A study on the national responsibility of CO2 emission by container shipping network

Master's Thesis

A STUDY ON THE NATIONAL RESPONSIBILITY OF CO2 EMISSION BY CONTAINER SHIPPING NETWORK

September 2017

Graduate School of Marine Science and Technology
Tokyo University of Marine Science and Technology
Master's Course of Marine Technology and Logistics

Kim Kwansub

Contents

1. Introduction 2
1.1. Objective of the Thesis 2
1.1.1. Necessity of the Thesis 2
1.1.2. Structure of the Thesis 4
1.2. Study Background 5
1.2.1. Trends in International Marine Container Transport 5
1.2.2. MEPC, 69th Session 9
2. The Importance of Cutting Off CO2 in the Shipping Industry 11
2.1. Mechanisms for Global Warming 11
2.1.1. Global Warming 11
2.1.2. Greenhouse Gas Effect 11
2.1.3. Types of Greenhouse Gas 12
2.2. Status of CO2 Emission 13
2.2.1. Climate Change by CO2 in the Atmosphere 13
2.2.2. Total CO2 Emission per Country 17
2.3. Worldwide Effort to Solve Global Warming 20
3. Energy Efficiency Operational Indicator 22
3.1. Definition of EEOI 22
3.1.1. Introduction 22
3.1.2. Objective of Guideline 22

3.2. Calculation of EEOI 23
3.2.1 Definitions 23
3.2.2 Calculation 24
4. Data Collection of Container Shipping for EEOI 26
4.1. Setting Targets 26
4.2. Liner Route 26
4.2.1. Liner Route of Japan to LA/LB 26
4.2.2. Liner Route of Korea to LA/LB 29
4.3 Export Containers of Japan to LA/LB and Korea to LA/LB 31
4.4 Information of Ships in the Liner 32
4.4.1. Liner Ships from Japan to LA/LB 32
4.4.2. Liner Ships from Korea to LA/LB 33
4.5. Fuel Consumption 34
4.5.1. Fuel Consumption of Japan to LA/LB 36
4.5.2. Fuel Consumption of Korea to LA/LB 36
5. Analysis of EEOI in Container Shipping 37
5.1. EEOI of Japan to LA/LB 37
5.2. EEOI of Korea to LA/LB 37
5.3. Comparative Analysis of EEOI 38
5.4. Proposal of Modified Liner 39
6. Conclusions 42
References 44

Abstract

Recently greenhouse gases emission from the shipping have become more important issue. Emission of air pollutants and greenhouse gases from the shipping sector have increased constantly for many years, contributing to both climate change and air pollution problems. In 1997, when the Kyoto Protocol first assigned responsibility for international transport emissions to IMO. The 1997 MARPOL Conference convened by the IMO adopted Resolution 8 on “CO2 emissions from ships”. Furthermore, the IMO Marine Environment Protection Committee (MEPC), 69th session, approved obligatory requirements for ships to report and record data on their fuel consumption for the marine transport by the ship.

Likewise, IMO has been trying to reduce greenhouse gases from shipping. However, although greenhouse gas is a necessary task for international cooperation, it does not clearly identify the responsibilities of each country. Therefore, in this study, I tried to distinguish the container shipping emission responsibility of each country from the efficiency of shipping. For this, Energy Efficiency Operational Indicator (EEOI) was used. Until now, there have been many studies on EEOI and analyzing EEOI for some shipping companies. However, there is a lack of study on EEOI model based on the global shipping network among national scale.

Further, the more research will be needed to distinguish national responsibilities in order for each country to work smoothly with the global agenda global warming.

Keywords: Energy efficiency operational indicator, CO2 emission, Container ship, Logistics

1. Introduction

1.1 Objective of the Thesis

1.1.1 Necessity of the Thesis

Since 1995, the Conference of the Parties (COP) has been held annually.

The main mission of the COP is to review the domestic communications and emissions lists submitted by the Parties. Based on this information, the COP assesses the effectiveness of the measures taken by the Parties and the progress of achieving them. The Kyoto Protocol was adopted in COP3, Kyoto, Japan, on 11th December 1997 and entered into force on 16th February 2005. In 2015, Paris agreement, a new international framework for climate change, was adopted in COP 21, France. The Paris Agreement is a United Nations Framework Convention on Climate Change (UNFCCC) agreement that deals with greenhouse gas emissions mitigation, adaptation and financing starting in 2020.

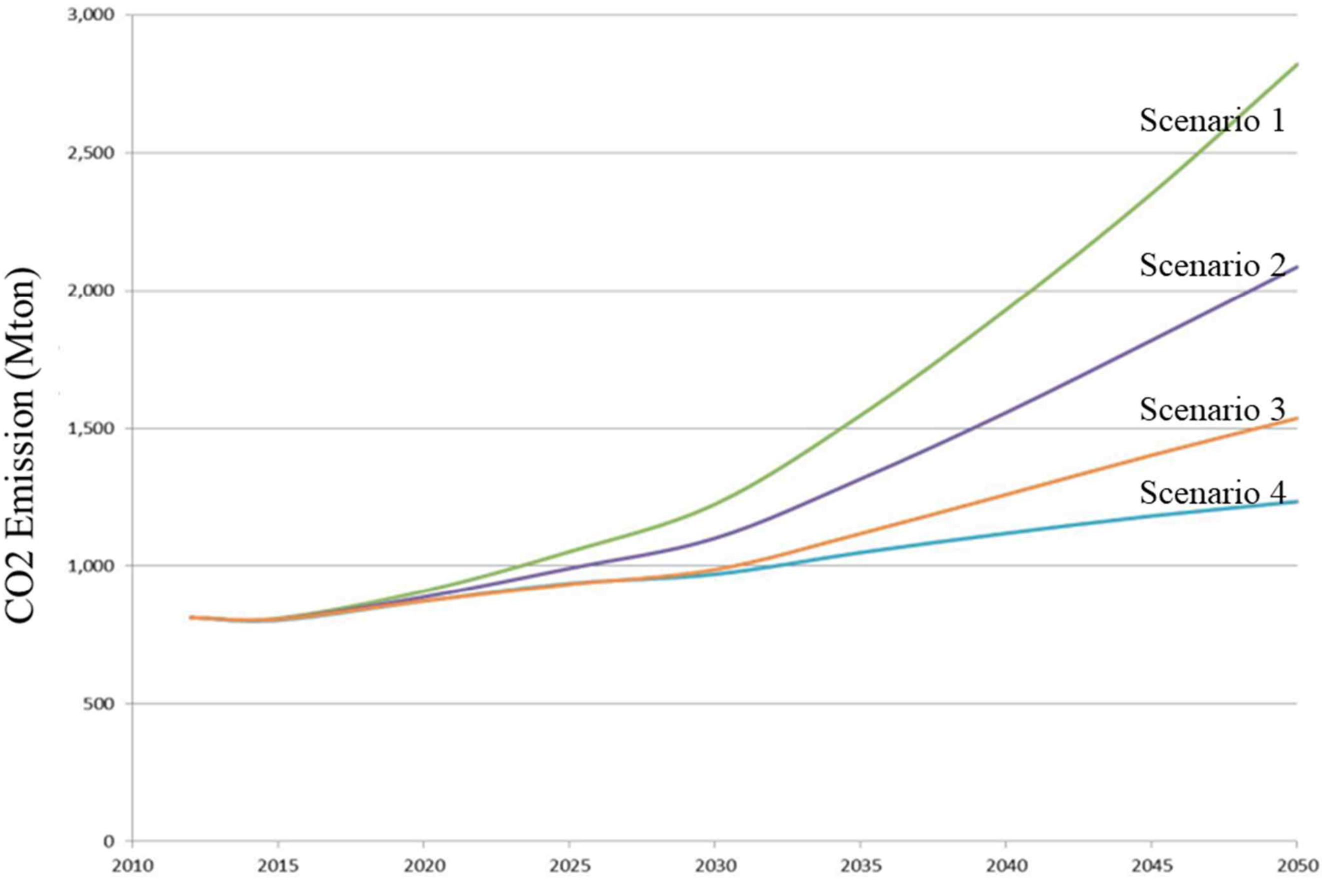


Figure 1: Projections of CO2 Emissions from International Maritime Transport 2012–2050

Source: Third IMO Greenhouse Gas Study 2014[1)]

In 2011, The International Maritime Organization (IMO) has adopted a new chapter in the Marine Pollution (MARPOL) Annex VI, which includes a package of essential technical and operational measures to reduce greenhouse gas (GHG) emissions from international shipping to improve the energy efficiency of ships. These measures came into force in 2013.

According to IMO, Maritime CO2 emissions are expected to increase significantly. Depending on future economic and energy developments, IMO's four scenarios are expected to increase between 50% and 250% by 2050, as shown in Figure 1. However, since MARPOL Annex VI was just implemented, there is a possibility that international cooperation for reducing CO2 emissions will be hampered by the lack of clarifying where the responsibility lies and penalties. Furthermore, with the need for CO2 emission cuts in the shipping industry and the rapid economic growth in China and other countries in Asia, a modest and sustainable reduction is required for future shipping industry.

Even though there has been much research on cost and system for shipping network, researches on the national responsibility of CO2 emission by shipping network are probably not enough yet. As shown in Figure 2 and Figure 3, especially the fuel consumption and the CO2 emission rate of the container ship is higher than other vessels and is chosen as the target of this study.

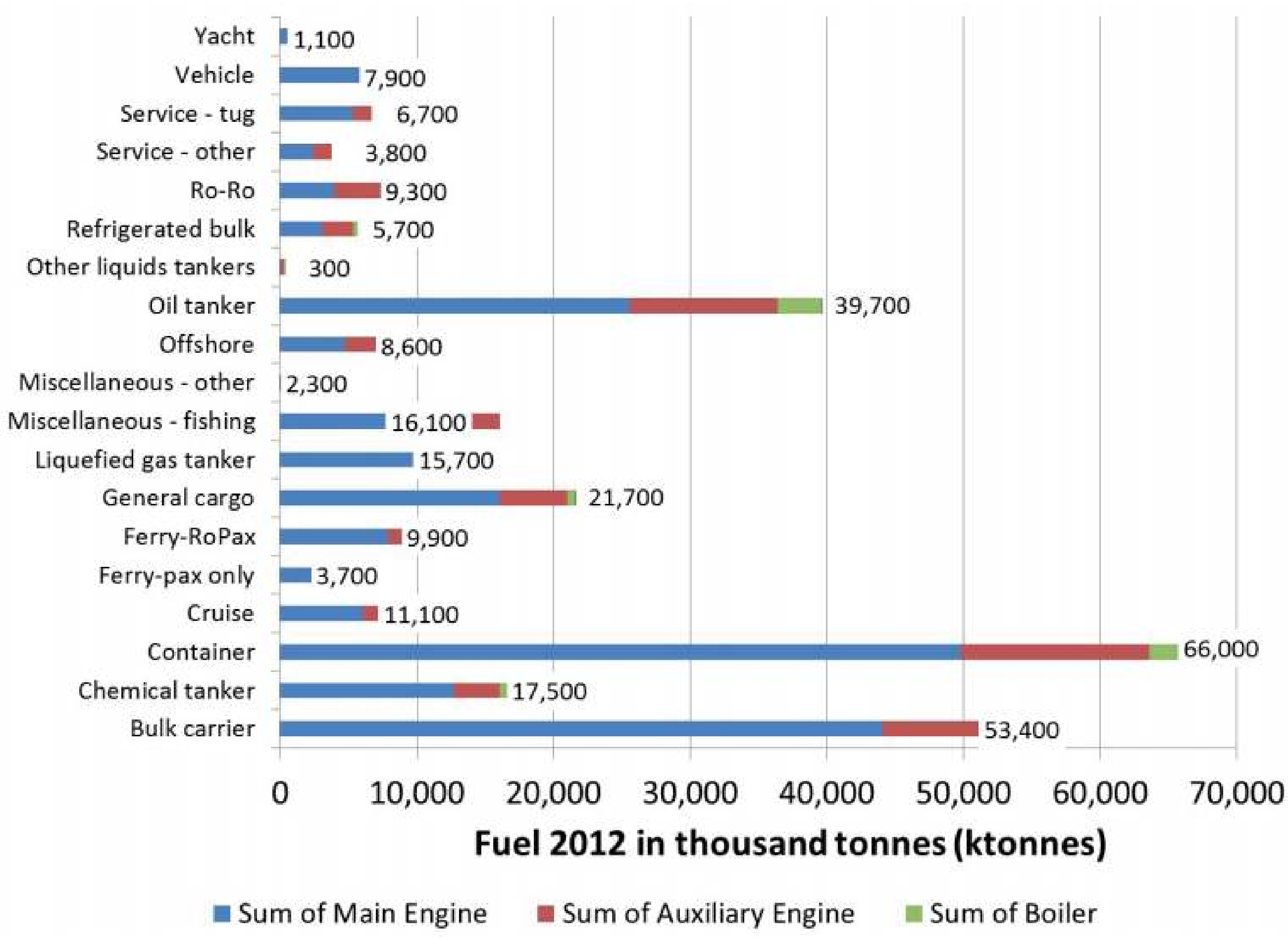


Figure 2: Summary graph of annual fuel consumption by ship type in 2012
Source: Third IMO Greenhouse Gas Study 2014[1)]

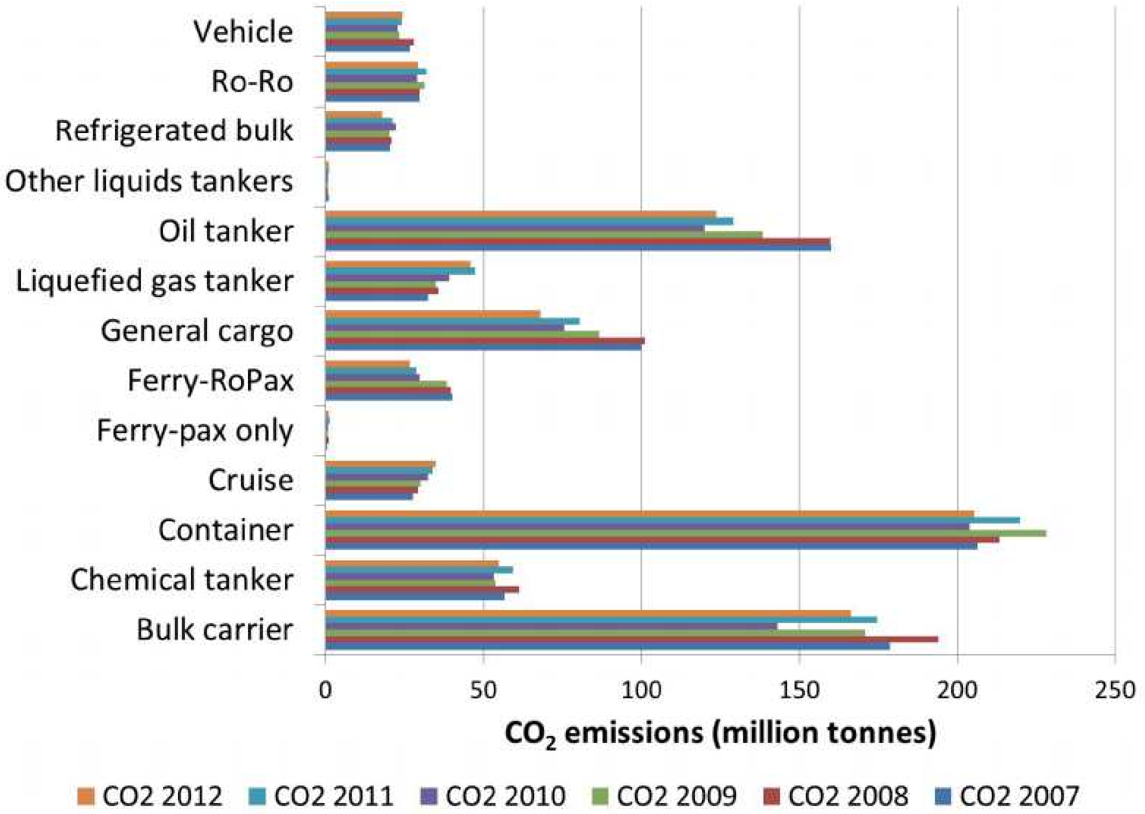


Figure 3: CO2 Emissions by Ship Type (International Shipping Only) for 2007–2012

Source: Third IMO Greenhouse Gas Study 2014[1)]

Generally, the volume of shipping cargo increase, so does CO2 emissions. However, the efficiency of CO2 emissions to transport unit cargo can vary depending on the shipping route and ship size of the country or companies.

This study aims at contributing to the sustainability and development of international shipping by clarifying the responsibility of each country 's CO2 emissions by studying the efficiency of each country' s shipping network. In order to rationally examine the efficiency of each country 's shipping network, the fuel consumption and traffic volume of maritime transportation were taken as data and the efficiency was judged based on this data.

1.1.2 Structure of the Thesis

This thesis will be divided into six chapters. A brief description of the contents of each chapter is given below.

Chapter 1: Introduction

This chapter presents the background information on the thesis, the overview of the thesis; its purpose and objective, and the general structure of the research.

Chapter 2: The Importance of Cutting Off CO_2 in the Shipping Industry

The purpose of this chapter is to explain the current state of global warming problems, the trends in shipping industry, and shows the necessity of this study on the view of international shipping network by clarifying environmental measures and importance of cutting off CO_2 in the shipping industry.

Chapter 3: Energy Efficiency Operational Indicator

The purpose of this chapter is to explain the definition of Energy Efficiency Operational Indicator (EEOI) which were used in this thesis. It also describes how the emission efficiency of the shipping network is analyzed through the EEOI.

Chapter 4: Data Collection of Container Shipping for EEOI

The aim of this chapter is to provide obvious explanations about the data. The data include liner routes, shipping volume, information of ships in the liner, and fuel consumption. The main sources of this data are International Transportation Handbook 2015 of Ocean Commerce Ltd., International handbook of maritime economics and Statistics data of each Port and Harbors Bureau.

Chapter 5: Analysis of EEOI in Container Shipping

This chapter's purpose is to analyze the EEOI of Korea – Los Angeles and Long Beach and Japan – Los Angeles and Long Beach to find the efficiency of CO_2 emissions for shipping. From analyzing the EEOI of each country, efficiency of Japan and Korea for export to LA/LB were found. The proposal of modified shipping liners is also provided in this chapter.

Chapter 6: Conclusions

As conclusion of this thesis, the amount of CO_2 per unit container varies with the amount of cargo, the volume of fleets and average size of the vessel used. This result shows the possibility that CO_2 emissions can be reduced more than the present according to the efforts of each country. In addition, this chapter describes the prospect of contributing to the regulation of GHG emission in the shipping industry and the international cooperation.

1.2 Study Background

1.2.1 Trends in International Marine Container Transport

The shipping network is the center of international logistics and supports world industries and the abundant life of people all over the world. With the increasing demand for logistics worldwide every year, ports are being improved in many countries around the world. The shipping industry is also changing every moment, such as the reorganization of global alliances of shipping companies in accordance with the global situation.

Especially, globalization of recent socioeconomic activities and IT industries are leading companies' globalization and price competition, and rationalization of logistics is becoming essential now. In addition, in order to improve the contents of services required by a variety of consumer values and timely delivery of small quantity batch production, it is important for global companies to develop a series of processes from production to consumption and reduce costs. Furthermore, the construction of a global logistics system of companies is carried out bidirectionally from all over the world, from raw materials to products, and most of them are maritime transportation through ports. Therefore, the efficiency of the shipping network should be considered because the container shipping volume of the world and the importance of the container terminal as a hub of international logistics are increasing.

Firgure.4 shows the world container trade volume. As can be seen from Figure.4, container transportation is expanding globally with economic development. Until 2008, there was a large increase trend, but in 2008, when the collapse of Lehman Brothers occurred, the trade volume temporarily decreased, but it continues to increase after that. In other words, it can be said that the importance of shipping network is increasing.

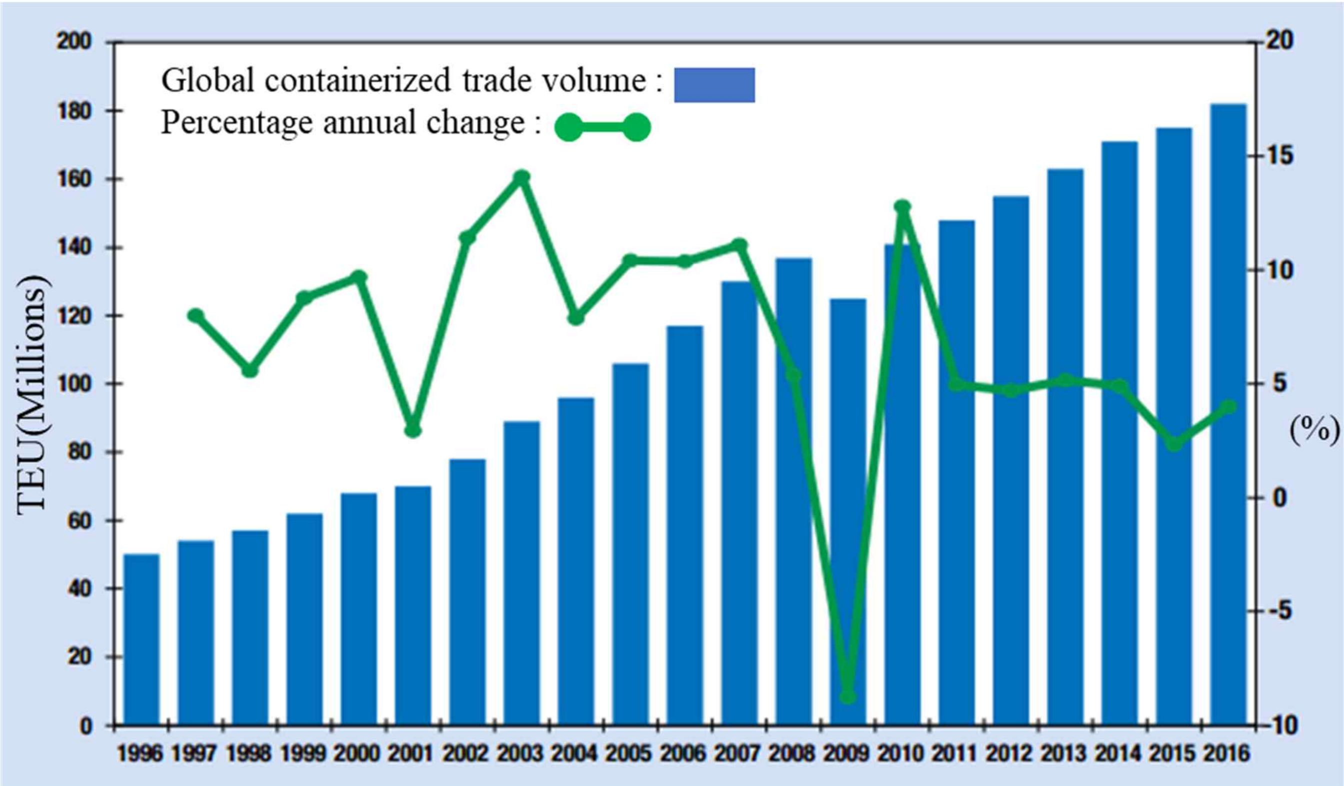


Figure 4: Global Containerized Trade, 1996–2016
(Millions of Twenty-foot Equivalent Units and Percentage Annual Change)
Source: Review of Maritime Transport 2016, UNCTAD[2)]

As shown in Table 1 and Table 2, the recent container freight volume has greatly increased worldwide in comparison with 2000. Especially, it can be seen that the container handling of Asian countries' ports has increased dramatically along with economic growth. This rate of increase will continue to rise with the development of Asian developing countries. This means that CO2 emissions from shipping industry in Asia will rise further.

Table 1: World Rankings of Container Handling

Source: 国土交通省 港湾関係情報 世界の国別コンテナ取扱個数ランキング [3)]

		2014			2000
Rank	Country	Container(10,000TEU)	Rank	Country	Container(10,000TEU)
1	China	18164	1	China	3548
2	U.S.A	4649	2	U.S.A	2730
3	Singapore	3483	3	Singapore	1709
4	South Korea	2380	4	Japan	1362
5	Malaysia	2272	5	Taiwan	1051
6	Hongkong	2230	6	South Korea	853
7	U.A.E	2090	7	Germany	769
8	Japan	2074	8	Italy	693
9	Germany	1969	9	U.K	652
10	Taiwan	1643	10	Netherlands	640
11	Spain	1471	11	Spain	575
12	Netherlands	1251	12	Belgium	505
13	Indonesia	1190	13	Arab Emirates	505
14	India	1166	14	Malaysia	461
15	Italy	1131	15	Indonesia	386
16	Belgium	1119	16	Philippines	360
17	Brazil	1068	17	Australia	350
18	Vietnam	953	18	Thai	326
19	U.K	935	19	Canada	292
20	Egypt	881	20	France	292
21	Thai	828	21	Puerto Rico	242
22	Panama	794	22	Panama	236
23	Turkey	762	23	Brazil	234
24	Australia	752	24	India	231
25	France	665	25	South Africa	202
26	Saudi Arabia	633	26	Sri Lanka	173
27	Philippines	587	27	Egypt	159
28	Canada	558	28	Turkey	157
29	Mexico	527	29	Saudi Arabia	150
30	Iran	516	30	Greece	139

Table 2: World Port Rankings of Container Handling

Source: 国土交通省 港湾関係情報 世界の港湾別コンテナ取扱個数ランキング [3)]

2014				2000			
Rank	Port	Country	Container (10,000TEU)	Rank	Port	Country	Container (10,000TEU)
1	Shanghai	China	3653	1	Hong Kong	China	1810
2	Singapore	Singapore	3092	2	Singapore	Singapore	1704
3	Shenzhen	China	2420	3	Busan	Korea	754
4	Ningbo	China	2062	4	Takao	Taiwan	742
5	Hong Kong	China	2011	5	Rotterdam	Netherlands	627
6	Busan	China	1946	6	Shanghai	China	561
7	Guangzhou	China	1762	7	Los Angeles	U.S.A.	487
8	Qingdao	China	1751	8	Long Beach	U.S.A.	460
9	Dubai	U.A.E.	1559	9	Hamburg	Germany	424
10	Tianjin	China	1410	10	Antwerp	Belgium	408
11	Rotterdam	Netherlands	1223	11	Port Kaelan	Malaysia	320
12	Port Kaelan	Malaysia	1189	12	Dubai	U.A.E.	305
13	Takao	Taiwan	1026	13	New York	U.S.A.	300
14	Antwerp	Belgium	965	14	Tokyo	Japan	289
15	Dalian	China	945	15	Manila	Philippines	286
16	Xiamen	China	918	16	Felix tow	UK	280
17	Tanjung Pelepas	Malaysia	912	17	Bremen	Germany	271
18	Hamburg	Germany	882	18	Gioia Tauro	Italy	265
19	Los Angeles	U.S.A.	816	19	Tanjung Priok	Indonesia	247
20	Long Beach	U.S.A.	719	20	San Juan	Puerto Rico	239
21	Laem chabang	Thailand	687	21	Yokohama	Japan	231
22	New York	U.S.A.	637	22	Kobe	Japan	226
23	Yingkou	China	592	23	Laem chabang	Thailand	219
24	Ho Chi Minh City	Vietnam	578	24	Salt field	China	214
25	Bremen	Germany	530	25	Qingdao	China	212
26	Tanjung Priok	Indonesia	520	26	Algeciras	Spain	200
27	Colombo	Sri Lanka	518	27	Keelung	China	195
28	Lianyun	China	500	28	Nagoya	Japan	191
29	Tokyo	Japan	462	29	Auckland	U.S.A.	177
30	Valencia	Spain	461	30	Colombo	Sri Lanka	173

In 2015, the fleet has risen by 8.5% from 2014 and is expected to rise by 4.5% during 2016, 5.6% during 2017 and 3.9% during 2018. (Table 3)

According to one study[4)], container line sizes up to 18,000 TEU can reduce shipping and port costs by only 5% of the maximum network cost. Rather, as the vessel size increases to more than 18,000 TEU, the economic efficiency may decrease.

Table 3: Container ship fleet projections (2015-2019)

Source: FleetForecast, Alphaliner, 2016[5)]

Fleet as at :	31 Dec 2015		31 Dec 2016		31 Dec 2017		31 Dec 2018		31 Dec 2019		Rise p.a. (3 years)
TEU nominal	ships	teu	ships	teu	ships	teu	ships	teu	ships	teu	teu terms
18000-21000	35	656 524	48	907 354	73	1 411 642	102	1 967 450	109	2 097 750	44,2%
13300-17999 *	109	1 572 072	130	1 876 108	149	2 143 108	163	2 339 958	165	2 367 958	14,2%
10000-13299	193	2 278 542	220	2 572 492	247	2 879 172	263	3 081 572	265	3 105 172	10,6%
7500-9999	454	3 985 032	487	4 291 437	489	4 310 237	489	4 310 237	489	4 310 237	2,6%
5100-7499	510	3 148 660	511	3 155 542	517	3 190 752	523	3 222 522	525	3 233 112	0,8%
4000-5099	735	3 335 118	737	3 343 118	741	3 359 118	741	3 359 118	741	3 359 118	0,2%
3000-3999	262	908 010	269	933 188	280	973 588	286	995 988	286	995 988	3,1%
2000-2999	648	1 639 599	681	1 719 220	711	1 796 973	729	1 846 909	732	1 855 309	4,0%
1500-1999	581	992 755	614	1 050 804	634	1 086 852	651	1 117 080	651	1 117 080	4,0%
1000-1499	696	807 604	715	828 551	735	852 751	742	862 171	742	862 171	2,2%
500-999	748	556 171	750	557 314	750	557 314	750	557 314	750	557 314	0,1%
100-499	182	57 978	182	57 978	182	57 978	182	57 978	182	57 978	
TOTAL	5 153	19 938 065	5 344	21 293 106	5 508	22 619 485	5 621	23 718 297	5 637	23 919 187	6,0%
TOTAL after Exp. Scrap/Slip	5 153	19 938 065	5 192	20 843 106	5 268	22 019 485	5 281	22 868 297	5 197	22 819 187	4,7%
Rise 12 months	2015 >	8,5%	2016 >	4,5%	2014 >	5,6%	2017 >	3,9%	2018 >	-0,2%	

Some researchers claim that the cost of a larger ship may be more than its profit. Disadvantages include reduced service frequency, increased pressure to operate cargo handling services, increased terminal capital and operating costs, reduced options for freight carriers, and increased supply chain risk.

1.2.2 MEPC, 69th Session

Marine Environment Protection Committee (MEPC), 69th Session, held in London from April 18 to 22, 2016, discussed key issues related to the protection of the marine environment. About 970 people attended the meeting, including 106 member countries, 67 representatives of international organizations. In particular, there has been much discussion and review of ship efficiency related to GHG emissions at this meeting. The most important discussion at this meeting was the mandatory collection system of fuel consumption data for ships. This system is a very important in this study which judges the efficiency and responsibilities of maritime transportation.

The contents of the mandatory collection of fuel consumption data in MEPC 69 session are as follows.

i) The International Maritime Organization's (IMO) Marine Environment Protection Committee (MEPC) has approved a mandatory requirement that vessels record and report fuel consumption in a clear and positive signal to the Organization's ongoing commitment to mitigating climate change.

ii) The mandatory data collection system was intended to be the first goal of a three-step process in which the analysis of the collected data provided MEPC with a basis for objective, transparent and comprehensive policy debate. This allows you to make decisions about whether you need to take additional steps to improve energy efficiency and address greenhouse gas emissions from international shipping.

iii) Under this system, over 5,000 tons of vessels must collect consumption data for each type of fuel they use and collect additional data, including representatives for transport operations. The aggregated data is reported to the flag State at the end of each year, and the flag State issues a Declaration of Conformity to the vessel after determining that the data has been reported according to the requirements. The flag state must then transfer this data to the IMO ship fuel consumption database.

iv) IMO must summarize the data collected and submit an annual report to the MEPC. The data is anonymous, so individual ship data is not recognized.

v) The mandatory data collection requirements draft will be adopted at the 70th MEPC session in October this year and may take effect in 2018.

vi) This data collection system is included in the amendments to the MARPOL Draft Convention approved by MEPC 69 at its IMO headquarters in London.

2. The Importance of Cutting Off CO_2 in the Shipping Industry

This chapter describes the mechanisms of global warming that are known to occur as CO_2 emissions increase and describes the state of CO_2 emissions. In addition, the impacts and international standards of GHG are summarized. It also grasps the efforts of international organizations to reduce CO_2 emissions.

2.1 Mechanisms for Global Warming

2.1.1 Global Warming

The temperature of the earth is considerably different when compared to the tropical region and the Arctic, but the average is about 15 ° C and the entire earth is in a state suitable for living. CO_2, methane and freon gas which is called "greenhouse gas" have a great influence on the Earth's temperature. If GHG does not exist on Earth, the average temperature of the Earth is known to be -19 ° C. In other words, greenhouse gases are essential for the survival of living things.

However, with the development of modern civilization, the mass consumption of resources has been promoted and the CO_2 emission is accelerating rapidly. As a result, the increase in the concentration of GHG including atmospheric CO_2 increases the greenhouse effect, causing global average temperature rise, which is called “Global warming”.

The air pollution of the earth is one of the important tasks in the continual development of mankind because it causes global warming and temperature change.

2.1.2 Greenhouse Gas Effect

The sun changes the climate of the earth. It mainly emits energy at very short wavelengths, such as a visible or near-visible part of the spectrum. About one-third of the solar energy reaching the Earth's atmosphere is reflected in space. The remaining two-third is absorbed by the surface of the earth, and only a portion is absorbed by the atmosphere. In order to balance the absorbed incoming energy, the Earth must release the same amount of energy back into space. Because the Earth is much colder than the Sun, it radiates at much longer wavelengths, primarily in the infrared part of the spectrum. (Figure 5)

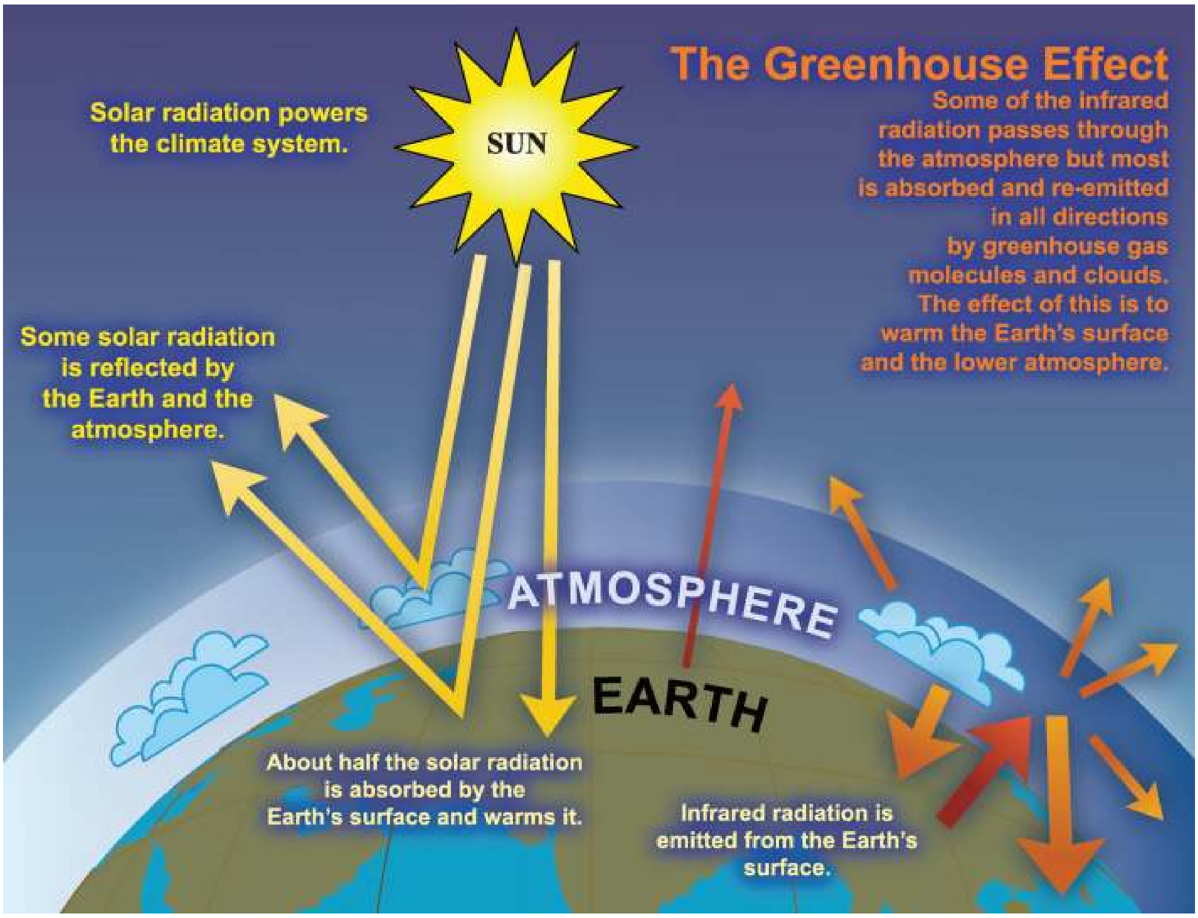


Figure 5: The principle of the natural greenhouse effect

Source: IPCC, Working Group I Fourth Assessment Report "The Physical Science Basis"[7)]

Much of this thermal radiation emitted by the land and ocean is absorbed by the atmosphere, including clouds, and reradiated back to Earth. This is called the greenhouse effect. Walls in the greenhouse reduce airflow and increase the temperature of the air inside. Similarly, the Earth's greenhouse effect warms the Earth's surface through different physical processes.

Without a natural greenhouse effect, the average surface temperature of the Earth will be below the freezing point of water. The Earth 's natural greenhouse effect creates the right environment for life. But human activity, mainly fossil fuel burning and deforestation, has greatly enhanced the natural greenhouse effect that causes global warming.

2.1.3 Types of Greenhouse Gas

In the Kyoto Protocol, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6) were defined as major greenhouse gases. The gas that has the most impact on the global warming phenomenon is CO_2.

Table 4: Major greenhouse gases

Source: Kyoto Protocol Reference Manual[9)]

Gas name	Chemical Formula
Carbon dioxide	CO_2
Methane	CH_4
Nitrous oxide	N_2O
Hydrofluorocarbons	HFCs
Perfluorocarbons	PFCs
Sulfur hexafluoride	SF_6

2.2 Status of CO2 Emission

2.2.1 Climate Change by CO2 in the Atmosphere

According to the Intergovernmental Panel on Climate Change (IPCC), the averaged combined land and ocean surface temperatures of the Earth warmed by 0.85 (0.65 to 1.06) °C on average between 1880 and 2012. The average temperature rise between 1850-1900 and 2003-2012 was 0.78 [0.72-0.85] °C. (Figure 6)

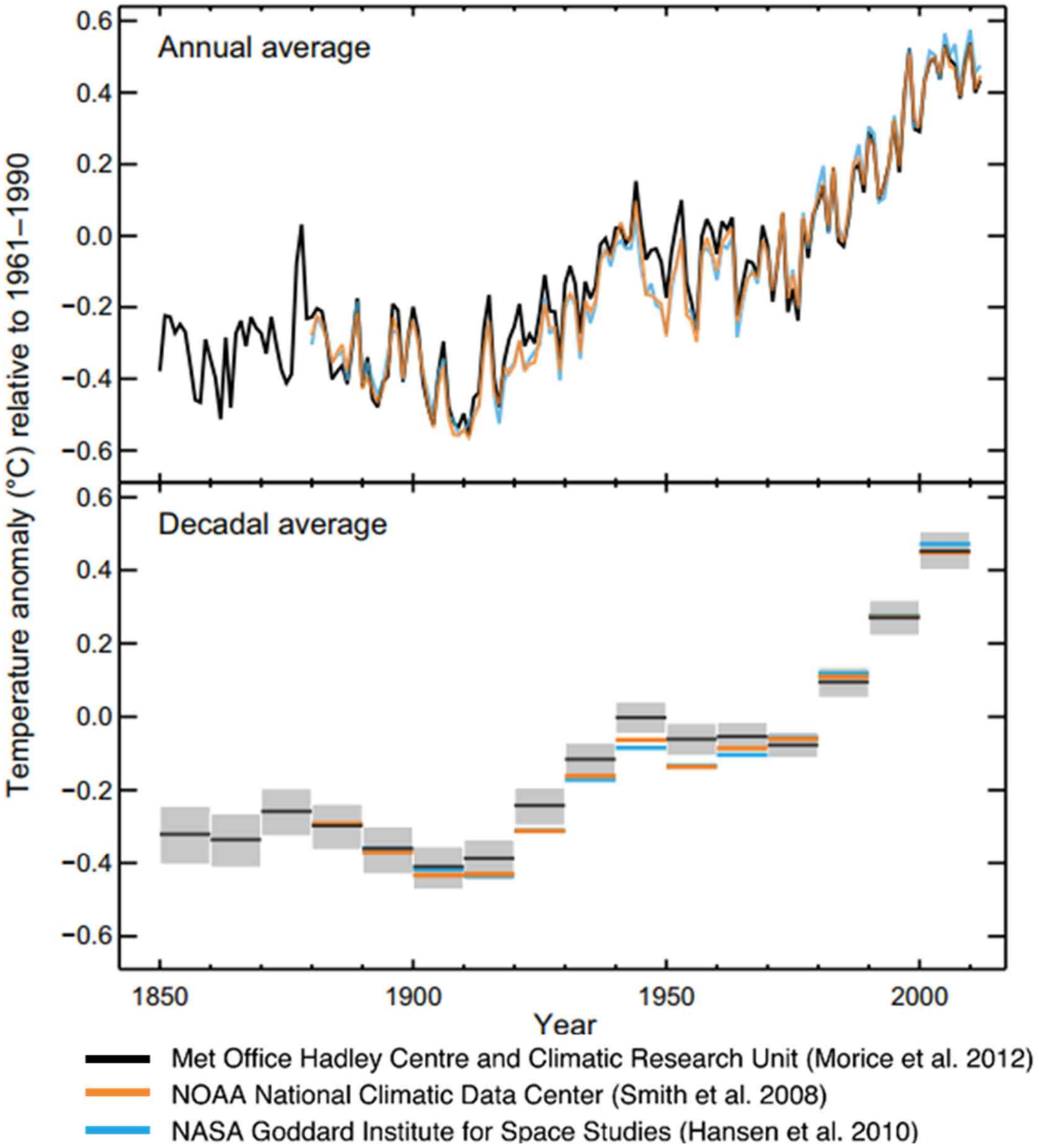


Figure 6: Observed globally averaged combined land and ocean surface temperature anomaly 1850 – 2012

Source: IPCC, Climate Change 2013[8)]

According to the National Oceanic and Atmospheric Administration (NOAA), the atmospheric concentration of CO has increased to an annual average of 1.80 ppm over the past 38 years (1979-2016). An average of about 1.5 ppm per year in the 1980s and 1990s, and 2.2 PPM per year for the last decade (2007-2016). The most recent record, January 2016 - January 2017 was 2.9 ± 0.1 ppm. In other words, it can be seen that the increase of CO2 is accelerating. (Figure 7 and Table 5)

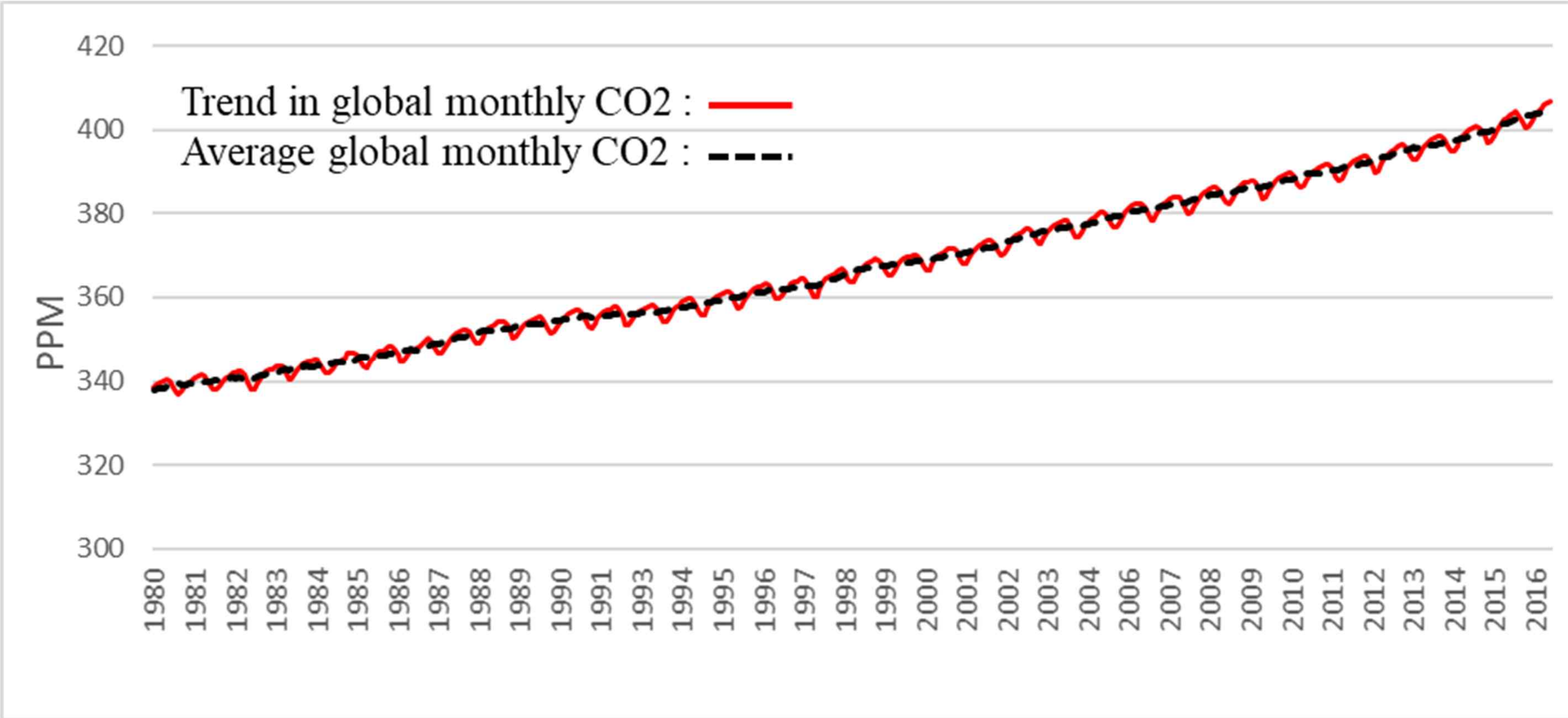


Figure 7: Global mean CO2 1980-2016

Source: National Oceanic and Atmospheric Administration (NOAA)[10)]

/

Table 5: Globally averaged marine surface annual mean CO2 data

Source: National Oceanic and Atmospheric Administration (NOAA) [10)]

Year	Mean (PPM)	Annual increase (PPM)
1980	338.80	1.70
1981	339.99	1.15
1982	340.76	1.00
1983	342.43	1.84
1984	343.98	1.24
1985	345.46	1.63
1986	346.88	1.04
1987	348.62	2.69
1988	351.14	2.24
1989	352.79	1.38
1990	353.96	1.18
1991	355.28	0.73
1992	355.99	0.70
1993	356.71	1.22
1994	358.20	1.68
1995	360.03	1.95
1996	361.79	1.07
1997	362.90	1.98
1998	365.55	2.80
1999	367.63	1.34
2000	368.81	1.24
2001	370.40	1.84
2002	372.42	2.38
2003	374.97	2.27
2004	376.78	1.55
2005	378.81	2.44
2006	380.93	1.77
2007	382.67	2.09
2008	384.78	1.78
2009	386.28	1.62
2010	388.56	2.44
2011	390.44	1.68
2012	392.45	2.39
2013	395.19	2.44
2014	397.11	2.00
2015	399.41	2.96
2016	402.85	2.93

2.2.2 Total CO_2 Emission per Country

Although emissions in China, India and other countries with emerging economies increased very rapidly in recent years, CO_2 emissions per capita is different. Where, since 1990, in the European Union CO_2 emissions decreased from 9.2 to 6.9 tons per capita, and in the United States from 19.8 to 16.1 tons per capita, they increased in China from 2.0 to 7.7. As such, Chinese citizens, together representing 19% of the world population in 2015, on average emitted about 0.8 tons of CO_2 per capita more in 2015 as the average European citizen. In contrast, India's emissions of 1.9 tons per capita are 5 tons per capita lower than the EU average.

In the lowest levels of CO_2 per capita of OECD-1990 countries in 2015 are those of France (5.1 tons CO_2/cap because of the amount of nuclear energy used in that country) and the highest levels were seen in Australia (18.6 tons CO_2/cap because of its very high share of coal in power generation). The per-capita CO_2 emissions in the United States decreased from 16.6 in 2014 to 16.1 tons CO_2/cap in 2015, and decreased in Japan to 9.9 tons CO_2/cap.

When comparing CO_2 trends between countries over a decade or more, trends in population numbers also should be taken into account, as population growth differs considerably, also among developed countries, with the highest growth rate since 1990 seen in Australia (40% between 1990 and 2015), in Canada (30%) and in the United States (27%). The populations of the European Union and Japan, however, increased much less (by 6.8% and 3.5%, respectively), and the Russian Federation even saw a decline of 2.8%. In comparison, the population of China increased by 19.2%, India 50.6% and Brazil 38.2% since 1990. The CO_2 emissions from G20 countries increased in the period from 1990 to 2015 by 60%. From 2014 to 2015 CO_2 emissions decreased with 0.5%. Of the total world population, 82% is living in countries which are member of the G20. The per-capita CO_2 emissions of G20 countries increased from 5.0 (1990) to 6.3 (2015) tons CO_2/cap, almost identical to the United Kingdom (6.2 tons CO_2/cap in 2015). The group of G20 countries account for 80% of the global GDP. Per unit of GDP emissions decreased with 28% in the 1990–2015 period. The remaining 194 countries account for 14.6 % to global CO_2 emissions in 2015. (Trends in Global CO_2 Emissions 2016 report).

It is clear that most of the CO_2 emissions currently occur in the G20 countries and that the problem of global warming has accelerated in the past rapid development of developed countries. In order to solve the global warming problem, it is necessary for developed countries to recognize the responsibility and act actively.

Table 6: Trends in global CO2 emissions

Source: European Commission, Emission Database for Global Atmospheric Research[11)]

(Unit: billion tons of CO2)

Country	1990	1995	2000	2005
World Total	**22.67**	**23.84**	**25.83**	**30.02**
China	2.29	3.30	3.63	6.17
U.S.A.	5.00	5.29	5.87	5.89
EU28	4.39	4.13	4.10	4.21
India	0.65	0.87	1.06	1.27
Russia	2.39	1.75	1.68	1.74
Japan	1.16	1.23	1.26	1.29
Germany	1.02	0.91	0.86	0.83
Int. Shipping	0.37	0.43	0.49	0.57
Iran	0.20	0.28	0.35	0.47
Korea	0.27	0.40	0.48	0.52
Canada	0.45	0.48	0.55	0.56
Saudi Arabia	0.17	0.22	0.26	0.31
Indonesia	0.16	0.24	0.29	0.36
Int. Aviation	0.26	0.29	0.36	0.42
Brazil	0.22	0.27	0.34	0.36
Mexico	0.29	0.32	0.38	0.41
Australia	0.28	0.30	0.36	0.41
South Africa	0.28	0.30	0.32	0.40
United Kingdom	0.58	0.55	0.55	0.56
Turkey	0.15	0.18	0.23	0.25
Italy	0.43	0.44	0.46	0.49
France	0.38	0.38	0.40	0.41
Poland	0.36	0.36	0.31	0.31
Thailand	0.09	0.16	0.17	0.23
Taiwan	0.13	0.17	0.23	0.27
Kazakhstan	0.25	0.18	0.14	0.19
Spain	0.23	0.25	0.31	0.37
Malaysia	0.05	0.09	0.12	0.18
Ukraine	0.82	0.50	0.39	0.37
Egypt	0.09	0.10	0.12	0.17
Other countries (181)	3.47	3.38	3.61	4.02

(Unit: billion tons of CO2)

Country	**2010**	**2013**	**2014**	**2015**
World Total	**33.87**	**35.87**	**36.27**	**36.24**
China	8.99	10.50	10.71	10.64
U.S.A.	5.52	5.26	5.31	5.17
EU28	3.88	3.62	3.42	3.47
India	1.85	2.19	2.33	2.45
Russia	1.74	1.82	1.82	1.76
Japan	1.22	1.31	1.28	1.25
Germany	0.81	0.82	0.77	0.78
Int. Shipping	0.66	0.62	0.63	0.64
Iran	0.57	0.60	0.63	0.63
Korea	0.60	0.61	0.61	0.62
Canada	0.55	0.57	0.57	0.56
Saudi Arabia	0.42	0.46	0.49	0.51
Indonesia	0.42	0.45	0.48	0.50
Int. Aviation	0.46	0.49	0.49	0.50
Brazil	0.42	0.49	0.51	0.49
Mexico	0.45	0.49	0.48	0.47
Australia	0.42	0.43	0.44	0.45
South Africa	0.43	0.42	0.43	0.42
United Kingdom	0.49	0.46	0.42	0.40
Turkey	0.31	0.32	0.35	0.36
Italy	0.42	0.36	0.34	0.35
France	0.38	0.36	0.32	0.33
Poland	0.32	0.30	0.29	0.29
Thailand	0.24	0.27	0.28	0.28
Taiwan	0.27	0.28	0.28	0.28
Kazakhstan	0.25	0.27	0.27	0.27
Spain	0.28	0.25	0.25	0.26
Malaysia	0.21	0.23	0.24	0.25
Ukraine	0.32	0.32	0.27	0.23
Egypt	0.21	0.22	0.22	0.23
Other countries (181)	4.42	4.51	4.57	4.70

2.2.2 Worldwide Effort to Solve Global Warming

International efforts to improve the global environment have been made since the United Nations Environment Program (UNEP), which manages environmental activities related to the United Nations Conference on the Human Environment held in Stockholm in 1972, Have been concluded. The activities of international organizations on climate change are as follows.

- **IPCC (Intergovernmental Panel on Climate Change)**

In 1979, the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) began research on climate and climate change, triggered by global weather events such as floods, droughts and riots. Since then, as international challenges for climate change have increased, the need for intergovernmental organization to provide comprehensive and scientific information on climate change has been raised so that governments can take effective action. In this context, IPCC (Intergovernmental Panel on Climate Change) was established by UNEP and WMO in 1988.

The IPCC produced the first evaluation report in 1990, the second evaluation report in 2001, the third evaluation report in 2007, the fourth evaluation report in 2007, and the fifth evaluation report in 2013. It organizes and evaluates the latest science, technology, socioeconomic knowledge, and provides advice to governments.

- **United Nations Conference on Environment and Development (UNCED)**

The United Nations Conference on Environment and Development (UNCED) was held in Rio de Janeiro, Brazil in 1992 with the aim of harmonizing environment and development with the idea of sustainable development. UNCED agreed on United Nations Framework Convention on Climate Change (UNFCCC) for climate change mitigation and Rio Declaration, agenda 21 for environment and development. After that, it became important task to carry out international cooperation about global environment conservation as specific measures.

- **Conference of the Party (COP)**

COP is the annual meeting of the Parties to discuss the specific implementation of the United Nations Framework Convention on Climate Change (UNFCCC) at the United Nations Conference on Environment and Development (UNCED) in 1992 to reduce long-term damage from global warming.

The UNFCCC entered into force in 1994 to cooperate internationally in efforts to combat global warming. Preventing "dangerous" human interference with the climate system is the ultimate aim of the UNFCCC. To this end, it imposes various obligations on the Parties, such as establishing and implementing a national plan for global warming measures and creating a GHG emission list. Since 1995, the COP has been held almost every year in order to shape the contents of the Convention and promote its development.

- **Kyoto Protocol**

The Kyoto Protocol was adopted in Kyoto, Japan in 1997 and came into force in 2005. The Kyoto Protocol has established internationally binding emission reduction targets through international agreements with the UNFCCC.

The Protocol recognizes that developed countries have a high sense of responsibility for atmospheric greenhouse gas emissions and are placing more burdens on developed countries in accordance with the principle of "common but differentiated responsibilities". Under the Protocol, developed countries were required to achieve an average reduction of 5% (6% in Japan, 7% in the US, and 8% in EU) from 1990 to 2012 for the six types of greenhouse gases. Japan was able to achieve this goal, but disagreed with the Protocol, which does not mandate cuts to developing countries, and absents the next second commitment period (2013-2020).

- **Paris Agreement**

In December 2015, COP21 was held in Paris, France, where the "Paris Convention" was adopted, an international framework for measures to address global warming after 2020. About 200 countries have agreed on this agreement. The main goal is to keep the global temperature below 2 degrees Celsius in this century and to try to limit the temperature rise to 1.5 degrees Celsius before the pre-industrial level.

3. Energy Efficiency Operational Indicator (EEOI)

In this study, the Energy Efficiency Operational Indicator (EEOI) proposed by IMO was used to find the efficiency and responsibility of CO2 emissions from the national shipping. EEOI has recently been widely used as a study and indicator of CO2 emissions from currently operating vessels. In addition, the EEOI is expressed as the mass ratio of CO2 per unit transport, indicating that the EEOI is suitable for this study to find national responsibility for transport efficiency.

This chapter describes the definition of EEOI and provides guidelines. It also explains the elements required for EEOI's formulas and calculations.

3.1 Definition of EEOI

3.1.1 Introduction

The Marine Environment Protection Committee(MEPC), at its fifty-ninth session (13 to 17 July 2009), agreed to circulate the Guidelines for voluntary use of the Ship Energy Efficiency Operational Indicator (EEOI) as set out in the annex.

In 1997 IMO adopted a resolution on CO2 emissions from ships. IMO Assembly further adopted resolution A.963(23) on IMO policies and practices related to the reduction of greenhouse gas emissions from ships, which requests the MEPC to develop a greenhouse gas emission index for ships, and guidelines for use of that index.

The Guidelines for the Use of Energy Efficiency Operational Indicators (EEOI) of ships are as follows:
- what the objectives of the IMO CO2 emissions indicator are;
- how a ship’s CO2 performance should be measured; and
- how the index could be used to promote low-emission shipping, in order to help limit the impact of shipping on global climate change.

3.1.2 Objective of Guideline

The Guidelines were developed to assist in the process of setting up a mechanism for achieving the restriction or reduction of greenhouse gases emitted through the shipping industry and this guideline introduced the concept of energy efficiency indicators for operating vessels.

The guidelines are expressed in the form of carbon dioxide emissions per cargo being shipped, and monitor the efficiency with which the vessel is operated. This meaning is intended to create a document for the monitoring work based on the purpose and performance for the guidance. These guidelines, which are actually recommended by the IMO, indicate the applicability of the EEOI. Shipowners are encouraged to implement these guidelines in their environmental management systems and should consider adopting performance monitoring policies.

3.2 Calculation of EEOI

3.2.1 Definitions

- **Indicator definition**

In its most simple form the Energy Efficiency Operational Indicator is defined as the ratio of mass of CO_2 (M) emitted per unit of transport work:

Indicator = M_{CO2}/(Transport work)

- **Fuel consumption**

Fuel consumption, FC, is defined as all fuel consumed at sea and in port or for a voyage or period in question, e.g., a day, by main and auxiliary engines including boilers and incinerators.

- **Distance sailed**

Means a sea-going mileage (logbook data) that has been sailed for a certain period of time

- **Ship and cargo types**

The Guidelines are applicable for all ships performing transport work

a) Ships:
- Dry cargo carriers
- Tankers
- Gas tankers
- Containerships
- Ro-Ro cargo ships
- General cargo ships
- Passenger ships including Ro-Ro passenger ships

b) Cargo:
Cargo includes but not limited to:
all gas, liquid and solid bulk cargo, general cargo, containerized cargo (including the return of empty units), break bulk, heavy lifts, frozen and chilled goods, timber and forest products, cargo carried on freight vehicles, cars and freight vehicles on ro-ro ferries and passengers (for passenger and ro-ro passenger ships)

- **Ship and cargo types**

In general, cargo can be defined as weight. The weight of cargo carried by bulk and general cargo ships is to be defined as M^3. For ships transported by a combination of container and general cargo, the unit box of the cargo container should be 10tonnes and the empty container should be 2tonnes.

Depending on the type of ship, the following units can be applied:

i) Bulk carriers and tankers: M^3

ii) Passenger ships: Number of passengers

iii) Car ferries: number of cars or occupied

iv) Container: Number of TEU (empty or full)

v) Railway and RO-RO: Number of railway cars and vehicles loaded with luggage

3.2.2 Calculation

The EEOI should be a representative value of the energy efficiency of the ship operation over a consistent period which represents the overall trading pattern of the vessel.

To calculate the EEOI, the following steps are generally required:
1. define the period for which the EEOI is calculated;

2. define data sources for data collection;

3. collect data;

4. convert data to appropriate format; and

5. calculate EEOI.

- **Fuel mass to CO2 mass conversion factors (C_F)**

C_F is a non-dimensional conversion factor between fuel consumption measured in gram(g) and CO2 emission also measured in g based on carbon content. The value of C_F is as follows:

Table 7: Carbon factor for EEOI

Source: Guidelines for Voluntary Use of the Ship Energy Efficiency Operational Indicator (EEOI)[12)]

Type of fuel	Reference	Carbon content	C_F (t-CO_2/t-Fuel)
1. Diesel/Gas Oil	ISO 8217 Grades DMX through DMC	0.875	3.206000
2. Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.86	3.151040
3. Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	0.85	3.114400
4. Liquified Petroleum Gas (LPG)	Propane Butane	0.819 0.827	3.000000 3.030000
5. Liquified Natural Gas (LNG)		0.75	2.750000

- **Calculation**

The basic expression for EEOI for a voyage is defined as:

$$\text{EEOI} = \frac{\sum_j FC_j \times C_{F\,j}}{m_{cargo} \times D} \quad \cdots (1)$$

Where average of the indicator for a period or for a number of voyages is obtained, the Indicator is calculated as:

$$\text{Average EEOI} = \frac{\sum_i \sum_j (FC_{i\,j} \times C_{F\,j})}{\sum_i (m_{cargo,i} \times D_i)} \quad \cdots (2)$$

- j is the fuel type
- i is the voyage number
- FCij is the mass of consumed fuel j at voyage i
- $C_F j$ is the fuel mass to CO2 mass conversion factor for fuel j
- m_{cargo} is cargo carried (tonnes) or work done (number of TEU or passengers) or gross tonnes for passenger ships
- D is the distance in nautical miles corresponding to the cargo carried or work done.

The unit of the EEOI depends on the unit or type of cargo being measured.
e.g., tonnes CO2/(TEU • NM), tonnes CO2/(person • NM), tonnes CO2/(tonnes • NM), etc.

4. Data Collection of Container shipping for EEOI

4.1 Setting Targets

In this study, the export route of Korea - USA LA / LB and Japan - USA LA / LB was selected as the subject of study in order to find national responsibilities according to shipping efficiency. The reasons for setting the target are as follows:

i) Japan and South Korea are geopolitically close and take similar routes when exporting to the same port

ii) Most of the container trade in the US-East Asia is done through the LA / LB port.

iii) There is no large continent or island between East Asia and LA / LB Port, and only the Pacific Ocean exists, so that any liner route takes a similar route.

4.2 Liner Route

In calculating the EEOI, the distance (D) for each liner service route is essential. The route of each liner service has a different port of call. Therefore, it is necessary to know the distance of each port to port. Kobe, Nagoya, and Tokyo in Japan are always included in the port of call for the same liner service, so they are calculated as the average distance according to the cargo volume of each port.

In this study, the Netpas program of Seafuture Inc. was used to calculate the distance, and the port of call information was referenced to the International Transportation Handbook 2015.

4.2.1 Liner Route of Japan to LA/LB

There are two main liner routes in Japan. The first is the route via Kobe - Nagoya - Tokyo. All liner service routes to Los Angeles and Long Beach in Japan are via Kobe - Nagoya - Tokyo except Central China 3 (CC3) which is a liner service via Yokohama. The second one is the liner service route from Yokohama to Los Angeles and has only one liner service CC3.

In Japan, there are a total of 4 regular service lines for LA / LB. The routes are as follows.

1. PA1 (Pacific Atlantic 1): The route is Kobe – Nagoya – Tokyo – Tacoma – Vancouver – Oakland – Los Angeles. It takes an average of 12 days and the average distance is about 5860NM from Japan to Los Angeles. (Figure 8)

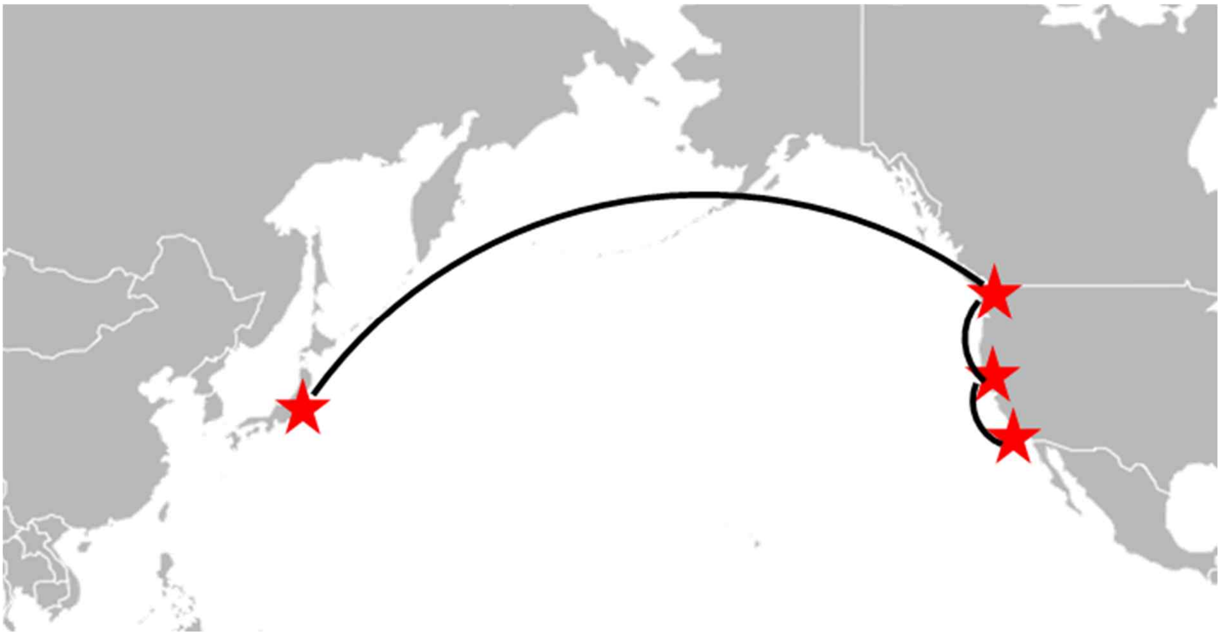


Figure 8: PA1 (Pacific Atlantic 1) route between Kobe, Nagoya, Tokyo and LA/LB
Source: International Transportation Handbook 2015[13)]

2. JPX (Japan Express): The route is Kobe – Nagoya – Tokyo – Sendai – Los Angeles. It takes an average of 12 days and the average distance is about 5120NM from Japan to Los Angeles

3. PSW-3 / JAS: The route is Kobe – Nagoya – Shimizu – Tokyo – Los Angeles. It takes an average of 12 days and the average distance is about 5139NM from Japan to Los Angeles. (Figure 9)

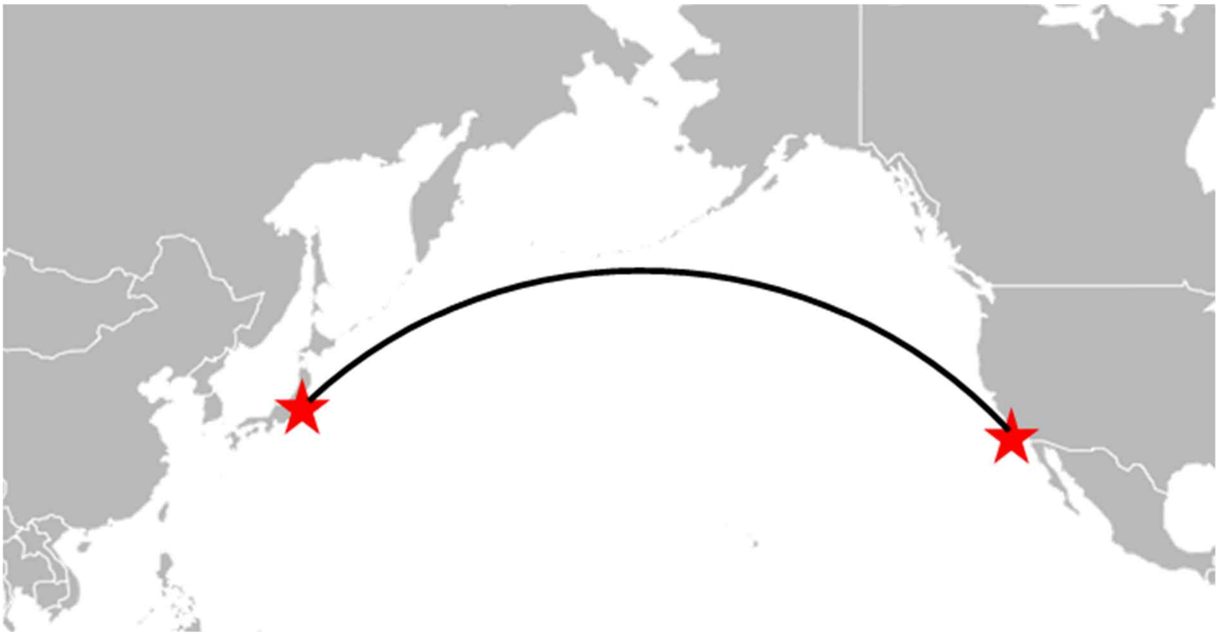


Figure 9: JPX (Japan Express), PSW-3/JAS route between Kobe, Nagoya, Tokyo and LA/LB
Source: International Transportation Handbook 2015[13)]

4. CC3: It is a liner service route from Yokohama to Los Angeles without passing through Kobe, Nagoya and Tokyo. It takes 11 days from Japan to Los Angeles and the distance is about 4854NM. (Figure 10)

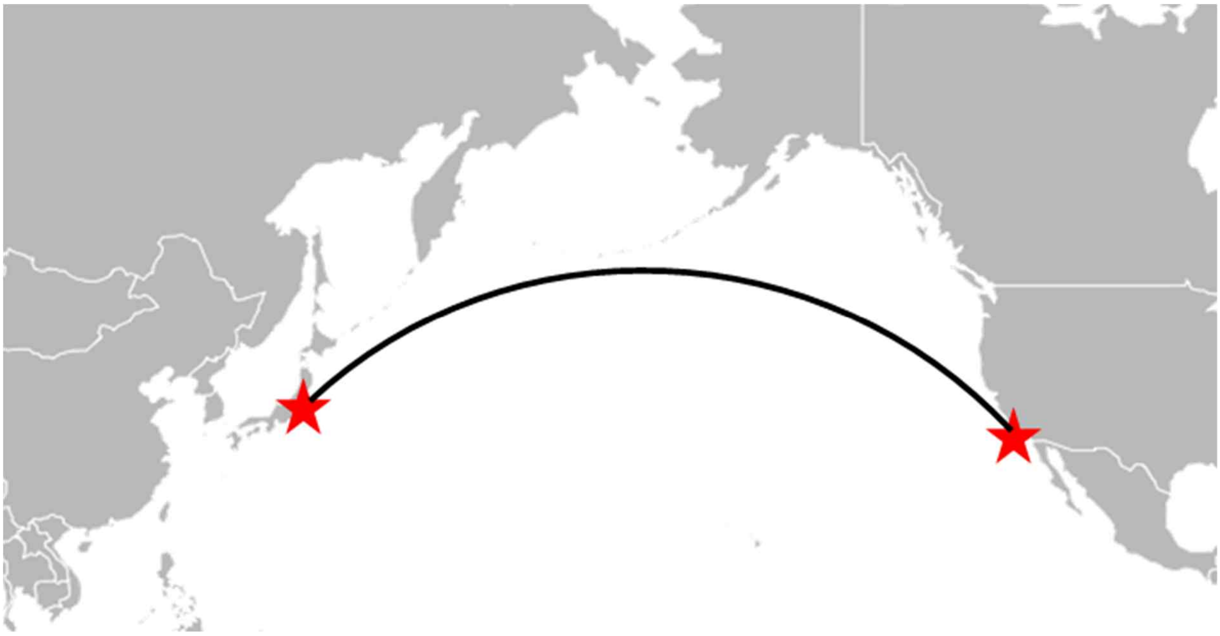


Figure 10: CC3 route between Yokohama and LA/LB

Source: International Transportation Handbook 2015[13)]

Table 8: Distance and travel time of liner service between Japan and LA/LB

Source: International Transportation Handbook 2015

Service name	Distance(NM)	Travel time(Day)
PA1 (Pacific Atlantic 1)	5860	20
JPX (Japan Express)	5120	12
PSW-3 / JAS	5139	12
CC3	4854	11

4.2.2 Liner Route of Korea to LA/LB

Korea's all liner service to Los Angeles and Long Beach are exclusively exported through port of Pusan. There are total of 6 liner services to Los Angeles and Long Beach via Korea. The routes are as follows.

1. PA1 (Pacific Atlantic 1): The route is Busan – Kobe – Nagoya – Tokyo – Tacoma – Vancouver – Oakland – Los Angeles. It takes 20 days from Korea to Los Angeles and the distance is about 6486NM. (Figure 11)

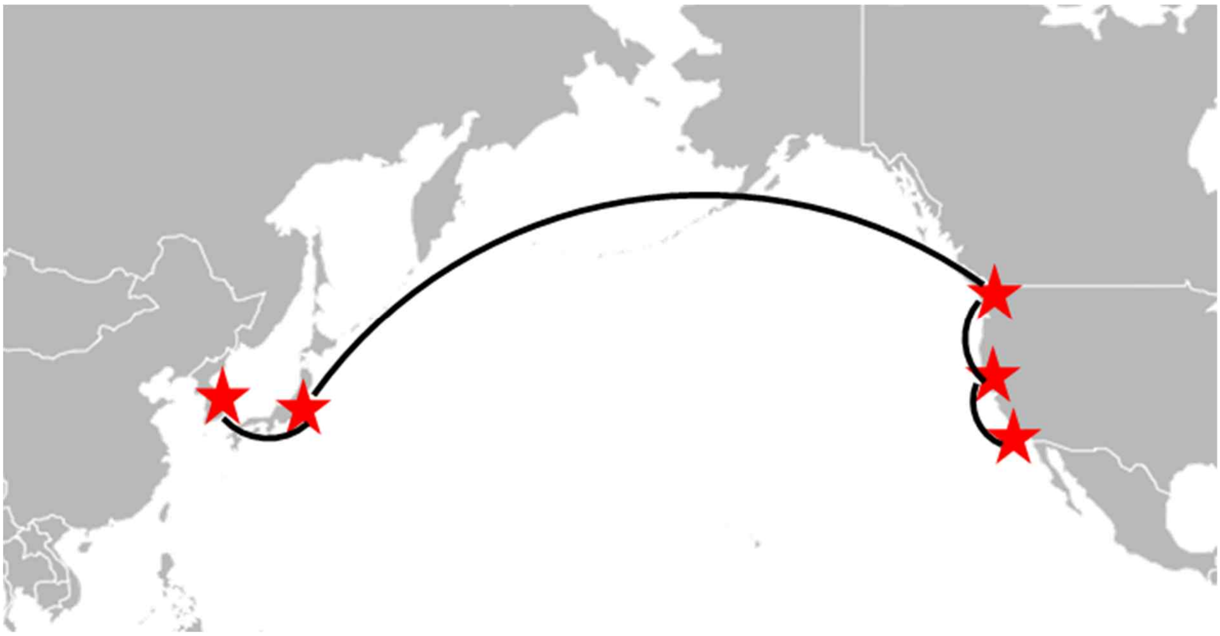


Figure 11: PA1 (Pacific Atlantic 1) route between Busan and LA/LB
Source: International Transportation Handbook 2015[13)]

2. CC1, MD1/PM1, AAS 2/AWS 1, PSX (Pacific Express Service): These four liner services have different ports of call. However, those have a common route to Los Angeles or Long Beach immediately after the arrival in port of Busan. It takes 11 ~ 12 days from Korea to Los Angeles or Long Beach and the distance is about 5239NM. (Figure 12)

Figure 12: CC1, MD1/PM1, AAS 2/AWS 1, PSX route between Busan and LA/LB
Source: International Transportation Handbook 2015[13)]

3. CC3: The route is Busan – Yokohama – Los Angeles. It takes 13 days from Korea to Los Angeles or Long Beach and the distance is about 5504NM. (Figure 13)

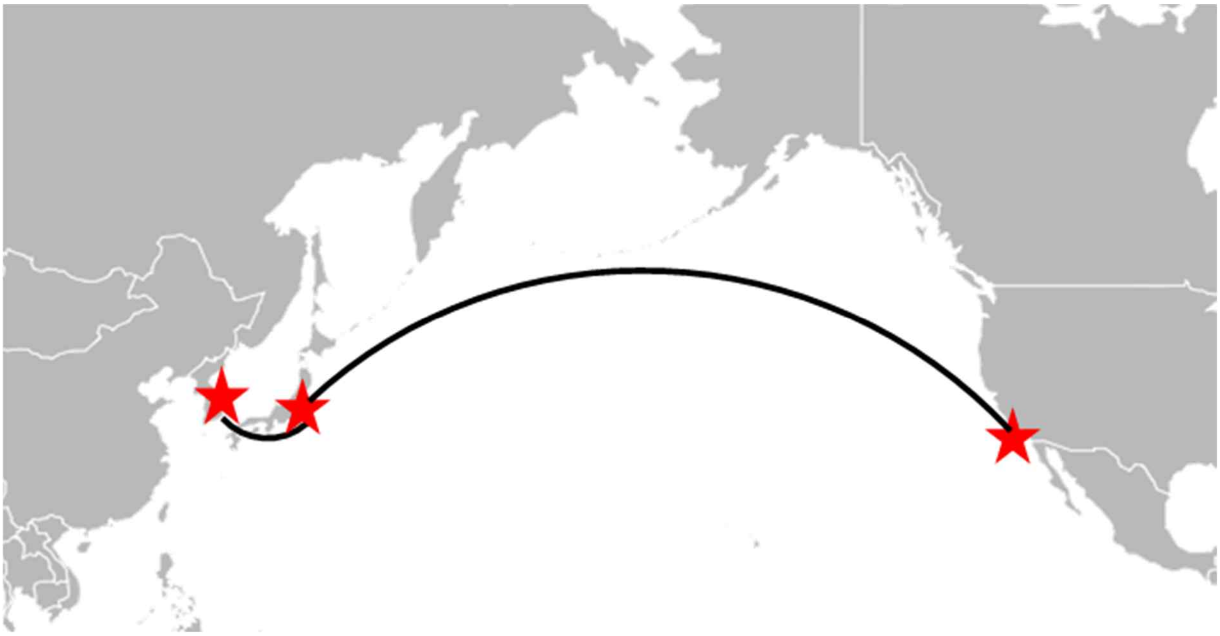


Figure 13: CC3 route between Busan and LA/LB
Source: International Transportation Handbook 2015[13)]

Table 9: Distance and travel time of liner service between Korea and LA/LB

Source: International Transportation Handbook 2015[13)]

Service name	Distance(NM)	Travel time(Day)
PA1 (Pacific Atlantic 1)	6486	20
CC1 (Central China1)	5239	12
CC3 (Central China3)	5504	13
MD1 / PM1	5239	12
AAS 2 / AWS 1	5239	11
PSX	5239	11

4.3. Export Containers of Japan to LA/LB and Korea to LA/LB

Los Angeles / Long Beach export data(m_{cargo}) from each port was obtained from the 2015 statistics of the Port Authority of each port.

Japan exported 260,575TEU to Los Angeles and 33,714TEU to Long Beach, exporting a total of 294,289TEU. South Korea exported 241,662TEU to Los Angeles and 389,829TEU to Long Beach, exporting a total of 631,491TEU. (Table 10)

Table 10: Volume of Export Containers in Japan to LA/LB and Korea to LA/LB

Source: Busan, Tokyo, Nagoya, Kobe, Yokohama Ports and Harbors Bureau

(Unit : TEU)

	Korea	Japan			
	Busan	Tokyo	Nagoya	Kobe	Yokohama
Los Angeles	241,662	86,002	83,652	62,878	28,043
Long beach	389,829	20,648	4,755	-	8,311
Total by port	631,491	106,650	88,407	62,878	36,354
Total by country	631,491	294,289			

4.4. Information of Ships in the Liner

Fuel consumption(***FC***) is one of the factors needed to calculate EEOI. The fuel consumption can be estimated by the size of the ship. Therefore, I obtained information on all the liner container ships from Japan or Korea to Los Angeles / Long Beach to obtain fuel consumption data.

4.4.1 Liner ships from Japan to LA/LB

The total number of liner container ships to Los Angeles / Long Beach via Japan is 30, and the average container ship size is 4650 TEU. (Table 11, Table 12)

Table 11: Tokyo / Nagoya / Kobe – LA / LB Liner ships in 2015

Source: International Transportation Handbook 2015[13)]

Service name	Vessel	TEU	Distance	Frequency	Traveling time
PA1 (Pacific Atlantic 1)	ATLANTA EXPRESS	4639	6,486	98	20
	AUGUSTA KONTOR	5060			
	DALLAS EXPRESS	4890			
	HALIFAX EXPRESS	4843			
	KOBE EXPRESS	4612			
	NYK CONSTELLATION	4888			
	NYK DAEDALUS	4882			
	NYK DEMETER	4882			
	NYK METEOR	4888			
	NYK NEBULA	4882			
	OAKLAND EXPRESS	4873			
	SEOUL EXPRESS	4890			
	SINGAPORE EXPRESS	4843			
	TOKYO EXPRESS	4890			
JPX (Japan Express)	BOX TRADER	3426	5,120	35	12
	HANJIN CONSTRANTZA	3398			
	SPRING R	3586			
	STADT AACHEN	3398			
	YM EFFICIENCY	4252			
PSW-3 / JAS	MOL ENDOWMENT	4800	5,139	35	12
	MOL EXPERIENCE	4803			
	MOL EXPLORER	4803			
	VERRAZANO BRIDGE	4014			
	VINCENT THOMAS BRIDGI	4014			

Table 12: Yokohama – LA / LB Liner ships in 2015

Source: International Transportation Handbook 2015[13)]

Service name	Vessel	TEU	Distance	Frequency	Traveling time
CC3	APL CHINA	5108	4,854	42	11
	APL HOLLAND	5510			
	APL JAPAN	5108			
	APL KOREA	5108			
	APL SINGAPORE	5108			
	APL THAILAND	5108			

4.4.2 Liner ships from Korea to LA/LB

The total number of liner container ships to Los Angeles / Long Beach via Korea is 60, and the average container ship size is 7490 TEU. (Table 13)

Table 13: Busan – LA / LB Liner ships in 2015

Source: International Transportation Handbook 2015[13)]

Service name	Vessel	TEU	Distance	Frequency	Traveling time
PA1 (Pacific Atlantic 1)	ATLANTA EXPRESS	4639	6,486	98	20
	AUGUSTA KONTOR	5060			
	DALLAS EXPRESS	4890			
	HALIFAX EXPRESS	4843			
	KOBE EXPRESS	4612			
	NYK CONSTELLATION	4888			
	NYK DAEDALUS	4882			
	NYK DEMETER	4882			
	NYK METEOR	4888			
	NYK NEBULA	4882			
	OAKLAND EXPRESS	4873			
	SEOUL EXPRESS	4890			
	SINGAPORE EXPRESS	4843			
	TOKYO EXPRESS	4890			
CC1	HYUNDAI HONGKONG	6763	5,239	42	12
	HYUNDAI LONG BEACH	6350			
	HYUNDAI SHANGHAI	6763			
	HYUNDAI TACOMA	6350			
	HYUNDAI TOKYO	6763			
	MOL PREMIUM	6350			
CC3	APL CHINA	5108	5,504	42	13
	APL HOLLAND	5510			
	APL JAPAN	5108			
	APL KOREA	5108			
	APL SINGAPORE	5108			
	APL THAILAND	5108			

Service name	Vessel	TEU	Distance	Frequency	Traveling time
MD1 / PM1	COSCO AMERICA	10060	5,239	112	12
	COSCO ASIA	10860			
	COSCO BEIJING	9469			
	COSCO EUROPE	10060			
	COSCO KAOHSIUNG	10000			
	COSCO NINGBO	9469			
	COSCO OCEANIA	10062			
	COSCO PRINCE RUPERT	8200			
	HANJIN AMI	10000			
	HANJIN BOSTON	7471			
	HANJIN BUDDHA	10000			
	HANJIN CHINA	9954			
	HANJIN JUNGIL	10000			
	HANJIN NAMU	10000			
	HANJIN SPAIN	9954			
	HANJIN TABUL	10000			
AAS 2 / AWS 1	CSCL EAST CHINA SEA	10000	5,239	42	11
	UASC TABUK	9300			
	XIN DA YANG ZHOU	8528			
	XIN FEI ZHOU	8528			
	XIN MEI ZHOU	8528			
	XIN OU ZHOU	8528			
PSX	HANJIN GERMANY	10070	5,239	42	11
	HANJIN GREECE	10114			
	HANJIN HAMBURG	9012			
	HANJIN LONG BEACH	9012			
	HANJIN NETHERLANDS	9954			
	HANJIN NEW YORK	9012			

4.5 Fuel Consumption

In this study, the fuel consumption estimation method proposed by the International Handbook of Maritime Economics[14)] was used to calculate fuel consumption. The fuel consumption estimation method is based on the size of the vessel. Therefore, in this study, it is used because fuel consumption can be estimated by using the International Transportation Handbook[13)] which contains the size information of the vessel. In the International Handbook of Maritime Economics, it has introduced a formula for calculating the daily fuel cost per TEU or ton according to parameters such as engine power and fuel consumption, as presented in Buxton (1985) and Cullinane and Khanna (1999). The Total Fuel Consumption(TFC_j) for a specific route / service $\boldsymbol{j}$ of $\boldsymbol{T}$ days (round trip) by $\boldsymbol{i}$ ($\boldsymbol{i}$ = 1…n) vessels is the sum of the fuel costs for main and auxiliary engines when the vessels are at sea($\boldsymbol{t_1}$), maneuvering in port or transiting through canals($\boldsymbol{t_2}$) and hoteling($\boldsymbol{t_3}$):

$$\mathbf{TFC}_{\boldsymbol{j}} = \sum_{i=1}^{n}\sum_{t=1}^{3}(\boldsymbol{P_m} \cdot \boldsymbol{FC_{m\,t}} + \boldsymbol{P_a} \cdot \boldsymbol{FC_{at}}) \quad \cdots (3)$$

with:

$\mathbf{TFC}_j$ Total fuel cost for a specific service j in USD;

t_1 Time when the vessel is at sea;

t_2 Time when the vessel is maneuvering or transiting through canals

t_3 Time when the vessel is hoteling (waiting and when at berth);

P_m Bunker price for the main engine (m);

$FC_{m\,t}$ Fuel consumption for main engine (m) per day for vessel i under status t;

FC_{at} Fuel consumption for auxiliary engine (a) per day for vessel i under status t;

When the vessel is at sea (t_1), the fuel consumption for the main engine (m) and vessel i (in grams/mile) can be estimated as:

$$\mathbf{FC}_{m\,t-gram\,s/nm} = \frac{(1+m_s)\cdot L_F\cdot S_{FOC}\cdot P_e}{V_0} \quad \cdots (4)$$

with:

m_s Sea-margin to consider weather conditions and expressed as a percentage;

L_F Load factor expressed as a percentage of the maximum continuous rate;

S_{FOC} Specific fuel oil consumption in g/kW-hr;

P_e Installed engine power in kW given for a TEU size and design speed V_0;

V_0 Design speed in nautical mile(nm)

This calculation assumes a sea-margin of 15% and a load factor of 80%. Regardless of the condition of the vessel, the fuel consumption of the auxiliary engine(FC_{ait}) was considered to be 10% of the main engine consumption. In order to estimate S_{FOC} and P_e for a vessel i at a given design speed V_0, information on container ships extracted from Lloyd's Fairplay Ship database (Lloyd's Maritime information services, October 2008)[15] was used. The sample consists of 2259 container ships.

Out of the 2259 container ships, 33.8% are 2000 ~ 3000TEU and 70.1% are less than 5000TEU. The average vessel size is 4332TEU, average age is 8 years and an average speed is 23.04 knots.

Out of the 2259 container ships, 97percent are using two-stroke slow-speed engines for which a value of 171 g-kW-hr is used as a proxy of S_{FOC}. In order to consider the impact of a change in the vessel's size on fuel consumption. It estimated the relationship between installed engine power (P_e) and vessel size (in TEU):

$$\mathbf{Log}\,(P_e) = \mathbf{1.996} + \mathbf{1.013}\mathit{Log}\ (TEU) \qquad R^2 = \mathbf{0.83} \quad \cdots (5)$$

Combining the above two equations and assuming as stated previously, a sea-margin of 15 percent, a load factor of 80 percent, a S_{FOC} of 171 g-kW-hr so that $\mathbf{C} = (1+m_s)\cdot L_F\cdot S_{FOC} = 1.15\times 0.8\times 171 = 157.3$, the total fuel consumption at sea for the main engine in grams/day and at given speed V_0 can then be estimated as:

$$\frac{\mathbf{FC}_{m\,t}}{at\ V_0} = \mathbf{24}\cdot C\cdot e^{1.996}\cdot TEU^{1.013} = \mathbf{3775}\ \cdot e^{1.996}\cdot TEU^{1.013} \quad \cdots (6)$$

4.5.1 Fuel Consumption of Japan to LA/LB

The data from Table 11 and Table 12 were used in the formula for the fuel consumption estimation method. As a result, it is estimated that Japan consumed a total of 374,997.6Tonnes of fuel for export to Los Angeles / Long Beach. (Table 14)

Table 14: Fuel Consumption of Japan to LA/LB

Service name	Using ships	Distance	Frequency	FC/Day	Traveling Time	FC/Year
PA1 (Pacific Atlantic 1)	14	5859.665	98	150.60106	16	125644.31
JPX (Japan Express)	5	5120	35	111.6323	12	69849.92
PSW-3 / JAS	5	5138.9835	35	139.05995	12	87011.80
CC3	6	4854	42	160.68017	11	92161.56
					Total	**374667.6**

(Unit: Ton)

4.6.2 Fuel Consumption of Korea to LA/LB

The data from Table 13 was used in the formula for the fuel consumption estimation method. As a result, it is estimated that Korea consumed a total of 914,913Tonnes of fuel for export to Los Angeles / Long Beach. (Table 15)

Table 15: Fuel Consumption of Korea to LA/LB

Service name	Using ships	Distance	Frequency	FC/Day	Traveling Time	FC/Year
PA1 (Pacific Atlantic 1)	14	6486	98	150.60106	20	157055.39
CC1	6	5239	42	204.20218	12	127772.22
CC3	6	5504	42	160.68017	13	108918.20
MD1 / PM1	16	5239	112	304.37174	12	190449.75
AAS 2 / AWS 1	6	5239	42	278.36267	11	159660.87
PSX	6	5239	42	298.23058	11	171056.54
					Total	**914913**

(Unit: Ton)

5. Analysis of EEOI in Container Shipping

This chapter compares and analyzes the EEOI of each port and each country in order to determine the efficiency of maritime transport and thus the national responsibility.

The EEOI of each port and the EEOI of the country were obtained through collected fuel consumption(**FC**), navigation distance(**D**), and cargo($\mathbf{m_{cargo}}$). Carbon factor(C_F) of Heavy Fuel Oil(HFO), which occupies most of the fuel of the ship, was applied as the carbon factor.

5.1 EEOI of Japan to LA/LB

The average EEOI of liner services via Kobe – Nagoya – Tokyo in Japan is 6.10E-04. All of Japan's liner services to LA or LB except for CC3 liner service via Yokohama have always had a route through three ports(Kobe – Nagoya – Tokyo), showing high EEOI as if they were being exported to a single port .

On the other hand, Yokohama's EEOI is about 2.6 times higher than the average EEOI of liner services via Kobe – Nagoya – Tokyo at 1.63E-03. This is attributed to the high consumption of fuel (92,162Tons) due to the large number of vessels input compared to the export volume (36,345TEU). (Table 16)

Table 16: EEOI of Japan to LA/LB

Port in Japan	Average Distance(NM)	TEU	FC(Ton)	C_F	EEOI
Kobe/Nagoya/Tokyo	5,587	257,935	282,506	3.114	6.10E-04
Yokohama	4,854	36,354	92,162	3.114	1.63E-03
Total	5,497	294,289	374,668	3.114	7.21E-04

5.2 EEOI of Korea to LA/LB

EEOI of Busan in Korea is 7.68E-04. Busan's export volume to Los Angeles / Long Beach is 631,491 TEU, about 2.1 times that of Japan. In addition, the average ship size is 7490TEU, which has relatively high fuel consumption. (Table 17)

Table 17: EEOI of Korea to LA/LB

Port in Korea	Average Distance(NM)	TEU	FC(Ton)	C_F	EEOI
Busan	5,740	631,491	914,913	3.114	7.86E-04

5.3 Comparative Analysis of EEOI

EEOI of Kobe – Nagoya – Tokyo liner service is the most efficient with 6.10E-04. EEOI of Busan is the second most efficient with 7.84E-04, and EEOI of Yokohama, which has many ships compared to its cargo volume, is significantly less efficient than the other two liner service routes. (Figure 14)

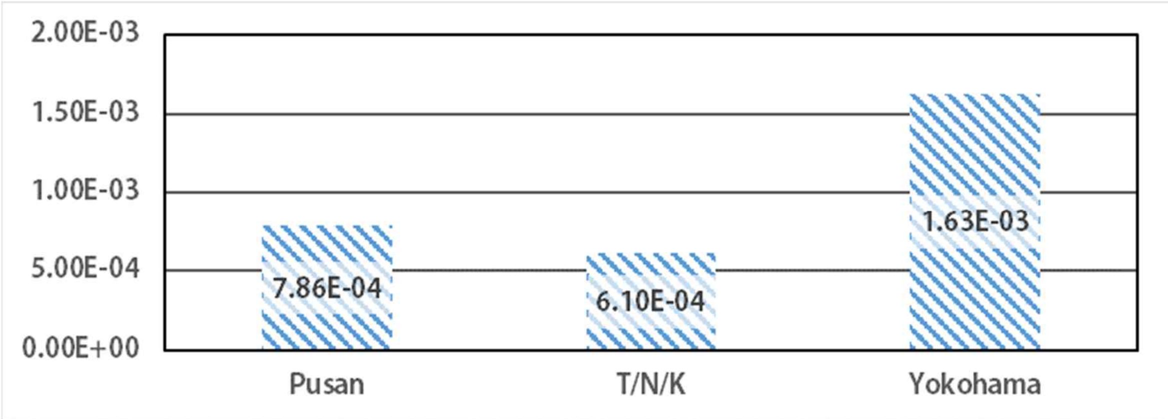


Figure 14: EEOI of each port to LA/LB

Comparing EEOI by country, we can see that Japan's transportation efficiency is better, with 7.86E-04 in Korea and 7.21E-04 in Japan. (Figure 15)

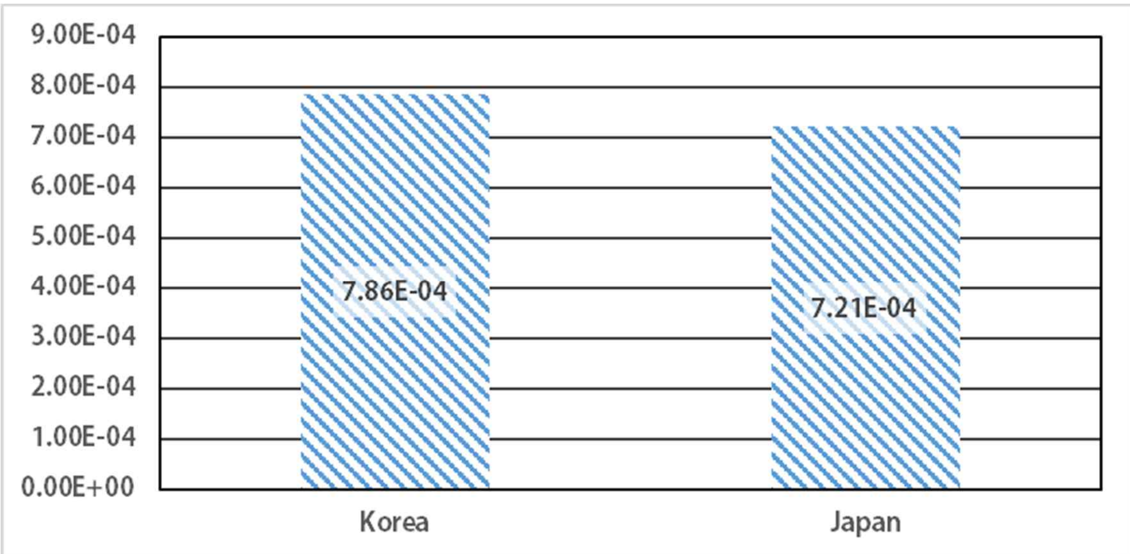


Figure 15: EEOI of each country to LA/LB

However, in terms of LA / LB exports, Korea has a much better environment than Japan. Because Korea uses only port of Busan as an export port and Japan uses four ports. In addition, Korea's average ship size (7,490TEU) is larger than Japan's average ship size (4,650TEU).

Figure 16 shows that CO2 emissions vary greatly depending on vessel size and age. According to the study, the daily emissions of 20,000 TEU vessels per unit container are much less than the daily emissions of 10,000 TEU vessels. The difference in carbon dioxide emissions can be as high as 50%. Therefore, large ships can reduce total emissions. (Sustainable Logistics for Europe)

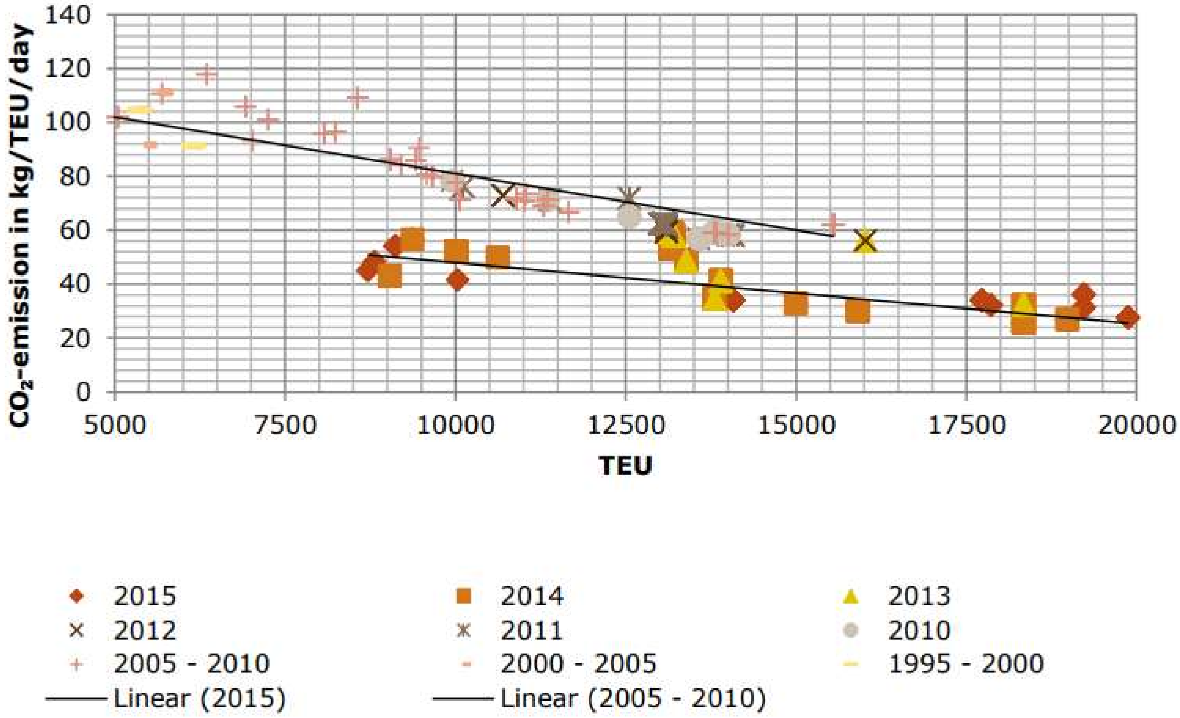


Figure 16 CO2 emission per TEU per day for vessels according to year of build and ship size

Source: Sustainable Logistics for Europe – Port of Rotterdam[16)]

In Korea, on the other hand, EEOI is relatively high despite using large ships on average. In other words, In other words, it seems to be adversely affected by the larger ship size than necessary..

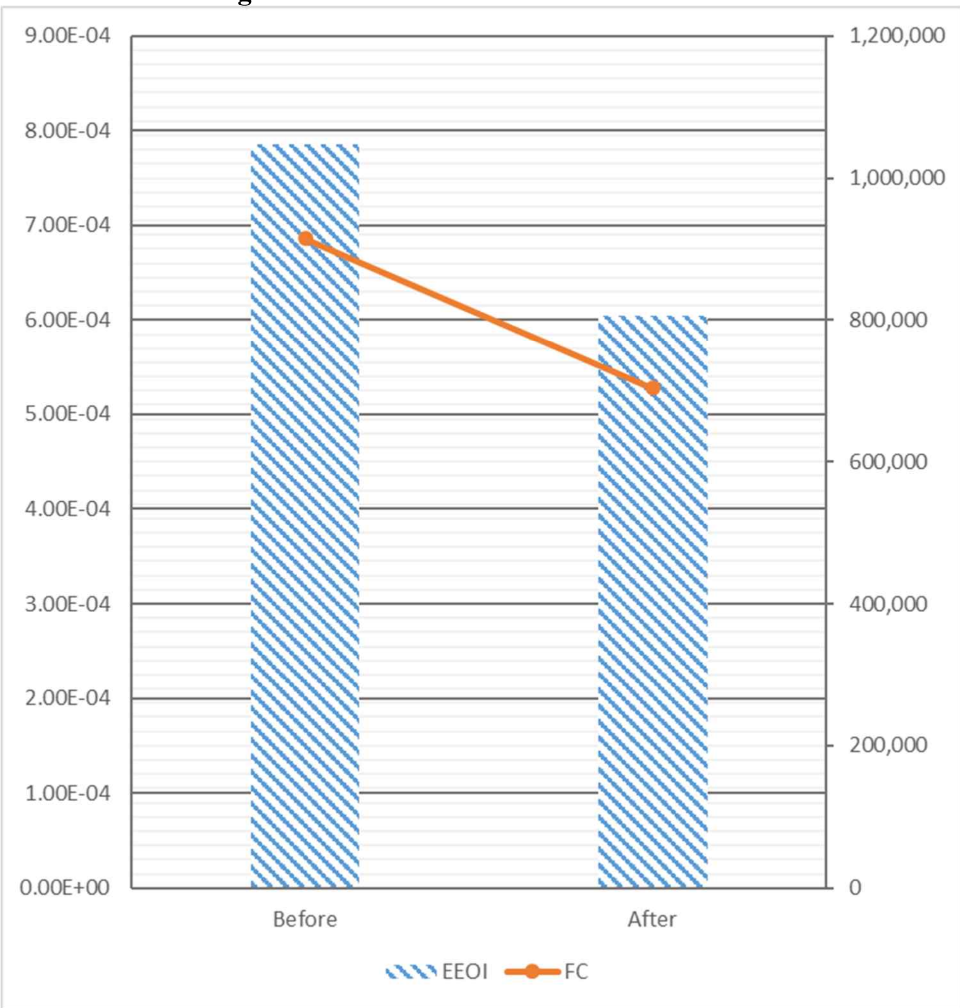
5.4 Proposal of Modified Liner

As mentioned above, the current problem in Korea is that size of liner ships is too large compared to exported cargo. Therefore, I calculated the EEOI assuming the average ship size in Korea(7490TEU) to be the average ship size in Japan(4650TEU). In 2015, the fleet of vessels used for export to Los Angeles / Long Beach by Korea was 404,496 TEU, totaling 54 vessels. If it is calculated as the average ship size in Japan and the fleet size compared to the cargo volume as Japan, a total of 64 vessels are needed. In this case, although the number of vessels increases, the size of the fleet will decrease to about 74%, and EEOI and fuel consumption will be reduced to about 77%. In other words, adjusting the fleet size to the cargo volume can greatly improve transportation efficiency. (Table 18, Figure 17)

Table 18: Proposal of Modified Liner of Korea to LA/LB

	Before	After
Volume of ship	404,496TEU	297,600TEU
A.Ship size	7,490TEU	4,650TEU
Number of Ships	54	64
EEOI	7.86E-04	6.05E-04
FC	914,913	703,893

Figure 17: EEOI of modified liner in Korea



The problem with the Japanese liner route lies in the dispersion of the port. Considering that the size of the country is larger than Korea and it is an island nation, it is an inevitable problem. In case of Kobe, Nagoya and Tokyo ports, these three ports are all in one rotation of liner services, so they show efficient shipping. However, only Yokohama has an independent liner service route, which causes the overall Japanese EEOI to rise. If Yokohama Port is included in the Kobe – Nagoya – Tokyo liner service route, or the cargoes of Yokohama Port are moved to Tokyo Port located in the same Tokyo Bay and exported together, it will be possible to lower EEOI of Japan to the level of EEOI of Kobe – Nagoya – Tokyo liner service route. (Figure 18)

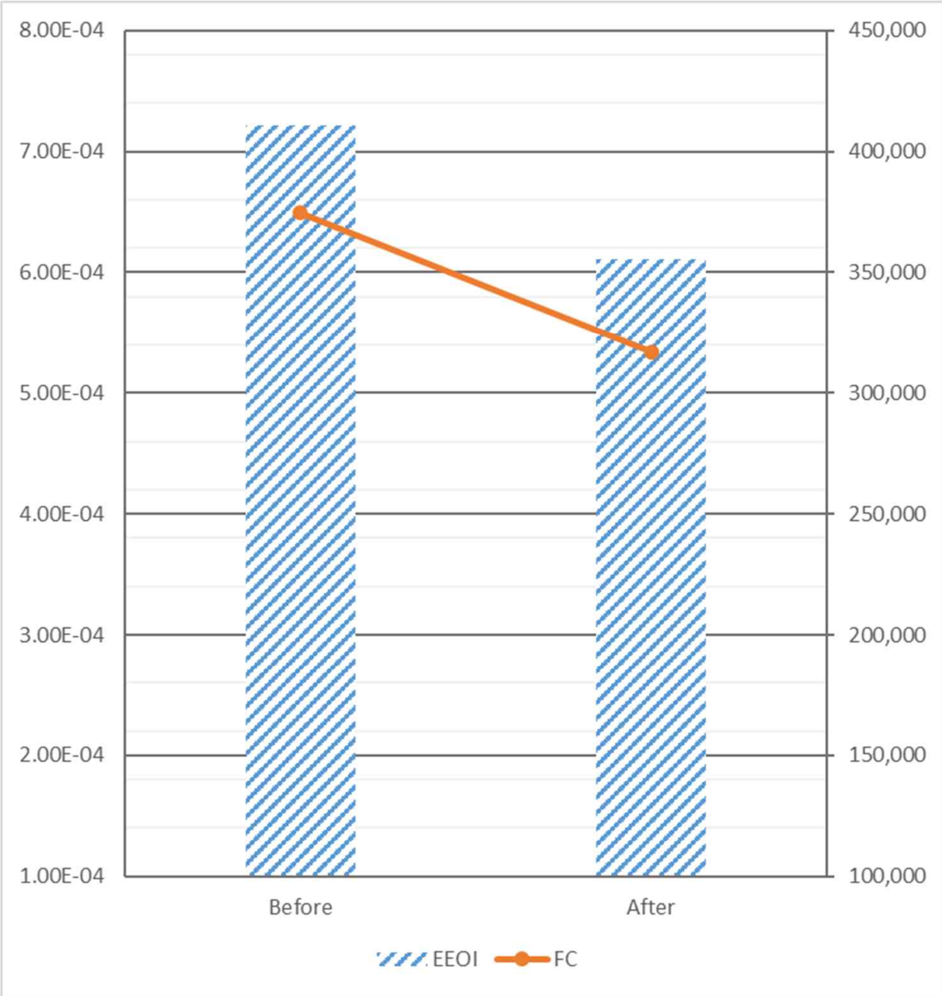


Figure 18: EEOI of modified liner in Japan

6. Conclusions

The trade volume has been steadily increasing with the economic growth in Asia, and this situation is expected to continue for the time being. In particular, the amendment of the MARPOL Treaty calls for reduction of CO2 emissions in the maritime industry, and it is urgently required to cooperate with each other for realistic and sustainable CO2 emissions and cost reduction.

Therefore, this study aims to contribute to the sustainable development of the international shipping industry by reducing the CO2 emission in the shipping industry by studying the Energy Efficiency Operational Indicator(EEOI) of the container liner service as a model to determine the CO2 emission efficiency and national responsibility of the shipping network.

For the study, export information, route information, and ship information are summarized in order to calculate the EEOI of liner service exported from Korea and Japan to Los Angeles / Long Beach. After analyzing EEOI based on the obtained information, new improvement methods were proposed. The results obtained in this process are summarized as follows.

1. One port in Korea and four ports in Japan are used for Los Angeles / Long Beach exports, but EEOI of Japan is even lower. Therefore, it was confirmed that even if exporting via a number of domestic ports, if a reasonable route is selected, efficiency as much as using one port can be produced.

2. Although CO2 emissions per 1 TEU is declining with the recent large-scale shipbuilding, considering the cost of large-scale shipbuilding and the decrease in the frequency of use of medium-sized vessels, it can not be said that it is effective to reduce CO2 emissions. Therefore it is important to choose the appropriate vessel size.

3. Even if the same volume of cargo is exported, the EEOI can vary greatly depending on the choice of route and the size of the fleet.

4. Both Korea and Japan have room for improvement in CO2 emissions per TEU, which will contribute to the reduction of international maritime emissions if each country realizes its responsibility.

Although no clear penalties have yet been established for the regulation of CO 2 emissions from shipping, there is a possibility that penalty costs for CO 2 emissions will occur in the future. Especially, in the case of the shipping company, shipbuilding company, shippers, etc. responsible for CO2 emissions, it is hard to clearly share responsibilities. This study can be an indicator for determining the share of these responsibilities.

In this study, the EEOI was analyzed to evaluate the efficiency of CO_2 emission in shipping networks and the responsibility and to suggest improvements. The results of this study are expected to contribute to the sustainable development of the shipping industry that will reduce the environmental impacts and costs in the international maritime network in the future. In addition, it is also expected that EEOI can serve as a standard in many research and international conventions as an indicator of energy efficiency in ship operation.

Although only Japan and Korea - Los Angeles / Long Beach exports were analyzed in this study, it is required to calculate accurate EEOI in whole world shipping network as a next assignment. In particular, since the mandatory collection of fuel consumption data is discussed in the Marine Environment Protection Committee (MEPC), 69th Session, it is expected that more accurate EEOI calculation and analysis will be possible in the future.

In addition, as internat ional cooperation is required to reduce CO_2 emissions from the international shipping industry, research and review of indicators for identifying responsibilities in the countries is also the assignment.

References

1) Third IMO Greenhouse Gas Study 2014, International Maritime Organization (IMO)
http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Third%20Greenhouse%20Gas%20Study/GHG3%20Executive%20Summary%20and%20Report.pdf

2) Review of Maritime Transport 2016, UNCTAD,
http://unctad.org/en/PublicationsLibrary/rmt2016_en.pdf

3) 港湾関係情報・データ, 国土交通省, 2015

4) Drewry Study, London, 2009,
https://www.drewry.co.uk/news/news/study-findings-warn-of-diminishing-economies-of-scale-from-new-generation-of-megaships

5) FleetForecast, Alphaliner, 2016,
https://www.alphaliner.com/liner2/research_files/liner_studies/nofleet/Alphaliner-FleetForecast-2016-01.pdf

6) International Maritime Organization Home Page, http://www.imo.org/en/

7) Climate Change 2007: The Physical Science Basis, Intergovernmental Panel on Climate Change (IPCC),
https://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4_wg1_full_report.pdf

8) Climate Change 2013: The Physical Science Basis, Intergovernmental Panel on Climate Change (IPCC),
http://www.climatechange2013.org/images/report/WG1AR5_ALL_FINAL.pdf

9) Kyoto Protocol Reference Manual, United Nations Framework Convention on Climate Change (UFCCC),
https://unfccc.int/resource/docs/publications/08_unfccc_kp_ref_manual.pdf

10) National Oceanic and Atmospheric Administration (NOAA) Home Page, http://www.noaa.gov/
Trends in Global CO2 Emissions 2016 report, Emissions Database for Global Atmospheric Research(EDGAR),
http://edgar.jrc.ec.europa.eu/news_docs/jrc-2016-trends-in-global-CO2-emissions-2016-report-103425.pdf

11) CO2 time series 1990-2015 per region/country, Emission Database for Global Atmospheric Research (EDGAR), European Commission,
http://edgar.jrc.ec.europa.eu/overview.php?v=CO2ts1990-2015

12) EEOI Guidelines, International Maritime Organization (IMO),
http://www.imo.org/en/OurWork/environment/pollutionprevention/airpollution/documents/technical%20and%20operational%20measures/mepc.1_circ.684_guidelines%20for%20voluntary%20use%20of%20eeoi.pdf

13) International Transportation Handbook 2015, Ocean Commerce Ltd.

14) Kevin Cullinane, International Handbook of Maritime Economics, University of Gothenburg

15) Lloyd's Fairplay Ship database, Lloyd's Maritime information services, 2008

16) Sustainable Logistics for Europe, Penteia, 2016