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How to integrate ports into the EU ETS: the CAS approach perspective

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Abstract
Purpose – The European Union's Emissions Trading System (EU ETS), which is already one of the EU's most impactful instruments for reducing greenhouse gases (GHGs), will soon include the maritime transport industry. Although ports are this industry's most environmental-friendly component, there are still some barriers to including ports in the system. Therefore, the purpose of the study is to identify these barriers and to reveal the barriers' interrelationships.
Design/methodology/approach – The study was conducted by identifying barriers from a literature review before analyzing the barriers with the Fuzzy DEMATEL method. Finally, based on the Complex Adaptive System Approach, various solutions are proposed to overcome these barriers.
Findings – The identified barriers were grouped into cause-and-effect groups. Two barriers, namely long payback period and high investment costs, were evaluated as triggers of the model while the others were more sensitive to the model.
Research limitations/implications – This study only includes the perceptions of green certificated ports in Türkiye. The results revealed an expectation that elimination of financial concerns will alleviate other barriers to including ports in the system. The study's findings can guide port managers on the integration of the managers' processes into the system.
Originality/value – This study provides novel findings regarding the relationships between barriers hindering ports from involvement in the EU ETS.

Keywords Emissions trading system, Ports, Fuzzy DEMATEL, Complex adaptive system approach, Barriers
Paper type Research paper

1. Introduction
The world's current growth model, in which economic development and innovation progress at an unprecedented rate, contributes significantly to human-induced climate change, which can cause irreversible damage to ecosystems and natural life. One of the most serious negative consequences is greenhouse gas (GHG) emissions and the resulting climate change. The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as "a change in climate as a result of human activities that directly or indirectly degrade the composition of the global atmosphere, in addition to natural climate change observed over a comparable period of time".

Unquestionably, warming has occurred in the oceans, soil and atmosphere due to human activity. A growing number of reliable research studies indicate that anthropogenic factors are responsible for the rise of well-mixed GHG concentrations since the 1750s in globally (IPCC, 2022), primarily due to the use of fossil fuels. Since the first measurements during the 1850s, the global surface temperature (GST) has risen continuously by an average of 0.99°C between the two decades of 1850–1900 and 2001–2020. Furthermore, the warming rate has

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accelerated over the past 20 years, such that the decadal GST average for 2011–2020 was 1.09°C warmer than 1850–1900.

While many restrictive actions, strategies and regulations have been implemented to reduce GHG emissions, the recent trend favors emissions trading. Two of the most prominent systems to create markets based on emissions allowances are the European Union's Emissions Trading System (EU ETS) and China's Emissions Trading Scheme. The EU ETS which had been implemented in various sectors over a number of years, has recently been preparing to include maritime transport. On 14 July 2021, the European Commission adopted a proposal to amend the EU ETS Directive to fully include the maritime sector in the scheme known as COM (2021) 551 (Piccoli *et al.*, 2021). The International Maritime Organization (IMO) predicts that global shipping CO_2 emissions will be cut in half by 2050 compared with 2008 (IMO, 2018). It is also an important system in terms of the harmonization of EU policies and IMO targets. Indeed, if mitigation measures are not swiftly introduced, emissions from transportation are projected to increase by 32% by 2030 with international maritime transportation producing over 155 million tonnes of CO_2 by 2030 (European Environmental Agency, 2021). However, while the inclusion of maritime transport in the EU ETS will help reduce emissions by 2030, China's Emissions Trading Scheme is having little effect on maritime supply chain emissions reduction (Kong *et al.*, 2022). Consequently, efforts should be made in advance to remove all barriers that may weaken the system's functionality.

As one of the main sources of atmospheric pollution within the maritime transport system, ports have carried out already implemented various strategies within several programs to control carbon emissions. In 2004, for instance, the Port of Rotterdam implemented its Regional Air Quality Action Program while San Pedro Bay Ports, run the Port of Los Angeles and Port of Long Beach introduced a Clean Air Action Plan in 2006. Meanwhile, international organizations have launched several programs related to climate change and CO_2 reduction for ports in recent years. For instance, the World Ports Climate Initiative (WPCI) released guidelines for ports to create and improve their GHG emissions inventories while PIANC (the World Association for Waterborne Transport Infrastructure) released guidelines for climate change mitigation and adaptation instructions. Finally, the World Ports Climate Action Program (WPCAP), launched in 2019 by the world's largest ports, is also encouraging port emissions reductions.

Climate neutrality involves eliminating harmful gases to alleviate the negative effects of the global climate crisis. Accordingly, the EU ETS involves cutting the GHGs produced from various activities, such as industrial production, transportation and construction, in the European Union Economic Area (EU EA). Awareness of climate neutrality is increasing in the supply chain and logistics operations. Ports are nodal points, especially for the cargo supply chain. Because cities have been developed close to ports, harmful air emissions produced by ports make all supply chain partners more responsible for climate neutrality nearby living spaces. Including ports in the EU ETS is therefore critical to achieving climate neutrality in the supply chain.

In the EU, the environmental aspects of ports have long been considered. In 1994, the European Sea Ports Organization (ESPO) produced an Environmental Conduct Code for Industrial Ports while in 1997 the Amsterdam Port Authority started the ECO INFORMATION project and Rotterdam Port launched its GREEN AWARD system. Since 1997, Valencia Port Authority (VPA) developed the ECOPORT Project while INDAPORT was initiated as an indicator system for practicing environmental port management. In 2003, the ECOPORTS FOUNDATION began its activities (Peris-Mora *et al.*, 2005) while the PEARL Project was conducted in the EU from 2006 to 2008 to provide an environmental information system for ports. The project aimed to enable data exchange between ports and enable port environmental managers and data users access and examine data (Darbra *et al.*, 2009). The ESPO Environmental Code of Practice was published by the ESPO in 1994 to alleviate environmental concerns stemming from ports before being revised in 2003 and replaced by the ESPO Green Guide in 2012. ESPO also included environmental performance indicators in the PPRISM (Port Performance Indicators Selection and Measurement) Project, which it conducted to assess the environmental performance of European ports (Puig *et al.*, 2015). In the UK specifically, several action plans to increase the sustainability of ports have been implemented. For example, the EcoPorts tool, an environmental management system (EMS) for UK ports, contains a self-diagnosis method (SDM) while the Port Environmental Review System (PERS) includes guidelines and example EMS documents and a Strategic Overview of Significant Environmental Aspects (SOSEA), which is a tool for identifying and ranking the significant environmental aspects of UK ports (Kuznetsov *et al.*, 2015; Oh *et al.*, 2018). Finally, in 2020, ESPO published a roadmap to implement the European Green Deal concerning CO_2 emissions from ships berthing in and hoteling in port areas.

Within the framework of its harmonization process with the EU, Türkiye implemented its Climate Change National Action Plan, which included reduction in CO_2 emissions as a criterion until 2023 (European Commission, 2012). As part of this, the Ministry of Transport and Infrastructure of the Republic of Türkiye has conducted a green port certificate program since 2014. To be awarded this certificate, Turkish ports must complete a number of other certification programs: TS EN ISO 9001 Quality Management System Certificate, TS EN ISO 14001 EMS Certificate and BS OHSAS 18001 Occupational Health and Safety Certificate, granted by the Turkish Standards Institution, as well as certificates related to the International Ship and Port Security (ISPS) Code (Ateş and Akın, 2014).

Regarding the scope of the EU ETS's application to maritime transport, there is no clear information that ports will be included. Nevertheless, their inclusion seems inevitable given the system's functionality and the compliance of ships with its rules. Given that ports are an integral part of the maritime trade system, the EU ETS's carbon-based emissions requirements for ships can be met through services received in ports. Here, the ports' responsibility in carbon trading will be significative in functionality of the system. Therefore, their integration into this system is inevitable in the near future.

Despite the importance of port facilities, research into the EU ETS and the maritime industry has ignored their role. Instead, studies of environmental applications in ports have generally focused on the strategies of port management and measures taken against risks. Hence, the lack of studies about integrating ports into the EU ETS represents a research gap. Accordingly, the present study identifies the barriers to including ports into the EU ETS and proposes suggestions for eliminating them.

The EU ETS is a complex system that involves many sectors and their sub-industries. These complexities emerged during the system's implementation. This study therefore applied the Complex Adaptive Systems (CAS) approach to identify and evaluate the barriers to including ports into the EU ETS. The study also analyzes the relationship between these barriers using the Fuzzy DEMATEL method to determine which barriers strongly affect others. The study investigates the inclusion of ports into the EU ETS, which is an open, complex system that involves relationships between macro and micro environmental actors. Understanding these relationships is vital for the EU ETS's sustainability. Therefore, the CAS approach was most appropriate for the research aims. In addition, the study attempts to identify the cause-effect relationships between the system components. Fuzzy DEMATEL method was selected for this analysis because it has the explanatory power to identify these relationships.

The study addresses two specific research questions:

(1) What are the barriers to including ports in the EU ETS?

(2) What are the cause-effect relationships between the identified barriers?

This study provides novel findings by identifying the barriers hindering the inclusion of ports into the EU ETS and providing suggestions for achieving this inclusion despite these barriers. This study first identifies the triggering barriers to determine which need to be dealt with first.

The second section introduces the EU ETS before reviewing the literature related to emissions trading in ports. The third section explains the theoretical background. The methodology section presents the Fuzzy DEMATEL method and its application steps. The fifth and sixth sections respectively present and discuss the findings. The paper concludes with suggestions for further studies.

2. Literature review

This literature review is organized using a standard method incorporating systematic mechanisms for identifying relevant articles. The database selected was Scopus because it includes the majority of top-ranking academic journals. A search was then initiated using the following search string: TITLE-ABS-KEY ("emission trading"*) AND TITLE-ABS-KEY (port *). This identified 29 potential studies. Scrutinization of the article abstracts indicated that seven were not directly relevant to the research, leaving 22 for inclusion in the literature review.

As the maritime industry prepares to integrate into the EU ETS, a number of studies have evaluated different kinds of strategies to enable maritime transport companies to adapt themselves to the system by reducing emissions. Dai *et al.* (2018) concluded that policies like emission limitations, emissions taxation and emissions trading schemes can effectively reduce emissions in the port hinterland. Villalba and Gemechu (2011) proposed that indicators of GHG emission prevention measures should be monitored. Lin *et al.* (2021) reviewed the literature regarding control of emissions in container terminals to assess the contribution of implementing a green truck appointment system. Many studies have focused on using alternative fuel systems for vehicles in the maritime transport system. For example, Farrell and Glick (2000) evaluated the potential for reducing emissions by using (liquid natural gas) LNG as a marine fuel for passenger ferries while Kong *et al.* (2022) developed a carbon abatement model of the maritime supply chain. Other studies have focused on controlling operational emissions in ports. Liu *et al.* (2019) investigated the role of shore power usage (cold ironing) in a voluntary GHG emission system while Piccoli *et al.* (2021) evaluated the inclusion of cold ironing in the EU ETS. Guo (2021) developed a non-road mobile machinery hybrid power transformation project and verified the model's ability to reduce port-area GHG gas emissions, especially those stemming from fossil fuel use.

A key element for overcoming the barriers to any ETS is providing appropriate incentives. According to Gianoli and Bravo (2020), for example, penalizing incentives are stricter than supportive incentives in the EU ETS industrial sector for evolving to carbon neutrality. Carballo-Penela *et al.* (2012) described a financial accounting model to calculate ports' carbon footprints. ETS strategies like carbon pricing or carbon trading provide the incentives that result from the system and are critical to how it is implemented. Davies (2006) described a pilot scheme to improve ships' environmental performance through trading in SO_X emissions. Mellin and Rydhed (2011) investigated the negative attitudes of Swedish ports regarding emission reduction regulations, finding that they are most sensitive to carbon-differentiated port dues. They also concluded that the carbon-reducing investments needed to establish the ETS should be economically encouraging for maritime stakeholders. Dai *et al.* (2019) analyzed the feasibility of cold ironing investments for ports and indicated that ports need to be profitable with the help of electricity sales against great financial losses due to investments. Finally, Peng *et al.* (2019) determined the sensitivity of the cold ironing system to electricity prices, demonstrating a trade-off between the total cost of cold ironing and ships' carbon emissions.

Although the EU ETS is expected to alleviate air pollution from maritime transportation, several barriers may hinder the healthy functioning of the system. Using a mixed allocation method, Zhou *et al.* (2021) differentiated between organizational and operational boundaries and determined that one of the main barriers is fiscally based. Mallidis *et al.* (2013) proposed a decision system model for supply chain stakeholders regarding CO_2 emissions costs. Similarly, Zhong *et al.* (2019) calculated carbon reduction costs for container terminals and developed a model to determine an optimal strategy for investing in the right equipment while minimizing expenditure. They also determined that ports' compliance with the system depends on the return on investment. Finally, they showed that terminal operators are unwilling to participate in ETSs due to the high free emissions quota percentage and low carbon trading price while convincing all stakeholders of the system's viability is also critical for collective action. Janssen *et al.* (2014) measured the practicability of the ETS scheme by examining the NO_X and SO_X values of ships entering EU waters.

It is also important that an ETS includes appropriate legal measures. Regarding the EU ETS, Ringbom (2011) concluded that its principles of imposes several enforcements on foreign ships that are allowed under international law. However, the design has some limitations. It is also critical to shape the system to avoid punishing those who follow the rules. Gianoli and Bravo (2020), for example, assessed how a carbon tax can lead to "carbon leakage", whereby port customers start preferring ports located in less rule-based regions. Jugovic *et al.* (2018) evaluated how carbon pricing affects the mode shift decision from road to rail in port hinterlands, concluding that pricing must be optimized to prevent carbon leakage in both foreland and hinterland. Finally, Lagouvardou and Psaraftis (2022) identified a reference point for the carbon price by performing a cost-benefit analysis to calculate the attractiveness level of carbon leakage.

Overall, a number of studies have focused on measures to reduce GHG emissions; they have ignored the ports' considerations regarding their implementation. For example, these studies highlight the importance in the EU ETS of implementing strategies like alternative fuel usage and shore power supply while ignoring the barriers related to including ports in the system. Studies evaluating the barriers to implementing the EU ETS have generally focused on just some of these factors. Consequently, analysis of these barriers is currently scattered across the literature, so they need to be analyzed together. The present study aims to fill these research gaps identified by the literature review, making it the first literature review study to integrate the notions of port and emissions trading. It thus takes a unique approach that concentrates on the barriers preventing ports from integrating into the EU ETS. By adopting a holistic approach, this study draws together these barriers that are currently scattered across the literature.

3. CAS approach

Systems thinking has influenced many areas of organization and management research since the early idea of considering organizations as "open systems" (Katz and Kahn, 1978) comprised of multiple interconnected or related components (Bertalanffy, 1956). As the number of components and their connections grow, the system becomes increasingly complicated, making it harder to predict cause-effect (Anderson, 1999) relationships because these components are also "in interaction" (Bertalanffy, 1956: 19).

One approach to investigating such a system is to consider it as a complex adaptive system (CAS), made up of independent agents with freedom to act in unpredictable ways and whose interrelated actions allow one agent's actions to alter the context for other agents

(Plsek and Greenhalgh, 2001: 625). The numerous parts of a CAS can adapt or learn as they interact and organize despite not being directed or managed by a single person (Holland, 1995). Relationships are crucial to understanding a CAS because behaviors within it arise from the interactions between agents within the system that are both independent and interconnected with other agents (or elements), which can be a human, cell, an institution, etc. The reactions of each agent can have far-reaching effects due to the many relationships within the system. In addition, agents may adopt different and varying roles as the CAS evolves and the environment changes. These agential interconnections are important because they allow different systems to respond adaptively and enable learning and co-evolution. Finally, a system cannot develop independently of its environment and the larger intertwined systems within it: systems change together (Plsek, 2003).

The CAS approach can therefore provide a very useful theoretical tool to understand a complex system with many elements, such as an ETS, because it enables better understanding of how an ETS, which is a living system, co-evolves with its challenging and dynamic environment and reveals the patterns that develop during this evolution. The availability of reliable information shared by all members and candidates of an ETS is crucial to the proper integration of the entire system. Therefore, an ETS should not be treated as just one system; it should be treated as a CAS because of its complex, adaptive and flexible structure.

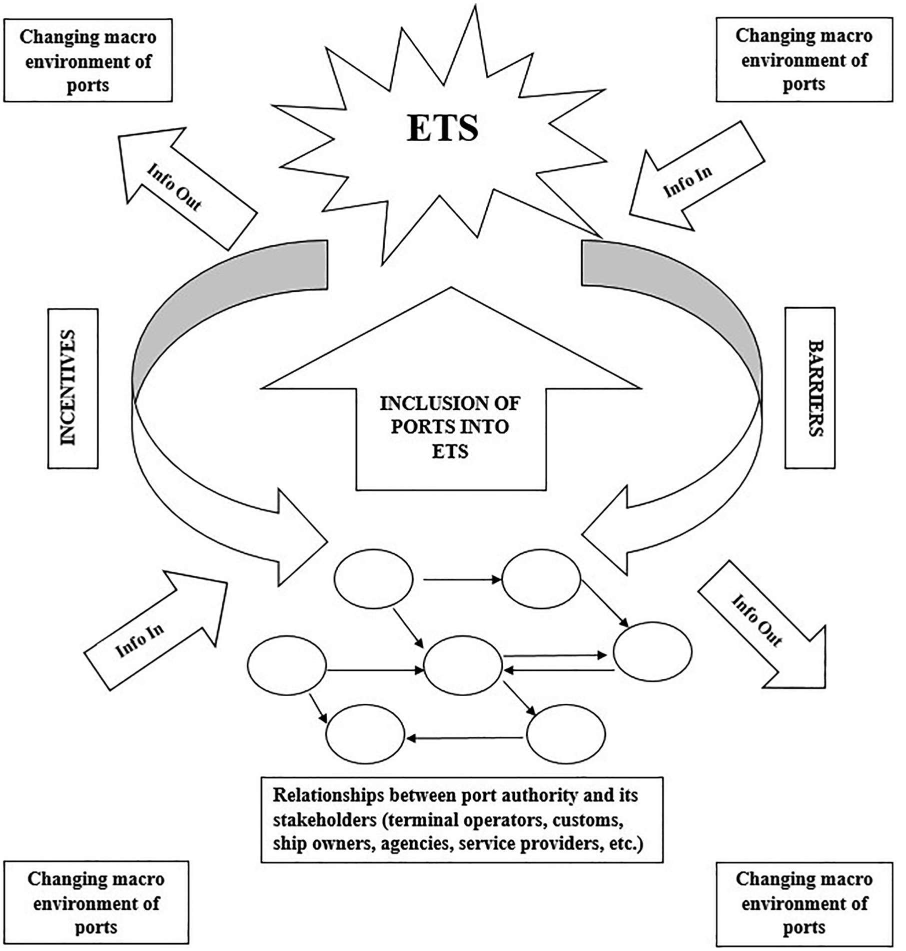
More specifically, this study assumes that the CAS approach can help identify the barriers to integrating ports into the EU ETS, as schematized in Figure 1, which was adapted from Tzafestas (2018). As the figure shows, the port authority and its stakeholders act as self-organizing agents that interact with each other to create the context for including ports into the EU ETS. This process depends on how agents are affected by the flow of information about both barriers and incentives. In addition, the process is affected by economic, social, legal, political and environmental developments within the port's macro environment.

4. Methodology

This study analyzed the relationship between the barriers to including ports into the EU ETS in order to determine the barriers' cause-effect relationships. Solving a composite decision-making problem, like the one examined here, by comparing the status of various activities within it often involves fuzziness and vagueness (Kim *et al.*, 2022). Accordingly, it is preferable to use the integrated forms of Multi-Criteria Decision-Making (MCDM) methods with fuzzy numbers to improve the analysis. For the present study, Fuzzy DEMATEL was selected as the analysis method for identifying the problem's causes and effects. This method involves conducting a relational analysis among the criteria that, by revealing the relationships between them, is especially useful for heuristic analyses. By classifying the criteria into cause groups and effect groups, Fuzzy DEMATEL enables the criteria to be interpreted in terms of the group they are categorized into.

In this study, the first step was to identify from the literature the barriers that affect the ports' adaptation into the EU ETS. Second, experts' qualitative evaluations were collected regarding the relationships between these factors. Third, these linguistic variables were transformed into fuzzy numbers, as shown in Table 1. Finally, the generated matrices were solved following the method's application steps detailed below.

The DEMATEL method was introduced to solve comprehensive and complex decision-making problems (Gabus and Fontela, 1972) and as a valuable tool to identify cause-effect relationships among the criteria (Lin and Tzeng, 2009). It reveals the reciprocal relationships between criteria and determines which criteria are influential on which criteria with what values (Başhan and Demirel, 2018). The DEMATEL method is applied using the following six steps (Chen-Yi *et al.*, 2007; Liou *et al.*, 2008; Wu and Lee, 2007).



Source(s): Adapted from Tzafestas, 2018: 448

Figure 1. A generic model for CAS for integration of ports into ETS (Tzafestas, 2018)

Linguistic terms	Triangular fuzzy numbers
No influence (No)	(0, 0, 0.25)
Very low influence (VL)	(0, 0.25, 0.5)
Low influence (L)	(0.25, 0.5, 0.75)
High influence (H)	(0.5, 0.75, 1)
Very high influence (VH)	(0.75, 1, 1)

Source(s): Başhan and Demirel (2019)

Table 1. Ersatz relationship between linguistic terms and fuzzy numbers

Step 1: Acquire an evaluation of the group decision-makers: After the pairwise comparison matrix has been constituted from the linguistics variables (see Table 1), fuzzy calculations are defuzzified and the defuzzified values are combined as a crisp value. Finally, the initial direct-relation fuzzy matrix (E ~) is obtained from the expert evaluations.

$$\begin{bmatrix} 0 & \cdots & \widetilde{E}_{1n} \\ \vdots & \ddots & \vdots \\ \widetilde{E}_{n1} & \cdots & 0 \end{bmatrix}$$

$$\widetilde{e}_{ij} = (l_{ij}, m_{ij}, u_{ij}) \tag{1}$$

Step 2: Construct the normalized direct-relation fuzzy matrix: To build the normalized direct-relation fuzzy matrix involved in the initial direct-relation matrix, $\widetilde{\beta}_i$ and γ should first be taken into consideration. The following formulas are employed to calculate each of these variables.

$$\widetilde{\beta}_i = \sum \widetilde{e}_{ij} = \left(\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij} \right) \tag{2}$$

$$\gamma = max\left(\sum_{j=1}^{n} u_{ij} \right) \tag{3}$$

A linear scale transformation is then used to convert the factors into ersatz scales. The normalized direct-relation fuzzy matrix ($\widetilde{F}$) is constituted from the expert evaluations as follows:

$$\widetilde{F} = \begin{bmatrix} \widetilde{\widetilde{F}}_{11} & \cdots & \widetilde{F}_{1n} \\ \vdots & \ddots & \vdots \\ \widetilde{F}_{n1} & \cdots & \widetilde{F}_{nn} \end{bmatrix} \tag{4}$$

Where $\widetilde{f}_{ij} = \frac{\widetilde{e}_{ij}}{\gamma} = \left(\frac{\widetilde{e}_{ij}}{\gamma}, \frac{\widetilde{e}_{ij}}{\gamma}, \frac{\widetilde{e}_{ij}}{\gamma} \right)$

Step 3: Calculate the total-relation fuzzy matrix: The normalized direct-relation fuzzy matrix is constructed from a total-relation fuzzy matrix assessment, ensuring that $\lim_{\omega \to \infty} F^{\omega} = 0$. The crisp case of the total-relation fuzzy matrix is then formed using the following formula:

$$\widetilde{T} = \lim_{\omega \to \infty} \left(\widetilde{F} + \widetilde{F}^2 + \ldots + \widetilde{F}^{\omega} \right) \tag{5}$$

$$\widetilde{T} = \begin{bmatrix} \widetilde{t}_{11} & \cdots & \widetilde{t}_{1n} \\ \vdots & \ddots & \vdots \\ \widetilde{t}_{n1} & \cdots & \widetilde{t}_{nn} \end{bmatrix} \tag{6}$$

Where $\widetilde{t}_{ij=} = (l''_{ij}, m''_{ij}, u''_{ij})$

$$Matrix\left[l''_{ij} \right] = F_l \, x \, (I - F_l)^{-1} \tag{7}$$

$$Matrix\left[m''_{ij} \right] = F_m \, x \, (I - F_m)^{-1} \tag{8}$$

$$Matrix\left[u''_{ij} \right] = F_u \, x \, (I - F_u)^{-1} \tag{9}$$

Step 4: Analyze the structural model: First, matrix $\widetilde{T}$, $\widetilde{r}_i + \widetilde{c}_j$ is solved, then $\widetilde{r}_i - \widetilde{c}_j$. Here, $\widetilde{r}_i$ and $\widetilde{c}_j$ represent the sum of the rows and columns respectively of matrix $\widetilde{T}$; $\widetilde{r}_i + \widetilde{c}_j$ represents the significance of factor i; and $\widetilde{r}_i - \widetilde{c}_j$ represents net impact of factor i.

Step 5: Defuzzify $\widetilde{r}_i + \widetilde{c}_j$ and $\widetilde{r}_i - \widetilde{c}_j$: $\widetilde{r}_i + \widetilde{c}_j$ and $\widetilde{r}_i - \widetilde{c}_j$ are defuzzified using the COA (center of area) defuzzification technique proposed by Ross (2005) to determine the best non-fuzzy performance (BNP) value. For a convex fuzzy number $\widetilde{\delta}$, a real number z^* equal to its center of area can be forecasted by the following formula (Gümüş *et al.*, 2013):

$$z^* = \frac{\int \mu_{\widetilde{\delta}}(z) z dz}{\int \mu_{\widetilde{\delta}}(z) dz} \tag{10}$$

The BNP value of fuzzy number $\widetilde{G} = (l_{ij}, m_{ij}, u_{ij})$ can be calculated by the following formula:

$$BNP_{ij} = \frac{u_{ij} - l_{ij} + m_{ij} - l_{ij}}{3} + l_{ij} \tag{11}$$

Step 6: C. the cause-effect relation diagram: Finally, the cause-and-effect relation diagram is created by combining the $r_i + c_j$ and $r_i - c_j$ dataset. This calculation can be made using the approach presented in Step 4.

5. Application

5.1 Problem description

The EU ETS, which was implemented to reduce GHG emissions in many sectors, is currently being prepared to include the maritime industry. For the present study, the barriers to including ports in the system were identified from a systematic literature review and categorized in terms of how they were conceptualized in the relevant articles. Finally, in order to be used as criteria for the analysis, the barriers were discussed with industry experts (Exp 3, Exp 8 and Exp 11 in Table 3) through semi-structured interviews. The criteria and data collection tool were then finalized based on this expert feedback. Table 2 presents the identified barriers, their definitions and the article(s) addressing each barrier.

5.2 Selecting experts

The barriers identified from the systematic literature review were then used to develop a questionnaire form to obtain evaluations from selected experts via email in port managerial positions regarding the barriers to including ports in the EU ETS. The experts were selected by purposive sampling. Specifically, the tool was sent to departmental managers working in Turkish ports that have been awarded the Green Port Certificate by the Ministry of Transport and Infrastructure of the Republic of Türkiye. To ensure representation of a variety of expert viewpoints regarding the barriers, senior managers from various port departments were approached. Out of 20 senior managers working in 20 certified ports that were invited to participate, 14 agreed.

Table 3 presents the 14 participants' professional profiles and the type of shipping served by the port they work in. Table 3 shows that the experts' average work experience is 17.71 years and the minimum is 10 years. Nine of them have bachelor's degrees while 4 of them have master's degrees and 1 has a PhD. Eleven of them work in a ports serving only

Criterion	Barriers	Definition	Reference(s)
C1	Uncertainty on legal grounds	Uncertainty regarding the jurisdiction of port states to stipulate and enforce obligations for foreign ships to surrender allowances for emissions occurring outside their own territory	Ringbom (2011)
C2	Investment leakage	Potential to divert investments from EU ports to less legally constrained locations due to restrictions imposed under EU ETS rules	Gianoli and Bravo (2020)
C3	Carbon leakage	Potential for ships to call at ports implementing a lower carbon pricing policy	Mellin and Rydhed (2011), Mallidis *et al.* (2013), Gianoli and Bravo (2020), Piccoli *et al.* (2021) and Lagouvardou and Psaraftis (2022)
C4	Lack of alternative fuel filling station	Insufficient infrastructure for alternative refueling of ships and operational vehicles in ports	Zhong *et al.* (2019)
C5	Long payback period	Long time-lag before the predicted carbon prices can meet the port's ETS investment costs	Dai *et al.* (2018), Dai *et al.* (2019), Piccoli *et al.* (2021) and Kong *et al.* (2022)
C6	High investment costs	High investment cost for appropriate carbon reduction tools for ports	Davies (2006), Dai *et al.* (2018), Peng *et al.* (2019), Dai *et al.* (2019), Gianoli and Bravo (2020) and Piccoli *et al.* (2021)
C7	Port congestion	Potential for port congestion due to extra time spent on EU ETS inspections, calculations etc.	Davies (2006)

Note(s): References in the table are provided in the extended list of references

Table 2.
Barriers to inclusion of ports in the EU ETS, definitions and article sources

Expert	Job title	Educational level	Work experience (years)	Port type
Exp 1	HSE supervisor	Bachelor	10	Bulk, container
Exp 2	Technical manager	Bachelor	22	Container
Exp 3	Operations manager	Bachelor	12	Cruise
Exp 4	Port manager	Bachelor	26	Bulk, chemical
Exp 5	Business manager	Bachelor	24	Container
Exp 6	Port manager	Bachelor	22	Bulk
Exp 7	Operations manager	Bachelor	12	Bulk, container, chemical
Exp 8	HSE supervisor	MSc	12	Ro-Ro, bulk
Exp 9	Port manager	PhD	20	Bulk, container, chemical
Exp 10	HSE supervisor	MSc	17	Container
Exp 11	Deputy port manager	Bachelor	24	Bulk, container
Exp 12	Port manager	MSc	25	Ro-Ro, cruise
Exp 13	HSE supervisor	Bachelor	10	Container, cruise
Exp 14	Marketing and sales manager	MSc	12	Container, Ro-Ro

Source(s): Produced by the authors

Table 3.
Expert professional profiles

cargo ships while one of them works in a port serving only cruise ships and two of them work in ports serving for both cargo and cruise ships. This information is very valuable regarding the experts' perspectives from different port types.

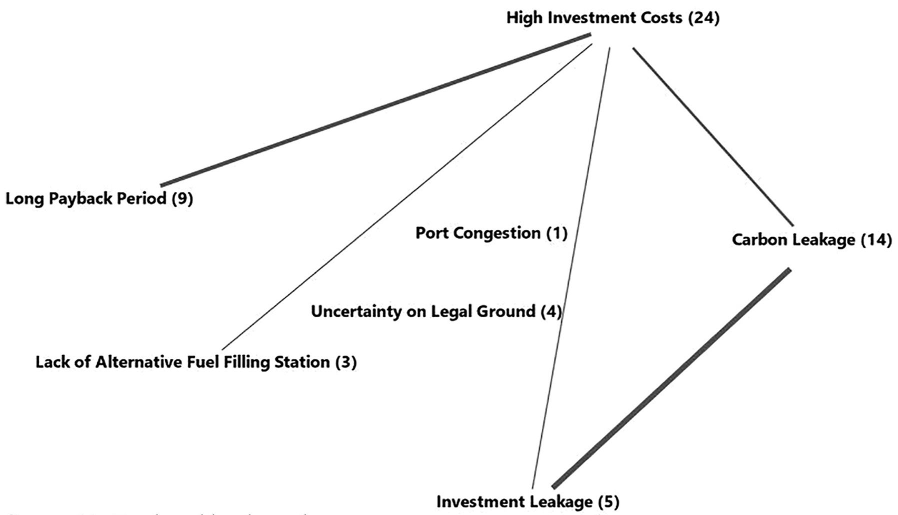
5.3 Findings

Using the MAXQDA 2020 qualitative analysis program, the criteria for the DEMATEL analysis were coded based on the barriers identified in the literature review. Each barrier was then analyzed in terms of how frequently it was coded and its relationship with other criteria. Criteria linked with each other with thicker lines were co-coded more than the others. This enabled a code co-occurrence model to be constructed for the barriers to including ports in the EU ETS, as shown in Figure 2.

The criterion most frequently mentioned in the relevant literature as a barrier to involving ports in the EU ETS was high investment costs, followed by carbon leakage and long payback period. Regarding the frequency of barriers being co-coded, high investment costs had a direct relationship with most barriers. More specifically, it was co-coded at least three times with carbon leakage, investment leakage, long payback period and lack of alternative fuel filling station while carbon leakage and investment leakage were co-coded together at least 3 times.

Each fuzzy matrix from the evaluations of one expert was aggregated using the geometric mean method to obtain the normalized initial direct-relation fuzzy matrix (Table 4). Table 5 shows the crisp values of $\widetilde{ri}, \widetilde{cj}, \widetilde{ri} + \widetilde{cj}$ and $\widetilde{ri} - \widetilde{cj}$ from the fuzzy DEMATEL analysis of the data generated from the experts' relational evaluations of the barriers identified from the literature. Figure 3 shows the cause-effect relations diagram of the criteria based on these values.

Figure 3 shows which barriers fell into the cause group or effect group. The analysis also showed that the cause group barriers all influence the effect group barriers. Table 5 and Figure 3 show that long payback period (C5) has the highest $ri - cj$ score (1.01), meaning that



Source(s): Produced by the authors

Figure 2. Criteria code co-occurrence model

it has the biggest impact on the whole model. The other cause group member, high investment costs (C6), has the second highest $ri - cj$ score (0.97).

In the effect group, uncertainty on legal grounds (C1) had the highest $ri + cj$ score (3.05), indicating that legal uncertainties regarding EU ETS sanctions is the biggest effect barrier for ports. This barrier is closely followed by carbon leakage (C3) with an $ri + cj$ score of 3.02

Table 4. Normalized initial direct-relation fuzzy matrix

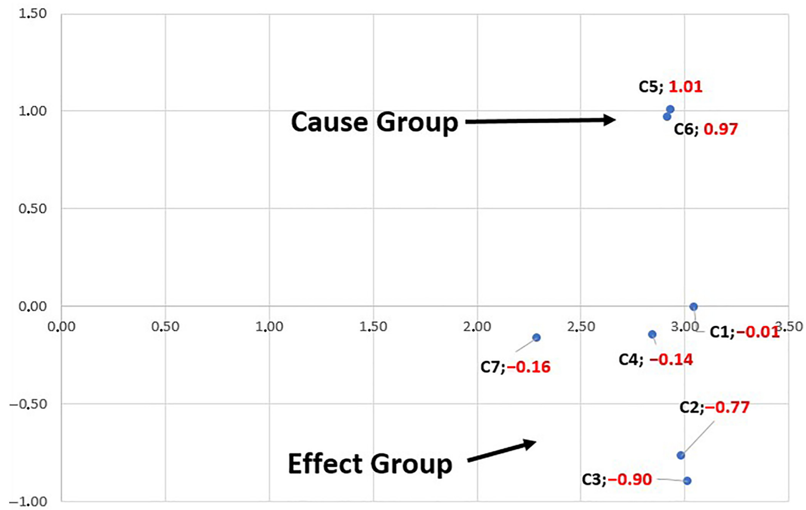
	C1			C2			...	C6			C7		
C1	0.00	0.00	0.25	0.41	0.55	0.68	...	0.07	0.13	0.38	0.13	0.20	0.41
C2	0.09	0.14	0.38	0.00	0.00	0.25	...	0.00	0.00	0.25	0.11	0.16	0.38
C3	0.07	0.13	0.38	0.09	0.16	0.39	...	0.00	0.02	0.27	0.16	0.21	0.41
C4	0.32	0.45	0.59	0.27	0.39	0.59	...	0.04	0.07	0.32	0.05	0.11	0.34
C5	0.30	0.45	0.64	0.46	0.68	0.82	...	0.32	0.45	0.61	0.18	0.27	0.46
C6	0.45	0.61	0.71	0.50	0.73	0.84	...	0.00	0.00	0.25	0.21	0.30	0.48
C7	0.11	0.16	0.39	0.13	0.18	0.39	...	0.05	0.11	0.34	0.00	0.00	0.25

Source(s): Produced by the authors

Table 5. Crisp values of $\tilde{r}_i$, $\tilde{c}_j$, $\tilde{r}_i + \tilde{c}_j$ and $\tilde{r}_i - \tilde{c}_j$

Criterion	r_i	c_j	$r_i + c_j$	$r_i - c_j$
CR1	1.52	1.53	3.05	−0.01
CR2	1.11	1.87	2.98	−0.77
CR3	1.06	1.96	3.02	−0.90
CR4	1.35	1.50	2.85	−0.14
CR5	1.97	0.96	2.93	1.01
CR6	1.94	0.97	2.92	0.97
CR7	1.06	1.22	2.29	−0.16

Source(s): Produced by the Authors



Source(s): Produced by the authors

Figure 3. Cause-effect relations diagram

while the other three effect barriers – investment leakage (C2), lack of alternative fuel filling station (C4) and port congestion (C7) – were also important, with $r_i + c_j$ scores of 2.98, 2.85 and 2.29, respectively.

6. Discussion

The literature review conducted for this study revealed that high investment cost is a prominent barrier for ports to join the EU ETS. In contrast, the fuzzy analysis indicated that long payback period is the most important barrier, although high investment cost remained one of the most important causal factors in the model. In other words, high investment cost is a critical barrier to including ports in the EU ETS according to both empirical studies (Davies, 2006; Dai *et al.*, 2018, 2019; Peng *et al.*, 2019; Gianoli and Bravo, 2020; Piccoli *et al.*, 2021) and the views of selected experts in managerial position in certified green ports in Türkiye. In short, ports have financial concerns regarding the potential benefits from participating in the EU ETS carbon trading market.

Based on the data obtained from the literature review, the MAXQDA 2020 analysis revealed that the high investment cost barrier is related to both carbon leakage and investment leakage risks. More specifically, the Fuzzy DEMATEL quantitative analysis used the views of port experts to demonstrate that the high investment cost barrier influences both the carbon leakage and investment leakage barriers. This implies that strategies to help a port to better absorb the high investment costs of joining the EU ETS will also reduce its concerns about the risks of carbon leakage and investment leakage.

The research part of the present study revealed that uncertainty on legal grounds is the barrier most affected by other factors. This implies that this barrier can be overcome by eliminating the other barriers in the model. Unfortunately, this barrier has been ignored in the literature, except for one study (Ringbom, 2011). Both authors placed in our literature review and experts in this study believe that legal concerns are not so important because the EU ETS has already been implemented in other sectors. Nevertheless, given the unique characteristics of international maritime law, the legal grounds should still be considered while including the maritime industry in the EU ETS.

Both the literature review and analysis indicate that the lack of an alternative fuel filling station has been neglected. Only one study (Zhong *et al.*, 2019) has discussed this barrier while the port experts categorized it in the effect group. This implies that eliminating ports' financial concerns regarding the EU ETS will increase their willingness to invest in alternative fuel filling stations.

Drawing on the CAS approach, the present study analyzed the barriers hindering the integration of ports into the EU ETS. Port stakeholders play an essential role in this process, especially in terms of information distribution. Therefore, they require some incentives to remove these barriers. For instance, it is critical to provide governmental subsidies, incentive programs, funding and greater credit viability in order to overcome the financial barriers to ETS participation. A number of useful incentives can be suggested to assist this integration: public-private investment partnerships to absorb the costs; reward programs to shorten the long payback periods; carbon tax standardization to decrease port concerns regarding leakage risks.

7. Conclusions

The EU ETS is one of the world's most effective schemes for reducing GHG emissions from industrial production. Recently, it has been proposed to include maritime transport, which is one of the largest atmospheric polluters. Given that ports are one of the main actors in maritime transport, the present study analyzed the barriers hindering their inclusion in the EU ETS. For this purpose, a relational analysis was conducted using the Fuzzy DEMATEL method.

Based on the analysis, financial and economic barriers were categorized within the cause group of the model. That is, these barriers trigger others. The managerial implication of this result is that incentive policies should be developed to reduce high investment costs and increase ports' share of carbon prices. This is because the elimination of economic and financial concerns can be predicted to alleviate other barriers hindering the inclusion of ports in the system.

The other critical barriers identified from the literature were categorized within the effect group of the model. Of these, the most significant barrier was concerns on legal grounds. This implies that despite the longstanding application of the EU ETS in other sectors, there is still uncertainty regarding how to harmonize the system's dynamics with international maritime law. However, the analysis also suggested that these legal uncertainties will gradually disappear once the system is implemented. The analysis also showed that financial support can be expected to alleviate concerns about carbon leakage and investment leakage. The inclusion of these two barriers related to leakage into the effect group supports the model's construction due to the structure of these barriers that is sensitive to incentives.

Piccoli *et al.* (2021) evaluated the payback period of the cold ironing system, which is thought that it will be useful with the EU ETS. Similarly, our model included the investment payback period as a barrier. The results of Piccoli *et al.* (2021) are encouraging in terms of integrating the maritime industry into the EU ETS. Zhong *et al.* (2019) demonstrated that carbon trading pricing was one of the most effective tools for implementing an emissions trading scheme in China while our analysis revealed that the long payback period and high investment costs are causal barriers to ports' inclusion in the EU ETS. This implies that it is critical to identify the most effective carbon trading price to alleviate ports' concerns regarding the investment costs and payback period. Lagouvardou and Psaraftis (2022) tried to determine a carbon trading price cap for ports in the European Economic Area (EEA) to eliminate the competitive disadvantage against non-EEA ports. In our study, this concern of EEA ports was examined in terms of carbon leakage and investment leakage. The analysis indicates that it is crucial to determine the optimum carbon price to reduce the risks to participating ports of carbon leakage and investment leakage.

This study is original revealing the relationships between the various barriers hindering the inclusion of ports in the EU ETS. The study also makes a theoretical contribution as the first to apply the CAS approach to investigating the integration of maritime transport in the EU ETS. After identifying these barriers through a literature review, the study used the Fuzzy DEMATEL method to analyze the cause-effect relationships between them. Finally, the study makes a practical contribution because the analysis results can provide a guide for port managers for integration their processes in the EU ETS. Port managers should consider the barriers identified in this study, especially the triggers, in order to make the integration proceed more smoothly. Good governance of this integration process, which will inevitably take place in the coming decades, can even bring advantages to maritime transport in its competition with other transport modes.

This study has several limitations. First, the managerial experts were selected from only accredited green ports located in Türkiye. Second, the data were collected before the EU ETS has implemented for maritime transport, so the experts have no experience of the actual system yet. To build on the present findings, future studies can investigate the incentives related to integration into the EU ETS for maritime transport and ports specifically. Moreover, it can be tested whether the results can be generalized by expanding the sample. Finally, other MCDM (Multi-Criteria Decision-Making) methods can be used to analyze the determinants of inclusion in the EU ETS for maritime transport, such as Fuzzy AHP (Analytic Hierarchy Process), Best-Worst Method, or Fuzzy ANP (Analytic Network Process) to prioritize or compare them with each other.

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