View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by CURVE/open

Evolution of green shipping research: themes and methods

Shi, W., Xiao, Y., Chen, Z., McLaughlin, H. & Li, K.

Author post-print (accepted) deposited by Coventry University's Repository

Original citation & hyperlink:
Shi, W, Xiao, Y, Chen, Z, McLaughlin, H & Li, K 2018, 'Evolution of green shipping research: themes and methods' Maritime Policy and Management, vol 45, no. 7, pp. 863-876.
https://dx.doi.org/10.1080/03088839.2018.1489150

DOI 10.1080/03088839.2018.1489150
ISSN 0308-8839
ESSN 1464-5254

Publisher: Taylor and Francis

This is an Accepted Manuscript of an article published by Taylor & Francis in Maritime Policy and Management on 27/06/2018, available online: http://www.tandfonline.com/10.1080/03088839.2018.1489150

Copyright © and Moral Rights are retained by the author(s) and/ or other copyright owners. A copy can be downloaded for personal non-commercial research or study, without prior permission or charge. This item cannot be reproduced or quoted extensively from without first obtaining permission in writing from the copyright holder(s). The content must not be changed in any way or sold commercially in any format or medium without the formal permission of the copyright holders.

This document is the author's post-print version, incorporating any revisions agreed during the peer-review process. Some differences between the published version and this version may remain and you are advised to consult the published version if you wish to cite from it.

Evolution of Green Shipping Research: Themes and Methods

Wenming Shi, Yi Xiao, Zhuo Chen, Heather McLaughlin & Kevin X. Li

Abstract

Over the past 30 years, there have been growing concerns on the environmental impacts of maritime transportation, which have attracted great attention from both academia and practitioners. Understanding developments in this area can help guide future research. We conducted a comprehensive review of green shipping research, comprising 213 papers published in transportation journals in SSCI of 2017 over the period 1988–2017. We find that research on green shipping has increased greatly since 2012, accounting for 77.5% of the reviewed papers. The main focus today on green shipping was on air pollution, and the classification of green shipping practice, such as technical measures, operational options, market-based measures, and recycling and reusing, is becoming clear. According to the existing studies, future research on green shipping must strengthen technology research to not only solve practical problems, but also to establish a theoretical green shipping system. Moreover, researchers from different countries could cooperate with each other to give effective suggestions on setting standards and laws of green shipping. Finally, we identify the future research themes will focus on setting up green shipping system and legislation and policy.

Keywords: Green shipping; Pollution; Green shipping practice; Green policy; Air emissions; Literature review

1. Introduction

With the great development of world trade, shipping accounts for 90% of the trade volume because of its dependable, efficient, and low-cost means of transporting goods globally compared to other transport modes. Meanwhile, shipping is traditionally regarded as a major source of air and water pollution. Measures of shipping air pollution from 2007–2012 show that the percentages of annual NO_X, SO_X, and CO_2 emissions from anthropogenic sources were 15, 13, and 3%, respectively (Wan et al. 2016). Water pollution was caused by the transfer of invasive aquatic species through ship ballast water, oil discharge, sewage discharge and garbage discharge, which has caused great ecological damage. Recently, both the adoption of the Paris Agreement and a synthesis report from the United Nations Environment Program (UNEP) emphasized that the seas and oceans are a key part of deep reductions in global emissions. Faced with the long-standing issue, IMO promulgate an International Convention for the Prevention of Pollution from Ships, which is short for MARPOL. MARPOL is comprised by six Annex, including Annex I (Regulations for the

Prevention of Pollution by Oil) entering into force in 1983, Annex II (Regulations for control of pollution by noxious liquid substances in bulk) entering into force in 1987, Annex III (Regulations for Prevention of Pollution by harmful substances carried by sea in package form) entering into force in 1992, Annex IV (Regulations for the Prevention of Pollution by Sewage from Ships) entering into force in 2003, Annex V (Regulations for the Prevention of Pollution by Garbage from Ships) entering into force in 1988, Annex VI (Regulations for the Prevention of Air Pollution from Ships) entering into force in 2005.

Green shipping is efficient marine transport with minimal health and ecological damage (Wan et al. 2016). Green shipping could realize energy-efficient means of moving huge quantities of cargo and a worldwide transition to a low-carbon green economy. As a result, green shipping is widely believed to be efficient in controlling pollution emissions and in achieving a more friendly environment. This, in turn, makes green shipping a worldwide concern, and an increased number of studies have been conducted over the last three decades.

Previous studies generally deal with environmental problems from both experimental and practical perspectives. For example, Woo and Moon (2014) used the system dynamic environmental evaluation model to test whether, as voyage speed affects the operating costs and CO_2 emissions, one can then determine the optimal voyage speed as a solution to maximize the reduction of CO_2 emissions at the lowest operating cost, thus satisfying the reduction target of IMO. Regarding the establishment of standard measures and evaluation pollution emissions, a variety of methods have been proposed in the existing research. For instance, Winnes and Fridell (2010) quantified the emissions of NO_2 and particles during the ship maneuvering phase by measuring engine exhaust of two types of ships (tanker and ferry). Song and Xu (2012) developed an operational activity-based method to estimate CO_2 emissions. Chang, Song and Roh (2013) used a bottom-up approach based on individual vessel characteristics and used data on vessels processed by the port in 2012 to estimate greenhouse gas (GHG) emissions. Tian et al. (2014) examined the GHG emission trajectories and features of Chinese freight transport patterns to help Chinese policy makers set a standard measure to evaluate GHG emissions for energy saving and pollution reduction.

Another research focus is to analyze the relationships between environmental protection and economic performance. For example, Hoffmann et al. (2012) estimated the possible capital expenditure paid by the shipping industry for taking measures to reduce CO2 emissions. Yang et al. (2013) collected survey data from container shipping firms in Taiwan to examine the relationships between green shipping practice, green performance, external green integration, and firm competitiveness, and found that good green performance could boost firm competitiveness. Lai et al. (2013) investigated how the green shipping practices on shipping design for compliance adopted by shipping firms is related to their financial performance regarding the role of company policy and procedures and examination of shipper cooperation. Gong, Wu and Luo (2018) evaluated the economic efficiency, cargo efficiency and environmental efficiency of the container and bulk shipping company by considering

undesirable outputs. Qiu et al. (2018) analyzed the impacts of liner vessel sharing along the maritime silk road from the economic and environmental perspectives, and concluded that vessel sharing could both improve the liner shipping companies profit and the carbon emissions significantly.

However, previous literature reviews have emphasized examining the potential of multi-objective optimization in a specific research area to improve sustainability in maritime shipping or relevant research of green ports (e.g., Davarzani et al. 2015; Mansouri, Lee and Aluko 2015). Centobelli, Cerchione and Esposito (2017) presented a literature review on environmental sustainability among the logistics service providers from 1960 to 2014, and identified eight research questions. Bouman et al. (2017) provided a review on measures for reducing GHG emissions from shipping. Consequently, this paper aims to classify different research directions and methods on green shipping and to confirm current research emphases and deficiencies. This study offers several advances. Understanding how research in this area has developed and the status of current research can guide researchers to target the urgent directions for future research. New findings can then be used to assist with the formulation of new practice and policies to realize green shipping.

The rest of this paper is organized as follows: Section 2 introduces the method, data, and scope of study. Section 3 analyzes the status of green shipping from the perspectives of the general trends, evolution of the geographic location, classification of research areas, and methodology. Discussion and research findings are given in Section 4, and conclusions are provided in Section 5.

2. Method, data, and scope of the study

We collected papers on green shipping from all of the transportation journals in SSCI of 2017 and categorized them in terms of aspects such as title, research area, location and affiliation of the author(s), citation, keywords, main content, and methods. Examining the evolution of the green shipping research papers in this way allowed us to confirm the current status and guide the future directions for probable research.

In total, 213 articles published from 1988–2017 were collected from 18 journals of SSCI under the transportation category (see table 1). The time period is chosen in terms of the enforcement time of MARPOL and its research process. The scope of this study is limited from port to port shipping, with papers only concentrating on mobility vehicles; studies on aircrafts without any information on ships were excluded. Technical reports, conference proceedings, book chapters, and non-English journal papers were excluded.

Until now, green shipping has not set up a systematic theory. According to literature review of green shipping research, the percentage of existing papers about green shipping practice and green policy accounts for 63.8%. The collected papers cover green shipping practice involving uses of environment-friendly design of shipbuilding such as double skin, non-toxic paint, electric deck machines, ballast water handling systems, and waste-heat-recovery systems (e.g., Gradoset al., 2009, Yang et al., 2012); uses of clean-burning, low-sulphur fuels (e.g., Yiğit et al., 2016); adaptation of optimal vessel speed and routing systems (e.g., Chang and Wang 2014,

Wang et al., 2016); and emissions trading and carbon levy schemes (e.g., Sterner, Dahl and Franzen1992, Wang, Fu and Luo 2015). The collected papers cover green policy involving partial contents of green shipping practice and laws or standards of port and maritime environment management (e.g., Hickman and Banister 2007, Lindstad and Eskeland 2016, Barnes-Dabban, Van Koppen and Mol 2017).

3. Status of green shipping

3.1 General trends

Table 1 presents the number of published papers and journals grouped in five-year intervals over the past 30 years. Although environment-friendly research has a long history in shipping, the marked increase in both the number of papers and the number of journals occurred in the most recent five-year period. This phenomenon may be due to increasing concerns about the environmental impacts of shipping activities, the greater development of alternative energy technology, engines and materials used to decrease pollution, and the challenges for policy makers enforcing all environmental treaties.[1] In addition, the increased availability of different types of data and greater computational power allow researchers to do much more today. These factors may explain the increasing achievements of this research area.

Of the 213 papers, 145 (68.1%) were published during the most recent five-year period, and 87.8% were published during the past 10 years. Before 2012, the number of papers was fewer than 10 per year, while in the past five years, this number has increased by more than 2 times, it's worth mentioning that the number of papers was 48 in 2017. The number of journals covering green shipping also increased dramatically, from just two to 18. Transportation Research Part D, ranked first in Table 1, published 72 papers in this area over the longest period, accounting for 33.8% of the total number of papers. The journals of Maritime Policy & Management and Transportation Research Part E, ranked second and third, published 39 and 25 papers, respectively.

The total number of papers containing research on both sea and air pollution was 46 before 2012, whereas that of papers related to air pollution was 167 after 2012. Rarely did papers address water contamination.

Table 1. Journals on green shipping research from 1988 to 2017.

NO.	Journals	1988-1992	1993-1997	1998-2002	2003-2007	2008-2012	2013-2017	1988-2017
1	Transportation Research Part D	0	0	0	3	15	54	72
2	Maritime Policy & Management	2	1	1	0	11	24	39
3	Transportation Research Part E	0	0	2	0	2	21	25
4	International Journal of Shipping Transport Logistics	0	0	0	0	1	11	12
5	International Journal of Sustainable	0	0	0	0	4	7	11

[1]The International Maritime Organization (IMO) developed an international convention (MARPOL 73/78) to prevent pollution from ships in 1973. Until now, IMO has adopted 52 treaties regulating ship design and operation.

	Transportation							
6	Transport Policy	0	1	0	2	3	5	11
7	European Journal of Transport and Infrastructure Research	0	0	0	7	0	0	7
8	Maritime Economics &Logistics	0	0	1	0	1	6	8
9	Transportation Research Part A	0	1	0	0	1	4	6
10	Transport Reviews	1	0	1	1	0	3	6
11	Journal of Transport Geography	0	1	0	0	1	3	5
12	International Journal of Transport Economics	0	0	0	0	0	2	2
13	Journal of Transport Economics and Policy	1	0	0	0	1	0	2
14	Transportation Letters	0	0	0	0	0	2	2
15	European Transport Research Review	0	0	0	0	1	0	1
16	Research in Transportation Economics	0	0	0	0	1	0	1
17	Transportation Journal	0	0	0	0	0	2	2
18	Transportation Research Part B	0	0	0	0	0	1	1
Total		4	4	5	13	42	145	213

3.2 Evolution of the geographic location

We use the number of researchers as an index to describe the popularity or capacity of research on green shipping in a certain country. In the collected papers, the researchers are based in 32 countries, as determined by their affiliations, including Europe, Asia, North America, South America, and Australia.

In Europe, especially Norway and UK, there are many researchers of green shipping. The percentages of researchers from the China and Norway are 11.3% and 9.9%, respectively, followed by UK (9.4%), USA (8.0%) and Sweden (8.0%).

Table 2 summarizes the evolution of the regional distribution of green shipping research. Before 1997, few European and American researchers did some research in this field. After 1997, researchers mainly from Asia and Europe became new forces in the global research team. Especially since 2013, the number of Asian and European researchers has grown dramatically. The number of Asian researchers increased more than 5-fold: from 20 during 2008–2012 to 111 during 2013–2017. The number of European researchers has increased more than four-fold, from 42 during 2008–2012 to 169 during 2013–2017. This indicates that, in this field, although European institutions still have a leading position, Asian researchers are catching up and gaining status.

Table 2. Evolution of the number of researchers by region.

	1988-1992	1993-1997	1998-2002	2003-2007	2008-2012	2013-2017	1988-2017

Europe	6	6	1	17	42	169	241
Asia	0	0	0	2	20	111	133
North America	0	1	7	11	14	24	57
South America	0	0	0	0	0	2	2
Australia	0	0	1	0	0	5	6
India	0	0	0	0	0	1	1
United Arab Emirates	0	0	0	0	1	3	4

Furthermore, Table 3 shows information about the top performance countries or regions and their corresponding main organizations. Green shipping has attracted the interest of worldwide organizations and research centers, with more contributions from researchers in Europe and Asia.

Table 3. The top performance countries/regions and organizations.

Country/Region	No. of articles	Main organization
China (Mainland)	24	Shanghai Jiao Tong University
Norway	21	Norwegian University of Science and Technology
UK	20	University of Plymouth
USA	17	University of Delaware
Sweden	17	Chalmers University of Technology
Taiwan	15	National Kaohsiung Marine University
Germany	11	Kühne Logistics University
Korea	11	Inha University
Greece	11	National Technical University of Athens
Hong Kong	9	Hong Kong Polytechnic University

3.3 Classification of research themes

To establish a whole expression of green shipping, Figure 1 will show the co-occurrence and frequency of keywords from all papers. The nodes mean high-frequency keywords of reviewed papers, its colors are changed from light green to bottle green with the increased frequency. The keywords like GHG, sustainability and emission reduction with bottle green appear frequently. The weight of edges means the connectivity of each two words, namely, the thicker the edge, the higher the value. For instance, sustainability and carbon emissions as keywords appear in the same paper regularly.

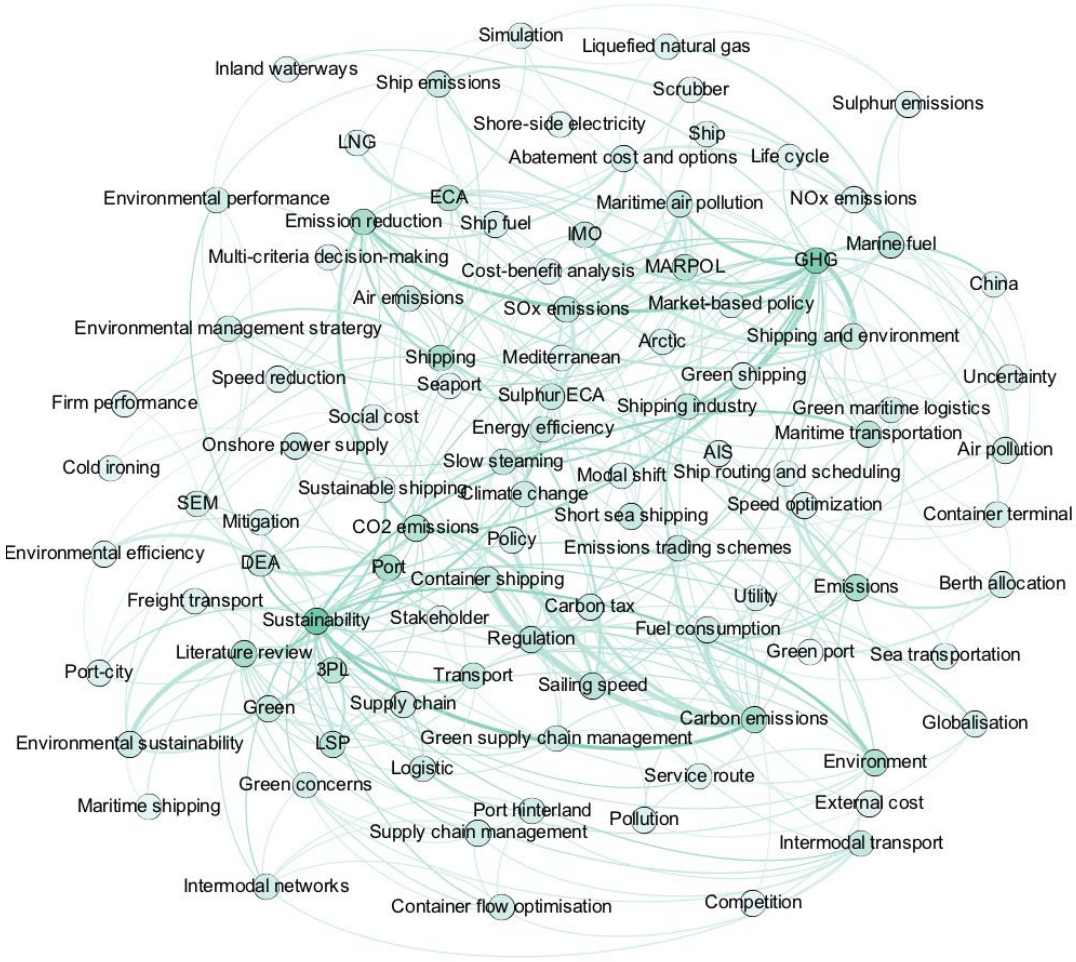

Figure 1. Co-occurrence graph of keywords.
Source: Own realization based on Gephi 0.9.2.

Depending on the main concerns and dimensions, the research themes of green shipping can be divided into five modules (Table 4). The most popular research theme is green shipping practice taken to reduce pollution, with a proportion of 37.1% of all research in the field, followed by green policy and green port performance assessment with a proportion of 26.8%. The remaining research themes show proportions of 20.2%, 10.8% and 5.2% for evaluating relationships between environmental and economic performance, emissions calculation and relevant reviews about green shipping, respectively.

Table 4. Classification of research themes.

Module	No. of articles	Research themes
1	23	Emissions calculation
2	79	Green shipping practice taken to reduce pollution
3	57	Green policy and green port performance assessment

4	43	Relationships between environmental and economic performance
5	11	Relevant review about green shipping

Using the citation data, we determined the popularity of each article. Table 5 shows the top five articles of each module, which could be considered as the leading articles of each research area. By calculating annual ship and truck emissions, Berechman and Tseng (2012) estimated the emission costs of ships and trucks in the Port of Kaohsiung. Corbett, Wang and Winebrake (2009) used a profit-maximizing equation to assess the effect of speed reduction on CO2 emissions. Greene and Wegener (1997) summarized transportation sustainability issues and compared policy approaches in the Europe and North America. Carter, Kale and Grimm (2000) provided an initial examination of the effect of environmental purchasing on firm performance. Wang, Meng and Liu (2013) presented a critical and timely literature review on mathematical solution methods for bunker consumption optimization problems.

Table 5. The top five articles of each module.

Module 1	Citation	Module 2	Citation	Module 3	Citation
Berechman &Tseng (2012)	86	Corbett, Wang &Winebrake (2009)	367	Greene &Wegener (1997)	338
Winnes &Fridell (2010)	58	Cariou (2011)	224	Hickman &Banister (2007)	182
Maragkogianni & Papaefthimiou (2015)	46	Qi &Song (2012)	158	Geurs et al. (2004)	75
Tight et al. (2005)	42	Du et al. (2011)	135	Chang &Wang (2012)	71
Chang, Song &Roh (2013)	31	Eide et al. (2011)	120	Cullinane et al. (2014)	69
Module 4	Citation	Module 5	Citation		
Carter, Kale &Grimm (2000)	504	Wang, Meng &Liu (2013)	75		
Psaraftis &Kontovas (2010)	176	Mansouri, Lee &Aluko (2015)	55		
Yang et al. (2013)	142	Lam &Gu (2013)	46		
Hong et al. (2012)	79	Davarzani et al. (2016)	32		
Lam (2015)	51	Abbasi et al. (2016)	23		

Note: The citations are from www.scholar.google.com. Date: 2018/05/09

Measures for reducing pollution, accounting for the largest percentage of research themes, can be further classified in terms of existing papers. A close inspection of publications reveals that both shipping industries and governments contribute to waste reduction, resource conservation, and sustainability improvement. More specifically, governments establish effective implementation and enforcement of green policy, and

then shipping industries enact these standards. Meanwhile, governments make policies to encourage shipping industries to invest in technology research and development for green shipping. Among these policies, the definition of green policy is concerned with implementing an environmental policy to create a vision or culture of environmental protection, and green shipping practice is undertaken by shipping industries with an emphasis on waste reduction and resource conservation in handling and distributing cargo (Lai et al., 2011).

Psaraftis and Kontovas (2010) made a conclusion on three main ways including technical measures, market-based instruments and operational options to reduce maritime emissions. Based on it, this paper presents four components of operating green shipping practice (GSP): technical measures (TM), market-based measures (MBM), operational options (OO), and recycling and reusing (RR). Specifically, more efficient ship hulls and propulsion, energy-saving engines, alternative fuels, cold ironing in ports, and devices to trap exhaust emissions (such as scrubbers) are modes of TM. Emissions trading and carbon levy schemes are modes of MBM. Speed optimization, optimized routing, improved fleet planning, and berth allocation strategy are OO. Ship scrapping and empty container reusing are common phenomena of RR. These measures could reduce emission of greenhouse gases from ships and prevent and control the transfer of invasive aquatic species through ship ballast water and hull fouling.

The relationship between GSP and green policy shows some overlap because governments set green policies, while shipping industries implement these standards. For instance, the measures for realizing efficient marine transport with minimal health and ecological damage and improving sustainability in both GSP and green policy are comprised of TM, MBM, OO, and RR. The numbers of articles merely regarding TM, MBM, OO, and RR are 24, 11, 31 and 1, respectively. In addition, before 2012, only 13 articles addressed measures. After 2012, the number of articles about measures increased by more than 4 fold. In addition to four kinds of measures included in GSP and green policy, each has its own factors.

3.4 Evolution of research methods

A summary of single and combined research methods used in green shipping research is presented in Table 6, which can be further divided into 11 groups as shown in Figure 2, including mathematic and statistical analysis (39.57%), economic modeling (15.32%), case study (12.34%), literature review (9.36%), bottom-up activity-based model (6.81%), scenario (4.26%), survey (2.98%), sensitivity analysis (2.98%), simulation (2.13%), bench testing (2.13%), conceptual, content, and qualitative analysis (2.13%).

Before 2012, the early studies in green shipping research usually adopted very basic methods such as case study, literature review, and mathematical and statistical analyses. After 2012, studies often used combined methodologies and multi-disciplinary approaches to solve problems.

Table 6. Methodologies used in green shipping research.

Methodology	
ADP (1)	Literature review (17)
AHP (1)	Life-cycle assessment (LCA)(1)
Backcasting study approach (1)	Meta-analysis (1)
Bench testing (5)	Multi-objective genetic algorithms (2)
Bottom-up/ top-down/activity-based approach (13)	Multi-criteria analysis (1)
Comparative analysis (2)	Multi-criteria optimization model (1)
Case study (19)	Multiple regression model (3)
Conceptual, content and qualitative analysis (5)	Management models （1）
Consistent and transferable methodology (1)	Optimization model (4)
Cost model (3)	Quantitative and qualitative evaluations (12)
Cost-benefit analysis (4)	Scenario (1)
Cost-effectiveness approach (3)	Ship Traffic Emission Assessment Model (1)
Cash flow modeling (1)	SEM (1)
DEA (8)	System Dynamic Environmental Evaluation Model (1)
Economic model (16)	Sensitivity analysis (4)
Fuzzy optimization (1)	Shapley decomposition model (1)
Game theory (3)	Simulation (2)
Generalized Smoothly Mixing Regression (GSMR) (1)	Survey (11)
GTAP-E (1)	Stochastic model (3)
Input-output analysis (2)	Two quadratic outer approximation approaches (1)
Linear programming model (1)	The BAP model (1)
Combined methodology	
AHP, ANP (1)	
AHP, GRA (1)	
AHP, TOPSIS (2)	
ANP, Quality Function Deployment (1)	
Autoregressive distributed lag (ARDL), Vector Error Correction Model (VECM) approach (1)	
Bottom-up approach, Scenario (1)	
Cluster analysis, ANOVA (1)	
Confirmatory factor analysis (CFA), Hypothesis test (1)	
Contraction-convergence approach, Scenario (1)	
Case study, Activity-based method (1)	
Case study, Literature review (2)	
Case study, Sensitivity analysis (1)	
Case study, Mathematical model (5)	
Exploratory factor analysis (EFA), Confirmatory factor analysis (CFA) (1)	
Exploratory factor analysis (EFA), Confirmatory factor analysis (CFA), SEM (1)	
Fuzzy AHP, VIKOR (1)	
Fuzzy logarithmic least squares, Fuzzy TOPSIS (1)	
GEM-E3, PRIMES-TREMOVE (1)	
Geospatial modeling, DEA (1)	
Heuristic Branch-and-Price (H-B&P), Constraint Programming Mode (CPM) (1)	

Literature review, mathematic and statistical analysis (3)
Log-linear regression, Path analysis, Time series (ARIMA), Curve estimation (1)
Modal split model, Sensitivity analysis (1)
Meta-analysis, GIS Spatial Analyst (1)
Multiple-objective optimization model, Case study (1)
MarPEM, Simulation (1)
Spatiotemporal analysis, Case study (1)
Scenario, Activity-based model (1)
Scenario, Mathematical model (8)
Simple Static Model, Simple Vehicle Model (1)
Simulation, Case study (2)
Sustainability model, Sensitivity analysis (2)
Survey and SEM (1)
Volume-based approach, Operation-based approach, Activity-based approach (1)

To examine how these research themes have been addressed, we try to identify the most popular research method for each module. For example, the method of a bottom-up activity-based approach has been widely applied in module 1 to calculate air emissions (e.g., Farrell et al., 2003, Song and Xu 2012). The methods of mathematical and statistical analyses, economic modeling, scenario and mathematical model, and case study have been widely applied in module 2 to discuss different kinds of measures taken to reduce emissions (e.g., Kim, Rahimi and Newell 2012, Kontovas and Psaraftis 2011, Rodrigues et al., 2015, Zhu, Nowak and Erikstad 2016, Venturini et al., 2017). The methodologies of DEA and AHP have been applied in module 3 to evaluate the efficiency of green policy and green port (e.g., Cui, 2017, Sun et al., 2017, Asgari et al., 2015). The method of performing surveys and interviews has been widely applied in module 4 to analyze the relationships between environmental problems and economic performance (e.g., Carter, Kale and Grimm 2000, Giziakis and Christodoulou 2012). The method of literature review has been widely applied in module 5 to illustrate the current conditions of certain areas in green shipping.

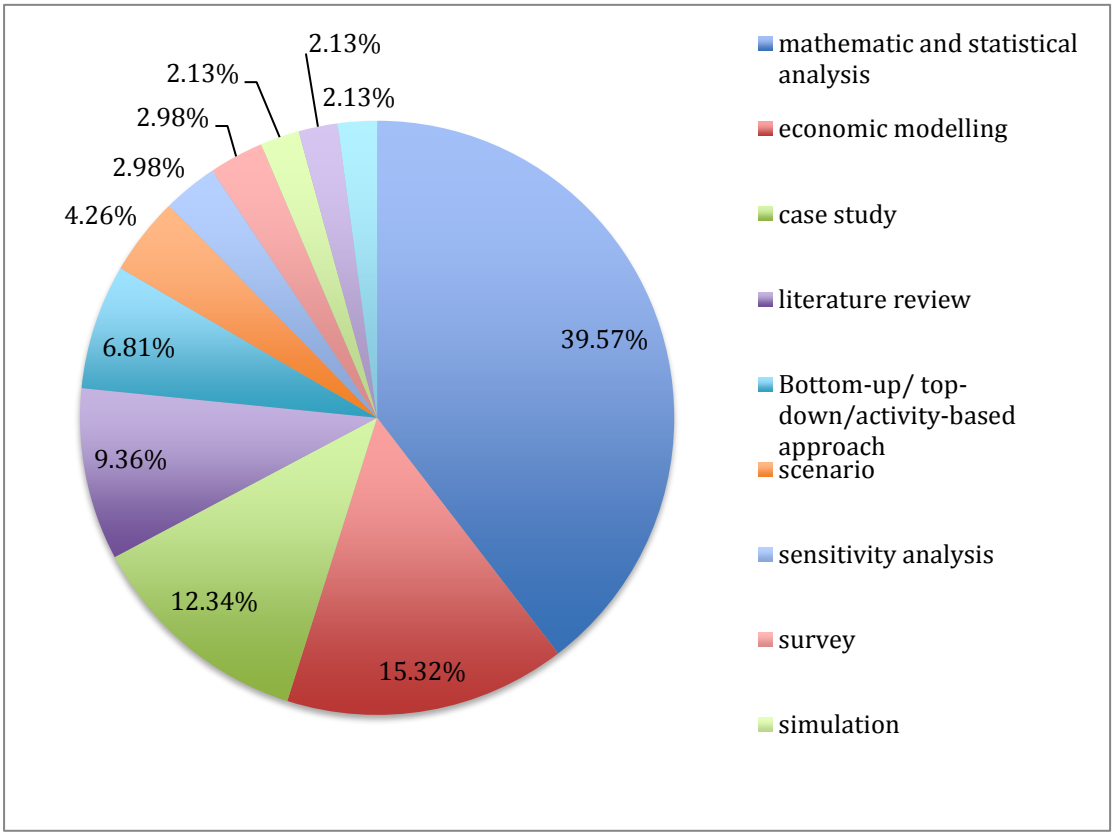

Figure 2. The proportion of each methodology.

4. Discussions and research findings

In recent years, great effort has been directed to promote green shipping due to the increasing concerns about the environmental impacts of shipping activities. This effort involves greater development of technology of alternative energy, engines, and materials used to decrease pollution and the challenges for policy makers promoting enforcement of all environmental treaties, which is reflected in the published papers. Policy makers especially IMO face great challenges on making shipping industries from different countries implement treaties effectively. After all, shipping industries need to increase their costs to balance the relationship between environmental and economic performance in the short term.

Through a comprehensive literature review of green shipping research, we found many trends. First, the number of papers and journals published in the last five years has increased rapidly compared with the past. European researchers did some research in the area, discussing environmental port management before 1997. North American, Asian, and Australian researchers became new forces in the global research team after 1997. Especially since 2013, the number of Asian and European researchers has grown dramatically due to their emerging presence in international trade, which heavily counts on ships to transport cargo from places of production to places of consumption.

Second, few papers are related to water pollution. Among 213 papers, only two papers described oil pollution (Jin and Kite-Powell 1999, Xu et al., 2009), and one paper discussed mandatory ballast water (Yang and Perakis 2004). Ballast water is recognized as a vector for the unintentional introduction of non-indigenous species (NIS) into ports and waterways, which caused substantial economic and ecological problems for those countries with marine trade (Mackey, Tagg and Parsons 2000; National Research Council Committee on Ships' Ballast Operations (NRC), 1996; Parsons et al., 1997). Thus, IMO has been in the process of introducing international controls on ballast water. In recent years, few papers separately discussed sea pollution caused by ballast water in transportation journals in SSCI of 2017, and sometimes sea pollution was included in papers mainly about air pollution. The reason why oil pollution is seldom under study is that Annex I as the pioneer convention proposed by IMO has made a contribution on reduction in the amount of oil spilled into the sea. According to the International Tanker Owners Pollution Federation Limited (ITOPF), there were 358 spills of medium sized spills (7-700 tonnes), resulting in 1,134,000 tonnes of oil lost in the 1990s while there have been 53 spills of 7 tonnes and over, resulting in 47,000 tonnes of oil lost in the period 2010-2017. Another probable explanation for this phenomenon is that Annex VI was amended and entered into force in July 2010, the focus today pays more attention on atmospheric pollution.

Third, the most popular dimensions in green shipping research are calculating emissions, taking green shipping practice to reduce emissions, green policy and green port performance assessment, evaluating relationships between environmental and economic performance, and relevant reviews on green shipping. The first dimension of calculating emissions focuses on more accurately evaluating GHG emissions. The second dimension of taking measures to reduce emissions deals with the operations of green shipping practice included by TM, MBM, OO, and RR. The number of articles about measures increased more than 4 times after 2012. The third dimension of green policy and green port performance assessment can improve environmental sustainability with better policies and more effective measures. The fourth dimension of evaluating relationships between environmental and economic performance seeks ways to balance the relationships. The last category of reviews of green shipping can increase researcher knowledge of previous studies in a certain research area. Finally, the methods of articles in green shipping research are mainly divided into 11 groups: mathematic and statistical analysis, economic modeling, case study, literature review, bottom-up activity-based model, scenario, survey, sensitivity analysis, simulation, bench testing, conceptual, content, and qualitative analysis. Before 2012, the studies in green shipping research usually adopted very basic methods such as case study, literature review, and mathematical and statistical analyses. After 2012, studies tried to use multi-disciplinary approaches to solve problems. The methodology representing the largest proportion of studies is mathematical and statistical analyses (39.57%), followed by economic modeling (15.32%) and case study (12.34%).

5. Conclusions

We undertook a comprehensive literature review of green shipping research in this study. A total of 213 papers published in transportation journals in SSCI of 2017 over the period of 1988-2017 was collected to understand how the field has evolved can increase researcher knowledge of past studies, the current research status, and how to fill the knowledge gaps. First, the theoretical system of green shipping is in the early stage, its concept and contents have not been crystallized. The current research is in solution of practical problems, for example, the main focus today on green shipping was on air pollution, and the classification of measures of green shipping practice, such as technical measures, operational options, market-based measures, and recycling and reusing, is becoming clear. It mainly depends on the current pollution conditions and government policy, more narrowly, oil pollution has improved greatly, air pollution still needs to be solved and Annex VI of MARPOL showing regulations and possible green practice in details was amended in recent years. Second, few researchers have studied how to design standards and laws of green shipping or green policy impact on the relationships between environmental and economic performance using quantitative analysis. Moreover, researchers from different countries have rarely cooperated with each other to give effective suggestions on setting standards and laws of green shipping.

Therefore, future research on green shipping must strengthen technology research to not only take effective measures to reduce emissions, including sea and air pollution, but also to propose diverse solutions and a sophisticated pollution evaluation system. Moreover, researchers from different countries could cooperate with each other to give effective suggestions on setting standards and laws of green shipping. Finally, the scope of green shipping is restricted to port to port, and the MARPOL as the binding precedent makes regulations on shipping. In the future, from the perspective of supply chain, setting up green shipping system and legislating green policy is essential to make further research.

References

Asgari, N., Hassani, A., Jones, D., Nguye, H. H. (2015). Sustainability ranking of the UK major ports: Methodology and case study. Transportation Research Part E: Logistics and Transportation Review, 78, 19-39.

Abbasi, M., & Nilsson, F. (2016). Developing environmentally sustainable logistics: Exploring themes and challenges from a logistics service providers' perspective. Transportation Research Part D: Transport and Environment, 46, 273-283.

Berechman, J., &Tseng, P. H. (2012). Estimating the environmental costs of port related emissions: the case of Kaohsiung. Transportation Research Part D: Transport and Environment, 17, 35-38.

Bouman, E. A., Lindstad, E., Rialland, A. I., & Strømman, A. H. (2017). State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping–A review. Transportation Research Part D: Transport and Environment, 52, 408-421.

Barnes-Dabban, H., Van Koppen, K., & Mol, A. (2017). Environmental reform of West and Central Africa ports: the influence of colonial legacies. Maritime Policy & Management, 44(5), 565-583.

Carter, C. R., Kale, R., &Grimm, C. M. (2000). Environmental purchasing and firm performance: an

empirical investigation. Transportation Research Part E: Logistics and Transportation Review, 36, 219-228.

Corbett, J. J., Wang, H., &Winebrake, J. J. (2009). The effectiveness and costs of speed reductions on emissions from international shipping. Transportation Research Part D: Transport and Environment, 14, 593-598.

Cariou, P. (2011). Is slow steaming a sustainable means of reducing CO_2 emissions from container shipping? Transportation Research Part D: Transport and Environment, 16, 260-264.

Chang, C. C., &Wang, C. M. (2012). Evaluating the effects of green port policy: case study of Kaohsiung harbor in Taiwan. Transportation Research Part D: Transport and Environment, 17, 185-189.

Chang, Y. T., Song, Y., &Roh, Y. (2013). Assessing greenhouse gas emissions from port vessel operations at the Port of Incheon. Transportation Research Part D: Transport and Environment, 25, 1-4.

Chang, C. C., &Wang, C. M. (2014). Evaluating the effects of speed reduce for shipping costs and CO_2 emission. Transportation Research Part D: Transport and Environment, 31, 110-115.

Cullinane, K., & Bergqvist, R. (2014). Emission control areas and their impact on maritime transport.

Centobelli, P., Cerchione, R., & Esposito, E. (2017). Environmental sustainability in the service industry of transportation and logistics service providers: Systematic literature review and research directions. Transportation Research Part D: Transport and Environment, 53, 454-470.

Cui, Q. (2017). Environmental efficiency measures for ports: an application of RAM-Tobit-RAM with undesirable outputs. Maritime Policy & Management, 44(5), 551-564.

Du, Y., Chen, Q., Quan, X., Long, L., & Fung, R. Y. (2011). Berth allocation considering fuel consumption and vessel emissions. Transportation Research Part E: Logistics and Transportation Review, 47(6), 1021-1037.

Davarzani, H., &Fahimnia, B., Bell, M., Sarkis, J. (2015). Greening ports and maritime logistics: A review. Transportation Research Part D: Transport and Environment, 48, 473-487.

Eide, M. S., Longva, T., Hoffmann, P., Endresen, Ø., & Dalsøren, S. B. (2011). Future cost scenarios for reduction of ship CO2 emissions. Maritime Policy & Management, 38(1), 11-37.

Farrell, A. E., Redman, D. H., Corbett, J. J., Winebrake, J. J. (2003). Comparing air pollution from ferry and landside commuting. Transportation Research Part D: Transport and Environment, 8, 343-360.

Greene, D. L., &Wegener, M. (1997). Sustainable transport. Journal of Transport Geography, 5, 177-190.

Geurs, K., & van Wee, B. (2004). Backcasting as a tool for sustainable transport policy making: the environmentally sustainable transport study in the Netherlands. European journal of transport infrastructure research, 4(1), 47-69.

Grados, C. V. D., Uriondo, Z., Clemente, M., Jiménez Espadafor, F. J. Gutiérrez, J.M. (2009). Correcting injection pressure maladjustments to reduce NOx emissions by marine diesel engines. Transportation research Part D: Transport and environment, 14, 61-66.

Giziakis, C., &Christodoulou, A. (2012). Environmental awareness and practice concerning maritime air emissions: the case of the Greek shipping industry. Maritime Policy & Management, 39, 353-368.

Gong, X., Wu, X., & Luo, M. (2018). Company performance and environmental efficiency: A case study for shipping enterprises. Transport Policy.

Hickman, R., &Banister, D. (2007). Looking over the horizon: transport and reduced CO_2 emissions in the UK by 2030. Transport Policy, 14, 377-387.

Hong, N. (2012). The melting Arctic and its impact on China's maritime transport. Research in transportation economics, 35, 50-57.

Hoffmann, P. N., Eide, M. S., & Endresen, Ø. (2012). Effect of proposed CO2 emission reduction scenarios on capital expenditure. Maritime Policy & Management, 39(4), 443-460.

ITOPF (2017). http://www.itopf.com/knowledge-resources/data-statistics/statistics/

Jin, D., &Kite-Powell, H. L. (1999). On the optimal environmental liability limit for marine oil transport. Transportation Research Part E: Logistics and Transportation Review, 35, 77-100.

Kontovas, C., &Psaraftis, H. N. (2011). Reduction of emissions along the maritime intermodal container chain: operational models and policies. Maritime Policy & Management, 38, 451-469.

Kim, J., Rahimi, M., &Newell, J. (2012). Life-cycle emissions from port electrification: A case study of cargo handling tractors at the port of Los Angeles. International Journal of Sustainable Transportation, 6, 321-337.

Lai, K. H., Lun, V. Y. H., Wong, C. W. Y., Cheng, T.C.E. (2011). Green shipping practices in the shipping industry: Conceptualization, adoption, and implications. Resources, Conservation and Recycling, 55, 631-638.

Lai, K., Wong, C. W. Y., Lun, Y. H. V., Cheng, T.C.E. (2013). Shipping design for compliance and the performance contingencies for shipping firms. Transportation Research Part E: Logistics and Transportation Review, 55, 74-83.

Lam, J. S. L., &Gu, Y. (2013) Port hinterland intermodal container flow optimisation with green concerns: a literature review and research agenda. International Journal of Shipping and Transport Logistics, 5, 257-281.

Lam, J. S. L. (2015). Designing a sustainable maritime supply chain: A hybrid QFD–ANP approach. Transportation Research Part E: Logistics and Transportation Review, 78, 70-81.

Lindstad, H. E., &Eskeland, G. S. (2016). Environmental regulations in shipping: Policies leaning towards globalization of scrubbers deserve scrutiny. Transportation Research Part D: Transport and Environment, 47, 67-76.

Mackey, T.P., Tagg, R.D., &Parsons, M.G. (2000, May). Technology for ballast water management. The 8th ICMES/ SNAME New York Metropolitan Section Symposium, New York.

Mansouri, S. A., Lee, H., &Aluko, O. (2015). Multi-objective decision support to enhance environmental sustainability in maritime shipping: a review and future directions. Transportation Research Part E: Logistics and Transportation Review, 78, 3-18.

Maragkogianni, A., & Papaefthimiou, S. (2015). Evaluating the social cost of cruise ships air emissions in major ports of Greece. Transportation Research Part D: Transport and Environment, 36, 10-17.

National Research Council Committee on Ships' Ballast Operations. (1996). Stemming the Tide: Controlling Introductions of Nonindigenous Species by Ship Ballast Water. National Academy Press, Washington, DC.

Parsons, M.G., Cangelosi, A., Harkins, R.W., Mackey, T.P., Munro, D.J. (1997). Design of the Great Lakes ballast technology demonstration project. Transactions SNAME 105, 323–348.

Psaraftis, H. N., &Kontovas, C. A. (2010). Balancing the economic and environmental performance of maritime transportation. Transportation Research Part D: Transport and Environment, 15, 458-462.

Qi, X., &Song, D. P. (2012). Minimizing fuel emissions by optimizing vessel schedules in liner shipping with uncertain port times. Transportation Research Part E: Logistics and Transportation Review, 48, 863-880.

Qiu, X., Wong, E. Y., & Lam, J. S. L. (2018). Evaluating economic and environmental value of liner

vessel sharing along the maritime silk road. Maritime Policy & Management, 45(3), 336-350.
Rodrigues, V. S., Pettit, S., Harris, I., Bereford, A., Piecyk, M., Yang, Z., Ng, A. (2015). UK supply chain carbon mitigation strategies using alternative ports and multimodal freight transport operations. Transportation Research Part E: Logistics and Transportation Review, 78, 40-56.
Sterner, T., Dahl, C., &Franzen, M. (1992). Gasoline tax policy, carbon emissions and the global environment. Journal of transport economics and policy, 109-119.
Song, D. P., &Xu, J. (2012). An operational activity-based method to estimate CO_2 emissions from container shipping considering empty container repositioning. Transportation Research Part D: Transport and Environment, 17, 91-96.
Sun, J., Yuan, Y., Yang, R., Ji, X., & Wu, J. (2017). Performance evaluation of Chinese port enterprises under significant environmental concerns: An extended DEA-based analysis. Transport Policy, 60, 75-86.
Tight, M. R., Bristow, A. L., Pridmore, A., May, A.D. (2005) What is a sustainable level of CO_2 emissions from transport activity in the UK in 2050? Transport Policy, 12, 235-244.
Tian, Y., Zhu, Q., Lai, K., Lun, Y.H.V. (2014). Analysis of greenhouse gas emissions of freight transport sector in China. Journal of Transport Geography, 40, 43-52.
UNEP, FAO, IMO, UNDP, IUCN, World Fish Center, GRID- Arendal. (2012). Green Economy in a Blue World. Retrieved from http://www.unep.org/pdf/green_economy_blue.pdf
UNFCCC. (2015). Adoption of the Paris Agreement (FCCC/CP/2015/L.9). Retrieved from https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf
Venturini, G., Iris, Ç., Kontovas, C. A., & Larsen, A. (2017). The multi-port berth allocation problem with speed optimization and emission considerations. Transportation Research Part D: Transport and Environment, 54, 142-159.
Winnes, H., &Fridell, E. (2010). Emissions of NOx and particles from manoeuvring ships. Transportation Research Part D: Transport and Environment, 15, 204-211.
Wang, S., Meng, Q., &Liu, Z. (2013). Bunker consumption optimization methods in shipping: A critical review and extensions. Transportation Research Part E: Logistics and Transportation Review, 53, 49-62.
Woo, J. K., &Moon, D. S. H. (2014). The effects of slow steaming on the environmental performance in liner shipping. Maritime Policy & Management, 41, 176-191.
Wang, K., Fu, X., &Luo, M. (2015). Modeling the impacts of alternative emission trading schemes on international shipping. Transportation Research Part A: Policy and Practice, 77, 35-49.
Wan, Z., Zhu, M., Chen, S., Sperling, D. (2016). Pollution: Three steps to a green shipping industry. Nature, 530,275-277.
Wang, K., Yan, X., Yuan, Y., Li, F. (2016). Real-time optimization of ship energy efficiency based on the prediction technology of working condition. Transportation Research Part D: Transport and Environment, 46, 81-93.
Xu, J. (2009). The law and economics of pollution damage arising from carriage of oil by sea.
Maritime Policy & Management, 36, 309-323.
Yang, Z., &Perakis, A. N. (2004). Multiattribute decision analysis of mandatory ballast water treatment measures in the US Great Lakes. Transportation Research Part D: Transport and Environment, 9, 81-86.
Yang, Z. L., Zhang, D., Caglayan, O., Jenkinson, I.D., Huang, M., Yan, X.P. (2012). Selection of techniques for reducing shipping NOx and SOx emissions. Transportation Research Part D: Transport

and Environment, 17, 478-486.
Yang, C. S., Lu, C. S., Haider, J. J.,Marlow, P. B. (2013). The effect of green supply chain management on green performance and firm competitiveness in the context of container shipping in Taiwan. Transportation Research Part E: Logistics and Transportation Review, 55, 55-73.
Yiğit, K., Kökkülünk, G., Parlak, A., Karakas, A. (2016). Energy cost assessment of shoreside power supply considering the smart grid concept: a case study for a bulk carrier ship. Maritime Policy & Management, 43, 469-482.
Zhu, W., Nowak, M. P., Erikstad, S. O. (2016). Emission allocation issues in repositioning transportation. International Journal of Sustainable Transportation, 10, 365-375.