The Effect of the Offshore Port Systems to Container Sector' Energy Efficiency

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Abstract: Shipping sector has some duty and responsibilities like other gas emitter sectors. When it is thought that ships are mobile emitters, so these duty and responsibilities should be handled at international conjecture. At the international level, UN, EU, US and IMO play a remarkable role to catch future emission and energy efficiency targets with the aid of projects, policies and regulations. As highest level authority for maritime sector, IMO aims to set in motion all maritime sectors with their all components from building to scrapping. This target can be reached when technologies, methods and systems are combined ideally and adapted to the sector correctly. In this frame, the aim of this paper is that to make contribution to energy efficiency with the aid of a new port system which is offshore port system. The paper will focus on container sector and offshore port by investigating container sector developments and the paper suggest the offshore ports as a response to developments in the container sector. Specifically, the contribution of the offshore ports to energy efficiency of the sector is examined in the light of data from container shipping. It is assessed that the possible effect of the offshore ports to liner operator behaviours in terms of economies of scale, alliances among leader container companies in order to provide efficiency. As a conclusion, it is expected that offshore port systems could be future's energy efficient and eco-friendly port systems.

Keywords: energy efficiency, offshore port, container transportation
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1 Introduction

Globalization is one of the last years` most remarkable economic phenomena. Rodrigue and Smith (2012) defines the maritime sector as most globalized industry and good connector for the majority of the international trade. Also, it cannot be denied that the international shipping is the most energy efficient transport mode compared to other transport modes in term of longest distance to transport one ton of cargo using 1 kWh of energy (Figure 1).

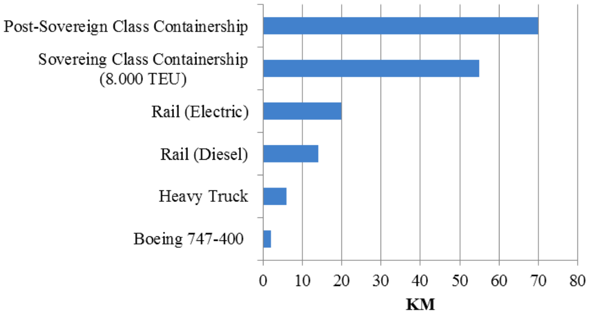

Figure 1- Distance Travelled for One Ton of Cargo Using 1 kWh of Energy (Rodrigue, 2009)

According to EU resources, it can be seen in Figure 2 that the shipping sector makes 3.3% CO_2 contribution to world's GHG emissions and this figure is equal to 13.6% CO_2 emission in Europe when CO_2 contribution only from transport sector is considered (EU, 2014). While the situation for Europe is as presented in Figure 2, CO_2 emission of the international shipping is 2.7% of the global emissions (Buhaug et al., 2009).

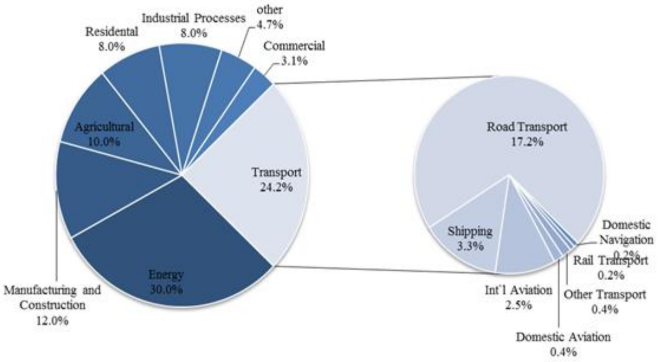

Figure 2 - EU27 greenhouse gas emissions by sector and mode of transport, 2007 (EU, 2014)

In the new global economy, energy consumption has become a central issue for maritime transportation. This issue has grown in importance in the light of recent findings with regards to the negative effects of fossil fuel on the environment and lack of alternatives. Despite the fact that the

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maritime sector offers energy efficient transport, the emissions from shipping continue to increase in parallel with world trade volume. A number of researchers have reported that any change in the global energy consumption is directly linked with gas emission values produced by the shipping sector (Buhaug et al., 2009, McKinnon, 2012). Buhaug et al. (2009) note that CO_2 emissions from shipping may increase by a factor of 2 to 3 by 2050 if no action is taken. On the other hand, if technical and operational measures are combined and implemented, the emissions could be reduced by a ratio between 25% and 75% (Buhaug et al., 2009). All the above mentioned figures cover only ships and sea leg of the shipping activities. However, the shipping industry has two types of environmental impacts which can be subcategorized to impacts due to ships and due to the marine infrastructure e.g. ports (Smith, 2012). According to IMO, a sustainable marine transport system should be designed as a co-operation of ships, ports, logistics systems and their all components from governments and organizations to crews of merchant vessels in terms of safe, secure, efficient and reliable transport of goods across the world. For robust and sustainable energy efficient shipping, the success of this co-operation plays an important role.

The current energy consumption and the future emission predictions show that the shipping sector needs immediately applicable solutions for energy efficient and sustainable marine transport system. This paper will seek to address the energy efficiency problem by analysing the container sector market and its behaviour. The paper begins by giving a brief overview of the recent energy efficiency improvement solutions. It will then go on to applied port-based solutions to improve energy efficiency and it suggests offshore ports system to able to make contribution the energy efficiency of the container sector.

Broadly, this paper develops a transport model that examines container sector and offshore ports to improve energy efficiency of the maritime sector with a view to minimizing the container vessels` fuel consumption and maximizing the energy efficiency of the overall transport system.

2 Energy Efficiency Improvement Solutions

One of biggest challenges in the current maritime sector is to able to carry goods and commodities utilising more energy efficient vessels at a lower transport cost. Although the maritime sector known as the most energy efficient and the most cost-effective transportation mode, the sector has a significant potential for the further reduction of its energy consumption and eventually its energy bill. To materialise this potential, the maritime sector carries out research towards energy efficient improvement solutions. These solutions include:

- Policy and regulation based solutions
- Technical and design based solutions
- Alternative fuel and power sources based solutions
- Operation based solutions

2.1 Policy and regulation based solutions

With regard to policy and regulation International Maritime Organization (IMO) is a major stakeholder in the maritime sector. Also, key member states such as European Union (EU), Norway, Japan and the United States (US) are prominent actors with their energy related policies and research, while other nations have developed their own policy and regulations.

In policy and regulation framework the most important measures were the establishment by IMO of the EEDI, SEEMP and EEOI. The Energy Efficiency Design Index (EEDI) was introduced as a technical measure for all new ships in order to promote the design of more energy efficient hulls, engines and energy consuming systems. The Ship Energy Efficiency Management Plan (SEEMP) and Energy Efficiency Operational Indicator (EEOI) were introduced as operational measures for the improvement the continuous monitoring of the energy efficiency of a ship throughout its operational life.

EU aim to be at the forefront of the environmental protection initiatives, has been expressed through the endorsement of a number of energy and climate policies. In this framework, EU has determined specific energy and climate goals. EU aims to reduce energy consumption for a 20% by 2020 and its long term goal is to cut greenhouse gas emissions by 80-95% by 2050 (Capros et al., 2013). Also, EU runs various energy efficiency related programmes about the maritime sector (e.g. PACT, Marco Polo) and also funds a number of research projects (e.g. JOULES, Refresh, Targets).

In general terms, the aim of these policies, regulations and action plans is to shape future`s maritime sector in a more efficient, administratively well-organised, eco-friendly, innovative and sustainable manner. However, with the exception of IMO, the aforementioned policies, regulations and projects do not focus to shipping. They cover all transportation modes. On the other hand, the energy efficiency of the maritime sector cannot be considered independently of other transportation modes. Hence, the most effective way to address the energy efficiency problem is to introduce policies that cover the overall intermodal transport systems.

2.2 Other energy efficiency improvement solutions

According to DNV-GL (Dimopoulos and Kakalis, 2014), three pathways have been identified for the improvement of the energy efficiency in accordance with policies and regulations:

- Through the proper design of the ship and its systems/components i.e. onboard technologies.

- Through the optimal operation of the ship's systems and components, with the possibility of some retrofitting i.e. operational optimisation.

- Through the optimisation of trading, operating, and ship management procedures.

Various energy efficiency improvement solutions can be seen under the three pathways in Table 3.

Table 1 – Ship energy efficiency improvement solutions (Dimopoulos and Kakalis, 2014)

	Design	Operation	Procedures
Hull form optimisation	x		
Propulsion efficiency devices	x	x	
New materials	x		
Anti-fouling and coatings		x	x
Waste heat recovery	x		
Auxiliary engine`s economisers	x	x	
Engine/components tuning	x	x	
Electrification and DC grids	x		
Operational optimisation		x	x
Speed control of pumps, fans, etc.	x	x	
Trim optimisation		x	x
Weather routing		x	x
Speed optimization			x
Port/ship logistics			x
Performance/energy monitoring		x	x
Improved power management	x	x	x
Crew awareness			x

Table 1 shows that the ship energy efficiency improvement solutions cannot be considered separate from each other. This is the perspective adopted in this paper.

3 Port Based Energy Efficiency Solutions

Ports are an important component of the intermodal transport system for the safe cargo handling and the delivery of various other services. Today, the shipping has become more complex, ports have grown and the increasing flows of cargoes led to the development of specialized port terminal concepts, such as oil, container and ro-ro terminals. A terminal is defined by Stopford (2009) as "a section of the port consisting of one or more berths devoted to a particular type of cargo handling". The containerised cargo volume especially, has increased in a significantly faster rate than the rest and this led to more investments on specialised port terminals for container transportation. Table 2 illustrates that out of the world`s top 20 busiest container ports, 16 are located in Asia.

Table 2 - Containerised traffic of top 20 container ports in million TEU (WorldShippingCouncil, Wikipedia, 2014)

Port, Country	2012	2011	2010	2009	2008
Shanghai	32.53	31.74	29.07	25.00	27.98
Singapore	31.65	29.94	28.43	25.87	29.92
Hong Kong	23.10	24.38	23.70	21.98	24.25
Shenzhen	22.94	22.57	22.51	18.25	21.41
Busan	17.04	16.18	14.20	11.95	13.43
Ningbo-Zhoushan	16.83	14.72	13.14	10.50	11.23
Guangzhou	14.74	14.42	12.55	11.19	11.00
Qingdao	14.50	13.02	12.01	10.26	10.32
Jebel Ali	13.30	13.00	11.60	11.12	11.83
Tianjin	12.30	11.59	10.08	8.70	8.50
Rotterdam	11.87	11.88	11.14	9.74	10.78
Port Kelang	10.00	9.60	9.18	8.58	9.68
Kaohsiung	9.78	9.64	8.87	7.31	7.97
Hamburg	8.86	9.01	7.91	7.00	9.73
Antwerp	8.64	8.66	8.47	7.31	8.66
Los Angeles	8.08	7.94	7.83	6.75	7.85
Dalian	8.06	6.40	6.54	6.00	5.60
Keihin ports	7.85	7.64			
Tanjung Pelepas	7.70	7.50	5.82	4.68	5.04
Xiamen	7.20	6.47	5.26	4.55	4.50

In this fast growing sector, energy efficiency concerns for ports have been raised focusing on the anticipated impacts due to the new legislation (Gibbs et al., 2014). The GHG Protocol, used by the World Ports Climate Initiative (WPCI), divides emissions into the following groups (Gibbs et al., 2014):

- Direct GHG emissions from sources owned or controlled by the company and under the day-to-day operational control of the port.
- GHG emissions which result indirectly from the port`s electricity demand.
- Other indirect emissions from the activities of the port including employee travel, outsourced activities, movement of vessels and trucks, and construction activities.

In the container transportation, the role of the container ports is very important for the overall energy efficiency of the container sector. However, the current general approach for improving the energy efficiency is to reduce gas emissions arising only from port operations. On the other hand, ports, ships and intermodal systems, are components of the container sector and have an important role for the improvement of the container sector's overall energy efficiency. For containerised cargoes the energy efficiency can be defined as the number of containers delivered door-to-door for same amount energy (i.e. TEUs/kWh).

A newly developed concept is that of "port-centric logistics" (Falkner, 2006, Wall, 2007). Mangan et al.(2008) define them "as the provision of distribution and other value-adding logistics services at a port". Another recent development is the single window concept established by the United Nations Centre for Trade Facilitation and Electronic Business (UN/CEFACT) for the maritime transport. It aims at exchanging efficiently information between governmental organizations and trade facilities (Fjortoft et al., 2011). Both these concepts are applicable to all shipping sectors and the main aim of these concepts is that to improve port-based productivity. Their introduction will have a positive impact to the energy efficiency of the maritime sector as it will improve the productivity of the ports.

Another port system is the hub port system. The hub port systems are classified into the following three categories by Rodrigue (2009) and Asgari et al. (2013):

- *Hub and spoke:* It connects feeder lines to mother lines.
- *Relay:* These hub ports are interchange points for transoceanic shipping lanes. They are located at bottleneck region like the Straits of Malacca which is a bottleneck point for Singapore.
- *Interlining:* while serving a different set of port calls, these hub ports are acting as interfaces between several pendulum routes along the same maritime range.

Shanghai, Singapore, Hong Kong, Rotterdam and Long Beach are known as five major hub ports around the world. Most containerised cargoes at a hub port are generally transhipment cargoes and hub ports are designed to give service to transhipment cargoes which arrives to and departs from either other regional smaller ports or mother ship does not call ports. At hub ports, feeder services are of vital importance to deliver containers to destination ports. The following figure shows a basic hub and spoke container shipping distribution methods.

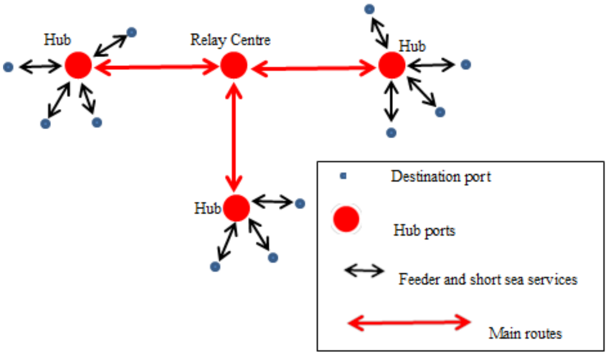


Figure 3 – Hub and spoke container shipping distribution methods (Foresight, 2014)

This hub port system aims to increase the productivity of container lines by using large mother vessels in the main shipping routes such as Far East – America or Far East – Europe and by using smaller vessels as feeders. Additional, there are various different IT applications, management systems and port structural implementations (e.g. berthing methods; intended, conventional and channel, location related structural implementation) available to increase the productivity of the ports and subsequently their energy efficiency. From those proposed the offshore port system has been considered as a new and very promising solution to the intermodal efficiency problem.

4 Offshore Port System Approach

Today's ports that serve huge trans-ocean vessels are located near major coastal cities of the industrial areas. With the offshore port system approach, future's ports will be located 15 - 50 miles away from shore. The first actual implementation of this concept was the Mulberry Harbour which was developed by the British in World War II as a portable temporary harbour, for ship-to-ship transfer on the sea. The method was helpful to handle cargoes from large vessels with high draught to smaller vessel. The US Navy developed the sea basing concept to provide the necessity support to its naval forces without reliance on land bases within the operational area (Quantico, 2014). Additionally, in the oil sector, oil platforms are built to minimise operational risk arising from oil operations at ashore ports.

More recently, the Venice Port Authority announced its plan to build an offshore container terminal. Its specification, provide by the VPA is the following: "With 20 m natural draught, Venice's new offshore terminal will let the world's largest vessels berth. Containers will be taken by barges to the shore and will bring both economic and environmental benefits" (PortofVenice, 2014). A related simulation video of the project can be seen as the following link; http://www.youtube.com/watch?v=MoH4enFiNYM. Also, the economic analysis of the offshore port concept was presented by three business schools namely Northwestern University's Kellogg School of Business, UC Berkeley's Haas School of Business and Dartmouth's Tuck School of Business in San Francisco, 2014 (Seasteading). According to their reports(Seasteading, 2014) "Offshore ports would not only achieve much more security, but they would also help provide an economy of shipping". The offshore port concept can make a positive contribution to the energy efficiency of the container sector. In order to identify this contribution, we need to analyse the components of the container sector which are the main container routes, the container vessel fleet and the sector attitudes.

4.1 The Container Sector

In parallel to the growth in the international trade, the container sector has been growing. According to Alphaliner, today's world container fleet reached 5.955 active ships on liner trades for 18.022.486 TEU and this fleet including 4.968 fully cellular ships for 17.550.256 TEU (Alphaliner, 2014). The following companies are in the leading position of the container sector: APM-Maersk, MSC, CMA CGM Group, Evergreen Line, COSCO Container L., Hapag-Lloyd, APL, Hanjin Shipping, CSCL and MOL which are top 10 container companies with their fleet capacity and they hold 65% of the global container vessels fleet (Alphaliner, 2014).

The containership sector replaces small vessels with larger ones to obtain the benefits from economies of scale. The order books of the top 10 container companies show that the average capacity of their 157 vessels on order is 11719 TEU while current fleet' average capacity is 4644 TEU (Alphaliner, 2014, SEA-WEB, 2014). These figures imply that the leader container shipping companies are planning to replace their small vessels by significantly larger ones, obviously equipped with the latest technology. Today's largest vessels are those of the Triple-E class. According to latest data from Sea-Web, the global container fleet can be seen into the following table. The first ultra large container vessel (ULCV), Emma-Maersk which has a nominal capacity of 15.500 TEU, was constructed in 2006 to bring a solution to energy and economies of scale concerns by consuming less fuel per unit cargo.

Table 3 – Global container fleet distribution (SEA-WEB, 2014)

Vessel capacity (TEU)	Number of vessels	Distance per voyage (nm)	Speed (knots)	Duration of cargo voyage (days)	Number of cargo voyages	Draught (m)	Depth (m)
0-1000	1006	650	17	6	49	6.90	9.35
1001-2000	1225	1000	19	8	45	9.40	13.50
2001-3000	660	2500	21	10	32	11.50	17.00
3001-5100	995	7000	23	24	14	12.70	20.00
5101-10000	873	11000	25	31	11	14.20	24.30
10001-14500	193	11000	25	31	11	15.50	29.60
14501-Larger	18	11000	25	31	11	16.00	30.20

The economies of scale create the potential for gas emission reductions and cost savings. Thus, the use of larger vessels suggests that the energy efficiency in the container sector will improve. Operating larger vessels in appropriate routes is the best way to materialise the beneficial influence of the larger vessels to the container sector. The appropriate routes for larger vessels are obviously the main container routes, in which considerable amount of container trade is plied, to gain maximum economical and energy based efficiency. In this framework, the possible routes to adapt larger vessels can be seen in Table 4.

Table 4 – Top Trade Routes (TEU Shipped) in 2012 (WSC, 2014)

Route	West Bound	East Bound	North Bound	South Bound	Total
Asia-North America	7.529.000	14.421.000			21.950.000
Asia-North Europe	8.959.000	4.406.000			13.365.000
Asia-Mediterranean	4.371.000	1.875.000			6.246.000
North Europe-North America	2.632.000	1.250.446			3.882.446
Asia-Middle East	2.802.151	1.250.446			4.052.597
Australia-Far East			1.072.016	1.851.263	2.923.279
Asia-East Coast South America			550.000	1.399.000	1.399.000
North Europe/Mediterranean-East Coast South America			824.000	841.000	1.665.000
North America-East Coast South America			667.000	574.000	1.241.000

Top trade routes for liner shipping are shown in the above table with figures in 2012. In these nine main lines the total container flow is 56.724.322 TEU. According to data from World Bank (2014), the global container traffic has reached 600 million TEU in 2012, with the data referring to both coastal and international shipping. In this figure transhipped TEUs are counted twice at the intermediate port. It includes also empty units. The distribution of global container traffic by countries can be seen in Figure 4.

When larger ships and offshore port concept are harmonized, building offshore mega hub ports could be an effective solution to increase the energy efficiency of larger vessels and main routes. As a support of this idea, it is recommended that building six offshore mega ports in Seattle, Oakland, Los Angeles-Long Beach, the Gulf of Mexico, Georgia and New York could bring an effective solution to energy issue for Asia – America and Europe – America container routes (Seasteading, 2014). Neal Brown, vice-president of technology for Float Incorporated, suggests that "floating offshore ports could be about 400 acres in size and built with reinforced, pre-stressed concrete with a density less than water"(Seasteading, 2014). With today's ports dimensional constraints and the increasing containership sizes tomorrow's ships (e.g. Triple-E class) will face a problem to utilise their full potential. For example it has been reported that Triple-E class vessels cannot operate currently at US port. These vessels can only be operated at only 16 ports around the world, all of which are located in Asia and in Europe. Therefore, the above US locations are suitable for the development of offshore ports as well as regions in which the ratio of container flow is sufficient to operate ULCV and offshore ports beneficially such as Asia, Europe, and Mediterranean Sea.

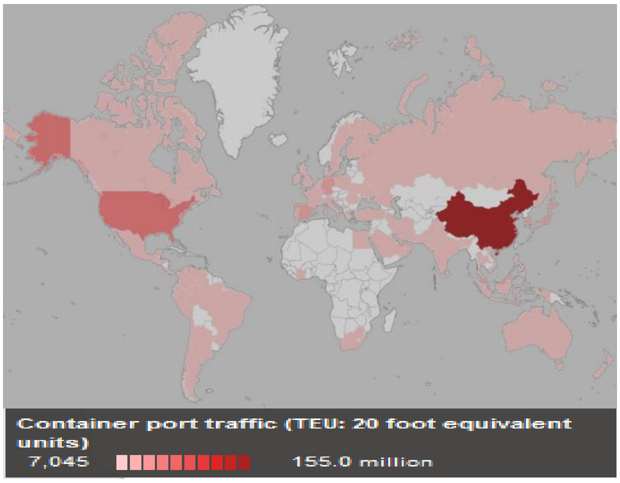


Figure 4 – Global container traffic by countries, 2012 (WorldBank, 2014)

The possible offshore port building areas can be determined with reference to global container traffic. This approach is the best way if offshore ports are to be designed as mega hub ports on main container routes. If the global container flow is considered by the guidance of Table 4 and map in Figure 4, the possible areas should be off the coast of East and South China, Malaysia and Singapore area, off the coast of West and East United States, North Europe and Mediterranean Sea.

4.2 Why offshore port system?

As it was mentioned before, for wet bulk cargoes, offshore terminals are pretty common approach to prevent potential operational risks arising from oil and chemical tanker during loading and unloading operations. Additional to risks, generally, oil tankers have high water draught and it causes some cargo operation and sailing problems at ashore ports, so oil terminals are built as offshore terminals to eliminate these problems of oil tankers. For other maritime sectors, there is no known example of offshore port, and the reason of that might be unfeasible cargo operation facilities for other cargo types. However, the container sector has an important advantage in terms of cargo handling when compared to other sectors. The container sector has easiest cargo handling system with aid of modern cargo handling equipment, which makes transhipment also easier. In the light of these advantages of the container shipping, growths in container trade and vessel capacity create need for bigger port structures. The following table is suggestive to understand the growth in container vessel capacity. The table shows that the capacity of ULCVs will increase by 31%, 30% and 9% in 2014, 2015 and 2016 respectively and total ULCV capacity in 2016 will reach 4.736.530 TEU. It corresponds to 8.4% of container flow in top trade routes.

Table 5 - Scheduled deliveries of ULCVs between 2014 and 2016

	2013		2014		2015		2016		
	Number of vessels in service	Capacity (TEU) in service	Number of vessels in service	Capacity (TEU) in service	Number of vessels in service	Capacity (TEU) in service	Number of vessels in service	Capacity (TEU) in service	Total ULCV capacity in 2016
Over 18.000 TEU	4	73.080	10	182.690	19	344.820	3	54.810	655.400
16000 -17.999 TEU	3	48.060	0	-	6	96.000	3	53.577	197.637
15.000-15.999 TEU	8	124.400	2	31.816	4	63.632	0	-	219.848
14.000-14.999 TEU	23	322.592	4	56.000	20	280.000	11	154.000	812.592
13.000-13.999 TEU	97	1.287.069	22	295.415	5	69.350	0	-	1.651.834
10.000-12.999 TEU	61	682.761	22	230.208	14	143.300	13	142.950	1.199.219
Total over 10.000 TEU	196	2.537.962	60	796.129	68	997.102	30	405.337	4.736.530
Year-on-year growth %				31		30		9	

Based on the above, it is suggested that the offshore ports provide a better alternative to the existing port facilities without the dimensional or navigational limitation faced at the latter. The maximum benefit from offshore ports could be obtained if the offshore port system is designed as;

- Mega hub port (like relay centre) to improve energy efficiency of main container routes, in this approach they will take the place of today’s transhipment hub ports, e.g. six mega offshore hub port suggestion for America coastal.

- Regional transhipment port at low water-draught area to meet demand of ports at around and to improve energy efficiency by pulling larger vessels e.g. Venice Port Offshore Terminal project.

Broadly, it can be said that the installation of the offshore port system at specific sea areas, which should be determined by a result of correct analysis, could provide risk-free, free of the dimensional challenges, energy efficient and eco-friendly container shipping. The growing capacity in the container sector and easy cargo handling opportunities of container boxes, make the container sector the best potential sector to improve energy efficiency as a result of useful collaboration among offshore port systems and the container sector.

4.3 Energy Efficiency Factors in the Container Sector

The following factors are affecting the energy efficiency in the container sector.

4.3.1 Time in Ports

As it is mentioned before that the shipping companies replace smaller vessels with larger vessels to obtain benefits from economies of scale term. However, the recent scenario in the liner services, a container vessel calls a number of ports on its route and every single time spent at port affects the energy efficiency negatively. Time spent increases proportionally with ship's size. The average number of ports of call for the Asia – Mediterranean Sea routes, which contains 4 different routes of Maersk Line Shipping Company, is 13 ports. This means that an 8500 TEU container vessel spends 35% of its time in port for an average 37-day voyage from Asia to Mediterranean Sea if the vessel sails at 19 knots.

Table 6 – Asia – Mediterranean Sea Routes (Maersk, 2014)

Route	Number of ports	Number of ships	Ship capacity mean	Round Trip
1	15	13	7250	87
2	14	11	11250	76
3	11	9	6500	62
4	14	11	9000	72

Although, hub ports are a common concept to reduce port times to increase productivity of main lines, almost all leader shipping company' schedules have been designed as seen above, and the same scenario can be seen at other main container routes. This tendency has been appeared to meet regional demands through main lines. Reducing port number could be an effective solution to improve energy efficiency, but market conditions, competitions among companies and structural inadequacy of ports are big obstacles to change companies' behaviours. It is supposed that the offshore port concept can be an effective solution to reduce the number of ports of call if it is designed as a mega hub port of regional hub ports on main routes by supporting feeder lines to regional ports located on shore. As a result of decrease in port of call, the sailing time will automatically increase for vessels in main routes and this will return as decrease in fuel consumption per unit cargo.

4.3.2 Speed

Low speed was adopted by shipping companies as an answer to the negative reasons of the financial crisis in 2008-2009`. However, it is significant factor that can improve energy efficiency considerably. According to the correlation in Figure 5, if an 8500 TEU container vessel slows down from 24 knots to 21 knots, the fuel consumption of the vessel reduces by about 33% Rodrigue (2009).

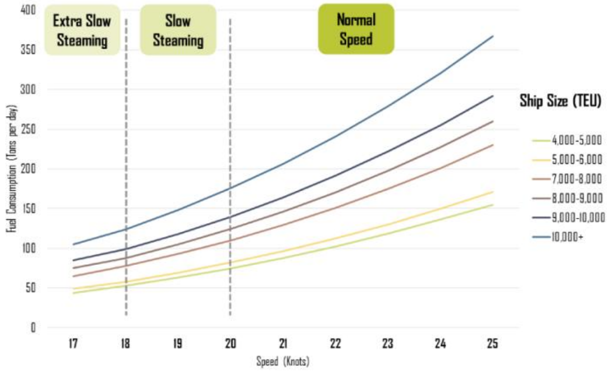


Figure 5 – The correlation of speed – fuel consumption (Rodrigue, 2009)

Operating at low speed has also advantages in terms of economics and safety if there is no legal agreement such as charter party, which can be an obstacle to operate ships at a lower speed. The problem for the liner shipping is the strict schedule, but it is adopted on pendulum routes by shipping companies. Rodrigue (2009) notes that slow steaming have possible impacts on supply chain management, maritime routes and the use of transhipment hubs. The offshore port concept can give opportunity to liner operators to operate their ships at low speeds if shipping companies change their current operation strategies as usage of offshore port. Time spent at port for vessels, which will use offshore ports, will reduce as depending on reduce port of call. Thanks to this system, liner operators will have the chance to operate ships at low speeds by adding 2-6 days to journey times for the Europe-Asia route. However, they will need to expand their fleet for serving at same frequency. In this situation, decision makers should decide that the line will be operated with more vessels at low speed or vice versa.

4.3.3 Structure

The growth in vessel size~~s~~ has brought some infrastructure problems. One of them -maybe the most important - is the increase of their main dimensions (length, beam and draught). This causes operational and navigational difficulties. For example; the water draught of the vessel must be less than the depth of the water in the port, and also the air draught must be lower than the high of the cranes at ports and the lowest bridge. A real example about the air draught and beam problem at Hong Kong Port, is highlighted by Peter Levesque, Modern Terminals's chief commercial officer. He maintains in JOC that "What we see is that ships are getting bigger, staying longer, with fewer moves per call". This is causing lower berth productivity with longer turnaround times for overhead gantries. "Quay cranes applied to the largest ships have a significant increase in travel time per move because of the increased distances the quay cranes have to cover," (Knowler, 2014). These problems can only be solved by dredging and development of port infrastructure, but the size of these larger vessels is a significant obstacle to access ports and to operate large ships particularly in the developing countries (Smith, 2012). These size problems reduce the productivity and the energy efficiency of the sector. The most important barrier is the draught, which limits the vessel` sizes. The offshore port concept could be a remedy with its location advantages. Other problems arising from the larger beam, air draught and even length of the larger vessel are not problems for the offshore port system which will be built as a mega hub port. The mega-port could have enough berthing space for any ship length and while having modern and high operation capability cranes to handle large vessels such as ULCV.

4.3.4 Capacity Utilisation

Another important factor is that capacity utilisation of the container sector. Subject to increase in larger vessel number, the total container capacity shows an upward trend, and the trend which is to build larger ships to obtain economic and efficiency benefits, causes overcapacity problem. However, the developing cooperation through various methods such as the conference system and alliances among container companies has become important for minimising the unutilised capacity issue. The effective implementation of the offshore port system could be a helpful solution method to reduce the capacity utilisation problem. When it is assumed that main route container trade is located on two mega offshore hub ports, -one of them is located at one side and other one is built at other side of the main route-, these offshore ports provide the opportunity to maintain the container trade with a unique line at the specific main route. In real scenario, the leader liner operators are aiming to operate main route container traffic with this concept by forming alliances with joining of larger ships to these alliances. The aim of alliances among container companies is that to operate main routes together with companies in the alliance by giving container slots each other for their consumers' containers. As a result of the alliance, it is expected that there will be a decrease in the number of lines on a specific main route. Thus, the companies plan to solve overcapacity problem. The offshore port system has structural and location advantages to support the alliance approach for main routes because the offshore port system approach aims to service main routes where ULCVs operate. Furthermore, the offshore port system approach brings another advantage for companies in alliances, by aiming to use two mega offshore hub ports to meet the demand in main routes. The proposed offshore port system approach can be seen in the following figure:

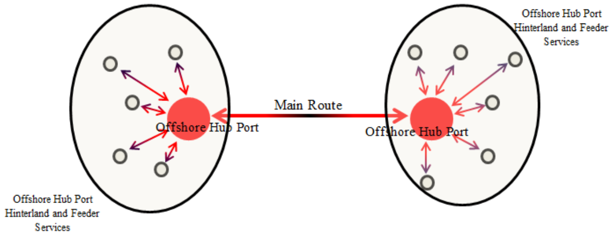


Figure 6 – A mega hub offshore port system

5 Case Study

The case study aims to show how the energy efficiency of Asia – the Mediterranean Sea Container Route could be improved in terms of speed reduction and economies of scale by building an offshore port to the Mediterranean Sea while replacing current fleet (average 8.500 TEU) with 18.000 TEU Triple-E vessels. In order to apply this case to Asia-Mediterranean container route, the Mediterranean Sea needs an offshore port because the Port of Piraeus is unique port able to handle Triple-E class container vessels after investment from COSCO Container L., while there are 9 ports to able to handle these new Triple-E class vessels in Asia.

Firstly, the location of the offshore port is determined by measuring distances between 23 major container ports in the Mediterranean Sea including Black Sea. They have been chosen as one port per country. Distances between 23 ports shows that the Port of Piraeus (Greece), Candarli Port (Turkey) and Marsaxlokk Port (Malta) have advantage with their 16,576, 17,368 and 18,306 nautical miles distances respectively, in total (Sea-Distances). The following map districts the Mediterranean Sea. The Marsaxlokk Port is located in GM04 area, Candarli Port is located in GM06 area and the Port of Piraeus is located in intersection area of GM04 and GM06. The figures show that GM04 and GM06 areas have advantage to build an offshore port for the Mediterranean Sea and these areas have distance related easy access to other ports in the Mediterranean Sea and in the Black Sea.

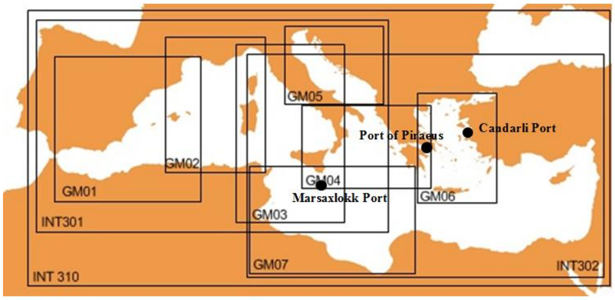
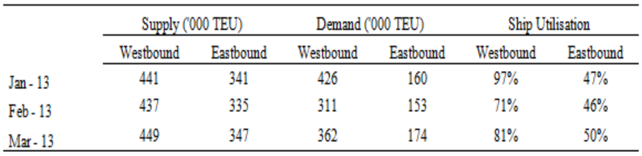


Figure 7 – The Mediterranean Sea in districts

For the case study it is assumed; that the Piraeus Port is the most favourable due to its distance, so it is assumed as the offshore port for the voyage calculation from Asia to the Mediterranean Sea. Also, it is assumed that all containers will be handled to the offshore port while the main vessels continue their current schedule back to Asia. Another assumption is that all containers are carried at one line and according to figures in Table 7, monthly container capacity is determined as 450.000 TEU to meet the highest present demand.

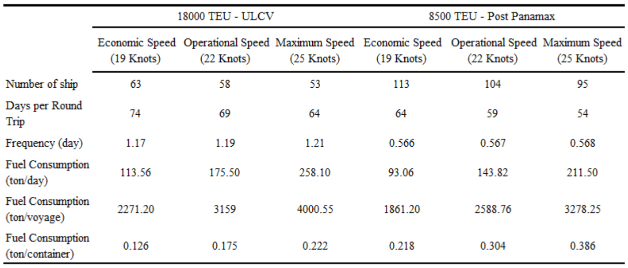
Table 7 – Asia – Mediterranean – estimated monthly supply/demand position (Drewry, 2013)



	Supply ('000 TEU)		Demand ('000 TEU)		Ship Utilisation	
	Westbound	Eastbound	Westbound	Eastbound	Westbound	Eastbound
Jan - 13	441	341	426	160	97%	47%
Feb - 13	437	335	311	153	71%	46%
Mar - 13	449	347	362	174	81%	50%

The case was carried out by using 8.500 TEU container vessels and then by using 18.000 TEU container vessels at two different speeds i.e.19 knots, 22 knots and 25 knots respectively. The assumed route included 7 major ports call in Asia. After their last port call, the vessels will sail to the Mediterranean Sea via Suez Canal and will berth to the offshore port without any port call in the Mediterranean Sea. This schedule will be also followed on the return voyage. Another assumption is that cranes are appointed at the rate of 3/2 for 18.000 TEU container vessel vis-a-vis 8500 TEU container vessel.

Table 8 - Fuel Consumption Values for 9500-NM Far-East/the Mediterranean Sea Route



	18000 TEU - ULCV			8500 TEU - Post Panamax		
	Economic Speed (19 Knots)	Operational Speed (22 Knots)	Maximum Speed (25 Knots)	Economic Speed (19 Knots)	Operational Speed (22 Knots)	Maximum Speed (25 Knots)
Number of ship	63	58	53	113	104	95
Days per Round Trip	74	69	64	64	59	54
Frequency (day)	1.17	1.19	1.21	0.566	0.567	0.568
Fuel Consumption (ton/day)	113.56	175.50	258.10	93.06	143.82	211.50
Fuel Consumption (ton/voyage)	2271.20	3159	4000.55	1861.20	2588.76	3278.25
Fuel Consumption (ton/container)	0.126	0.175	0.222	0.218	0.304	0.386

The results in Table 8 are calculated for 9500 nm Asia-the Mediterranean Sea container route. Functions in the following are used to reach the results in above table.

$$Monthly\ container\ capacity =$$

$$\frac{Number\ of\ ships \times Ship\ container\ capacity}{Days\ per\ round\ trip} \times 30 \qquad (1)$$

$$Number\ of\ Ships = \frac{Days\ per\ round\ trip}{Frequency} \qquad (2)$$

The relationship between speed (V) and fuel consumption (F) is shown by the following function.

$$\left(\frac{V}{V_0}\right)^n = \frac{F}{F_0} \qquad (3)$$

Where V_0 is reduced speed, F_0 is fuel consumption at reduced speed and n is known constant. In most paper, a cubic relation is used, and in this paper n is equal to 3, although it is taken as an exponent of 4 in ship design textbooks for faster vessels than 20 knots (Barrass, 2004, Kontovas and Psaraftis, 2011). Daily fuel consumption values of vessels at design speed (25 knots) are received from Sea-Web database and speed related fuel consumption at 22 knots and 19 knots is calculated by using a cubic relationship between speed and fuel consumption. In this case, referring to Table 7, 65% ship utilization is used to obtain realistic fuel consumption per container, because, generally, a container line has heavy and light legs.

As seen from the results in Table 8, if the transportation service is provided by the large vessels, the applied system results to advantages in terms of number of ships (capital investment) and fuel consumption, though there is disadvantage for days per round trip. The reason of this disadvantage is that 18.000 TEU container vessel needs 1.4 times more handling time than 8500 TEU container vessel.

The important point is that the usage of 18.000 TEU vessels cuts fuel consumption up to 42% at 25 knots per container. Additional to this benefit, when the speed of vessel is reduced to 22 knots and 19 knots, the fuel consumption can reduce at rate of 32% and 56% respectively. Another point in favour of the usage of larger vessels is the number of seafarers and the main route related vessel traffic around ports decrease based on decline in the number of vessels. The decrease in the number of seafarers and vessels in main route means that decrease for operational expenses. Also, this enables marine transport components to give safe, secure, efficient, economic and reliable transportation service. On the other hand, the emergent disadvantaged situation which is long round trip as a result of the usage of larger vessels can be removed by reducing the number of calls to ports.

5 Conclusions and Future Research

This paper investigated the role of the offshore port system, which was undertaken to design a more efficient and environmentally friendly marine transport system and to evaluate the container sector using a new hub port concept in accordance with policy and regulations. The investigation of the container sector has shown that the sector needs mega hub ports in terms of economic reasons and to eliminate factors which affect energy efficiency negatively. The conclusion from the present study is that the offshore port system could be a solution to the challenges of the container sector`s mega hub port need. The advantages in terms of energy efficiency identified assist in our understanding of the role of the offshore port system approach. However, the study has not included the techno-economic aspects of the offshore port system, as there is no applied example of this system at this level for the container sector. The inclusion of such data would help validate the feasibility of such an investment. Therefore, it is recommended that further research should be undertaken in the following areas:

- Technical feasibility of offshore mega hub ports,
- The container sector's approach to this port system; investment decision in terms of capital cost and profitability.
- The feasibility of the feeder services and short sea shipping, the number of the feeder services, their capacity analysis, schedules and effects to energy efficiency and cost.
- The competition among offshore ports and current ports; location choice in terms of other ports location and market components such as freight volume, serving company capacity and other investments etc.
- The effect of offshore ports to logistics applications such as door-to-door and just-in-time transportation in terms of energy efficiency and costs
- Energy sources of offshore port systems (from land or producing on port) and transport of stevedores and other crews and its cost
- Risk assessment of offshore port in terms of insurable risks and international and national legislations.

As a conclusion, it is argued that the offshore port system can be an alternative solution today's port approach to improve the energy efficiency of the container sector.

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