the most environmentally friendly mode of transport. However, environmental concerns have recently become one of the main issues in the shipping industry because of its rapid growth (Winnes et al., 2015: 73). Consequently, actions were taken to reduce the negative effects on the environment caused by maritime emissions. All the actors involved in maritime transportation agreed with the United Nations' 2030 and 2050 targets for emission reduction (Romera, 2016; Hilmola, 2019; Li et al., 2019: 1). Ports, being one of the main bodies of maritime transportation, also accommodated environmentally friendly applications. Therefore, there is a need to identify strategies to prevent ports from creating air pollution and to facilitate the implementation of these strategies. This study aims to introduce strategies to reduce air emissions originating from port operations and prioritize them in terms of their impact level through the help of expert evaluations.

Many forces are applying pressure to ports to become more environmentally sustainable. One of these forces is the application of national regulations, for instance, the Rotterdam Climate Initiative. These regulations are intrinsic to the plans of port authorities, terminal operators, and logistics service providers. Another force is the application of broader scale regulations, such as the California Air Resource Board (CARB) regulations, and EU regulations (Alamouh et al., 2020). *Norsworthy and Craft* (2013) found that the voluntary 'Clean Truck Program' in US Ports had a significant effect on reducing emissions in port areas. In the maritime industry, small-scale problems regarding regulations and management of environmental issues are generally handled comprehensively. Thanks to this treatment, global acts can be supported at the lowest level (Gritsenko and Yliskylä-Peuralahti, 2013: 4). The role of port states on ship emissions reduction policies has become more powerful in comparison to flag states (Gritsenko and Yliskylä-Peuralahti, 2013: 2). *Winnes et al.* (2015) determined the following precautions as the main strategies to reduce air emissions stemming from ships in port areas: a transition to alternative fuel, emission efficient ship design, and emission efficient operations. To reduce emissions in the port area, policymakers should first focus on terminal operations that are the main energy consumer and the main CO<sub>2</sub> emission producer in port areas (Martinez-Moya et al., 2019: 313). Drayage trucks are responsible for between 25 and 43% of NO<sub>x</sub> emissions in port areas, so projects to renew drayage fleets might contribute to emission reduction strategies (Norsworthy and Craft, 2013: 23). However, transformation to carbon-neutral equipment usage cannot be achieved without successful stakeholder management (Jonathan and Kader, 2018: 1348).

Emissions stemming from ships while navigating were reduced with the help of IMO regulations (IMO 2050 aim), ship design improvements (Energy Efficiency Design Index (EEDI), the Ship Energy Efficiency Management Plan (SEEMP)), and slow steaming strategies (Aregall, 2018: 23). *Tichavska et al.* (2019: 128) stated that ships emit much more while berthing than when they are manoeuvring close to the quay. Ships spend, on average, 20% of their time on the high seas, therefore, they spend the rest of their time in

the port areas (55% of their time at berth and 25% of their time sailing on the nearby coast) (Deniz and Kılıç, 2010: 107). *Chang et al.* (2013) revealed that ships emit 96% of their emissions in the port area while they are entering the waterway and berthing. According to *Chang et al.* (2013), international car ferries are the biggest emitters in the Port of Incheon. *Tzannatos* (2010) found that cruise ships caused 2600 tons of air emissions annually in port areas and the cost of this was 51 million euros. One of the main causes of air pollution in the port area is the use of onboard auxiliary diesel engines by ships during hoteling to provide electric energy for its lightning, load movement, air conditioning, and emergency equipment requirements (Adamo et al., 2014: 983). In European ports, all ships were forced to use fuel oil that contains less than 0.1% sulphur and use shore power if they stayed more than two hours. *Tichavska et al.* (2019) concluded that this regulation in a port area alleviated air emissions significantly. *Sciberras et al.* (2014) determined that cold ironing applications that supply shore power to ships by ports, reduced CO<sub>2</sub> emissions by 42% during ship hoteling compared to the running of diesel-fuelled generator sets. *Tzannatos* (2010) found that using 0.1% sulfur content fuel oil while ships are berthing and applying a cold ironing strategy decreases overall cost by nearly 25% in one case port. Green ports are generally attributed as having their own electric energy from renewable sources. So then, some emission mitigating strategies such as power plant efficiency, replacing fossil-fuelled electric power sources with renewable and clean electric power resources, and utilizing carbon capture sequestration and storage, should be provided (Balbaa et al., 2019: 2). Moreover, *Sifakis and Tsoutsos* (2021) emphasized the significance of measures of ports against climate change and they evaluated the port concept that produced almost all its energy on its own.

Emission reduction policies have included speed reduction for ships around the port area, shore power supply to ships (cold ironing), and LNG usage during loading-discharging operations towards the foreland of the ports, however, only a few ports developed any policy to reduce emissions in its hinterland (Acciaro et al., 2014; Winkel et al., 2016; Styhre et al., 2017; Winnes et al., 2015; Aregall et al., 2019: 194). If we cannot handle the port system as a whole, it would be difficult to bring port-centric emissions under control (Tzannatos, 2010: 428). *Aregall et al.* (2018) found that port congestion is one of the main drivers of air emissions. *Liu et al.* (2019: 599) revealed that air emissions in the hinterland are based on cargo and ship traffic flow, infrastructure, and transport time. *Bergqvist et al.* (2015) presented precautions such as internalization of externalities, pricing policy for roads, a quota for mode-share, and extra port dues to reduce emissions through the hinterland of ports. *Aregall et al.* (2019) concluded that air emission precautions have the biggest impact on the sustainability of the port hinterland as a result of the investigation of 165 incentives. Using dry ports and railway integration can be seen as the most effective emission reduction strategies in the port hinterland (Li et al., 2019: 2). *Li et al.* (2019) calculated that some strategies, such as using at least two dry ports for each Chinese port and scaling hinterland transport back, decreased emissions by above 30%. *Lättilä et al.* (2013) concluded that dry port usage could reduce CO<sub>2</sub> emissions considerably by encouraging intermodal transport. China has had the highest container throughput since 2005 and has seven of the top 10 container ports in the world. Alongside this, 85% of its

port hinterland transport has relied solely on road transport (Tao et al., 2017: 265). *Tao and Wu* (2021) revealed that using a road-rail combination in the hinterland rather than all-road transport significantly alleviated emissions and energy consumption.

Most of the studies in port emission literature focused on emission assessments. Some of them assessed the emission level of a port. *Deniz and Kılıç* (2010) showed that ship emissions in the Ambarlı Port region are equivalent to the emissions stemming from the entire railway system of Turkey. To reduce these emissions *Alamoush et al.* (2020) evaluated all of the measures applied by ports and they categorized them as follows: information measures, equipment measures, energy measures, energy efficiency measures, operational measures, hinterland measures, and foreland measures. Some of the studies assessed the effects of emission reduction measures. *Liao et al.* (2009) revealed that CO<sub>2</sub> emission reduction can be achieved by using an intermodal transport system rather than only road transport mode usage in the hinterland (Lättilä et al., 2013: 26). *Adamo et al.* (2014) assessed the effects of the cold ironing strategy on CO<sub>2</sub> and NO<sub>x</sub> reduction in different terminals. *Martinez-Moya et al.* (2019) proved that the transition of terminal tractors' fuel from diesel to LNG and retrofitting RTGs reduced CO<sub>2</sub> emissions in the port terminals by 24% and 43% respectively. *Krämer* (2019) evaluated the benefits, deficiencies, and requirements of the autonomous modal split by railway in the hinterland in terms of economic, social, and environmental matters. Some authors were concerned about the economic costs of the emissions. *Berechman and Tseng* (2012) demonstrated that tankers, container ships, bulk ships, and trucks are the main contaminator of air in port areas and their costs to the port are over \$123 million per year. *Tichavska and Tovar* (2015) calculated one case port's external costs and environmental performance in conjunction with emission assessment. They found that NO<sub>x</sub>, SO<sub>x</sub>, and PM<sub>2.5</sub> were the highest pollutants among the GHGs in that port area. They also revealed the costs of each ship type to the port in terms of environmental damages. In other respects, *Liu et al.* (2021) calculated that the volatility of the freight rates increases CO<sub>2</sub> emissions in the port hinterland, and to reduce this, they proposed utilizing railways throughout the hinterland for container cargo. Some studies proposed models to mitigate air pollution by electrification in the port area. *Jonathan and Kader* (2018) proposed an emission reduction standard for equipment electrification and found that this model decreases emissions by 4% per year. *Balbaa et al.* (2019) proposed a new optimization system for using electric power in ports. They observed the system's positive impact on reducing CO<sub>2</sub> emissions and retarding the greenhouse effect. This study evaluated air emission reduction strategies applied in the ports' foreland, terminal area, and hinterland using a holistic approach. Novel to this paper, hinterland strategies were included in a holistic model to reduce emissions stemming from ports for the first time.

In this study, the idea that ports should be evaluated with their foreland, terminal area, and hinterland was defended. From this point of view, hinterland strategies for emission reduction were considered to reduce emissions originating from ports. Emission reduction strategies for foreland, terminal area, and hinterland were collected from the literature, and these strategies were inserted into a methodology. As a result of the methodological application, it was determined which strategies might come into prominence to reduce

port-induced emissions. The second part of this study presented the priority analysis method employed and its application steps. Afterward, the problem was identified, the experts who made evaluations to solve the problem were introduced and the application of the method and its results were displayed. Finally, the results were interpreted and suggestions for further studies were proposed.

## 2. Methodology

The Analytic Hierarchy Process (AHP) method was proposed by *Thomas L. Saaty* (1980) and has attracted attention widespread in academic studies. This method is one of the most effective ways to solve complex problems and prioritize main and sub-criteria related to decision-making. However, classic AHP was criticized when used to solve uncertain situations (Mollaoglu et al., 2019). Herein, fuzzy logic was involved and was integrated into the method. By this means, sharp and subjective evaluations were avoided (Demirel et al., 2018). The first application of the Fuzzy AHP method was seen in the study of *van Laarhoven and Pedrycz* (1983). Afterward, *Buckley* (1985) integrated the geometric mean into the method. *Chang* (1996) applied synthetic extent analysis for extended values of pairwise comparisons using triangular fuzzy numbers. In this study, the Fuzzy AHP method proposed by Buckley was employed to prioritize main and sub-criteria. This method performs the defuzzification process more simply. The applications steps of the method were displayed as follows (Buckley, 1985).

It is better to transform linguistic terms into fuzzy numbers, rather than integrating the multifaceted experiences, views, ideas, and motives of the individual or group decision-maker. Accordingly, the process of solving group decision problems required the generation of fuzzy numbers. A triangular fuzzy number can be defined as a triplet  $\tilde{A} = (l, m, u)$  where  $l$ ,  $m$ , and  $u$  denote lower, medium, and upper numbers of the fuzzy which is crisp and real numbers ( $x \leq y \leq z$ ). In this regard, Table 1 shows a triangular fuzzy number. The membership function of a triangular fuzzy number can be defined as follows (Demirel et al., 2018: 62).

$$\begin{cases} 0, & x < l \\ (x - l)/(m - l), & l \leq x \leq m \\ (u - x)/(u - m), & m \leq x \leq u \\ 0 & x \geq u \end{cases} \quad (1)$$

### 2.1. Fuzzy AHP Application Steps

**Step 1:** Pairwise comparison matrices were constructed based on experts' evaluations. Each element of the pairwise comparison matrix  $(\tilde{a}_{ij})(\tilde{a}_{ij})$  is a fuzzy number that is related to the linguistic term. Thereby, pairwise comparison matrices were presented below:

$$\tilde{A}^k = \begin{vmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{a}_{m1} & \tilde{a}_{m2} & \cdots & 1 \end{vmatrix} \quad (2)$$

where  $(\tilde{a}_{ij})$  symbolizes the expert’s evaluations on comparison of an *i*th element with a *j*th element.

In this method, triangular fuzzy numbers were identified to compare criteria by utilizing various linguistic variables such as “equal importance”, “weak”, “moderate importance”, “moderate plus”, “strong importance”, “strong plus”, “very strong”, “very strong plus” and “extreme importance”. This fuzzy nine-level scale was represented in Table 1 (Jiang and Fan, 2002).

**Table 1.** Triangular Fuzzy Numbers

Real Numbers	Linguistic Variables	Triangular Fuzzy Numbers	Reverse Triangular Fuzzy Numbers
1	Equal Importance	(1, 1, 1)	(1, 1, 1)
2	Weak	(1, 2, 3)	(1/3, 1/2, 1)
3	Moderate Importance	(2, 3, 4)	(1/4, 1/3, 1/2)
4	Moderate Plus	(3, 4, 5)	(1/5, 1/4, 1/3)
5	Strong Importance	(4, 5, 6)	(1/6, 1/5, 1/4)
6	Strong Plus	(5, 6, 7)	(1/7, 1/6, 1/5)
7	Very Strong	(6, 7, 8)	(1/8, 1/7, 1/6)
8	Very Strong Plus	(7, 8, 9)	(1/9, 1/8, 1/7)
9	Extreme Importance	(8, 9, 9)	(1/9, 1/9, 1/8)

**Step 2:** The geometric mean of each row of matrices was calculated to prioritise the criteria. At first, the geometric means of the first parameters in each row’s triangular fuzzy numbers were calculated.

$$\begin{aligned}
 a_{1l} &= [1 \times a_{12l} \times \dots \times a_{1nl}]^{1/n} \\
 a_{2l} &= [a_{21l} \times 1 \times \dots \times a_{2nl}]^{1/n} \\
 &\dots \\
 a_{il} &= [a_{n1l} \times a_{n2l} \times \dots \times 1]^{1/n}
 \end{aligned}
 \tag{3}$$

And then, the geometric means of each row’s triangular fuzzy numbers’ second and third parameters were also assessed respectively.

$$\begin{aligned}
 b_{1m} &= [1 \times b_{12m} \times \dots \times b_{1nm}]^{1/n} \\
 b_{2m} &= [b_{21m} \times 1 \times \dots \times b_{2nm}]^{1/n} \\
 &\dots \\
 b_{im} &= [b_{n1m} \times b_{n2m} \times \dots \times 1]^{1/n}
 \end{aligned}
 \tag{4}$$

The geometric means of the third parameters were assessed as follows:

$$\begin{aligned}
 c_{1u} &= [1 \times c_{12u} \times \dots \times c_{1nu}]^{1/n} \\
 c_{2u} &= [c_{21u} \times 1 \times \dots \times c_{2nu}]^{1/n} \\
 &\dots \\
 c_{iu} &= [c_{n1u} \times c_{n2u} \times \dots \times 1]^{1/n}
 \end{aligned}
 \tag{5}$$

The sum of the geometric means in the row is  $a_{1s}$  for lowest parameters,  $a_{2s}$  for medium one and  $a_{3s}$  for highest parameters. Lastly,  $\tilde{r}_{ij}$  matrix was gained by using the values of  $a_{ij}$ .

$$\tilde{r}_{ij} = \begin{pmatrix} \left( \frac{a_{1l}}{a_{3s}}, \frac{b_{1m}}{a_{2s}}, \frac{c_{1u}}{a_{1s}} \right) \\ \left( \frac{a_{2l}}{a_{3s}}, \frac{b_{2m}}{a_{2s}}, \frac{c_{2u}}{a_{1s}} \right) \\ \vdots \\ \left( \frac{a_{il}}{a_{3s}}, \frac{b_{im}}{a_{2s}}, \frac{c_{iu}}{a_{1s}} \right) \end{pmatrix} \quad (6)$$

**Step 3:** Fuzzy weights were assessed based on the equation 7 as follows:

$$\tilde{U}_i = \sum_{j=1}^n (\tilde{W}_j \tilde{r}_{ij}), \quad \forall i. \quad (7)$$

In equation 7, " $\tilde{U}_i$ " referred to the utility level of  $i$ th criterion, " $\tilde{W}_j$ " referred to the weight of the  $j$ th criteria. Plus, " $\tilde{r}_{ij}$ " expressed the performance of the  $i$ th alternative for the  $j$ th criteria.

**Step 4:** Fuzzy numbers were transformed into crisp numbers.  $\tilde{A} = (l, m, u)$  can be transformed into a crisp number by employing the below equation:

$$A = \sqrt[3]{(l * m * u)} \quad (8)$$

**Step 5:** After the defuzzification step, *Consistency Index* was calculated based on equation 9 as follows:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \quad (9)$$

Consistency Index value should be below 0.10.

### 3. Application

In this section are presented the application steps used to find out the most significant strategy aimed at reducing air pollution in Turkish container ports using the Fuzzy AHP method. First, air emission reduction strategies in port areas were revealed with the help of the literature (Norsworthy and Craft, 2013; Winnes et al., 2015; Sciberras et al., 2016; Aregall et al., 2018; Aregall et al., 2019; Alamoush et al., 2020). These strategies were categorized in terms of their impact areas such as foreland, terminal area, hinterland. In this study, each strategy was handled as a sub-criterion under main criteria such as 'Strategies to prevent foreland emissions', 'Strategies to prevent terminal emissions', and 'Strategies to prevent hinterland emissions'. These main and sub-criteria are shown in Table 2 with their definitions in the literature.

**Table 2.** Emission Reducing Strategies in Port Areas and their Definitions

Main-Criterion	Sub-Criterion	Criterion Number	Definition
Strategies to prevent foreland emissions	Cold Ironing	C1	To supply shore electric power to vessels
	Concession to Green Vessel	C2	To give precedence to vessels performing environmentally friendly applications
	Minimum Anchorage Duration	C3	To make plans that limit waiting time for berthing
	Minimum Hoteling Duration	C4	To perform effective operations while hoteling
	Electric-Tug Boat Usage	C5	To utilize electric power to tug vessels
Strategies to prevent terminal emissions	Electric-SSG Usage	C6	To utilize electric powered Ship-to-Shore Gantry crane for loading-unloading operation
	Electric-RTG Usage	C7	To utilize electric powered Rubber Tyred Gantry crane for stowing operation
	Alternative Fuelled Handling Vehicle Usage	C8	To utilize alternative fuelled (LNG, Methanol, Electric) terminal vehicle for transfer containers from the apron to the stowage area
Strategies to prevent hinterland emissions	Concession to Green Trucks	C9	To give precedence to trucks performing environmentally friendly applications
	Intermodal Link	C10	To use railway, which is more emission efficient transport mode, through the hinterland
	Traffic Regulator Pricing	C11	To implement extra pricing on busier days to spread traffic to other days

Second, a questionnaire form was developed to compare main criteria and sub-criteria with homogeneous ones categorized in the same group. This questionnaire was implemented to gain expert opinions from Health, Safety, Environment (HSE) managers and specialists of the 6 container ports located in various regions of Turkey. Selected experts evaluated emission reduction strategies to put more significant ones forward. Detailed information related to the selected experts is shown in Table 3 to highlight their expertise levels.

**Table 3.** Detailed Information on Selected Experts

Expert Number	Title	Education Level	Professional Experience
Expert-1	HSE Manager	MSc.	9 years
Expert-2	HSE Manager	MSc.	12 years
Expert-3	HSE Manager	MSc.	15 years
Expert-4	HSE Specialist	MSc.	5 years
Expert-5	HSE Specialist	Bachelor	7 years
Expert-6	HSE Specialist	MSc.	8 years

Finally, emission reduction strategies in the port area were ranked as a result of analyses based on these experts' evaluations. These rankings were determined with the help of the Fuzzy AHP method. In this part, primarily, sub-criteria were compared with



each other which were categorized under the same main criteria and local weights of each sub-criterion were then determined. Then, the main criteria were compared with each other, and weights of each main criterion were distributed to its sub-criteria. Thus, general weights of each sub-criterion were determined, and the ranking table was constituted based on these general weights. The weights of the main criteria, local and general weights of sub-criteria, and ranks of each main and sub-criterion are shown In Table 4.

**Table 4.** Results of the Study

Main Criterion Name	Main Criterion Weights		Code	Sub-Criterion Name	Local Weights		General Weights	
	Score	Rank			Score	Rank	Score	Rank
Strategies to prevent foreland emissions	0.19490	2	C1	Cold Ironing	0.30363	1	0.29589	4
			C2	Concession to Green Vessel	0.12715	4	0.12391	10
			C3	Minimum Anchorage Duration	0.10918	5	0.10640	11
			C4	Minimum Hoteling Duration	0.16255	3	0.15840	7
			C5	Electric-Tug Boat Usage	0.29738	2	0.28980	5
Strategies to prevent terminal emissions	0.63441	1	C6	Electric-SSG Usage	0.32047	2	0.60992	2
			C7	Electric-RTG Usage	0.43376	1	0.82554	1
			C8	Alternative Fuelled Handling Vehicle Usage	0.24551	3	0.46725	3
Strategies to prevent hinterland emissions	0.17010	3	C9	Concession to Green Trucks	0.28156	2	0.14368	8
			C10	Intermodal Link	0.28130	3	0.14355	9
			C11	Traffic Regulator Pricing	0.43708	1	0.22304	6

#### 4. Discussion

Emission reduction policies such as speed reduction for vessels around the port area, shore power supply (cold ironing), LNG usage during loading-discharging operations, etc. target the foreland of the ports. However, only a few ports have developed policies to reduce emissions in their hinterland (Acciaro et al., 2014; Winkel et al., 2016; Styhre et al., 2017; Winnes et al., 2015; Aregall et al., 2019: 194). *Aregall et al.* (2019) evaluated port-driven measures to contribute to sustainable hinterland transport. They determined all of the measures and goals related to environmentally sustainable transport around ports. They also categorized aspects of the strategies as measures against air emissions, noise, congestion, and modal shift. In this study, measures against air emission were evaluated, not only for port hinterlands but also for the foreland and terminal areas of ports.

Various strategies were determined in the literature such as internalization of externalities, pricing policy for roads, the quota for mode-share and extra port dues (Bergqvist, 2015), using dry ports and railway integration (Lättilä et al., 2013; Li et al., 2019), and using road-rail combination in the hinterland rather than all-road transport (Tao and Wu, 2021). In this study, strategies that appeared throughout the literature were included in the model. In addition, these strategies were evaluated based on the expert opinion of port professionals. Thus, in the case of Turkish ports, it was concluded that ports should focus more on their operations in the terminal area to be more environmentally friendly

in terms of preventing air pollution. This is the first study that has evaluated strategies that prevent both in-port and hinterland emissions.

## 5. Conclusion

This is the first study that has categorized air emission reduction strategies in port areas as foreland emissions, terminal emissions, and hinterland emissions. It also gathered together strategies to prevent in-port and hinterland emissions. These strategies were evaluated by experts working as HSE managers or specialists in Turkish ports. As a result of these expert evaluations, it was revealed that implementing strategies to prevent terminal emissions in the port area is the highest priority. In this regard, powering port equipment such as SSG, RTG, terminal trucks, etc. up with electric or other alternative fuels was seen as the most significant strategy to alleviate emissions. At this point, e-RTG usage stood out and this circumstance indicated that first, precautions should be taken against emissions stemming from stowage operations in the terminal areas. Experts' perspectives drove best practices for equipment usage in the leading ports for less emissions. In this regard, incentive policies may be included in investment policies for equipment usage with lower emissions in port areas.

Although strategies to prevent foreland emissions were of secondary importance, providing electric power to ships from the shore side (cold ironing) has become prominent among the other strategies in this category. However, there is no legal foundation to oblige ships to use shore power in Turkey. For this reason, the cold ironing strategy is not seen as feasible for Turkish ports due to a lack of legal structure. Additionally, safety zone applications can protect offshore installations and accordingly may avoid marine accidents threatening the environmentalism of the ports. Thus, the safety zone application may be one of the main emissions reduction policies for ports in the foreland. In the hinterland strategies category, it was demonstrated that trucks generate heavy traffic along the hinterland on busy days and emit much more these days. The extra pricing strategy on busy days was seen as the most important hinterland strategy to solve this problem. In this way, it is aimed to reduce the traffic density by ensuring that the trucks operate on other off-peak days.

This study investigated emissions in the port area and strategies to alleviate them. In this context, all the strategies in the literature were handled as criteria and it was attempted to reveal the most significant ones. While evaluating reduction strategies, both in-port-related and hinterland-related strategies were included in the model. The practical contribution of this study includes the attempt to express that responsibility of the ports on emissions is gradually extending towards the hinterland. Therefore, hinterland strategies of the ports on emission reduction should be considered at least as much as its strategies related to foreland and terminal areas. Hinterland greenness should be included in the evaluations in the scope of the Green Port concept. Moreover, each strategy handled in this study can be an incentive for ports to reduce air emissions. As a theoretical contribution of this paper, efforts were made to include hinterland strategies of ports into the model in the context of emission reduction as well as to gather emission reduction strategies related to the foreland, terminal area, and hinterland of ports that appeared throughout the literature. Research data was collected during the COVID-19 pandemic, and experts were

selected only from Turkish container ports. These circumstances may be considered as limitations of this study. For further studies, these strategies and experts can be extended, and the prioritization method can be diversified. Moreover, ports can be ranked with other multi-criteria decision-making methods in terms of their efficiency level in the context of emission reduction strategies.

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**Peer Review:** Externally peer-reviewed.

**Conflict of Interest:** Authors declared no conflict of interest.

**Financial Disclosure:** Authors declared no financial support.

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