Transportation Research Part D 48 (2016) 473–487

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Greening ports and maritime logistics: A review

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ARTICLE INFO

Article history:
Received 11 March 2015
Revised 17 June 2015
Accepted 11 July 2015
Available online 29 August 2015

Keywords:
Green
Port
Maritime logistics
Environmental sustainability
Literature review
Bibliometric analysis

ABSTRACT

This paper aims to examine the past and present research on 'green ports and maritime logistics' in order to identify established research streams and fertile research areas with potential for future investigations. Using rigorous bibliometric and network analysis tools, the paper completes a systemic mapping of the existing literature and identifies the key investigators, collaboration patterns, research clusters and interrelationships, and the "seminal research areas" that have provided the field with the foundational knowledge, concepts, theories, tools, and techniques. Major articles within each seminal research area are also identified. This will allow new researchers to quickly build understanding in a particular sub-field by reading these major articles. The findings obtained from the evolution of seminal research areas over time are important from both research and practice perspectives and can help the field grow in many dimensions.

Introduction

The emissions of port operations and shipping have long remained out of sight and out of mind, until recently. Disasters leading to oil spillages, culminating in the Exxon Valdez accident in Alaskan waters, prompted the MARPOL (Marine Pollution) convention and the phasing out of single-hulled oil tankers. This maritime based environmental disaster led to the Valdez Principles which then evolved to the CERES principles (Coalition for Environmentally Responsible Economies) and eventually the standard in corporate sustainability reporting from the global reporting initiative (Waddock and White, 2007). Thus, from a historical perspective maritime and port shipping emissions has had significant influence on corporate greening and environmental sustainability. Yet, it is only recently that emissions from ships and port equipment have been perceived as a problem and corresponding research has occurred.

Not only is there significance and focus on reducing emissions and reactive greening approaches for maritime and port logistics, but growth in a more proactive focus. This proactive focus includes topics and issues related to the greening of transportation and logistics across supply chains (Fahimnia et al., 2015a,b). For example, it has become evident that organizations need to strategically address various actors pressures to green their processes and products, especially the greening of their global logistics and transportation networks (Fahimnia et al., 2015c; Song and Parola, 2015). This extended focus requires the explicit consideration and management of port and maritime logistics within supply chains.

The concerns include technical, operational, and economic dimensions. For example, regulatory actors have caused concern about the impact of burning high sulfur fuel at sea on adjacent populated areas is leading to the introduction of

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http://dx.doi.org/10.1016/j.trd.2015.07.007
1361-9209/

Emission Control Areas (ECAs), starting with the coasts of North America, the Baltic Sea and the English Channel. In these areas, ships are required to switch to low sulfur fuel (currently no more than 0.1% sulfur by weight rather than 3.5% outside ECAs, according to Regulation 14 of the IMO[1]). Other measures include slow steaming in the vicinity of coasts and ports, the use of scrubbers and switching to cleaner fuels like diesel or liquefied natural gas (Zis et al., 2014).

More proactively, and competitively, in the context of ship construction and technology, some ships are more environmentally friendly than others by design, as measured by the Energy Efficiency Design Index (EEDI). Newer ships tend to be more energy efficient than older ones as hull and engine designs improve with time, and engines lose efficiency with age and use. Some ports have considered including the EEDI in the determination of port fees, to encourage more energy efficient shipping. Shipping lines now commonly optimize routes with respect to weather and currents to save fuel. Likewise ballast and trim can be optimized to save fuel.[2]

Operationally, in ports, there has been a move to encourage ships to turn off their engines and generators while at berth and connect to a landside electricity supply, a process referred to as 'cold ironing' (Zis et al., 2014). Landside electricity may also be used to power cranes and equipment for moving containers, perhaps accompanied by automation. The electrification of cranes opens up the possibility of introducing regenerative technology, enabling electricity to be generated when containers are lowered and reducing crane energy consumption by around 30%[3]. Research is ongoing on the use of batteries to power vehicles for moving containers horizontally in ports. In general, the impact of electrification on emissions and the environment will depend on how and where the electricity is generated. Ports are frequently in windy locations with space available, opening up the possibility of generating electricity in environmentally friendly ways on site by installing wind turbines or importing and burning biomass. Thus, a spectrum of practical organizational and supply chain issues arise for the port and maritime transportation greening.

A number of reviews have been completed on specific aspects of ports and maritime logistics such as risk assessment and analysis (Goerlandt and Montewka, 2015; Soares and Teixeira, 2001), fleet composition and routing (Hoff et al., 2010), and ship routing and scheduling (Christiansen et al., 2013). The more recent reviews with some sustainability focus have been more problem-specific, such as the use of multi-objective decision methods in sustainable maritime transport (Mansouri et al., 2015) or bunker consumption optimization methods (Christiansen et al., 2013). To the best of our knowledge, a comprehensive review on the literature of green ports and maritime logistics is none-existent. Given the recent developments in ports and shipping aimed at reducing emissions and improving energy efficiency, it is timely to look at how the corresponding academic research field is evolving. Using rigorous bibliometric and network analysis tools, this paper reviews the literature of green ports and maritime logistics to (1) provide some initial statistics of the key journals, authors and institutions that have contributed to the field, (2) identify research areas that are well-researched and the streams that have better potentials for making new contributions (literature classification and data clustering), and (3) identify the studies and research areas that have provided the field with foundational knowledge and base tools/techniques (we named this 'seminal research clusters').

The remainder of this paper is organized as follows. The 'research methodology' section discusses the data collection and analysis methods along with some initial statistics regarding recent publication trends in the area of green ports and maritime logistics. Next section presents the initial bibliometric analysis resulting in additional author and affiliation statistics. Next, a through network analysis is presented that identifies and evaluates the key clusters of primary research streams and seminal research areas. We conclude this paper with a discussion on research limitations and potential research directions.

Research methodology

Literature reviews aim to map and evaluate the body of literature and identify potential research gaps highlighting the boundaries of knowledge (Tranfield et al., 2003). Structured literature reviews are completed through an iterative cycle of defining appropriate search keywords, searching the literature and completing the analysis (Saunders et al., 2009). Rowley and Slack (2004) recommend a structured methodology for scanning resources, designing the mind map to structure the literature review, writing the study and building the bibliography. Seuring and Gold (2012) present content analysis as an effective tool for conducting a systematic and transparent literature review through four steps of material collection, descriptive analysis, category selection and material evaluation. Inspired by the work of Rowley and Slack (2004) and Seuring and Gold (2012), we use a four-step methodology for data collection and comprehensive evaluation of the field aiming to identify the most influential studies, determine the topical areas of current research interest and provide insights for current research interests and directions for future research in the field.

Defining the appropriate search terms

Identifying the appropriate search terms and keyword structure was completed through several trial and error attempts. We used the following iterative multi-step process to design an effective keyword structure:

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[1] http://www.imo.org/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Sulphur-oxides-%28SOx%29-%E2%80%93-Regulation-14.aspx, accessed 20 January 2015.

[2] Second IMO study on GHG emissions, www.imo.org/blast/blastDataHelper.asp?data_id=27795, accessed 20 January 2015.

[3] "FUEL FOR THOUGHT: Identifying potential energy savings in the Australian road and rail sectors", Australian Government, 2012.

- Defining initial set of keywords and search structure.
- Checking the resulting articles and journals to ensure the appropriate coverage (whether key articles and major journals are appearing in search results), and updating the keywords accordingly.
- Looking for irrelevant articles and research areas, identifying the 'exclusion keywords', and updating the keyword structure accordingly.
- Looking for irrelevant subject areas to narrow down the search space, updating the keyword structure accordingly.

The search terms were identified through several trial and error attempts, replying on the prior experience of the authors and the keywords utilized in other sustainability and maritime logistics review papers. Through this process, a sophisticated keyword structure was designed combining a three-level search structure and a four-level search structure (see Table 1). Both three- and four-level structures use a similar set of exclusion keywords; however, the three-level structure aims to cover those articles that could not be captured by the primary four-level search. In the four-level structure, any combination of the first two levels can potentially return relevant articles; however, for some keywords, only certain combinations can result in meaningful results which are captured in the three-level keyword structure.

Using the "title, abstract, keywords" search in Scopus database, we collected and stored articles for the keywords identified in Table 1. Managed by Elsevier publishing, Scopus is the largest abstract and citation database of peer-reviewed research literature in the fields of science, technology, medicine, social sciences, and arts and humanities. It covers over 20,000 peer-reviewed journals including those published by Elsevier, Emerald, Informs, Taylor and Francis, Springer and Inderscience. The Scopus coverage details can be found at http://www.info.sciverse.com/scopus/scopus-in-detail/facts. The Scopus database is more comprehensive than Web-of-Science database which would include only ISI indexed journals, limited to 12,000 titles only (Yong-Hak, 2013). Since we are focusing on peer-reviewed journals, we inferred that the Scopus database would capture the most reputable international journals, some of which may be relatively new, but influential. Scopus has been used and recommended as a good source of logistics and supply chain peer reviewed articles (Chicksand et al., 2012). One limitation of Scopus is the limited access to pre-1996 peer reviewed journal articles. We limited our search space to English 'journal' articles and excluded conference papers, book series, commercial publications and magazine papers. Some of the conference papers and book chapters may lack rigorous peer review process; and in many cases, their completed versions are published in related journals.

The initial search attempts resulted in a total of 11,279 *articles*. Maritime literature has expanded to a broad range of subject areas which were out of the scope of this review. Therefore, articles of the irrelevant subject areas needed to be excluded. Irrelevant subject areas are those that do not fall within the scope of logistics and maritime transportation. The irrelevant subject areas were determined through a consensus by the researchers with at least two members of the research team agreeing. The following subject areas were found to be irrelevant to our review scope: (1) Earth and planetary sciences, (2) agricultural and biological sciences, (3) medicine, biochemistry, genetics and molecular biology, (4) physics and astronomy, (5) pharmacology, toxicology and pharmaceutics, (6) immunology and microbiology, (7) veterinary, (8) health professions, (9) nursing, (10) psychology, and (11) neuroscience. This reduced the number of relevant articles to 2,180 *articles* (also shown in Table 1). The search results were stored in RIS[4] format to include all the essential article information such as article title, authors' names and affiliations, abstract, keywords and references.

Refinement of the search results

From 2,180 articles in Table 1, some articles appear in both three-level and four-level search results. Also among these are short non-refereed articles and those published in commercial magazines which are not regarded as scientific contributions. Two of the more senior authors went through 2,180 references for further refinement of the search results to eliminate duplications, non-refereed articles, commercial magazine papers, papers with unknown author names, and some other papers that were recognized as outliers. The refinement resulted in 338 *journal articles* published between 1975 and 2014 (note: that we imposed no time restriction on the Scopus search attempts). To create the corresponding refinements in the RIS file, the RIS data was imported to Endnote bibliography software, the elimination of papers was completed in Endnote and the format was reconverted to RIS. The resulting RIS file is used for further data analysis.

Initial data statistics

The initial statistics shows that 168 journals have contributed to the publication of 338 articles. It was found that ten journals have published 105 of these identified articles, representing approximately 32% of all the published articles. Table 2 shows the top publishing journals and their number of contributing articles. Sustainability and green operations are the primary focus area for many of the key journals identified in Table 2. However, journals like *Maritime Policy and Management* and *Transportation Research Part E* (which have broader logistics and transportation focus areas) appearing in the list of top contributing journals may be a proof of the increasing interest in this research area within the general context of logistics

[4] RIS is a standardized tag format developed by Research Information Systems, owned by the Institute for Scientific Information (ISI). The format is supported by different reference management software and digital databases. It enables exchange of the data between different platforms and software.

Table 1
The proposed search terms and the initial search results.

Search Keywords	Search results[a]	
	Before	After
(a) A four-level search structure: Maritime OR port OR harbor OR harbour OR waterway OR container OR cargo OR bulk Or breakbulk OR deepsea OR shortsea OR sea OR ocean AND Logistics OR supply OR transport OR transportation OR shipping AND Green OR (sustainability environmental) OR (sustainable environmental) OR (sustainability environmentally) OR (sustainable environmentally) OR emission OR ("environmental performance") OR ("environmental management") OR emission OR (carbon footprint) OR pollution AND NOT Fisheries OR fishery OR sediment OR algae OR trout OR salmon OR fisherman OR fishermen OR mussel OR molecular OR herring OR larva OR oyster OR ("sea bass") OR aerosol OR (atmospheric chemistry) OR (atmospheric deposition) OR troposphere OR sewage OR ozone OR microbe OR microbial OR biology OR organism OR animal OR electron OR species OR eutrophication OR odor	10,581	1,711
(b) A three-level search structure: (port operation) OR (naval architecture) OR (ship design) OR (ship build) OR (ship construction) OR (harbor operation) OR (harbour operation) AND Green OR (sustainability environmental) OR (sustainable environmental) OR (sustainability environmentally) OR (sustainable environmentally) OR emission OR ("environmental performance") OR ("environmental management") OR emission OR (carbon footprint) OR pollution AND NOT Fisheries OR fishery OR sediment OR algae OR trout OR salmon OR fisherman OR fishermen OR mussel OR molecular OR herring OR larva OR oyster OR ("sea bass") OR aerosol OR (atmospheric chemistry) OR (atmospheric deposition) OR troposphere OR sewage OR ozone OR microbe OR microbial OR biology OR organism OR animal OR electron OR species OR eutrophication OR odor	698	469
Sum	11,279	2,180

[a] Number of articles before and after removing the unrelated subject areas.

and supply chain management. Fig. 1 shows the publishing trend using the quantity of publications in a given year. While still in its early growth and expansion period, the area of green ports and maritime logistics is attracting a geometric growth in the number of academic publications. This significant growth is more noticeable after 2006.

Data analysis

Given the nature of a citation analysis study, we adopt an inductive approach for the purpose of data analysis (Seuring and Müller, 2008). The literature classification part is completed before the actual data analysis using a deductive approach. Data analysis is conducted in two parts including 'bibliometric analysis' and 'network analysis'. Bibliometric analysis using BibExcel and OpenRefine provides additional data statistics including author, affiliation and keyword statistics. BibExcel is a tool for analyzing bibliographic data or any data of a textual nature formatted in a similar manner (Persson et al., 2009). BibExcel is chosen due to its flexibility to work with large data sets and the compatibility with different computer applications including Excel, Pajek and Gephi (Persson et al., 2009). BibExcel is also used to prepare the input data for a detailed network analysis. OpenRefine (formerly Google Refine) is a powerful tool for cleaning and transforming messy data from one format to another (www.openrefine.com). The network analysis part uses Gephi to perform a citation analysis, co-citation analysis and the topical content-based classification of the existing literature of green posts and maritime logistics. Gephi is chosen over the existing network analysis software such as Pajek (Batagelj and Mrvar, 2011) and VOSviewer (van Eck and Waltman, 2013) given its capability to work efficiently with large data sets and providing a range of innovative analysis and investigation options.

Bibliometric statistics

BibExcel allows modifying and/or adjusting the data imported from various databases including Scopus and Web of Science. The data output can be exported to Excel or any program that takes tabbed data records. This high degree of flexibility makes BibExcel a powerful tool, yet relatively difficult to work with especially in performing the initial setups. We use BibExcel to perform some initial bibliometric and statistical analysis and to prepare the input data for additional network analysis in Gephi.

The data source that we use as input into BibExcel is in RIS format (Scopus output) containing the bibliographic information of the articles. Our analysis focuses on the following data fields: authors, title, journal, publication year, keywords, abstract, affiliations, and references. These analyses require reformatting of the RIS file into a number of different formats and hence producing several file types. Interested readers can refer to Paloviita (2009) and Persson et al. (2009) for more

Table 2
The most popular host journals and quantity of articles contributed.

Journal	No. of articles
Transportation Research Part D: Transport and Environment	29
Maritime Policy and Management	14
Environmental Science and Technology	13
Energy Policy	12
Ocean Engineering	10
Marine Technology	7
Transportation Research Part E: Logistics and Transportation Review	7
Science of the Total Environment	6
Transactions of the Royal Institution of Naval Architects Part A: International Journal of Maritime Engineering	5
Journal of Cleaner Production	4
Total	107

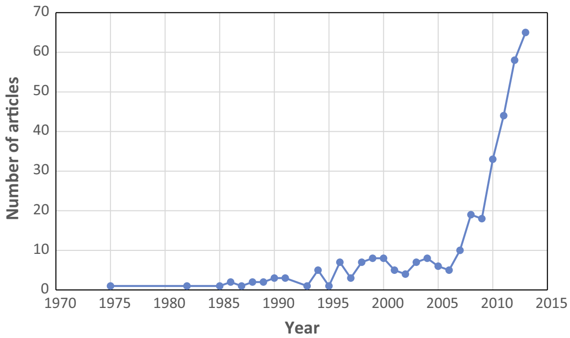

Fig. 1. Publication trend in the area of green posts and maritime logistics.

detailed procedure and applications of Bibexcel in bibliometric and statistical analysis. BibExcel can extract the required data from the data fields of the RIS file, but the extracted data is usually messy with no unique and standardized format. To tackle this, OpenRefine was used in conjunction with BibExcel to prepare the data for further analysis.

Authors statistics

BibExcel can be used to analyze the frequency of occurrence of a text in different fields of the bibliographic data. The author field was extracted from the data file and frequency of appearance of all authors was recorded. It was found that only 11% of 757 contributing authors have contributed to more than one article, leaving 675 authors appearing in only one article. Table 3 shows the most prolific authors based on the number of published articled. We also completed an analysis to identify the top paired authors (i.e. those appearing on multiple joint articles). Table 4 shows the results. Interestingly, seven of the ten prolific authors (Table 3) are also appearing in the list of the most prolific paired authors (i.e. Corbett J., Wang C., Kontovas C., Winebrake J., Psaraftis H., Eide M., Lindstad H.).

Affiliation statistics

The affiliations of the authors were extracted from the RIS file in BibExcel. For each affiliation, the city where the organization is located was obtained. Using the coordinates of these cities in gpsvisualizer.com, Fig. 2 shows the geographical locations of organizations contributing to the literature. The size of the red circles is proportional to the contribution degree of each organization. Greater density of contributing organizations can be found in the Western Europe and the Eastern United States. The figure also provides a summary of the number of articles published by the contributing counties. The top performing organizations, their geographical locations and the quantity of the contributing articles are shown in Table 5. The geographical dispersion of these organizations demonstrates that green ports and maritime logistics has attracted organizations and research centers from around the globe, with numerous contributions from researchers and practitioners in Europe and North America.

Our analysis on the national collaborations statistics shows that the United States holds the highest national collaboration rate. There are 33 articles with USA-only affiliations, followed by 12 articles with UK-only affiliations. This could be most likely encouraged by the many top authors and organizations within United States. USA is also the most active internationally, being one leg of 78% of international collaborations.

Table 3
The most prolific authors.

Author	No. of published articles	Author	No. of published articles
Corbett J.	11	Kontovas C.	4
Wang C.	5	Winebrake J.	4
Psaraftis H.	4	Deniz C.	4
Eide M.	4	Chen G.	3
Lindstad H.	4	Yang Y.	3

Table 4
The most prolific paired authors.

Author 1	Author 2	Number of joint publications
Corbett J.	Winebrake J.	4
Corbett J.	Wang C.	4
Cheng T.	Lai K.	3
Kontovas C.	Psaraftis H.	3
Eide M.	Longva T.	3
Lai K.	Wong C.	3
Asbjørnslett B.	Lindstad H.	3
Cheng T.	Wong C.	3

Fig. 2. Geographical location of contributing organizations.

Keyword statistics

A similar analysis is conducted to identify the most frequently used words/phrases in the article title and the list of keywords. The top 20 words used in article titles (from a pool of 1,051 keywords) and the top 20 keywords (from a pool of 2,893 phrases) are outlined in Tables 6 and 7, respectively. OpenRefine was used to clean the extracted keyword data and heuristics algorithms including Key Collision Methods (finger print, N-gram finger print, and phonetic Fingerprint) and Nearest Neighbour Methods (Levenshtein Distance and PPM) were used for data refinement. These heuristics were used to manage different spellings of the same words (e.g. optimization and optimisation, modeling and modelling, CO 2 and CO2) and singular/plural form of the words. From these tables, we find that many of the most frequently used keywords are those related to greenhouse carbon emissions (e.g. greenhouse gas, emission control, carbon dioxide, carbon emission, carbon monoxide, CO2 emissions, gas emission, carbon footprint, carbon dioxide emissions, carbon, carbon oxide, CO emissions, and CO2). Nitrogen oxide, oil spill and sulfur dioxide are also among the popular keywords after carbon-related keywords.

Network analysis and literature mapping

A network analysis of the published articles is now completed using Gephi, an open source software package that uses a 3D render engine to develop illustrations of large networks in real-time and assist in speeding up the exploration process

Table 5
The top performing organizations.

Organization	Country	No. of articles
Department of Marine Engineering, Istanbul Technical University	Turkey	4
Centre for Maritime Studies, University of Turku	Finland	3
Department of Shipping and Transportation Management, National Kaohsiung Marine University	Taiwan	3
Federal Institute for Health Protection of Consumers and Veterinary Medicine	Germany	3
Department of Biological and Environmental Sciences, University of Helsinki	Finland	3
Department of Civil and Environmental Engineering, University of California	United States	3
College of Marine and Earth Studies, University of Delaware	United States	3
Department of Logistics and Maritime Studies, Hong Kong Polytechnic University	Hong Kong	3
Graduate School of Logistics, Inha University	South Korea	3

Table 6
The top 20 words/phrases used in the list of keywords.

Frequency	Keyword phrase	Frequency	Keyword phrase
91	Ships	34	Gas emissions
70	Shipping	30	Marine pollution
65	Greenhouse gas	28	Energy efficiency
58	Emission control	27	Environmental protection
57	Carbon dioxide	27	Maritime transportation
50	Air pollution	27	United States
45	Article	25	Environmental impact
35	Nitrogen oxides	24	Cost-benefit analysis
35	Oil spill	24	Port operation
34	Carbon emission	23	Exhaust emission

Table 7
The most frequently used words in article titles.

Frequency	Word	Frequency	Word
102	Emission	27	Energy
51	Ship	26	Green
48	Shipping	24	Vessel
35	Environment	24	Oil
35	Port	23	Transportation
35	System	23	Analysis
35	Marine	22	Design
29	Container	22	CO2
29	Case	22	Study
28	Maritime	21	Gas

(Gephi, 2013). The flexible and multi-task architecture and innovative approaches allows Gephi to work with complex data sets and produce insightful visual aids. Gephi provides easy and broad access to network data and assist in specializing, filtering, navigating, manipulating and clustering of data (Bastian et al., 2009). The bibliographic data obtained from Scopus (in RIS format) cannot be directly used for network analysis purposes. Gephi accepts a number of graph data formats including '.NET' which is what BibExcel is able to generate using the RIS output of Scopus.

Citation analysis

Different methods have been used in the past to measure the significance of an article. The most common method is a citation analysis which aims to determine the '*popularity*' of an article by counting the number of times it is cited by others in a given network (Cronin and Ding, 2011). Ding et al. (2009) argue that in addition to '*popularity*' of an article measured by the number of citations, the '*prestige*' is another important indicator which is the number of times an article is cited by highly cited articles. In other words, a popular article (a highly-cited paper) may not necessarily be a prestigious one although in some cases there might be a strong positive correlation between the two measures. PageRank is therefore used as a measure for both popularity and prestige.

PageRank (Brin and Page, 1998) was introduced to prioritize web pages when a keyword search is performed in a search engine. Although originally defined to discover the connectivity of webpages, PageRank could also be extended to find the citation link between articles. Assume article A has been cited by articles $T_1,\ldots, T_n$. The parameter d is a damping factor, set between 0 and 1, and represents the fraction of random walks that continue to propagate along the citations. Also $C(T_i)$ is

Table 8
Top 10 articles based on a PageRank citation measure.

Article	PageRank	Local citation[a]	Global citation[b]
Bailey and Solomon (2004)	0.0348	7	46
Corbett and Fischbeck (2000)	0.0308	5	34
Corbett et al. (2009)	0.0298	7	80
Wang et al. (2007)	0.0209	3	37
Eide et al. (2009)	0.0190	2	35
Corbett (2002)	0.0185	3	14
Corbett and Robinson (2001)	0.0185	2	7
Tzannatos (2010)	0.0185	2	28
Höfer (1998)	0.0185	2	4
Gallagher (2005)	0.0183	2	12

[a] Local citation: the number of citations within the pool of 338 articles.
[b] Global citation: the Scopus citation.

defined as the number of citations going out of article T_i (i.e. out-degree). The PageRank of article A (denoted by PR(A)) in a network of N articles can be calculated from:

$$\mathrm{PR}(A) = \frac{(1-d)}{N} + d\left(\frac{\mathrm{PR}(T_1)}{C(T_1)} + \cdots + \frac{\mathrm{PR}(T_n)}{C(T_n)}\right)$$

Note that if $C(T_i) = 0$, then PR(T_i) will be divided to the number of articles instead of $C(T_i)$. The PageRanks form a probability distribution over articles, so the sum of all articles' PageRanks will be equal to one. Using this formula, PageRank is calculated based on an iterative algorithm, and corresponds to the principal eigenvector of the normalized citation matrix of the articles. In the original Google PageRank algorithm of Brin and Page (1998), the parameter d was chosen to be 0.85. This value was prompted by the anecdotal observation that an individual surfing the web will typically follow of the order of 6 hyperlinks, corresponding to a leakage probability $1/6 \cong 0.15 = (1-d)$, before becoming either bored or frustrated with the search and beginning a new search. In the context of citations, Chen et al. (2007) show entries in the reference list of a typical article are collected following somewhat shorter paths of average length 2, making the choice $d = 0.5$ more appropriate for a similar algorithm applied to the citation network.

Gephi is able to evaluate the importance of articles based on their PageRank. A total of 80 articles out of 338 cite each other which are used for PageRank analysis. Table 8 shows the top ten articles based on a PageRank measure. For these articles, the table also shows the number of citations (both local citation and global citation), the pure 'popularity' measures. Clearly, a higher number of local and global citations cannot guarantee a higher PageRank value (e.g. Corbett and Fischbeck (2000) vs. Corbett et al. (2009), and Tzannatos (2010).

Co-citation analysis

A co-citation network consists of a set of nodes representing journal articles, and a set of edges/links representing the co-occurrence of articles within the reference list of other journal articles (Leydesdorff, 2011). Therefore, two articles are called to be co-cited if they appear together in the reference lists of other articles. That is, if both document A and B are included in reference list of article C, then A and B are co-cited. Articles which are cited together more often are more likely to present similar subject areas or be related (Hjørland, 2013). The initial co-citation mapping with Gephi revealed that there are only 30 articles out of a total of 338 that have been co-cited by other articles within this sample.

In the following sections, we first use this co-citation concept to classify the existing literature of green ports and maritime logistics, then we complete a similar analysis to classify the articles that are cited by these articles (referred to as 'seminal research areas').

Literature classification: data clustering

The article co-occurrences in a network can be divided into clusters (or modules) where the density of these co-occurrences is greater between journal articles of the same cluster compared to those of different clusters (Clauset et al., 2004; Leydesdorff, 2011; Radicchi et al., 2004). Because of the co-occurrences, a cluster can be viewed as a group of well-connected articles in a research area with limited connection to articles in another research area. Data clustering can be used as a classification tool for grouping of a set of given articles (Radicchi et al., 2004). Clustering allows for the topological analysis of networks, identifying topics, interrelations, and collaboration patterns. Clustering has received increasing attention from scholars turning it into a critical research field in social network analysis (Blondel et al., 2008).

The default clustering tool in Gephi is based on the Louvain algorithm, an iterative optimization model that aims to determine the optimal number of partitions that maximize the clustering index (Blondel et al., 2008). The clustering index of a partition is a scalar value between -1 and +1 that measures the density of links inside clusters versus the links between

Table 9
Literature classification – data clustering results.

Cluster	Research area
1	Emissions (e.g. evaluation of emissions from vehicles, emission mitigation strategies: their costs and benefits)
2	Eco-efficiency (e.g. berth allocation strategies, bunker consumption optimization, bunker levies, low carbon shipping)
3	Energy eco-efficiency (e.g. energy intensity and economic costs)
4	Climate change policy, regulation and carbon tax
5	Carbon footprint case studies
6	Ship mobility emissions (e.g. emissions from maneuvering ships, direct and feeder services)
7	Ship design (e.g. energy efficiency and cost effectiveness)

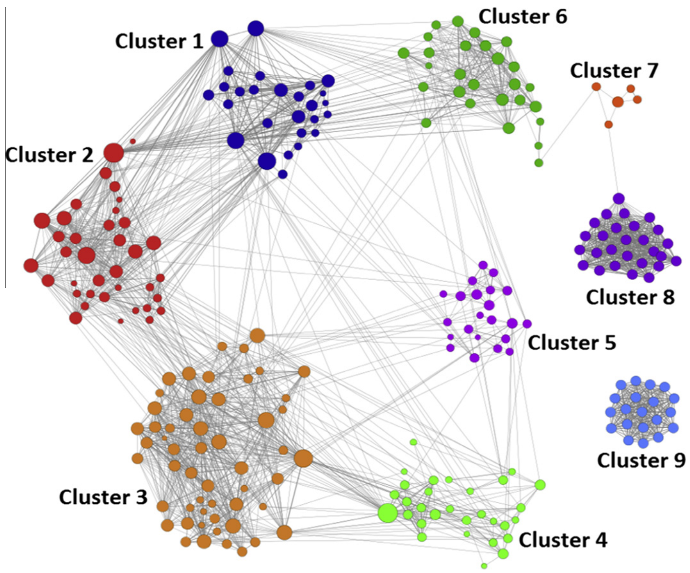

Fig. 3. The positioning of the seminal clusters.

Table 10
The seminal research areas.

Seminal clusters	No. of articles	Research area
1	27	General port/maritime/ship emissions (e.g. internal combustion engine, exhaustive emissions, radiative climate forcing)
2	37	Air emissions focus (e.g. exhaust emissions, air quality, environmental sustainability)
3	54	Eco-efficiency of ports and maritime logistics (e.g. speed optimization, berth allocation, crane scheduling, shipping routeing and scheduling)
4	30	Operational emissions modelling (e.g. empty container repositioning, operational efficiency)
5	22	Risk focus (e.g. risk assessment, cost-benefit, decision-making under uncertainty, Bayesian networks)
6	27	Logistics and Supply chain focus
7	5	Fuel consumption, diesel engines, routeing
8	27	Energy and exergy (e.g. energy and environmental impact, ecosystems, exergy)
9	20	Port development and construction

clusters. For networks with weighted links, such as the number of co-occurrence of two articles in the reference lists, the clustering index can be formulated as (Blondel et al., 2008):

$$Q = \frac{1}{2m}\sum_{ij}\left[A_{ij} - \frac{k_i k_j}{2m}\right]\delta(c_i, c_j),$$

where A_{ij} represents the weight of the co-occurrence of articles i and j, k_i is the sum of the weights of the co-occurrences with an article i ($k_i = \sum_j A_{ij}$), c_i is the cluster to which article i is assigned, $\delta(u, v)$ is equal to 1 if $u = v$ and 0 otherwise, and finally $m = \frac{1}{2}\sum_{ij} A_{ij}$.

Table 11
The top five articles of each seminal research area.

Seminal cluster 1	Seminal cluster 2	Seminal cluster 3
Streets et al. (2000)	Corbett et al. (2007)	Psaraftis and Kontovas (2009)
Corbett and Koehler (2003)	Eyring et al. (2005)	Notteboom (2006)
Corbett and Fischbeck (1997)	Endresen et al. (2007)	Corbett et al. (2009)
Bailey and Solomon (2004)	Saxe and Larsen (2004)	Fagerholt et al. (2010)
Lawrence and Crutzen (1999)	Schrooten et al. (2008)	Bierwirth and Meisel (2010)
Seminal Cluster 4	Seminal Cluster 5	Seminal Cluster 6
Notteboom and Vernimmen (2009)	Otto et al. (2002)	Wong et al. (2009a)
Liao et al. (2009)	Pedersen (1995)	Wong et al. (2009b)
Choong et al. (2002)	Goerlandt and Kujala (2011)	Lun and Browne (2009)
Cullinane and Khanna (2000)	Stipa et al. (2007)	Lun et al. (2008)
Beckx et al. (2009)	Gehring (2008)	Vachon and Klassen (2008)
Seminal Cluster 7	Seminal Cluster 8	Seminal Cluster 9
Sonesson (2000)	Dincer (2000)	Everett (2007)
Mihelcic and Zimmerman (2010)	Chen (2006)	Qiu (2008)
Johansson (2006)	Chen and Ji (2007)	Shen (2009)
Tavares et al. (2009)	Crane et al. (1992)	Sun (2009)
Lloyd and Cackette (2001)	Rosen and Dincer (2001)	Woodburn (2007)

Applying this algorithm to the proposed 30-article citation network (30 co-cited papers) resulted in the creation of seven clusters. Articles within each cluster are cited together more often and these articles are more likely to present similar subject areas (Hjørland, 2013). To identify the area of research focus for each cluster (i.e. characterizing/labeling of clusters), we carefully evaluated the contents and research areas of all articles. To avoid possible conflicting judgments, all authors of this paper were involved in this process. Table 9 summarizes the areas of research focus for each of the seven clusters.

Classification of seminal research areas

A second clustering and co-citation analysis is now completed for the ‘‘references” of the articles that are directly contributing to green port and maritime logistics. Therefore, here we go one step further and analyze the articles that have been cited by articles forming the seven research areas shown in Table 9. The extraction of reference lists results in 5,914 articles, 95% of which are cited by one article only (5,612 articles) and so cannot be included in a co-citation analysis. The remaining 302 articles (5,914 minus 5,612) are considered for co-citation analysis.

When opening the ‘.NET’ file for 302 journal articles in Gephi for the first time, the positioning of the articles in the citation map is randomly generated by the software. A clearer citation map requires the positioning of the journal articles in a more appropriate layout to better differentiate related articles. Gephi offers a variety of algorithms for creating different layouts. Force Atlas is a force-driven algorithm and the most recommended layout by the developers in terms of simplicity and readability. The network is arranged in a way that linked articles attract and non-linked articles repulse each other. It also allows for the manual adjustment of the repulsion strength, gravity, speed, article size and other characteristics (Bastian et al., 2009). With this algorithm, the most connected articles move to the center of the network while the more isolated (less connected) articles move to the borders. The remote articles in groups of two or three (articles co-cited only with one or two other articles) are seen as outliers and can be excluded from the network. This exclusion will leave the network with a total of 249 articles and 2,177 citation co-occurrences.

Applying the clustering algorithm (as discussed in Section ‘Literature classification: data clustering’) on the resulting 249-article network generates nine clusters. We call these ‘seminal clusters’ or ‘seminal research areas’ as these have set the foundation for green port and maritime logistics research, providing the field with the base knowledge, concepts, theories, tools and techniques. The number of articles in each cluster varies from only five articles in cluster 7 to 54 articles in cluster 3, the largest cluster. Fig. 3 presents the extracted nine clusters, thicker arcs between the nodes shows higher frequency for co-occurrence of the two articles in the reference list of other documents.

To identify the area of research focus for each cluster, we needed to identify and evaluate the top articles of each cluster (it was not practical to complete this assessment for all 249 seminal articles). We used a PageRank measure to identify the top articles of each cluster. Although PageRank is originally designed for use in directed graphs (like a citation graph), it can also be applied to undirected graphs (Perra and Fortunato, 2008). For example, Ding et al. (2009) use PageRank algorithm to rank authors in a co-citation network and Yan and Ding (2011) do this in a co-authorship network. For co-citation networks, the PageRank algorithm gives higher weights to the articles that are co-cited with different articles and to articles that are co-cited with highly co-cited articles. We also observed that most of the articles with high PageRank possess a high citation count.

The top five articles of each seminal cluster (using a PageRank measure) were considered as the lead articles of that cluster. We carefully evaluated the contents and research areas of the lead articles to be able to determine the area of research focus for each seminal cluster (i.e. labeling of seminal clusters). Table 10 summarizes the research focus areas for each of the nine seminal research areas. The top five articles of each seminal area are also shown in Table 11.

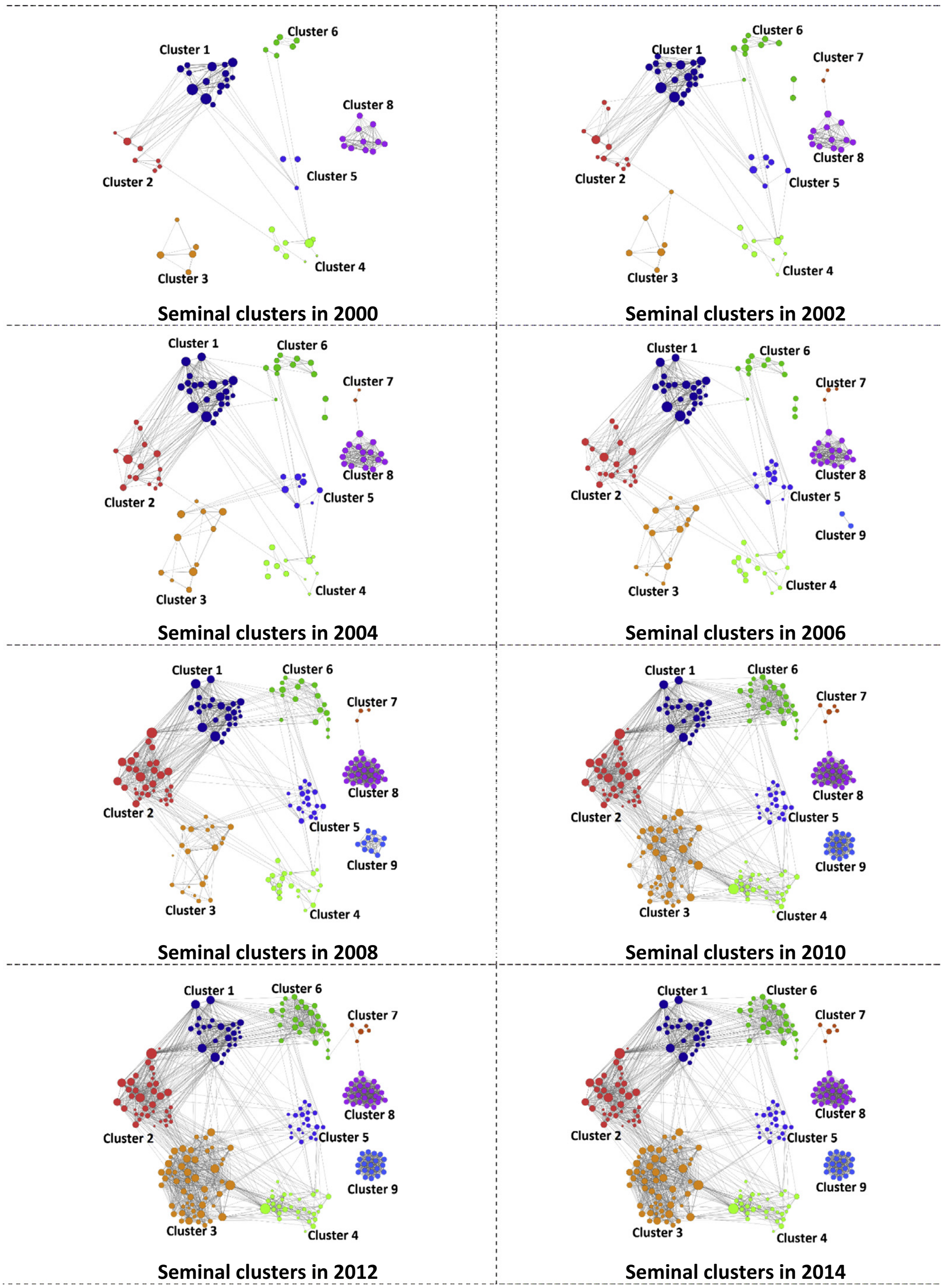

Fig. 4. The evolution of clusters over time.
The focus of the seminal clusters: (1) General port/maritime/ship emissions, (2) air emissions focus, (3) eco-efficiency of ports and maritime logistics, (4) operational emissions modelling, (5) risk focus, (6) logistics and supply chain focus, (7) fuel consumption, diesel engines, routeing, (8) energy and exergy, and (9) port development and construction.

From Fig. 3 and Table 10 we observe that most seminal research areas are well-connected and indeed a number of studies have cited articles from multiple clusters. Clusters 7, 8 and 9 are however isolated from the other research clusters. This result indicates the disconnection between ship construction research and post development and maritime logistics research. Ship construction/technology research is the subject of Naval Architecture departments in universities, to be found in engineering faculties. Naval architects are an inward looking community, well networked among themselves, highly

Table 12
The top ten seminal articles: Betweenness centrality analysis.

Author, year	Betweenness centrality
Corbett et al. (2007)	7,092
Gollasch et al. (2007)	6,755
Derraik (2002)	6,272
Mihelcic and Zimmerman (2010)	6,107
Lloyd and Cackette (2001)	5,427
Dincer (2000)	5,252
Celik and Er (2006)	3,201
Notteboom and Vernimmen (2009)	2,746
Corbett et al. (2009)	2,378
Corbett and Fischbeck (1997)	1,872

focused on ship design and building, but not particularly interested in or well connected with other maritime or port communities. By contrast, those interested in port development will be coming from a wide range of backgrounds, disciplines and directions, including civil engineering, economics, operations research, business, geography, and planning. One would hardly find naval architects at the conferences that those interested in port development would be attending. We recognize this as an important direction for future research aiming to bridge the gap between naval architects and other research clusters within the context of maritime logistics and ports. Interestingly, this literature review is the first article that is co-citing articles from all research clusters.

Evolution of seminal research areas over years

To help understand the evolution of seminal research areas over time, we also complete a dynamic co-citation analysis covering all articles in the nine seminal clusters. The evolution is graphically illustrated in Fig. 4. The size of a circle represents the PageRank of the article and hence the larger the size of a circle, the more highly-cited and prestigious the corresponding article.

Cluster 1, general port/maritime/ship emissions, was the first to shape followed by a slow evolution since the year 2000. Cluster 2 (air-emission focus), cluster 3 (eco-efficiency), and cluster 6 (supply chain focus) have been the fastest growing clusters during the past decade. These results are not surprising given the supply chain management research focus of many universities and research institutes and global eco-efficiency and emission reduction trends. Clusters 7 and 9 are the youngest among all, which may also explain why they are still disconnected from other research areas. These observations reinforce the need for more integrated multidisciplinary research that connects ship construction/technology research with other research clusters. We expect research in this domain to grow during the next decade or so.

Betweenness centrality analysis of the seminal research areas

The centrality measures are based on the shortest path between the articles allowing for the comparative analysis of the measures (Brandes, 2001b). Centrality is a topological metric that determines the stability and dynamics of a network and allows the identification of major articles and their roles based on their positioning in the network (Abbasi et al., 2012; González et al., 2010). Network diameter is the main parameter to measure when analyzing the centrality of articles. The diameter is the longest graph distance between any two articles in the network (i.e. how far apart are the two most distant articles). Connected articles have graph distance 1. Three main indicators are measured: closeness centrality, eccentricity and betweenness centrality. Here we only focus on betweenness centrality measure.

Betweenness centrality measures how often an article appears on the shortest paths between articles in the network. Betweenness centrality $C_B(v)$ is calculated as (Freeman, 1977a)

$$C_B(v) = \sum_{s \neq v \neq t \in V} \frac{\sigma_{st}(v)}{\sigma_{st}},$$

where $\sigma_{st} = \sigma_{ts}$ denote the number of shortest paths from $s \in V$ to $t \in V$, and $\sigma_{ss} = 1$. $\sigma_{st}(v)$ represents the number of shortest paths from s to t that passes through $v \in V$.

Betweenness centrality refers to the frequency of an article acting as a connection between a pair of other articles; that is being on the geodesic or shortest path that connects the two articles. The shortest path refers to the time it takes information to diffuse through the network (Freeman, 1977b; Newman, 2003; Wasserman and Pattison, 2004). In a citation/co-citation analysis, articles with high betweenness centrality potentially hold substantial power and control to pass on knowledge or withhold it and support communication between research areas by citing and being cited by journal articles from multiple disciplines (Freeman, 1977b; González et al., 2010). Authors of articles with high betweenness centrality are expected to have expertise in multiple research fields and are able to connect critical research topics in multiple disciplines. Gephi applies the algorithm suggested by (Brandes, 2001a) to calculate betweenness centrality. Betweenness centrality for the proposed network of authors varies between 0 and 7,092 in this network. Table 12 outlines the top ten articles using a betweenness centrality measure.

The seminal cluster 7 has two articles of Lloyd and Cackette (2001) and Mihelcic and Zimmerman (2010) with a very high betweenness centrality of 5,427 and 6,107. The role of these two articles in passing knowledge from one area to another is evident in Fig. 3 connecting Cluster 8 with the rest of the network. Also cluster 9 which is completely separate from the rest of the network holds an average betweenness centrality of zero (implying that none of the articles are connected to other clusters). Corbett et al. (2007) with highest betweenness centrality value is a key article in connecting clusters 2 and 6, two of the fastest evolving research areas.

Conclusions

Evidenced by the increasing quantity of published articles, more noticeable since 2006, green ports and maritime logistics has become an important research area and a critical branch of sustainable supply chain management research. This article utilized bibliometric and network analysis tools to examine the evolution of the field by (1) providing author, affiliation and keyword statistics and (2) identifying the established and emerging research clusters as well as seminal research areas through a set of citation and co-citation analyses. The results of our objective literature review and analysis can help interested researchers and students establish their research agendas in this area.

Overall, while still in its early growth and expansion period, it is expected that the field will continue to grow in a number of directions as practitioners and governments face challenges that research can help solve. An important insight from our observations is that the gap between naval architects and researchers from other clusters within the context of port and maritime logistics needs to be bridged in the interests of a better mutual understanding of the relationship between ship design and construction on one hand and ports and maritime logistics on the other. Naval architects have taken a detailed interest in the relationship between the design of the hull and engine, emissions and energy efficiency. Those in the wider port and maritime logistics fields should be more cognisant of this work. Similarly, naval architects should perhaps engage more in broader maritime issues. This could be underpinned by research and we see this as a fertile direction for future research.

Although interesting results and findings occurred from this study, limitations do exist. (1) The keyword structure was designed through a number of trials to ensure the most effective and feasible search space. However, there may still be some related works that this keyword structure has not captured. (2) The categorizations and titles of both the actual modeling categories and generative studies are not necessarily homogenous. Multiple and different topical areas exist in some areas and a more nuanced, sub-categorization evaluation may provide ample room for identification of sub-clusters or variations in interpretations. (3) The Scopus database is relatively comprehensive and has certain advantages as a database, but is not as encompassing in capturing information as Google Scholar. Not all journals that are on the listing appeared in Scopus for all years. Thus, some early publications may have been missed. Also, Scopus may have limited electronic information before the 1978 time period, potentially limiting pre-1978 articles that may have been captured in older electronic systems. (4) The literature mapping and network analysis methodology presented in this paper shows how a subject area can be objectively reviewed to identify the major articles and investigators. However, the methodology is not able to interpret the knowledge in these articles to explore the reasons why particular articles have been central to the development of the field. Future review efforts can focus on the development of tools and methodologies to address these limitations.

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