Bibliometric Analysis and Knowledge Mapping of Greenhouse Gas Emissions in Ports: A Review

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Abstract. Globally, the freight transport sector is a significant contributor to greenhouse gas emissions. Within international supply chains, seaports play a crucial role. The aim of this research is to analyse how the scientific literature addresses the issue of greenhouse gas emissions in ports. With the application of the software VOSviewer, bibliometric analysis and knowledge mapping will be used to investigate the research sectors studying polluting emissions in ports. The aim is to identify and define clusters associated with the most frequently used keywords. Literature reviews typically begin with a limited set of keywords, which can constrain the scope and allow for personal bias. Several researchers have conducted literature reviews, but they have typically focused on only one specific aspect.

Data was collected from the Scopus database, focusing on English language publications that addressed the following topic: greenhouse gas emissions at seaports. Two categories of terms were selected. The first category was related to greenhouse gas emissions. It included terms such as "emission(s)", "GHG" and "greenhouse gas". The second category was referred to the localization area, i.e. seaports, and included terms such as "port(s)" and "seaport(s)". The search was conducted for the terms in the title, abstract, and keywords, restricted to only articles published in journals, resulting in 1,556 documents, between 2009 and March 2024. The documents were subjected to a preliminary evaluation by reading the title and the abstract and based on the co-occurrence of the most frequently used keywords, five clusters were identified using the VOSviewer software.

The work will be presented as follows. Section 2 will be dedicated to the literature review, which will address the literature on port emissions. Section 3 will provide information about the data collection. The Sect. 4 will focus on the methodology used, while Sect. 5 will illustrate the main results. Finally, the last chapter will summarise the work and present some proposals for further research.

Keywords: ghg emissions · bibliometric analysis and knowledge mapping · port

1 Introduction

Globally, the freight transport sector is a significant contributor to greenhouse gas emissions [1]. Within the international maritime transport sector, seaports play a crucial role and are significant contributors to pollutant emissions [2].

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Ports are under increasing pressure to reduce their negative impact on the climate and environment [3]. Their roles and functions in transport systems and the economy make them a key factor in promoting sustainability [4].

This study examines how the scientific literature addresses the issue of port greenhouse gas emissions. With the application of the software VOSviewer, bibliometric analysis and knowledge mapping will be used to investigate the research sectors studying polluting emissions in ports. The objective is to identify and define clusters associated with the most frequently used keywords. For instance, Guo et al. [5] used bibliometric analysis to review the progress of smart city research.

Literature reviews typically begin with a limited set of keywords, which can constrain the scope and allow for personal bias. To address this issue, for example, Guo et al. [5] reviewed the progress of smart city research using a bibliometric analysis. Nevertheless, most researchers conduct literature reviews typically focused on only one specific aspect.

In the following sections, the study will be described in more detail. Section 2 will be dedicated to the literature review, which will address the literature on port emissions. Section 3 will provide information about the data collection. The Sect. 4 will focus on the methodology used, while Sect. 5 will illustrate the main results. Finally, the last chapter will summarise the work and suggest some potential avenues for future research on the topic of pollutant emissions in ports.

2 Literature Review

Through a systematic review, Alamoush et al. [6] review and categorise ports' technical and operational measures to reduce greenhouse gas emission and improve energy efficiency. The authors have proposed dividing the measures into two groups: portside and ship-port interface. Within these groups, seven categories have been defined: information, equipment, energy, energy efficiency, operation, land transport, and ship-port interface measure. Alamoush et al. [7] investigate the role of ports in decarbonizing shipping, beginning with a bibliographic search. The main findings suggest that only a small number of incentive schemes are implemented by ports due to their burdensome nature. Azarkamand et al. [8] carry out a literature review based on initiatives and methodologies to reduce carbon emissions and climate change effects in ports. The results of their work indicate that although many ports have begun calculating and reporting their carbon footprint, this still varies between authorities and operators, making it challenging to compare results. Additionally, not all sources of GHG emissions occurring within ports are considered in some cases. Therefore, the authors suggest the development of a standardised tool for calculating carbon footprints in ports. In their opinion, this could enable the establishment of benchmarks and facilitate comparisons of results between ports. Bojić et al. [9] suggest that the development of a standardised system for quantifying shipping emissions would aid in predicting and mitigating ship-sourced emissions in the future. The study also proposes a method generated through a multi-layered analysis approach.

A comprehensive review of pollutant emissions in ports was conducted by Barberi et al. [2]. The authors demonstrate a correlation between emissions and port infrastructures. They also show that proper interventions can help reduce both pollutant emissions

and financial costs. Bjerkan and Seter [4] reviewed 70 scientific articles on tools and technologies for sustainable ports. They categorized them into four main groups: port management and policies, power and fuels, sea activities, and land activities.

Ports are struggling to reduce their energy consumption and, consequently, their pollutant and greenhouse gas emissions. In this regard, Iris and Lam [10] present a literature review on operational strategies, technologies, and energy management systems for achieving energy efficiency in green ports. The authors suggest that ports should start implementing several methods, technologies and management systems only after having carried out a careful economic, technical and environmental analysis. Serra et al. [11] carried out a survey based on a literature review of port key performance indexes (KPIs) considering the environment dimension of port sustainability.

Existing measures to reduce carbon emissions often focus on the control and management of fossil fuels. Vessel optimization and port operations are currently top priorities. Such measures have limited potential to optimise emissions reductions in ports in the future. Operational measures could reduce emissions by 20% to 55%, while energy-related measures have the potential to reduce emissions by more than 80%, excluding nuclear energy [12]. Therefore, the authors conclude that energy-related measures could be the answer for future decarbonisation of ports.

Issa Zadeh et al. [13], Serra and Fancello [14], and Song [15] conduct a literature review focused on seaport decarbonization, based on the options and the efforts that could be taken in order to meet net zero emissions. Wang and Li [16] attempted to find reduction strategies of port carbon emissions in literature.

3 Data Collection

Data was collected on April 10, 2024, from the Scopus database. Scopus database contains over 70 million bibliographic citations, abstracts, and bibliometric data for peer-reviewed scientific publications. It covers various subject areas, including social sciences and humanities, physical sciences, health sciences, and life sciences.

The collection focused on English language publications that addressed the following topic: greenhouse gas emissions at (sea)ports. Two categories of terms were selected. The first category was related to greenhouse gas emissions. It included terms such as, “emission(s)”, “GHG” and “greenhouse gas(es)”. The second category was referred to the localization area, i.e. seaports, and included terms such as “port(s)”, “seaport(s)”.

A search was conducted for the terms in the title, abstract, and keywords. Only studies meeting both categories were selected, resulting in a total of 17,059 documents. Then, the document type was restricted to “Article” while the source type was limited to “Journal”, resulting now in 11,203 articles. At this stage, a further restriction was added to refine the sample. Unrelated subjects, such as medicine, biochemistry, physics, planetary science, and others, have been excluded. At this point, 3,289 documents between 1964 and 2024 were obtained.

Finally, after a first manual screening to exclude papers that focused on irrelevant topics, a dataset of 1,556 articles was obtained. Only the articles published between 2009 and March 2024 will be considered. All documents were exported in ‘full record and reference’ text file format. Figure 1 shows the change in the number of publications from 2009 to March 2024, with a significant increase observed from 2017.

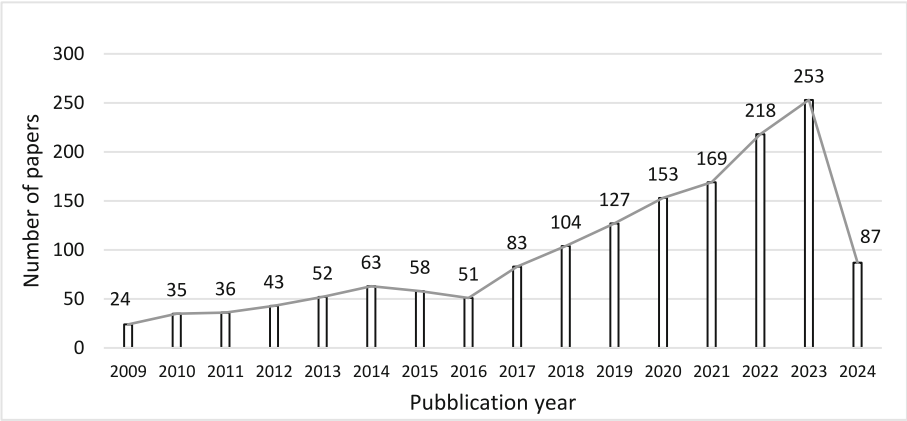

Fig. 1. Distribution of the number of published papers from 2009 to March 2024.

4 Methodology

This paper presents a detailed bibliometric analysis based on knowledge mapping. The combination of these two methods is increasingly recognized by researchers as a valid approach [17].

4.1 Bibliometric Analysis

Bibliometric analysis is a quantitative and objective method used to identify the state of the art of a research field and predict future development trends [18]. It analyses bibliographic information in academic literature, such as article titles, author names, and publication dates [19]. Bibliometric analysis visualises the distribution and relationships of literature attributes using statistical and mathematical theories [20].

For this purpose, the VOSviewer software, a computer program designed for viewing bibliometric maps, will be used. VOSviewer constructs maps using the VOS (visualization of similarities) mapping technique [20]. Maps can be created based on co-citation data for authors or journals or based on co-occurrence data for keywords. For example, Fan et al. [21] conducted a bibliometric analysis to review carbon emissions in transportation using CiteSpace and VOSviewer. A bibliometric knowledge mapping approach was also used by Moshiul et al. [22]. The authors reviewed the research progress and future trends in the use of alternative marine fuels to break down port emissions.

4.2 Knowledge Mapping

Knowledge maps are diagrams that represent ideas as node-link assemblies [23]. According to Balaid et al. [24], research on knowledge maps is still in its early stages, but progress is being made in areas such as network analysis, information visualization, and text mining. Few researchers highlight its importance for researchers to identify topics for conducting systematic reviews [17, 18, 25, 26].

Scientific literature is often analysed with two network-based methods: co-citation and keyword co-occurrence networks [27, 28]. Co-citation network analyses links between citations in the literature, while the co-occurrence network focuses on examining the links between keywords.

4.3 Co-occurrence Networks

In this study, the co-occurrence network method will be applied. Co-occurring keywords are identified to determine the most frequently appearing keywords in publications [22]. Keywords provide a brief summary of the significant content and essential points of a body of articles [29]. A weighted network is created by treating each keyword as a node and each co-occurrence of a pair of words as a link between those two words. The weight of the link connecting two keywords is determined by the number of times they co-occur [30].

5 Results

This study utilized VOSviewer software to analyse and generate a co-occurrence map of the most frequently used keywords. A fractional counting co-occurrence method was used. All keywords with a minimum of 10 occurrences were included in the analysis. The final total number of keywords was 468.

Figure 2 displays the mapped distribution of keywords, providing information on the hotspots of the topic under examination. The network comprises nodes and edges, with each node representing a keyword and its diameter being proportional to its frequency of occurrence.

Keywords within the same cluster share a high degree of similarity with the research themes and form subsets. Each cluster is assigned a tag based on its constituent keywords. Under each cluster, a table presents the top 25 keywords for each cluster, along with the number of occurrences, links, and total link weight for each keyword. Displaying co-occurrence clusters in a scientific knowledge map enables the analysis of the structure, rules, and distribution [31].

5.1 Cluster 1 (Red): Pollution

The largest cluster, colored in red, is characterised by the keywords “atmospheric pollution”, which appears 185 times, followed by “air pollution” (173) and “air quality” (158). Most of the terms are related to human activities or activities that are not strictly related to ports, given that ports are often located in urban areas with high human activity. This cluster can be defined as a cross-cutting one, as it includes mainly words linked to the concept of environmental sustainability and air quality. This cluster comprises 150 keywords. Table 1 lists the top 25 keywords.

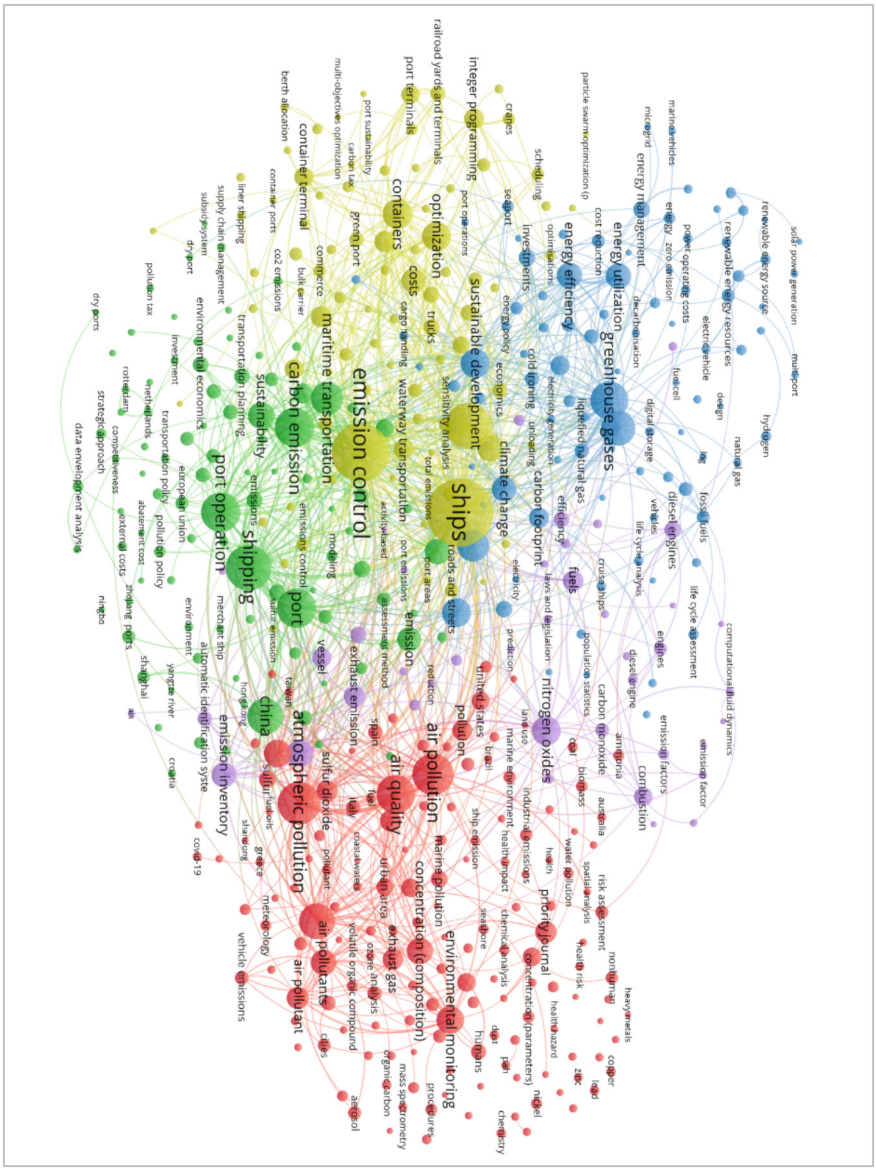

Fig. 2. Co-occurrence keyword map.

5.2 Cluster 2 (Green): Maritime Transport

The second cluster (green) pertains to the topic of shipping and sea transport. The most frequently occurring keyword is “shipping” with 205 occurrences. This cluster is associated with activities that occur near ports, specifically on the seaside. The topic of this cluster focus mainly on emissions caused by ships during port entry and exit operations,

Table 1. Cluster 1, Top 25 keywords.

Keyword	Occurrences	Links	Total link strength
atmospheric pollution	185	388	185
air pollution	173	388	166
air quality	158	366	157
particulate matter	141	344	141
environmental monitoring	92	310	91
traffic emission	92	345	92
concentration (composition)	86	285	86
air pollutants	81	312	81
air pollutant	66	289	66
priority journal	63	283	63
ship	63	309	62
sulfur dioxide	63	305	63
exhaust gas	59	278	59
pollution	56	298	55
controlled study	49	265	49
human	49	271	49
pollution monitoring	49	280	49
united states	47	261	47
urban area	45	273	45
marine pollution	41	211	41
sulfur	41	246	41
humans	36	222	36
Spain	35	258	35
city	34	231	34
analysis	33	209	32

as well as emissions resulting from maneuvering operations within the port. This category includes emissions associated with port berthing periods. According to literature, solutions such as cold ironing, battery usage, and alternative propulsion sources can be implemented to reduce these emissions. Table 2 lists the top 25 keywords.

5.3 Cluster 3 (Blue): Energy Efficiency

The third cluster, in blue, represents keywords linked to energy efficiency, which in some cases can lead to a reduction in the emission of greenhouse gases. The most frequently term within this cluster is “greenhouse gases”, which appears 153 times. Other keywords

Table 2. Cluster 2, Top 25 keywords.

Keyword	Occurrences	Links	Total link strength
shipping	205	422	204
port	163	413	162
carbon emission	160	378	158
port operation	160	389	160
China	139	385	139
maritime transportation	120	367	119
sustainability	87	259	84
greenhouse gas	80	303	80
emission	76	318	75
fuel consumption	57	217	57
maritime transport	46	194	43
numerical model	41	223	41
emissions	39	180	39
environmental economics	38	199	38
Europe	38	218	38
transportation planning	38	227	38
logistics	35	162	34
shipping emissions	35	219	35
simulation	35	194	33
freight transport	34	189	33
container ship	33	207	33
environmental protection	32	203	32
traffic congestion	32	181	32
cost analysis	31	195	31
environmental policy	31	211	31

are “energy efficiency”, “energy management”, “energy utilization”, as well as keywords related to alternative energy sources such as hydrogen, natural gas, fuel cells, and cold ironing. Table 3 lists the top 25 keywords.

5.4 Cluster 4 (Yellow): Port Terminals

The fourth cluster (yellow) shows a significant correlation with the second and third clusters. The most occurring keyword is “ship”, which appears 378 times, ranking first among all keywords. Its position suggests its centrality in relation to the sample under examination. Additionally, within the cluster we can find other terms that refer to a

Table 3. Cluster 3, Top 25 keywords.

Keyword	Occurrences	Links	Total link strength
greenhouse gases	153	356	152
gas emissions	131	364	131
ports and harbors	114	402	114
sustainable development	101	298	100
environmental impact	100	375	100
energy efficiency	81	248	80
energy utilization	80	234	79
climate change	78	294	76
carbon footprint	56	286	56
global warming	52	233	52
environmental management	42	223	41
investments	42	190	42
energy management	41	151	39
cold ironing	33	162	32
energy conservation	33	159	33
liquefied natural gas	33	185	33
renewable energy resources	32	116	32
life cycle	31	168	31
cost reduction	30	159	30
fossil fuels	30	174	29
greenhouse gas emissions	30	163	30
fleet operations	26	155	26
seaport	25	144	25
cost effectiveness	24	162	24
energy	24	98	24

specific zone of ports, namely port terminals. Port Terminals are areas of significant interest due to the various activities that take place within them. The key terms include "port terminals", "container terminals", "containers". Additionally, there are terms that refer to activities that take place in the landside port area, such as "tracks", "railroad yards". Furthermore, in relation to activities carried out within the port terminals, the keywords "optimization" and "costs" suggest topics related at improving port operations, which could result in a reduction of greenhouse gas emissions. Table 4 lists the top 25 keywords.

Table 4. Cluster 4, Top 25 keywords.

Keyword	Occurrences	Links	Total link strength
ships	378	456	377
emission control	297	435	296
carbon dioxide	207	397	206
containers	103	301	103
optimization	100	248	100
carbon	87	325	87
costs	75	291	75
carbon emissions	62	204	59
decision making	62	240	62
integer programming	56	171	56
waterway transportation	55	289	55
freight transportation	53	247	53
container terminal	52	185	52
port terminals	49	170	48
emission reduction	43	192	43
trucks	41	189	41
green ports	40	190	39
supply chains	38	192	38
economics	37	229	37
railroad yards and terminals	37	152	37
green port	35	149	33
economic and social effects	34	192	34
transportation	33	199	32
international trade	32	182	32
roads and streets	32	236	32

5.5 Cluster 5 (Purple): Engines

Cluster 5 (purple), the smallest cluster, is characterised by a high concentration of the term "engine" in various forms. The most frequently occurring term is "nitrogen oxides" with 99 occurrences. This cluster is related to the theme of engine efficiency, and it emphasizes the growing recognition of one of the principal sources of port-related pollution, namely ships at berth that require their engines to remain operational in order to power services on board. Table 5 lists the top 25 keywords.

Table 5. Cluster 5, Top 25 keywords.

Keyword	Occurrences	Links	Total link strength
nitrogen oxides	99	320	98
ship emissions	88	296	83
emission inventory	77	298	77
exhaust emission	61	262	61
fuels	58	272	58
vessel	53	272	53
combustion	50	218	48
automation	42	238	42
diesel engines	42	216	41
efficiency	36	167	36
automatic identification system	33	193	33
carbon monoxide	32	198	32
engines	30	125	27
environmental regulations	23	133	22
emission factors	22	137	22
emission inventories	22	151	22
pollution control	22	186	22
diesel engine	21	138	21
forecasting	18	117	17
nitric oxide	18	172	18
computational fluid dynamics	17	69	17
fuel economy	17	72	16
laws and legislation	16	140	16
machine learning	16	97	16
emission factor	15	55	14

6 Conclusions

The issue of emissions in ports is constantly evolving due to the global trend to reduce emissions. It is therefore important that scientific research develops all current issues.

The combined bibliometric analysis and knowledge mapping of greenhouse gas emissions in ports, presented in this paper, allows us to define some preliminary assessments. The construction and definition of co-occurrence keyword clusters could be the first step towards a more detailed literature review, that can include a subsequent subdivision of papers by thematic areas and sub-cluster categories. The five clusters provide some initial indications of potential future research areas, such as pollution, maritime

transport, energy efficiency, port terminals and engines. In particular, the emergence of energy-efficient technologies and alternative fuels could influence the policies of reduction of emissions in ports.

However, further investigations are necessary to investigate the individual clusters in a more specific way. Furthermore, as was discussed in the data collection section, the sample was extrapolated only from the Scopus database. Therefore, it is necessary to include other databases, such as Web of Science and others.

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