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Sustainability ranking of the UK major ports: Methodology and case study

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ABSTRACT

Maritime supply chain sustainability has not been widely studied to date. This paper investigates the sustainability performance of five major UK ports. The UK port system is one of the largest and busiest port systems both in Europe and worldwide. The scope of sustainability narrows down to economical and environmental dimensions. A questionnaire is developed to collect data from port managers and logistics experts. The AHP method is utilized to rank the ports using the collected data. Sensitivity analysis is conducted on the obtained data to verify the consistency among data and outcomes.

1. Introduction and background

1.1. Maritime supply chain

The maritime industry with around 90% of global trade by volume and 70% by value is one of the most globalized and largest industry sectors in the world (Asgari et al., 2013). Different categories can be considered for maritime industry such as: maritime transportation, maritime logistics, and maritime supply chain.

Maritime transportation is only focusses on the transport of products that flow between two seaports by sea, while logistics integrates many activities to control the flow of products from supplier points to end customers (Song and Panayides, 2012). Logistics can be defined as a part of supply chain. While logistic activities are only concerned about the management of material and information flow from supply points to demand points, the supply chain is wider in scope as it involves managing and coordinating the tasks of the whole chain. Supply chain management therefore includes the management of many key business aspects such as: transportation, material control, manufacture and distribution from supplier until the end customer (Harrison and Hoek, 2008). Maritime transportation is considered as a linkage in this chain (Banomyong, 2005).

Two main sectors in the maritime supply chain are liner shipping and ports. Liner shipping plays the role of a customer for port systems. Ports play a key role in the maritime supply chain since they are located as the center link between land and sea transportation for international trade. Processing 16,786 millions tons volume of cargoes in 2011, the port system has to

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deal with a huge demand of goods movement worldwide. Therefore, any significant improvement that can be achieved in its infrastructure and the quality of services will have a significant effect on the efficiency of maritime supply chains.

The new trend of worldwide maritime logistics is concerned not only about new developments in techniques, management and liberalization but also about creating more competition (Song and Lee, 2009). Consequently, maritime logistics brings higher quality services to customers by conducting transportation in the supply chain in a more effective and efficient manner.

1.2. Importance of sustainability

Supply chain sustainability is a combination of the economic, environmental and social dimensions of supply chain management (Carter and Rogers, 2008). Fig. 1 shows the interfaces between these dimensions. Accordingly, a sustainable supply chain can be defined as the management of information, operations, funds and resources in order to maximize economic efficiency, maximize social welfare and minimize environmental impacts (Denktas-sakar and Karatas-cetin, 2012).

In the recent years, sustainability has attracted a lot of attention from both the academic and industrial sectors. Regarding the economic and social dimensions, it aims to optimize the operations by improving cost-effectiveness as well as the working conditions in the supply chain. On the other hand, the environmental aspect refers to reducing the associated negative environmental impacts.

1.3. Maritime sustainability

In recent years, the maritime industry has generally moved toward a sustainable supply chain which aims to improve the quality of logistics services as well as ensuring more wider benefits. Ports form an important part of any supply chain sustainability considerations. Therefore, it is necessary to assess the sustainability of ports in order to make optimal decisions and choose sustainable development strategies with regard to maritime supply chains.

In the maritime industry, all tasks are conducted in the context of a network of seaports. Products flow by transportation through this network. The economic aspect aims to optimize the operations, reduce costs such as fuel and shipping cost, and create value-added services. Besides that, the goal of the environmental aspect is to reduce negative environmental impacts. The social aspect plays an important role in sustainability as it aims to maximize the level of well-being in society (Denktas-Sakar and Karatas-Cetin, 2012).

1.4. Literature review and gap analysis

There are a few studies in the literature in which the impact of sustainability in port management is studied. The main portions of these studies only consider the environmental aspect of sustainability. Goulielmos (2000), Peris-Mora et al. (2005), Le et al. (2014), and Villalba and Gemechu (2011) are relevant examples. Gibbs et al. (2014) consider the emission from berths rather than ports. They analyze a set of UK ports in this study. Lu et al. (2012) consider the case of Taiwanese ports and assess the importance of sustainability criteria.

Table 1 summarizes the related works and presents the problems, techniques, and achievements of each work.

Most studies in this area are case studies. But, what highlights the importance of this study is that to the best of our knowledge and shows in Table 1, there is no study which considers both economic and environmental impacts simultaneously. Moreover, the gathered data for this study is primary data obtained from a survey of port and logistics experts.

Note that we investigate sustainability criteria in the United Kingdom port systems as a case study. The port system in the UK is one of the largest port systems in the world. It is ranked among top container exporter and importer in the world in 2009 and 2010, exporting 1.4 and 1.5 Million TEU (Twenty-foot Equivalent Units) and importing 2.3 and 2.5 Million TEU respectively. Table 2 depicts its ranking in the world and European Union based on TEU (World Shipping Council).

As the UK port system is among largest ones in the world, this approach could be utilized for similar research on other port systems. Regarding that our data are secondary data, which achieved through surveys, we verify the results to make sure of its consistency with the secondary data available on ports.

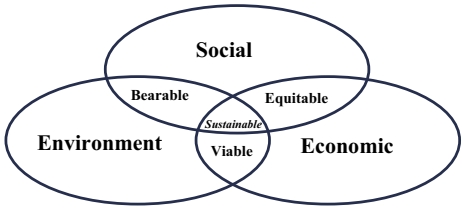

Fig. 1. Sustainability dimensions.

Table 1
List of literatures on maritime industry and port sustainability.

References	Maritime sustainability	Case/research study	Technique	Problem/achievements
Wooldridge et al. (1999)	Port and harbor	Case study of UK ports	Mapping and monitoring protocol	Evolve the environmental management protocols in port areas by integrating policies and techniques
Goulielmos (2000)	Port environment	Case study of European ports	Analysis of the function of port production	Determine the policy for port activities and environment, control accidents, and prevent pollution through international safety management code
Marlow and Casaca (2003)	Port performance	Research study	Measure the lean port performance (internal, external) toward an agile port	Build up a framework to transform from lean port performance to a dynamic network (agile ports)
Peris-Mora et al. (2005)	Sustainable port management	Case study (Project ECOPORT in Spanish and European ports)	EMS (ISO 14001)	Develop an indicator system for the sustainability of port management
Bichou and Gray (2004)	Port performance	Research study	Analysis of the trade-off between cost and customer satisfaction	Establish a framework of port performance/ improve the efficiency and quality of logistics
Fitzgerald et al. (2011)	International maritime transport	Case study of New Zealand	To calculate the amount of fuel consumption and hence the greenhouse gas emission	Provide the results of fuel consumption and GHG emission from import and export activities
Villalba and Gemechu (2011)	Maritime ports	Case study of the port of Barcelona	Calculate the total amount of CO_2 emission for both land and sea-side	Estimate the amount of GHG emission and its sources in the port
Lu et al. (2012)	International ports	Case study of Taiwanese Ports	Multi criteria decision making (MCDM)	Assess the importance ranking of sustainable criteria and port performance
Le et al. (2014)	Port performance	Case study of Vietnam and Cambodia	Environmental Management System (EMS)	Design a list of sustainable criteria for assessment/ ranking the studied ports
Gibbs et al. (2014)	Seaports	Case study of the UK ports	Interviews	Calculate the emission of shipping from berths rather than from the port
This Research	Port management	Case study of the UK ports	AHP	Port ranking based on both economic and environmental aspects

Table 2
The UK port system ranking (2010).

	United Nations	European Union
Import	18	2
Export	7	4
Total	10	2

This research tries to answer the following questions:

1. What are the criteria to evaluate maritime sustainability considering environmental and economic aspects?
2. What are the weights (relative importance) of each criterion/sub-criterion?
3. What methodology is suitable to investigate ports sustainability performance? Why?
4. How can we verify the results extracted from secondary data?

The rest of the paper is organized as follows: Section 2 describes the UK maritime supply chain and its importance among other world port systems. Section 3 presents the problem statement. In Section 4, the research methodology is explained in detail and the research protocol is provided. Section 5 explains the primary data collection method, and using the gathered data, the proposed methodology is implemented. Section 6 provides some insights to validate the results. Section 7 concludes, and the limitations of this research and future direction are presented.

2. The UK maritime supply chain

2.1. The UK port authority

There are more than 100 ports in the UK. The five largest ports in terms of tonnage are: Tees and Hartlepool, London, Grimsby and Immingham, Southampton, and Milford Haven, totally handling more than 200 million tons per year. Oil products account for a major part in the total volume accounting for half of total trading volume in UK ports. The port industry is a

vital part in UK's economy. The port system in the UK is mostly governed by port authorities and companies such as Port of London Authority, British Ports Association (BPA) and Brookfield Ports Company (PD Ports).

A port authority is regarded as an entity which has responsibility to administer and manage all port facilities and infrastructures, as well as control all activities in the port. The governance of port authorities is under national law (Verhoeven, 2010). Nowadays, the demand for port operations in the UK arises not only from the international but also from the local communities. It is expected the UK ports will be expanded in size, number of locations, and infrastructure to adapt to a higher demand in international trading and domestic services. As well safety, legislation, technical and environmental standards are expected to enhance the quality of the port's system. Regarding sustainability, port authorities have the responsibility to guide the port operations toward this trend. To be successful in sustainable development, the port authorities have to develop new strategies and policies which ensure the integration of the economic, social and environmental dimensions. Since 2002, Britain's leading ports operator has started to reform the framework of environmental management. These changes in policies are designed to achieve the following sustainable development related objectives:

- Reduce environmental damages from port operations.
- Achieve efficiency in using natural resources.

Following the trend of sustainable development, Brookfield Ports Company (PD Ports) has made more efforts to prevent environmental pollution and improve environmental management system toward ISO 14001 certification. In the environmental policy, the role of law, training and energy-efficiency is more concentrated.

2.2. The UK ports

There are 120 ports in the UK which are distributed throughout the country providing different types of service. The port system in the UK is the second largest one in Europe with a significant amount of shipping: about 560 million tons per year, where 80% of that is handled by the top 16 ports (Baird and Valentine, 2006).

None of the UK ports are government owned. Two kinds of Port management in the UK exist:

- All large ports are owned by the private sector and included in the group of ports that belong to the Association British Ports (ABP) such as: Forth, Tee & Hartlepool, Felixstowe and Liverpool.
- The ports are owned by a trust. These ports are independent from the government and shareholders such as: London Authority.

The environmental dimension, maritime life and security of ports have been the target of significant attention in recent years and these have become the main targets for future development (The UK Ports Industry – A profile, 2008). Environmental issues become significantly more important in sustainable strategies of port administration as the serious threat from global climate change becomes better known and understood. There are two factors which are able to create economic value for ports: port location and port authorities.

This study is scoped to include the group of the five largest ports in the UK which are ranked regarding the volume of total traffic in Fig. 2. These statistics are obtained for the 30 major ports in UK. The group of 5 largest ports takes 44% of total port traffic. Brief information of these five ports is presented in Table 3. Fig. 3 shows the location of these five ports on the map of the UK (GOV.UK, 2013).

2.3. The sustainable performance of UK ports

In 2013, environmental issues in the UK had a high level of visibility with a lot of green port-related projects undertaken. For example, the project of new port London gateway premiered at the end of 2013, which is built with the goal of being an environment-friendly port. This port is built on the philosophy of an effective combination of economic and environmental goals.

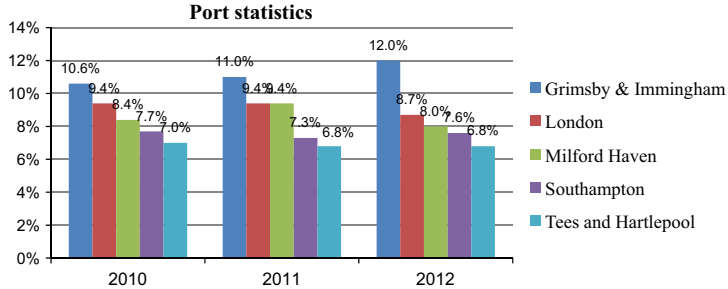

Fig. 2. The traffic volume of five major ports in UK. *Source:* https://www.gov.uk/government/collections/maritime-and-shipping-statistics.

Table 3
Brief information of major UK ports.

No.	Port and group ports	Location
1	Grimsby and Immingham	This group of ports is considered as the center of the UK and Europe, which is developed in the integration of 2 UK largest ports: Grimsby and Immingham. The combination of 2 UK largest ports brings a huge capacity for this region Immingham port is mainly specialized in logistics and services for local industry (It can connect with Iceland, The Baltic, Rotterdam and Scandinavia (Immingham) Grimsby port: is named as the food town of Europe because the food industry and fishing (it supplies 20,000 tonnes of fresh fish per year) are the focal point of this port (Grimsby) The Grimsby and Immingham port provides the access to international trading routes through North and South America, Africa, Europe, Middle East, Australia and Far East
2	London	One of three main functions of London port is inter Port trade. There are totally 70 terminals which are connected in the shipping network with 80 countries (Port of London Authority, 2013). The Port of London is located by the River Thames, to the northeast of Southampton Port
3	Milford Haven	The biggest port is located in Wales, which specializes in the trading of oil and gas (Environmental Performance Report, 2012). Thus, this port is connected in two main trading routes: tanker routes from Qatar, Asia Pacific, West Coast and UK pipeline network from Algeria, Malaysia, Trinidad and Egypt (Q&A: Liquefied natural gas, 2009)
4	Tees and Hartlepool	This is a combination of the port systems of Teesport and Hartlepool, which are located on the north-east coast of England • *Teesport:* It is located next to the mouth of River Tees and lock-free connects with the North Sea. Thus, it receives 5000 vessels and 34 million tones cargo per year • *Hartlepool port:* It is located three miles from the River Tees. It has free access to the sea and North Basin. The port specializes in the sectors of oil, gas, wind energy, and bulk cargo. (TEESPORT AND HARTELPOOL PORT HANDBOOK, 2013)
5	Southampton	This port is located in the south coast of UK. This is one of the busiest ports in the country. This port handles the product flows which come from Far East to Britain, particularly container traffic. It is also the largest import export hub of motor vehicles in the country (Port of Southampton, The UK's most dynamic gateway, 2013)

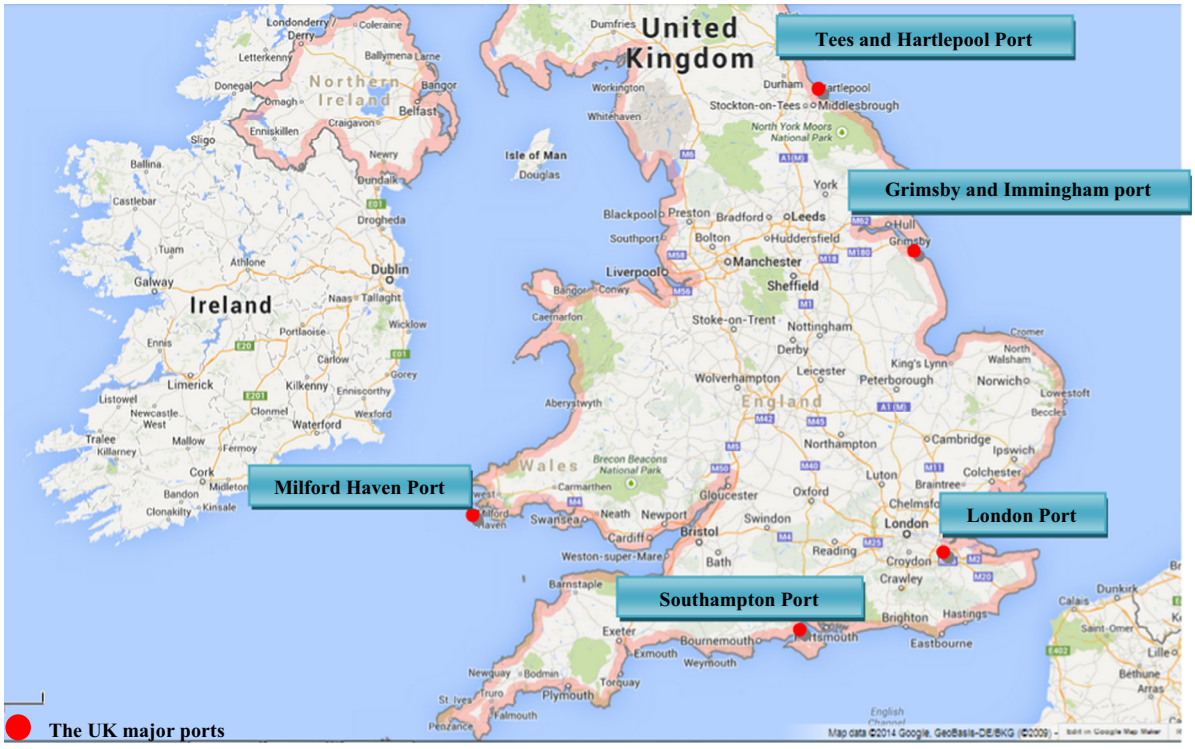

Fig. 3. Location of the 5 top ports of the UK.

There are three certifications used for improving sustainable performance in ports: ISO 14001, Green Ports and Ecoports.

- *ISO 14001:* This is a group of management system standards that are applied to improve the environmental performance in organizations. These standards exist in order to assess, organize and reorganize toward sustainable development in business organization. They help to reduce pollution from each part of the system (Saengsupavanich et al., 2009).

- *Green Ports:* A certification that shows balancing between environmental protection and economic demand. It aims to provide new environmental solutions for ports and terminals.
- *Ecoports:* This is integration between two concepts: effective environmental and port management. It is mostly applied for ports in Europe (ESPO/Ecoports)

In this paper, the standards of 14001 are applied for sustainable assessment of the port group as they are the most general, and hence appropriate for this study. After that, the port ranking is established which aims to assess the success of their efforts in sustainable development.

3. Problem statement

3.1. Problem description

The UK port system is an integral sector for the economic growth of the country; so good policy making is very important to manage this system. As mentioned earlier, the UK port system is the second largest in the EU with a large annual trade, and it is independent of government control. Therefore, factors which make this system a modern port system in European zone are the topic of ongoing investigation (Asteris and Collins, 2010). Recently, sustainability has become an important standard to assess port activities. An analysis of the entire UK port system analysis with 120 ports and wide ranges of activities would be very complex and lead to a lack of focus due to the diverse nature of the activities; therefore, this study concentrates on the five largest ports in this country, which own a significant portion of the trading volume (44% of total port traffic).

In this study, the concept of sustainability is analyzed considering two dimensions: economic and environmental. This aims to show the core responsibility of policy and strategy making not only to achieve more cost-benefits but also to create more innovations and environmental friendly management techniques. Such factors are very important for sustainable long term development.

In this study, a list of indicators about economic and environmental dimensions is established from port activities. From those indicators, the set of criteria is applied to assess the sustainable performance of the UK port industry. A multi criteria decision making (MCDM) method is utilized to rank each alternative among the group of chosen ports which achieve efficiently a suitable balance between economic and environmental objectives.

The top 5 selected ports are located in different regions in the UK. In Table 4, related information is presented. As shown, these ports have a good performance in sustainability which is approved through different certifications on environmental management. This shows the effort of port administrations in investing in sustainable development.

3.2. Objectives

With regard to the maritime supply chain, this study is scoped to assess the sustainable performance of the 5 largest UK ports. The assessment includes economic and environmental dimensions.

- *Economic goals*

Ports are an integral part in the supply chain design related to achieve cost-efficiency goals from optimizing operation costs. Economic aims are to minimize operation costs such as: transportation cost, shipping cost and inventory cost. In addition, the quality of services is also an important criterion to attract more customers such as: reduce the service and waiting time and reduce port congestion.

- *Environmental goals*

These aim to decrease environmental impacts from both port and shipping operations in the port area. A set of environmental indicators is designed to measure pollution degrees, environmental legislations, renewables and the strategies of future development.

Table 4
Selected ports information.

Port name	Port location	Capacity (million tons cargo/year)	Port authority	Greenhouse gas emission (CO_2 equivalent tons)	Green port	ISO 14001 (EMS)	Other green certifications
Grimsby and Immingham	The river Humber	55	PD port		✓		Ecoport
London	The river Thames	53	London Port	1772 (2011)	✓	✓	Ecoport
Milford Haven	South West Wales	35	Milford Heaven		✓		Ecoport
Southampton	Central South Coast	39	ABP			✓	
Tees and Hartlepool	River Tees	56	PD Ports			✓	

Accordingly, the list of criteria is designed following the standards of environmental management system (EMS) ISO 14001 and previous research. In corresponding to each criterion, there are the indicators which are measured to evaluate the port performance using the criteria.

3.3. Sustainable criteria and indicators

In the first step, a set of economic and environmental criteria and indicators are considered. To do so, we used environmental management systems standards (ISO 14001) and UK ports authority. ISO 14001 is a certification of environment management system (EMS). It provides a framework for organizations to undertake the efforts of reducing environment impacts and continuous improvement. It is also a good standard to develop a system for sustainable assessment.

In addition, a set of environmental and economic indicators is needed. In correspondence to these criteria, a set of indicators is determined by following steps (Peris-Mora et al., 2005):

- Determine impacts of the indicator on the process.
- Evaluate the levels of such impacts.
- Examine the relation among impacts.

Permala (2009) presented a potential indicator set for the economic, environmental, and social domains. This set is utilized to assess the criteria. The main objectives to develop sustainability in port performance are:

- To reduce negative effects on the air, noise and marine environments.
- To exam the port policy to reduce the environmental impacts.

4. Methodology

4.1. Multi criteria decision making (MCDM)

MCDM methodology is a paradigm which supports decision makers by considering a set of relevant criteria. This methodology is classified to two different types: multi-objective decision making (MODM) and multi-attribute decision making (MADM). According to Mendoza and Prabhu (2000) MADM ranks alternatives based on a set of discrete criteria and generated discrete solutions.

First, a set of alternatives is determined along with a number of attributes, considering the objective. In MADM, a comparison matrix is developed where rows are the desired choices and columns are set of attributes.

Inputs

Z_i: Set of attributes, obtained from the decision environment, $i = \{1,2,3,\ldots,K\}$.
X_j: Set of alternatives (choices), defined for evaluation, $j = \{1,2,3,\ldots,N\}$.
W_i: Set of weights for each attribute, $i = \{1,2,3,\ldots,K\}$

Objective function:

$$\text{Optimize } Z = f(x_1, x_2, x_3, \ldots, x_n) = \sum_i w_i f(x_i) \tag{1}$$

This method can solve complex problems with different objectives, information, benefit and data. Therefore, MADM is hence suitable to evaluate socio-economic problems such as sustainability-related problems.

Fig. 4 summarizes the MADM steps to compare attributes. According to MADM, the objectives are an origin of processes in the diagram. From the main objectives, a group of potential alternatives is selected. We need to identify a set of attributes. After that, the set of attributes is weighted to determine their importance. Lastly, they are normalized for comparison between criteria.

4.2. Analytical hierarchy process (AHP)

The analytic hierarchy process (AHP), proposed by Saaty (1988), is a powerful tool which supports decision making in a multi-attribute environment. The inputs and objectives are the same as those of MCDM. According to Ramanathan (2001), the AHP method is considered as a powerful tool for environmental impact assessment (EIA) for many reasons:

- This method can assess the trade-offs between environmental and economic impacts.
- The experts' point of views on the problem can be collected through surveys that only require pairwise comparisons between two criteria at a time.
- A consistency test exists that ensures the quality of judgments.

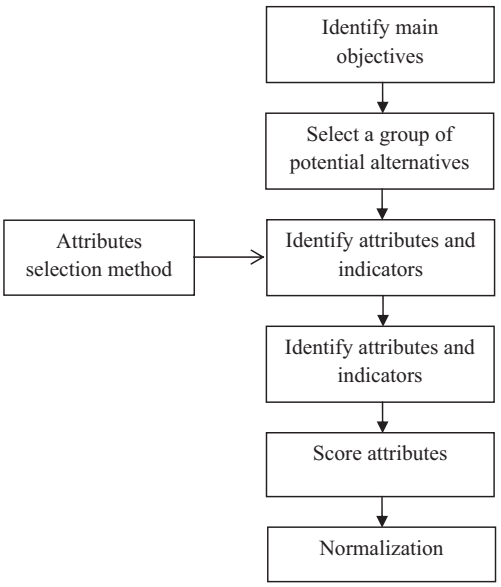

Fig. 4. The process of MADM method diagram.

Another advantage of this method is that it helps to reform the expert opinions into a numerical scale; however, it has to be checked with consistency ratio to ensure of the survey's quality.

Firstly, AHP decomposes the decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently. The elements of the hierarchy can relate to any aspect of the decision problem. Fig. 5 depicts this process.

In second step, the weights for attributes are computed. It starts with the comparison matrix ($k \times k$), where k is the number of attributes, and then sets it up the scale to assess the importance of attributes. The value of each entry is denoted by a_{ij} as shown in Fig. 6.

a_{ij} is calculated according to Table 5.

a_{ji} can be simply obtained using:

$$a_{ji} = \frac{1}{a_{ij}} \tag{2}$$

In the last step, consistency index is determined to assess how the consistency of the decision makers' comparison is. We refer interested readers to (Saaty, 1988).

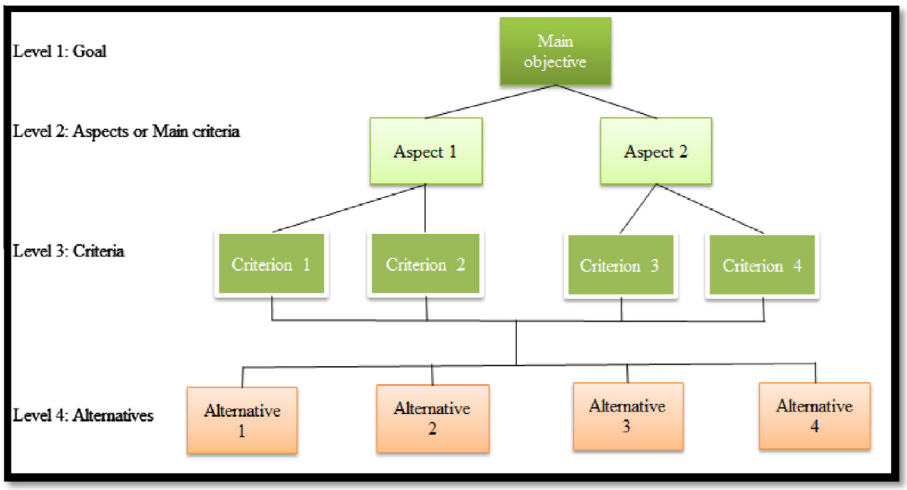

Fig. 5. The decision hierarchy diagram.

Attributes	$Z_1\ Z_2 Z_3\ \ \ldots\ \ Z_k$
Z_1 Z_2 Z_3 $\vdots$ Z_k	$A = \begin{bmatrix} 1 & a_{12} a_{13} & \ldots & a_{1k} \\ a_{21} & 1 & a_{23} & \ldots & a_{2k} \\ a_{31} a_{32} & 1 & \ldots & a_{3k} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{k1} a_{k2} a_{k3} & \ldots & 1 \end{bmatrix}_{k \times k}$

Fig. 6. Pairwise comparison matrix.

Table 5
The comparison scale in AHP method.

Value of a_{ij}	Important levels
1	Attribute i and j are equal important
3	Attribute i is weakly more important than j
5	Attribute i is strongly more important than j
7	Attribute i is very strongly more important than j
9	Attribute i is absolutely more important than j
2, 4, 6, 8	Give the intermediate values

4.2.1. Score the set of alternatives performance

Along with weighting of attributes, score calculation of each alternative is also very important. While weighting is used to determine priority for attributes (or criteria), scores are used to select alternatives.

Step 1: Develop pairwise comparison matrix for a group of alternatives based on their importance to assess the value of a_{ij}.
Step 2: Calculate W_{ij} as follows:

$$W_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{3}$$

Step 3: These weights create a new matrix (A_{norm})

$$A_{norm} = \begin{bmatrix} \frac{W_1}{W_1} & \frac{W_1}{W_2} & \frac{W_1}{W_3} & \cdots & \frac{W_1}{W_k} \\ \frac{W_2}{W_1} & 1 & \frac{W_2}{W_3} & \cdots & \frac{W_2}{W_k} \\ \frac{W_3}{W_1} & \frac{W_3}{W_2} & 1 & \cdots & \frac{W_3}{W_k} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \frac{W_k}{W_1} & \frac{W_k}{W_2} & \frac{W_k}{W_3} & \cdots & 1 \end{bmatrix} \tag{4}$$

The weight of each alternative is the average of weights in each row which can be considered as the score of alternatives. The alternative that has the highest score is the optimal solution. Fig. 7 summarizes the AHP steps.

In this study, the Expert Choice software package is utilized. The software is based on the theory of AHP. By inserting the obtained data from the survey, the AHP method derives weights for the criteria and scores for alternatives based on three types of comparison scales: numeral, verbal and graphical. The verbal comparison the most commonly used with nine levels from equal to extremely more important.

4.3. Research protocol

Considering to the field of sustainability, it is difficult to integrate the economic and environmental dimensions together since they are conflicting in their targets (Gilman, 2003). This is mainly because all economic strategies aim to bring more cost-efficiency by optimizing port operations, while most environmental strategies normally require a lot of investment. Therefore, it is very difficult to balance these dimensions that are the main goals of sustainability toward future development. A set of criteria is hence established to evaluate the performance and competiveness of each port.

According to AHP, the first step is to develop the decision hierarchy. We develop the hierarchies of environmental aspect based on the ISO 14001, standards of environmental management systems. ISO 14001 components are presented in Appendix A.

The research protocol is presented in Fig. 8. All inputs and steps of the proposed methodology are depicted in this figure.

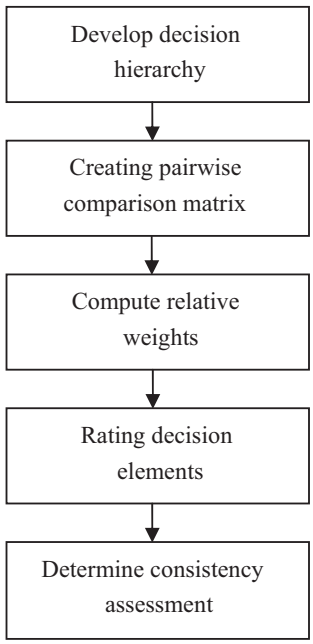

Fig. 7. The processing steps of analytic hierarchy process (AHP) method.

5. Implementation

5.1. Data

In order to rank the ports based on their sustainability performance, a survey is conducted based on two factors: the set of selected ports (alternatives) and the set of attributes (criteria). In order to collect data we follow the following steps:

(i) *Participants selection*

There are two types of participant who need to be invited: port managers and logistics experts. Port managers are the ones who develop strategies and policies toward sustainability. They directly control the port system to satisfy the desired targets. Logistics experts are ones who teach, work and research in this area, so they have valuable experiences and knowledge to evaluate the set of criteria and alternatives. They know the differences between ports. While port managers can evaluate the practical implementation of sustainable approaches and their effects in internal port organization, logistics experts who have a general view and knowledge of the UK port system can evaluate the effects of each attribute on each selected port precisely. All of the participants have to be people with local and port-related knowledge.

The surveys are sent to both port managers and logistics experts. 10 Surveys in two types: online and checkbox form are sent by email to port managers. Moreover, forms are sent to 2 academic logistics experts.

(ii) *Questionnaire survey*

After determining the participants, the survey is designed with questions aimed to reflect the specified targets. For each criterion, the set of ports is evaluated by the importance level following the previously described 1–9 scale. The structure of the questionnaire is as follows.

First of all, a set of questions aim to collect general information about environmental management system (EMS) as well as questions on applying the standards of ISO 14001 to improve sustainability. The main objective of this part is general understanding of sustainable development in each port, which will be reflected by policies and strategies.

Next, the most important part is to consult with the personal experiences and opinions of the port performance under a set of sustainable criteria. The assessment uses scale of 9 significant levels. Lastly, the ranking questions aims to evaluate the port performance according to the given set of multiple criteria. It is the base to score alternatives in correspondence to each criterion. The form of the questionnaire survey is provided in Appendix B.

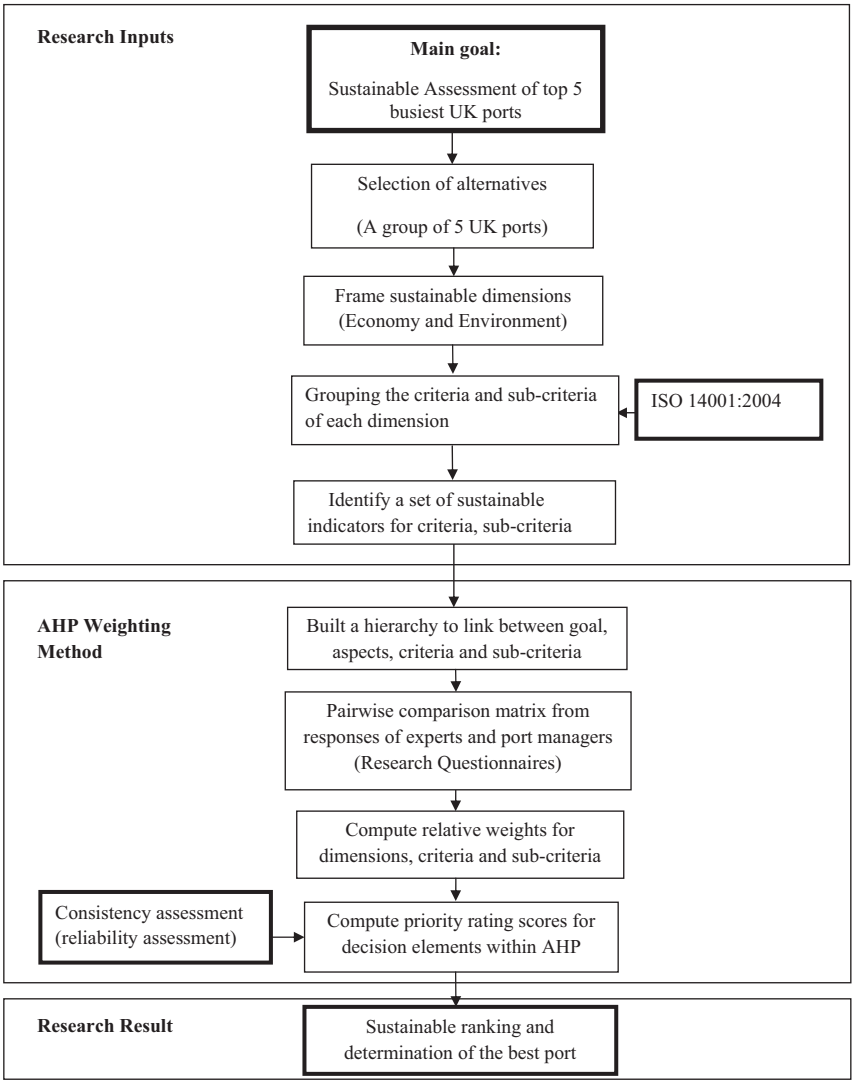

Fig. 8. Research protocol diagram.

5.2. Decision hierarchy formulating

After collecting data from surveys, the AHP is utilized in order to determine the priorities of the criteria. Table 6 presents the decision hierarchy in the questionnaire.

Table 6 depicts the hierarchy development from the main goal which is sustainable port performance for the set of criteria. In the second level, it shows two aspects of this study: economic and environmental. Next, a set of criteria is developed to measure the performance in each dimension. A set of environmental criteria is designed from ISO 14001. Besides that, as mentioned earlier, the economic dimension is also very important in the context of sustainability. With regard to sustainability, there are two sub-criteria that need to be considered: cost-efficiency and high quality service. The set of indicators for both economic and environmental aspects are provided in Appendix C.

5.3. Pair-wise comparison matrix

After the decision hierarchy is designed with four levels, the pairwise matrix is established to compare the pairs of criteria together at the same level. There are two ways to evaluate the criteria:

- *Top-down:* This way is developed from the top level (goal) to lower levels.
- *Bottom-up:* In opposition, the comparisons are made from the alternatives.

Table 6
Decision hierarchy.

Main objective	Dimensions	Criteria	Sub-criteria
Sustainable performance in UK ports	Environmental aspect	1. Establish environmental policies	
		2. Identify environmental impacts	
		3. Environmental objectives and priorities	
		4. Environmental dimension	4.1. Identify categories of environmental pollution
			4.2. Waste management
			4.3. Energy consumption
		5. Commitment identification	
		6. Training and awareness	
		7. Emergency preparedness and response	7.1. To minimize damages of environment
			7.2. Environmental risk management
	Economic aspect	8. Cost-efficiency	
		9. High quality of services	

In this study, the criteria evaluation follows "top-down" approach. As it can be seen from the decision hierarchy, there are totally four levels of objectives as shown in Table 7.

Entries of the comparison matrix are calculated as formula below:

$$\frac{n \times (n-1)}{2} \tag{5}$$

where n is the number of criteria or alternatives in a comparison matrix ($n \geqslant 2$) (Ishizaka and Labib, 2011).

According to this formulation, Table 8 presents the number of entries required in each level.

There are totally 147 entries required for this decision hierarchy. As a case in point, in level two, since there are 2 main criteria, we require one entry in comparison matrix. Table 9 shows this fact.

There are two types of comparison in level 3:

Table 7
The hierarchy description.

Levels	Description
1	Main goal/objective
2	Main criteria of two aspects: environment and economy
3	Two set of criteria which are developed from two main criteria
4	The sub-criteria are made from upper-criteria
5	The set of alternatives (ports)

Table 8
The entries for pairwise comparison.

Level	Entries
2	1
3	36
4	120
Total	147

Table 9
The pairwise comparison matrix.

Main criteria	Environmental aspect	Economic aspect
Environmental aspect	1	
Economic aspect		1

– *Cluster comparison:* This compares two clusters separately. A criteria cluster is defined as a set of criteria or sub-criteria which is developed from one criterion of its upper level. This comparison aims to assess the priorities of criteria in each cluster. There are two set of sub-criteria which require comparison matrices.

Table 10 represents the comparison matrix for the environmental dimension, and Table 11 depicts this matrix for the economic dimension.

– *Level comparison:* This comparison aims to do evaluation among all criteria in the same level. This study concentrates on this type of comparison, because it provides a general assessment on combination of two dimensions of sustainability.

The structure of questionnaires contained three parts:

- Part A aims to collect the participant's profile.
- Part B contained questions related to the ISO 14001 of environmental management system (EMS). It is mainly because a majority of criteria and sub-criteria are designed from the standards of this certification.
- Part C is the main part used to gather all evaluations of participants by ranking. The participants have to rank all criteria using 1–9 scale. After the criteria evaluation, the ports are scored based on each criterion and sub-criterion.

5.4. Results

Criteria or attributes in the same cluster are ranked based on the normalized weights. As well, the process of calculating follows the level. Therefore, if there are two clusters of criteria at the same level, they are ranked separately. The main target of the two comparison method is as follows:

- In each cluster, the ranking of the cluster is made to prioritize the set of criteria within one cluster. This aims to evaluate the relative level of importance of each criterion under one aspect.
- The second type of comparison is carried on the level. This aims to make overall prioritization and ranking of all criteria in each level. The outcomes of this evaluation show the combination of two aspects in one assessment. That is reason why the method can be applied to evaluate the combination of aspects which are conflicting.

In addition, a consistency test is done using Expert Choice software. During the time of evaluation, each participant is checked by the ratio of consistency (inconsistency). The acceptable of consistency ratio is less than or equal to 0.1.

Table 12 presents the relative weights which are obtained from the evaluations of both environmental and economic aspects. All criteria are ranked using a numeral scale: 1 is the most preferable. Regarding the evaluation, the environmental aspect has higher priority than economic aspect in the ranking with a mean weight of 52.95%.

Table 13 depicts that the cost-efficiency criterion as the most important one compared to the other criteria in this level with a mean weight of 26.42%. High quality services and identify environment objectives are ranked as the second and third most important ones in this level with 20.64% and 13.16%, respectively.

Table 10
The pairwise comparison matrix of the first cluster in level 3.

Criteria	1	2	3	4	5	6	7
1	1						
2		1					
3			1				
4				1			
5					1		
6						1	
7							1

Table 11
The pairwise comparison matrix of the second cluster in level 3.

Criteria	1	2
1	1	
2		1

Table 12
The results of comparison in both environmental and economic aspect.

Criteria	Participant 1 (%)	Participant 2 (%)	Participant 3 (%)	Participant 4 (%)	Participant 5 (%)	Mean (%)	Rank
Environmental aspect	31.89	54.99	66.67	36.19	74.99	52.95	1
Economic aspect	68.11	45.01	33.33	63.81	25.01	47.05	2

Table 13
The weights of criteria in level 3 of decision hierarchy.

Criteria	Participant 1 (%)	Participant 2 (%)	Participant 3 (%)	Participant 4 (%)	Participant 5 (%)	Mean (%)	Rank
Establish environmental policies	3.68	6.46	1.79	12.43	1.06	5.09	8
Identify environmental impacts	3.10	16.76	5.96	5.10	9.01	7.99	6
Develop environmental concepts	7.64	7.42	1.08	5.34	20.34	8.36	4
Emergency preparedness and response	5.08	6.25	9.69	1.05	9.57	6.33	7
Commitment identification	1.62	3.06	3.04	1.84	9.10	3.73	9
Training and awareness	2.59	3.68	11.99	1.39	17.83	8.29	5
Identify environmental objectives and priorities	8.19	11.36	29.11	9.05	8.07	13.16	3
Cost-efficiency	44.54	23.72	22.22	36.30	5.30	26.42	1
High quality services	23.57	21.29	11.11	27.51	19.71	20.64	2

Table 14
The comparison solution of sub-criteria in level 4 of decision hierarchy.

Criteria	Mean (%)	Rank 1	Weight (%)	Rank 2
Develop Environmental concepts	8.36		56.93	
Identify categories of environmental pollution	1.91	3	12.98	5
Waste management	2.35	2	15.97	4
Energy consumption	4.11	1	27.98	1
Emergency preparedness and response	6.33		43.07	
Minimize environmental damages	2.89	2	19.64	3
Environmental risk management	3.44	1	23.43	2

Table 15
Relative scores of UK ports.

Criteria	Ports (X_i)					
	Grimsby and Immingham (%)	London (%)	Milford Haven (%)	Southampton (%)	Tees and Hartlepool (%)	Weights of criteria (W_i) (%)
Environmental aspect	18.46	37.00	20.08	9.43	15.02	52.95
Establish environmental policies	17.75	38.32	18.46	9.36	16.12	5.09
Identify environmental impacts	14.28	39.53	18.77	7.67	19.76	7.99
Develop environmental concepts	14.58	33.45	25.27	10.76	15.95	8.36
Identify categories of environmental pollution	14.29	35.53	19.83	9.68	20.67	1.91
Waste management	15.36	35.36	23.68	8.89	16.70	2.35
Energy consumption	15.00	27.00	32.63	15.09	10.27	4.11
Emergency preparedness and response	23.04	35.48	16.72	12.92	11.85	6.33
Minimize environmental damages	18.14	36.56	17.61	13.57	14.12	2.89
Environmental risk management	27.15	35.30	14.71	12.37	10.46	3.44
Commitment identification	29.84	30.19	11.83	7.88	20.25	3.73
Training and awareness	21.14	34.93	23.96	10.34	9.63	8.29
Identify environmental objectives and priorities	18.85	39.24	17.56	9.65	14.71	13.16
Economic aspect	25.35	28.36	13.84	20.40	12.05	47.05
Cost-efficiency	32.95	24.21	15.43	13.86	13.55	26.42
High quality services	18.32	27.87	14.47	31.23	8.12	20.64
Overall score	46.96	69.31	37.85	31.75	28.83	
Rank	2	1	3	4	5	

Table 14 illustrates two types of ranking based on the weights

- *Rank 1:* Is to compare between sub-criteria in the same criterion. The criteria of energy consumption and environmental risk management have higher priority than others in their group.
- *Rank 2:* Is to compare sub-criteria in 5 levels. To conduct this ranking, the weights are calculated for the total weights of all sub criteria to be equal to 100%. Accordingly, the criteria are ranked with the highest priority of energy consumption criterion.

5.5. Score calculation

The next step is to calculate alternatives' scores. Like the criteria weights, the port performance scores are also evaluated by participants; then the score is obtained as the average of participants' evaluations. The group of ports is evaluated for each criterion and sub criterion. The overall score for each port in the group is calculated by the following formula:

$$\sum_{i=1}^{5} W_i \times f_i(x_i) \tag{6}$$

As shown by Table 15, with 69.31%, London port has the best performance in sustainability compared to the other ports.

6. Analysis

Obviously, the given evaluations depend on the set of weights given to the criteria. Accordingly, sensitivity analysis aims to examine scenarios corresponding to changes in the weights of the criteria. By doing so, we can validate the results using the common knowledge about the different ports. For example, as London ports achieved all the Environmental Certificates, it is intuitively expected that by increasing the environmental aspect, its score will go up.

The main purposes of sensitivity analysis are as follows (Chang et al., 2007):

- Reflect the importance of criteria on port performance.
- Being able to forecast the future changes which are possible to effect on the rank of port performance.
- Determine the criteria which most affect the results.
- Validate the obtained results.

6.1. Sensitivity analysis

A sensitivity analysis is carried on by changes in the weight of each criterion and sub-criterion:

(a) The weight of environmental aspect is increased from 53.32% to 75.55%. Accordingly, the economic aspect weight is decreased. This increasing led to a higher score for London, Milford Haven and Tees & Hartlepool port with 34.83%, 17.78% and 13.33%, respectively. In addition, there are changes in the ranking of ports; Tees & Hartlepool overtakes the Southampton to achieve fourth position in the ranking. Fig. 9 depicts the result.

Then, gradient analysis which displays the gradient of the ports priority in correspondence to environmental aspect is undertaken As expected, London port's priority increases as the environmental weight increases. Fig. 10 depicts this sensitivity analysis.

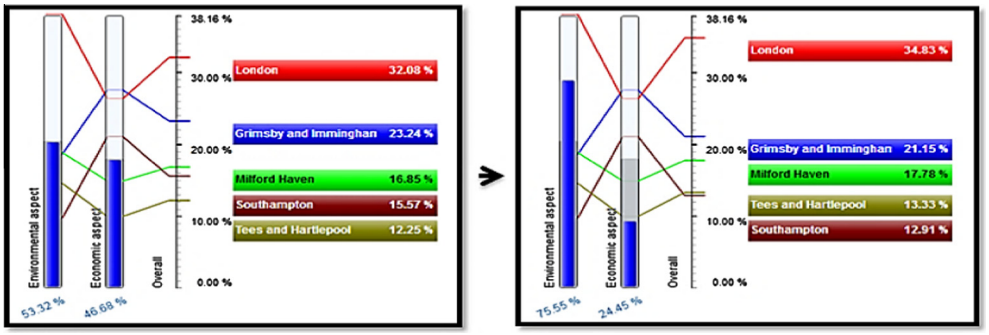

Fig. 9. The sensitivity of increase environmental aspect from 53.32% to 75.55%.

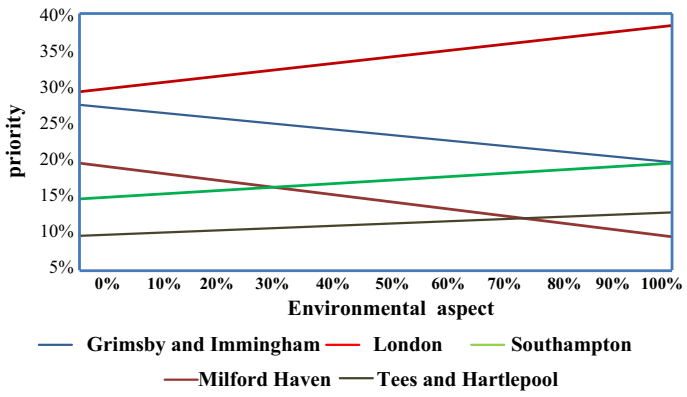

Fig. 10. The gradient sensitivity.

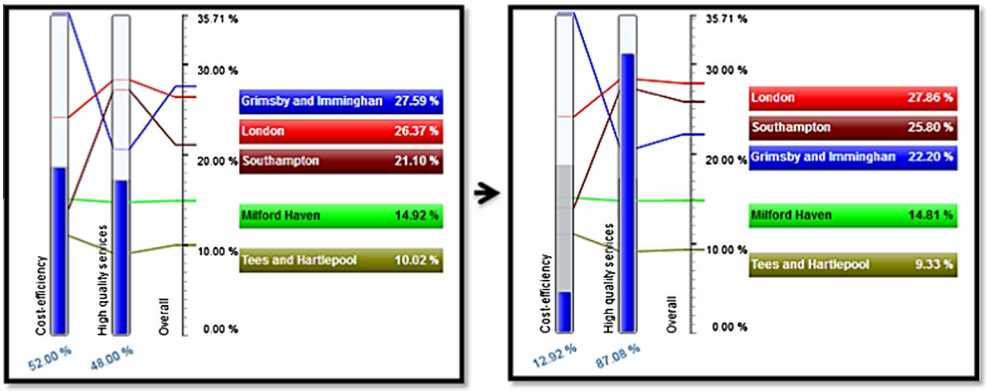

Fig. 11. The sensitivity of high quality service from 48% to 87.08%.

(b) The performance of sensitivity analysis when the criterion of high quality services is increased from 48% to 87.08%. As London port serves with the highest quality, increasing its weight causes the prioritizing of London port rather than the others. The results are depicted in Fig. 11.

6.2. Discussion

Based on the gathered data from port managers and experts in maritime supply chain, we rank the largest ports in the UK. Using the sensitivity analysis, we verify the results.

The obtained results of the sensitivity analysis can be summarized based on two aspects:

- *Environmental aspect:* The results of varying the weights of criteria showed that The London port has always the highest ranking even though the score reduces under effects of the increase of some of the criteria. It can be seen that this port performance achieves stability regarding this aspect.
- *In combination of both aspects:* It can be concluded that the rank of port in the sustainability is not changed that much comparing to the initial solution. The position of London port is remained at highest priority for both aspects after sensitivity.

According to the fact that London port invested a lot on environmental sustainability, the evidence of which is receiving different certificates as shown in Table 4, by increasing the weight of environmental aspect, it remains the top ranked port.

The methodology utilized in this research can be extended to the ports other than the studied ones. We provide a general framework, a set of criteria and sub-criteria to study the port sustainability performance considering five major ports in the UK. The outcome of this research can be used as a basis for further development in this area.

7. Conclusion

A maritime supply chain network is a relatively new concept in the context of supply chain management. This concept is focused on the management of key elements in business with respect to raw material, manufacturing, transportation and

distribution. Sustainability includes three dimensions: economic, environmental and social. Regarding the economic aspect, the main objective aims to minimize the costs. The environmental aspect aims to reduce environmental impacts occurred by operations. The last dimension relates to social-related factors in one organization such as: human rights and labor.

In the scope of the project, the 5 largest ports in the UK port system are studied regarding their sustainability performance with respect to environmental and economic aspects. A survey is conducted and 10 logistics experts and port managers were asked to fill it out. Based on the gathered primary data, the multi criteria decision making methodology is applied to evaluate the port performance. Moreover, the AHP method is utilized to select best sustainable port performance among the selected ports.

7.1. Research limitations

There are some limitations in this study. First, both of main concepts in this study, maritime supply chain and sustainability, are considered as one topic, sustainable maritime supply chain management. Both concepts are very wide and cover many important elements. Gathering data is not always simple. Normally, there are a few people who know this kind of information in details. Furthermore, the number of participants is limited. Increasing the number of participants will give more precise information. But, note that respondents should be appropriately qualified. Not necessarily, increasing the number of respondents increases the accuracy of information. There are, by nature, a limited number of potential respondents within the five ports studied who have the knowledge to fill out the questionnaire accurately. In this study, we have prioritized quality over quantity of response.

7.2. Future direction

This study provides a framework for sustainable assessment in maritime supply chain. By providing a set of criteria, it can be applied to measure the sustainable performance of not only ports but also other maritime sectors. There might be a need to change some criteria from a sector to the other, but the general approach would be the same. For instance, the main focus of the study can be expanded to the role of port authorities. Port authorities are the main organization to develop ports and decide toward port sustainability. Thus, the research could be conducted to assess the role of such authorities in development of the UK ports toward sustainability.

Regarding the methodology for ranking the ports, AHP-TOPSIS, as a new weighting method, also can be utilized. The obtaining results can be compared to those from AHP method. Moreover, regarding the fact that major ports are normally from different geographical points, geographical theme can be considered as attributes. Interested readers may find related information in Turner et al. (1998). Furthermore, a scenario from variety of points of view can be considered. For example, Puente-Rodríguez et al. (2014) propose the effect of knowledge management in socio-ecological sustainability achievement.

In addition, the assessment can be expanded from economic and environmental dimension to include the social dimension. Social aspect of sustainability has not been widely considered in the literature of sustainability. This approach can be investigated on other port systems performance.

Appendix A

See Table A.1.

Table A.1
ISO 14001 standards of environmental management system.

ISO 14001 standards of environmental management system
4.1. General • Establish environmental policies • Identify the environmental impacts from past, existing and future of port activities • Description environmental objectives of port management and priorities • Description of strategies to achieve the environmental objectives which are regarding to economic and environmental dimension
4.2. Environmental policy • Provide the policies statements of the port objectives to all port elements
4.3. Planning
4.3.1. Environmental dimension • Description environmental performance of UK port • Identify categories of environmental pollution • Waste management • Energy consumption
4.3.2. Legal and requirements • Environmental policies from Port Authority • Environmental policies form government

(continued on next page)

Table A.1 (*continued*)

ISO 14001 standards of environmental management system
• Environmental laws from IMO (international maritime organization) • Environmental guidance and policies of Annex VI 4.3.3. Objectives and targets • To achieve a sustainability performance of port from the connection of economic and environmental dimension 4.4. Implementation and operation 4.4.1. Commitment identification • Port manager • Port director • Supervisor • Workers 4.4.2. Awareness and training • All staffs have to be upgraded the awareness about sustainability • Training programs have to separate follow job position and commitment 4.4.3. Communication • Internal communication between all elements in port activities • External communication under procedure: annual reports, website 4.5. Operation control • To conduct surveillance 4.6. Emergency preparedness and response • To make emergency plan • To minimize damages for environment • Training for staffs 4.7. Checking and corrective actions 4.7.1. Monitoring and measurement • To conduct researches, annual report • To measure the effectiveness of process follow desired objectives 4.8. Management review • To evaluate about effectiveness from operation records

Appendix B

A. Personal details of the participant

1. Your name: ——
2. Address:
——
3. What is your position at the port: ————————————————————

B. General view about environmental management at the port:

In this part, there are some general questions about the sustainable policies in your port

1. Does the port establish or upgrade the "Green policies" annually?
   Yes/No/I don't know
2. Does the port have the part of EMS?
   Yes/No/I don't know
3. Have the port got Iso 14001 about EMS? If not, does the port have plans to get this certification?
   Yes/No/I don't know
4. Does the port have the part of environmental risk management?
   Yes/No/I don't know
5. Does the port have any activities to reduce environmental damages?
   Yes/No/I don't know

C. The assessment of the sustainable performance in the Port:

In this part, I would like to consult you about your evaluation about the sustainable performance in the port follow the set of standards. You can use the indicators from the scale to rank for the list of criteria and sub-criteria below:

See Tables B.1–B.8.

Table B.1
Ranking scale.

1	2	3	4	5	6	7	8	9
Equally important		More important		Strongly important		Very strongly important		Extremely important

Table B.2
The environmental and economic criteria.

Criteria	1	2	3	4	5	6	7	8	9
Environmental aspect									
1. Establish environmental policies									
2. Identify environmental impacts									
3. Environmental objectives and priorities									
4. Environmental dimension									
5. Commitment identification									
6. Training and awareness									
7. Emergency preparedness and response									
Economic aspect									
1. Cost-efficiency									
2. High quality of services									

Table B.3
The environmental sub-criteria I.

Sub-criteria	1	2	3	4	5	6	7	8	9
4.1. Identify categories of environmental pollution	□	□	□	□	□	□	□	□	□
4.2. Waste management	□	□	□	□	□	□	□	□	□
4.3. Energy consumption	□	□	□	□	□	□	□	□	□

Table B.4
The environmental sub-criteria II.

Sub-criteria	1	2	3	4	5	6	7	8	9
1.1. To minimize damages for environment	□	□	□	□	□	□	□	□	□
1.2. Environmental risk management	□	□	□	□	□	□	□	□	□

1: Less important, 5: extremely important.

Table B.5
Port ranking based on environmental aspect.

Criteria	Environmental policies	Environmental impacts	Environmental objectives and priorities	Environmental content (program)	Commitment identification	Training and awareness
Grimsby and Immingham						
London						
Milford Haven						
Southampton						
Tees and Hartlepool						

Table B.6
Port ranking based on economic aspect.

Criteria	Emergency	Emergency preparedness	Cost-efficiency	High quality of services
Grimsby and Immingham				
London				
Milford Haven				
Southampton				
Tees and Hartlepool				

Table B.7
Port ranking based on environmental sub-criteria I.

Sub-criteria	Environmental pollution measurement	Waste management	Energy consumption
Grimsby and Immingham			
London			
Milford Haven			
Southampton			
Tees and Hartlepool			

Table B.8
Port ranking based on environmental sub-criteria II.

Sub-criteria	Environmental damages reducing	Environmental risk management
Grimsby and Immingham		
London		
Milford Haven		
Southampton		
Tees and Hartlepool		

Appendix C

See Tables C.1 and C.2.

Table C.1
The environmental criteria and indicators.

Environmental criteria	Indicators
1. Establish environmental policies	1. Green policies
2. Identify environmental impacts	2. The level of impacts in port area. 1 = low, 3 = high
3. Environmental objectives and priorities	
4. Environmental dimension	
4.1. Identify categories of environmental pollution	4.1.1. Air pollution (CO_2 equivalent tonnes)
	4.1.2. Noise pollution
	4.1.3. Water pollution
4.2. Waste management	4.2.1. Solid waste (tonnes)
	4.2.2. liquid waste (tonnes)
4.3. Energy consumption	4.3.1. Fuel consumption (% of total energy)
	4.3.2. Electricity consumption (kW h)
5. Commitment identification	5.1. The sum of levels of environmental commitment in the organization. 1 = low, 3 = high
6. Training and awareness	6.1. Environmental certificates
a. All staffs are educated and trained about sustainability	
7. Emergency preparedness and response	
7.1. To minimize damages of environment	7.1. To be measured by level of environmental damages in port areas
7.2. Environmental risk management	7.2. The sum of hazard levels from environmental exposures

Table C.2
The economic criteria and indicators.

Economic criteria	Indicators
1. Cost-efficiency	1.1. Transportation cost (£/TEU)
	1.2. Fuel cost (£/ton)
	1.3. Electricity cost (£/kW h)
	1.4. Shipping cost (£/TEU)
2. High quality of services	2.1. Port congestion (days delay)
	2.2. Loading and unloading cost (£/1000 lbs)
	2.3. Infrastructure
	2.4. Service and waiting time (hours/ship)

References

Asgari, N., Farahani, R.Z., Goh, M., 2013. Network design approach for hub ports-shipping companies competition and cooperation. Transport. Res. Part A: Policy Pract. 48, 1–18.

Asteris, M., Collins, A., 2010. UK container port investment and competition: impediments to the market. Transp. Rev. 30 (2), 163–178.

Banomyong, R., 2005. The impact of port and trade security initiatives on maritime supply chain management. Maritime Policy Manage.: Flagship J. Int. Shipping Port Res. 32 (1), 3–13.

Bichou, K., Gray, R., 2004. A logistics and supply chain management approach to port performance management. Maritime Policy Manage.: Flagship J. Int. Shipping Port Res. 31 (1), 47–67.

Carter, C.R., Rogers, D.S., 2008. A framework of sustainable supply chain management: moving toward new theory. Int. J. Phys. Distrib. Logist. Manage. 38 (5), 360–387.

Chang, C.W., Wu, C.R., Lin, C.T., Chu, H.C., 2007. An application of AHP and sensitivity analysis for selecting the best slicing. Comput. Ind. Eng. 52 (2), 296–307.

Denktas-Sakar, G., Karatas-Cetin, C., 2012. Port sustainability and stakeholder management in supply chains: a framework on resource dependence theory. Asian J. Shipping Logist. 28 (3), 301–319.

Fitzgerald, W.B., Howitt, O.J.A., Smith, I.J., 2011. Greenhouse gas emissions from the international maritime transport of New Zealand's imports and exports. Energy Policy 39 (3), 1521–1531.

Gibbs, D., Rigot-Muller, P., Mangan, J., Lalwan, C., 2014. The role of sea ports in end-to-end maritime transport chain emissions. Energy Policy 64, 337–348.

Gilman, S., 2003. Sustainability and national policy in UK port development. Maritime Policy Manage.: Flagship J. Int. Shipping Port Res. 30 (4), 275–291.

Goulielmos, A.M., 2000. European policy on port environmental protection. Global Nest 2 (2), 189–197.

Harrison, A., Hoek, R.V., 2008. Logistics Management and Strategy Competing through the Supply Chain, third ed. Pearson Education Limited, Essex.

Ishizaka, A., Labib, A., 2011. Review of the main developments in the analytic hierarchy process. Expert Syst. Appl. 38 (11), 14336–14345.

Le, X.Q., Vu, V.H., Hens, L., Heur, B.V., 2014. Stakeholder perceptions and involvement in the implementation of EMS in ports in Vietnam and Cambodia. J. Clean. Prod. 64, 1–21.

Lu, C.S., Shang, K.C., Lin, C.C., 2012. Identifying Crucial Sustainability Assessment Criteria for International Ports.

Marlow, P.B., Casaca, A.C., 2003. Measuring lean ports performance. Int. J. Transp. Manage. 1 (4), 189–202.

Mendoza, G.A., Prabhu, R., 2000. Multiple criteria decision making approaches to assessing forest sustainability using criteria and indicators: a case study. For. Ecol. Manage. 131 (1), 107–126.

Peris-Mora, E., Diez Orejas, J., Subirats, A., Ibanez, S., Alvarez, P., 2005. Development of a system of indicators for sustainable. Mar. Pollut. Bull. 50, 1649–1660.

Permala, A., 2009. Transport and Logistics Developments. <http://www.efreightproject.eu/knowledge/defaultinfo.aspx?areaid=28&index=2> (retrieved from a freight).

Puente-Rodríguez, D., Giebels, D., Jonge, V.N.D., 2014. Strengthening coastal zone management in the Wadden Sea by applying 'knowledge-practice interfaces'. Ocean Coast. Manage.

Ramanathan, R., 2001. A note on the use of the analytic hierarchy process for environmental impact assessment. J. Environ. Manage. 63 (1), 27–35.

Saaty, T.L., 1988. What is the analytic hierarchy process? In: Mitra, G., Greenberg, H.J., Lootsma, F.A., Rijkaert, M.J., Zimmermann, H.J. (Eds.), Mathematical models for decision support, Springer, vol. 48. Berlin, Heidelberg, pp. 109–121.

Saengsupavanich, C., Coowanitwong, N., Gallardo, W.G., Lertsuchatavanich, C., 2009. Environmental performance evaluation of an industrial port and estate: ISO14001, port state control-derived indicators. J. Clean. Prod. 17 (2), 154–161.

Song, D.W., Lee, P.T.W., 2009. Maritime logistics in the global supply. Int. J. Logist. Res. Appl.: Leading J. Supply Chain Manage. 12 (2), 83–84.

Song, D.W., Panayides, P.M., 2012. Maritime Logistics: A Complete Guide to Effective Shipping and Port Management. Kogan Page, London.

Turner, R.K., Lorenzoni, I., Beaumont, N., Bateman, I.J., Langford, I.H., Mcdonald, A.L., 1998. Coastal management for sustainable development: analysing environmental and socio-economic changes on the UK coast. Geogr. J. 164 (3), 269–281.

Verhoeven, P., 2010. A review of port authority functions: towards a renaissance? Maritime Policy Manage.: Flagship J. Int. Shipping Port Res. 37 (3), 247–270.

Villalba, G., Gemechu, E.D., 2011. Estimating GHG emissions of marine ports – the case of Barcelona. Energy Policy 39 (3), 1363–1368.

Wooldridge, C.F., McMullen, C., Howe, V., 1999. Environmental management of ports and harbours – implementation of policy through scientific monitoring. Mar. Policy 23 (4), 413–425.

Web references

Environmental Management System. <http://www.pla.co.uk/Environment/Environmental-Management-System>.

Environmental Performance Report, 2012.

ESPO/Ecoports. <http://www.ecoports.com/about>.

GOV.UK, 2013. <https://www.gov.uk/government/policies/sustaining-a-thriving-maritime-sector>.

Green London gateway to open in 2013. <http://www.greenport.com/news101/europe/green-london-gateway-to-open-in-2013>.

IMO Announces Development of Sustainable Maritime Development Goals. <http://post2015.iisd.org/news/imo-announces-development-of-sustainable-maritime-development-goals/>.

PD Ports A Brookfield Ports Company. <http://www.pdports.co.uk/en/footer/enviroment/>.

Port of London Authority, 2013.

Port of Southampton, 2013. The UK's most Dynamic Maritime Gateway.

Q&A: Liquefied Natural Gas. <http://news.bbc.co.uk/2/hi/uk_news/wales/7881388.stm>.

Teesport and Hartelpool Port Handbook, 2013. Land & Marine Publications Ltd.

UK Tankship Port Gets EcoPorts PERS Certification. <http://www.marinelink.com/news/certification-tankship344654.aspx>.

World Shipping Council. <http://www.worldshipping.org/about-the-industry/global-trade/trade-statistics>.