Mohseni *et al. Journal of Shipping and Trade* (2023) 8:4
https://doi.org/10.1186/s41072-023-00136-x

Journal of Shipping and Trade

ORIGINAL ARTICLE Open Access

Economic assessment of transporting refrigerated cargo between West-Africa and Europe: a chain cost analysis approach

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Abstract
Determining which ports to call at in a maritime loop is considered as an important determinant factor for shipping companies which impacts not only on efficiency, and productivity but also on transportation costs. The port selection process becomes more challenging and sensitive if the market is for perishable goods such as fruits and vegetables. Specifically, this paper aims to develop an efficient maritime supply chain for reefer cargo. A case study of refrigerated cargo trade between West-Africa and West-Europe is investigated for which the main objective is to minimize the trade route's supply chain costs. To do so, the paper analyzes various scenarios based upon the different types of cargo (transshipment and non-transshipment), commodity types (dry and reefer), and a combination of different (un)loading ports in and the Rotterdam–Gibraltar range. Four African ports, namely Tema (Ghana), Douala (Cameroon), Abidjan (Ivory Coast), and Dakar (Senegal), are considered for the outbound leg (Africa–Europe), while several ports in the E.U. and the U.K. are selected as inbound leg. The analysis is initiated by applying a data-gathering strategy to get the relevant container flow from European ports to West-African ports. Then, a chain cost modelling approach is used to determine what the sailing schedule of the vessel should be. By performing the import/export cargo volume and maritime and supply chain costs are calculated, which can be used by the involved stakeholders to decide which ports are the best to call on a specific route.

Keywords: Chain cost model, Reefer and dry cargo, Maritime supply chain, African ports, European ports, Total transportation cost, Generalized chain cost

Introduction

Due to the growing global demand for perishables such as fruit and vegetables, the increasing number of trade routes and the shift from other modes of transport (conventional reefer ships and air transport) to reefer containers, the market for reefer containers is increasing and attracting much attention (Castelein et al. 2020). In 2019, the global reefer container market (food, pharmaceuticals, chemicals and flowers) accounted for a size of 3169.2 thousand twenty-foot equivalent units (TEU). The reefer container market research report of Prescient and Strategic Intelligence (2021) foresees a growth forecast of CAGR of 8% to 2030. This paper focuses on the' food' market segment; and more in particular on fruits and vegetables. Fruits and vegetables are generally quite sensitive to atmosphere and temperature variations, so the container's cargo temperature and air composition must be kept within certain limits (Sørensen et al. 2015). The reefer container market is characterized by the need for continuous temperature control of cargo in the container (Castelein et al. 2020).

Given the required facilities and services for the transport of reefer containers, port selection plays a significant role in the refrigerated maritime supply chain (MarSC). The choice of shipping route for unitized goods is a complex process involving many attributes of different actors and services (Tavasszy et al. 2011). Besides, shipping routes can affect both the operational cost of carriers and the customer service level (Tran 2011). Choosing an optimal port of call is paramount for shipping carriers to reduce their total transportation costs (Zavadskas et al. 2015).

This paper provides insight into port selection optimization by developing a case study for a company that is specialized in producing and exporting fruits from West-Africa to West-Europe. Next to the production of the fruits, the company is also controlling the total supply chain of their produced fruits from the production location to the warehouses in Europe. For the maritime transportation of the fruits from West-Africa to Europe, the company uses an own container vessels with reefer plugs. The transported reefer containers will be filled with own cargo in the northbound route (from West-Africa to Europe), while on the backhaul, other types of cargoes (preferably temperature-conditioned cargo) from other companies with a destination in West-Africa can be transported.

The main reason to deploy an own vessel (container vessel of 3000 TEU with 1200 TEU reefer slots) is to have control over the supply chain and to make sure that the reefer cargo will arrive on time and in the correct conditions to the warehouses in West Europe. For the current operation, the port of Antwerp is used as the main import port for the cargo, but it is not sure if possible other ports could better serve as main import port. Given the strong preference for a Dutch/Belgian import port, only the ports of Antwerp, Flushing and Rotterdam are considered as main import ports. This strong preference is given by the fact that these ports can handle the reefer cargo and are closely located to the main distribution centres of the imported reefer cargo. For the backhaul trip, different types of cargo can be transported, which can be loaded at different ports. These load centres for the backhaul can either be in one of the main Dutch/Belgian ports or a port between the Dutch/Belgian ports and West-Africa, here called the Rotterdam–Gibraltar range. Therefore, the main research objective of this paper can be formulated as identifying the possible benefits for the company of selecting different ports of call both for importing their cargo and transporting other cargo back to West-Africa in the Rotterdam–Gibraltar range.

The port selection involves two steps:

1. A selection needs to be made for the main port of call in North-West-Europe between Antwerp, Rotterdam, and Flushing.
2. An indication needs to be given of the potential cargo volumes to fill the backhaul voyage of the vessel by calling at an additional extra port of call on the route from Europe (i.e. Rotterdam–Gibraltar range) to West-Africa.

Fig. 1 Selected West-African ports. *Source*: author's composition

Table 1 Major EU and U.K. ports in the loop

	Considered ports
E.U. ports	Antwerp, Rotterdam, Flushing, Zeebrugge, Le Havre, Brest, Montoir de Bretagne, Vigo, Marin, Lisbon, Sines
U.K. ports	London Gateway, Felixstowe, Liverpool, Southampton

Four West-African ports are considered, namely Dakar (Senegal), Abidjan (Ivory Coast), Tema (Ghana) and Douala (Cameroon), from which reefer cargo originates and where dry cargo has its destination (see Fig. 1).

From the West-African ports, there is enough cargo to load a vessel to sail to West-Europe. However, there is great difficulty in finding enough return cargo to justify, from a cost perspective, the use of a dedicated container vessel. Therefore, next to the four African ports, the following European ports are considered in the analysis (see Table 1).

These ports are selected because they are on the route between West-Africa and West Europe. In this list of ports, there are two main types. First, there are the major gateway ports in the Rotterdam–Gibraltar range (Antwerp and Rotterdam) at which the reefer cargo needs to be unloaded. Second, there are smaller ports, which are not called at by the major shipping lines and could serve as potential loading centers for cargo that can be transported to West-Africa for backhaul trips.

Given the higher-mentioned control the company wants over the whole supply chain, this research considers the entire supply chain, including the hinterland leg, port, terminal operations, and maritime route. Such research approach allows revealing the best service design of the container service based on the highest cargo loading share (filling rate of the vessel) and lowest supply chain costs for the import of reefer cargo. Based on thus rationale the research question can be formulated as:

What are the possible benefits for a reefer shipping company of selecting different ports of call in the Rotterdam–Gibraltar range for West-Europe–West-Africa (reefer and dry) trade?

The remainder of this paper is organized as follows. "Literature review" Section presents the literature review results on the port selection criteria, supply chain cost, and reefer transport. "Research approach" Section discusses the data collection method, applied methodology, and calculation process. "Scenario development" Section provides the scenario development results, and "Economic assessment: results" Section interprets the obtained results per scenario and provides a comparison between them. The overall findings and conclusions are summarized in the last "Conclusion" section.

Literature review

The literature review section is categorized into two sub-sections. The first one provides a general overview of the port choice determinants from various port users. The second sub-section discusses supply chain cost and reefer transport.

Port selection criteria

The research on the port selection process and determinants have been investigated extensively in the literature. An overview of the literature study, covering the last two decades, is presented in Table 2. This table summarizes the objectives and results of the relevant publications. Next, this subsection explains some of the primary studies.

It is observed that most researchers investigated the port selection process and criteria by different stakeholders in maritime shipping worldwide, such as Asian, African and North-European ports. The results reveal that port efficiency, port costs, and geographical locations are the most dominant factors in the port selection from port users, shippers, carriers, and freight forwarders.

Supply chain cost and reefer transport

Global supply chains depend critically on efficient information and product flows among the chain suppliers, manufacturers, distributors, and retailers (Steven and Corsi 2012). These supply chains provide various benefits to the businesses and consumers, such as improvement in services, product innovation, efficiency, etc. (He and Yin 2020). Liu et al. (2020) develop research on the optimal design of low-cost supply chain networks in a case study of a fast-moving consumer goods supply chain in East Asia. Firms tend to be cost-effective, and an increase in cost can adversely affect the firm's performance (He and Yin 2020).

Ng and Gujar (2009a, b) assess the spatial characteristics of inland transport hubs based on analytical evidence from the users' choice of dry ports in South India and provide a platform for locational choice and the development of transport hubs and supply chains. Transport costs and times along the transport chain are the dominant factors for port competitiveness. Satisfaction, reputation and flexibility criteria are the other important decision criteria. The results also show how the availability of different modal alternatives impact on the position of a port. A ranking of routes for hinterland regions is done. Álvarez-San Jaime et al. (2015) investigate the stimulants to integrating port activities with inland transport services and its welfare implications under inter-ports competition. Several scenarios not leading to a welfare decrease are identified: asymmetries in port capacities, government regulation and efficiency gains.

Table 2 A literature review on port choice criteria

Reference	Objective	Results
Malchow and Kanafani (2004)	To assess the competition between ports, by using a discrete choice model	Oceanic and inland distances variables have the most significant impact on carriers' distribution of shipments, followed by port location
Ugboma et al. (2006)	To investigate the most critical factors of the port selection process in four ports in Nigeria	Port efficiency, frequency of ship visits, and adequate infrastructure are dominant factors, while the quick response to port users' needs is the least important criteria. Other factors are location, port charges, and reputation for cargo damage
Young-Tae Chang et al. (2008)	To investigate the factors influencing shipping companies' port selection process	Six essential variables are (i) local cargo volume, (ii) terminal handling charge, (iii) berth availability, (iv) port location, (iv) transshipment volume, and (v) feeder connection
Tongzon (2009)	To evaluate the factors influencing port choice in Southeast Asian	Port efficiency, followed by shipping frequency, adequate infrastructure, good geographical location, low port charges, quick response to port users' needs, and reputation for cargo damage
Tran (2011)	To investigate the optimal port selection process in liner shipping	Decreasing port calls can reduce ship, inventory, and port tariffs, leading to higher inland/feeder transport costs
Andrew Yuen et al. (2012)	To explore the importance of factors influencing a container port's competitiveness, including capacity availability and the size and hinterlands connectivity	Port location is the most critical factor for both forwarders and shippers
Nazemzadeh and Vanelslander (2015)	To determine the most significant factors impressing the port selection process for North-European ports	Port costs have the most critical effect on the port selection process for port users, followed by geographical location, quality of hinterland connections, productivity, and port capacity
Rezaei et al. (2019)	To assess the essential factors in port competitiveness	Transport costs and times are the dominant factors for port competitiveness, followed by satisfaction, reputation, and flexibility
Abdul Rahman et al. (2019a, b)	To investigate the selection of ports of call in regular intra-regional container services between Malaysian ports and other Asian ports	Provides a methodological framework assisting maritime stakeholders in evaluating the feasibility and competitiveness of specific intra-regional port-to-port liner service configurations
Talley (2019)	To investigate port choices by port service providers (port operators, shipper agents (freight forwarder and third-party logistics provider), harbor pilots, tugboat operators, shipping line agents, and customs brokers	Determinants of port choices are the revenues that the providers receive from users of their provided cargo port services
Baert and Reynaerts (2020)	To investigate the determinants affecting the attractiveness of the ports in the United States	Port charges and port congestion are vital factors
Hsu et al. (2020)	To assess the port choice of liner carriers for ship calls	Port choice factors with higher importance are cargo volume (local cargo volume, transit cargo volume, and import/export cargo balance), followed by terminal handling charges and port dues

Source: Author's composition based on selected literature

Furthermore, Chao and Chen (2015) developed a time–space mathematical model for accommodating special containers such as reefer containers. Due to the considerable amount of containers and high similarity, dry containers are usually moved in batches. In addition, leasing and pooling are also complementary strategies commonly used to adjust the allocation of empty dry containers. On the contrary, reefer containers have to be repositioned more precisely than dry containers because they can yield high profits and cannot be substituted easily. Defraeye et al. (2015) consider the ambient loading protocol for cooling citrus fruit during marine transportation in refrigerated containers to evaluate reefer containers' energy efficiency. Simulations show that low airflow rates, typical for refrigerated containers, do not only induce slower fruit cooling, compared to FAC airflow rates, but also the cooling heterogeneity between different layers of boxes (in height) and between individual fruit in a single box is larger. In addition, the presence of gaps between pallets invokes airflow short-circuiting, leading to highly reduced fruit cooling rates. Budiyanto and Shinoda (2020) explore the effect and energy saving of roof shade installation over storage yard in a reefer container storage yard. The simulation result confirms 9% energy efficiency by installation of roof shade during the day.

Research gap

Based on the performed literature review, it can be concluded that the viewpoint of a shipping line specialized in producing and distributing refrigerated cargo is not yet analyzed in detail. Also, the port choice for a specialized reefer transport shipping company is not analysed yet.

Research approach

As a complementary study to the literature, this paper investigates the port analysis to develop an efficient maritime supply chain for transporting containerized reefer and dry cargo on the maritime round trade route from West-Africa to Europe. This paper's main novelty is its concept, as it considers the import of reefer cargo from four West-African ports to three possible ports in West Europe, next to the different freight types for the backhaul. Next, the paper also deploys a modeling approach that includes the generalized supply chain cost from West-Africa to West-Europe.

To fulfill the main objectives of the study, the following research steps have to be made:

1. Data collection of the potential cargo flows:

    a. The major cargo flows of reefer and dry containers from West-Europe (- Rotterdam–Gibraltar range) to West-Africa (Agadir-Douala range) must be defined. Also, the potential dry container cargo flows from West-Africa to West-Europe need to be determined (dry cargo).
    b. The major reefer and dry cargo flow from non-direct ports of call in North-Europe (Ireland, Scandinavia, Poland, …) need to be defined. These cargo flows could be transhipped from ports in the Baltic, Ireland, and the Northern part of the North sea via Antwerp, Rotterdam, and Flushing ports to be shipped to West-Africa. This can be done possibly through a joint venture with other carriers.

Table 3 Loading cargo share in African ports*

African Port	Loading cargo share concerning the total capacity of the ship
Abidjan	20%
Douala	60%
Tema	20%
Dakar	–

*The loading share in African ports is obtained based on the consultation with the specialized company

2. An existing Chain Cost Model (CCM), in which alternative port simulations can be made, must be updated. This update involves the following aspects:

   a. New (African and E.U.) ports need to be built in the model
   b. The hinterland of West-Africa needs to be added to the model
   c. The specific vessel types need to be included in the model

In the next sub-sections, these steps are further detailed.

Data collection

In the first stage, desk research is employed to gather the availability of cargo flows from the West-Africa-to-Europe (outbound leg) and the Europe-to West-Africa (return leg) trade route.

In the outbound leg, the dry and reefer cargo flows originating from the four West-African ports, namely Tema, Douala, Abidjan, and Dakar, to Europe, are considered. In the return leg, the dry and reefer cargo flows departing from the major European container ports (non-transshipment cargo) to West-African ports are considered. Also, in this leg, the additional reefer cargo flows (transshipment cargo) originating from three regions (Baltic, Kattegat and Ireland) transhipped via the ports of Rotterdam, Flushing, and Antwerp to the four West-African ports are considered. For both legs, the data of dry and reefer cargo flows are selected at the port level.

Data collection for outbound leg

The reefer container cargo flows from the four main West-African ports to the E.U. are obtained by a third-party company specializing in producing, transporting, and distributing fruit and vegetables. Table 3 shows the loading cargo share for each African port with the destination in Europe.

Data collection for return leg

As mentioned above, the container cargo flows for the return leg are divided into two types: (i) non-transshipment cargo and (ii) transshipment cargo. Furthermore, at this stage, the container cargo flows (both transshipment and non-transshipment) must be split up into (iii) reefer and (iv) dry cargo flows. This section describes the data collection sources and division ratio process for these types of cargo.

Non-transshipment cargo For this type of cargo, the reefer and dry container cargo flow at port level are determined. As the study focuses on the four main West-African ports, a matching dataset for loaded TEU's originating from the 15 European ports was obtained from Dynamar B.V. The dataset reports the total of transshipment and non-transshipment cargo, which includes both dry and reefer containers, and does not segregate them by type.

The transshipment ratios for these 15 ports are based on Portopia,[1] which highlights the transshipment shares of major container ports. By directly applying these transshipment ratios to the dataset from Dynamar B.V., an approximation for the share of transhipped and non-transhipped TEU's on the Europe-to-West-Africa corridor is determined. For ports where transshipment ratios are not provided, a value of 35% is assumed.[2]

Similarly, to obtain an approximation for the ratio of dry and reefer containers, the container throughput statistics for the port of Las Palmas are used. These statistics reveal port-level data on the Europe–West-Africa trade lanes. The port of Las Palmas, being a major transshipment hub for the region, is finalized as a reference point, as it appears to have line item details (in Spanish) on all its container transshipment operations that include:

- Port of Origin
- Port of Destination
- Cargo type classifications
- Volume of containerized cargo (tons)

The data for the period 2017–2018 is taken into consideration. This includes data on loaded containers originating from the 15 European ports and destined for West-Africa, which were transhipped at Las Palmas. To separate the dry containers from the refrigerated ones, the cargo type classifications are studied in detail. A list of all available classifications is summarized in Table 4.

The distinction between dry and reefer cargo types is based on the above classification. By allotting all container volumes under the 'Agro-livestock and food' as reefer, an approximation for the ratio of dry to reefer containers is made. Once the type of container cargo is established, by narrowing down to the origin–destination pairs highlighted by the scope of the project, a suitable and unique reefer container ratio for cargo originating from the European region and moving towards West-Africa is identified (see Table 5).

The rationale behind establishing such a ratio at regional level (Antwerp–West-Africa) rather than on a port-by-port basis for the Las Palmas data set was that it provides a more consistent split. Next, it can also be applied to traffic on the trade lanes not transhipping at the port of Las Palmas. Wherever the ratio is unavailable, a conservative split of 20% reefer cargo is considered (Zeebrugge, Southampton, and Portsmouth).

[1] PORTOPIA—7th Framework Programme (2014). Towards a competitive and resource efficient port transport system.

[2] See Appendix 1 for more details about this approach.

Table 4 Commodity description in containers

Category (Spanish)	Category (translated)	Container type
Otras mercancias	Other Merchandise	Dry
Vehiculos y elementos de transporte	Vehicles and transport elements	Dry
Agro-ganadero y alimnetario	Agro-livestock and food	Reefer
Abonos	Fertilizers	Dry
Energetico	Energy	Dry
Material de construccion	Construction material	Dry
Minerals no metalicos	Non-metallic minerals	Dry
Quimicos	Chemicals	Dry
Siderometalurgico	Iron and steel	Dry

Source: Own elaboration and data based on Port of Las Palmas publications, 2017–18

Table 5 Split of dry and reefer container volumes

Origin port	Dry (%)	Reefer (%)
Antwerp	45.97	54.03
Brest	18.77	81.23
Felixstowe	84.52	15.48
Le Havre	45.20	54.80
Lisboa	65.89	34.11
Liverpool	94.06	5.94
London gateway port	92.09	7.91
Montoir de Bretagne	55.55	44.45
Rotterdam	25.54	74.46
Sines	92.43	7.57
Vigo	66.64	33.36

Source: Own elaboration and data based on Port of Las Palmas publications, 2017–18

Applying these ratios to the non-transhipped cargo in the detailed cargo flows analysis helps establish the number of reefer and dry container boxes transported from the 15 European ports to Dakar, Abidjan, Tema, and Douala. The main result of applying the ratios can be found in Table 6.

Transshipment cargo As mentioned, three regions are considered the possible origins of cargo flows that can be transhipped via the selected hub port for the return leg. These regions are detailed as follows:

- Baltic region: Poland, Finland, Sweden, Estonia, Russia, Latvia, and Lithuania
- Kattegat region: Denmark and Norway
- Ireland

The U.N. Comtrade database[3] is consulted to collect the cargo flows from these three regions to the West-African regions. The U.N. Comtrade database is quite detailed in the

[3] The U.N. Comtrade database is detailed in the different types of products that are shipped between different regions and lists down traded commodity volumes (in kilograms) by origin and destination, by period, and under respective trade flows (import/export).

Table 6 Overview of the direct potential market [TEU] of dry and reefer transport from Europe to West-Africa

To:	Douala		Tema		Abidjan		Dakar	
From:	Reefer	Dry	Reefer	Dry	Reefer	Dry	Reefer	Dry
Antwerp	5586	4752	20,321	17,287	14,795	12,586	9575	8145
Brest	64	15	87	20	24	5	136	31
Le Havre	3233	2667	1597	1317	7157	5904	8409	6936
Lisbon	107	206	42	81	21	41	133	257
Marin	58	117	31	62	78	156	49	98
Montoir	271	339	119	149	868	1084	1096	1370
Rotterdam	155	53	241	83	210	72	94	32
Sines	–	5	–	6	–	3	20	241
Vigo	85	169	34	68	134	268	86	171
Vlissingen	3	–	33	6	101	18	74	13
Zeebrugge	–	–	–	–	–	–	–	–
London	5	60	–	–	245	2852	71	830
Portsmounth	14	54	655	7628	–	–	–	–
Liverpool	3	49	6	88	2	29	–	3

different types of products that are shipped between other regions and lists down traded commodity volumes (in kilograms) by origin and destination, by period, and under respective trade flows (import/export). Appendix 1 uses the list of Harmonized System (H.S.) codes as defined by the scope of the project, to define the aggregated cargo flows for reefer containers.

As the data made available through U.N. Comtrade uses kilograms (kgs) as a measure of weight, a suitable conversion factor has to be adopted to convert it into TEU. Based on the literature, a factor of 12 tonnes per TEU[4] is adopted to get this conversion.

Finally, once the conversion from tonnes to TEU is performed, the aggregate cargo flows need to account for the market share of refrigerated cargo to that of breakbulk reefers, as U.N. Comtrade reports the total volume of goods moved between two trading countries. A default value of 85% is assumed for refrigerated containers, while the rest is assumed to move under breakbulk reefer vessels. The total potential reefer volume can be found in Table 7.

Chain cost model (CCM)

The purpose of the CCM[5] is to calculate the generalized chain cost per TEU from a selected point of origin (i) in the hinterland (A), via a predefined container loop, to a destination point (j) in another hinterland (B) (van Hassel et al. 2016a, b). In the CCM, several terms need to be determined: hinterland area, aggregated hinterland, logistics chain, characteristics of ports and terminals involved, and hinterland connections (van Hassel et al. 2016a, b). Figure 2 plots the concept of the CCM.

[4] The Shipping MRV Regulation—Determination of cargo carried, European Sustainable Shipping Forum (May 2017).

[5] The model is coded in C# and uses Microsoft Excel (data) and JMP11 (maps) as output formats.

Table 7 Loading cargo volume [TEU] in each transshipment cargo region

African Port	Transshipment cargo region		
	Baltic	Ireland	Kattegat
Dakar	546	90	474
Abidjan	2611	1026	206
Tema	1934	1904	852
Douala	4433	4450	1833
Total	9525	7470	3365

Source: Own compilation based on U.N. Comtrade data (2018)

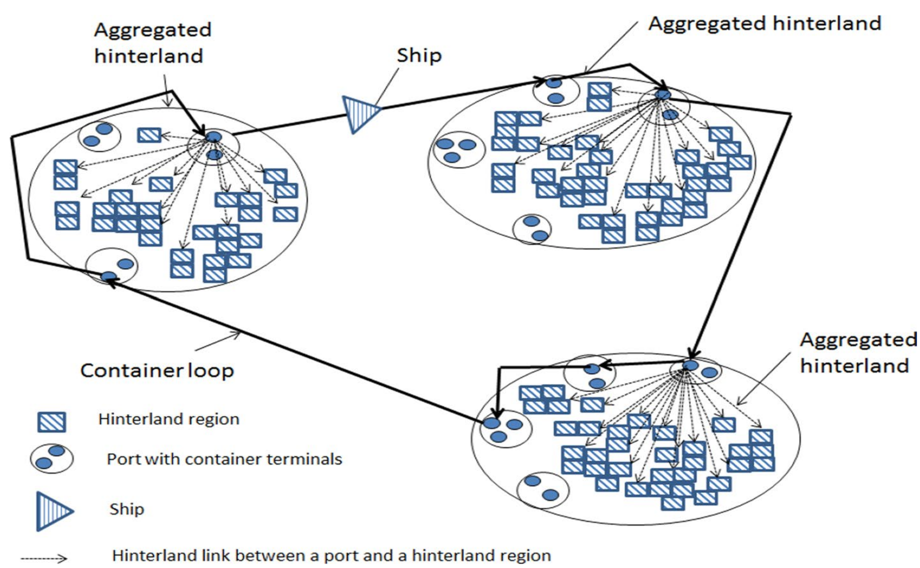

Fig. 2 General Concept of Cost Chain Model. Source: van Hassel et al. 2016a, b

A logistics chain consists of a starting point and ending point and is determined as a route from a specific hinterland region (i) to another hinterland region (j). A logistics chain holds three significant legs: maritime shipping, port process, and hinterland transportation. As shown in Fig. 2, in the CCM, different aggregated hinterlands are connected via a route (container loop) and ports (bold lines). The container loop encompasses the maritime leg of the supply chain. The aggregated hinterlands are a summation of smaller geographical areas corresponding to NUTS-2 regions in Europe. Each aggregated hinterland is served by at least one or several ports (van Hassel et al. 2016a).

Generalized chain cost

The generalized cost is calculated in the maritime, port, and hinterland sub-models, which are then summed to obtain the overall chain cost.

To calculate the generalized chain cost (EUR/TEU) from the point of origin (*i*) in the hinterland (A) to a destination point (*j*) in another hinterland (B), the model takes into account various cost items. The generalized cost is composed of two main elements (i) monetary (out-of-pocket) cost and (ii) non-monetary cost. The monetary cost of maritime transport includes operational, voyage, and capital costs of ship size *i*, which is the ship's total cost. In addition, the out-of-pocket cost includes other costs belonging to the different chain cost elements. In contrast, the non-monetary part is the monetized value of the time spent in the maritime journey and is related to flexibility, service, reliability, and port information system quality. Equation 1 explains the generalized chain cost calculation.

$$GC_{i,j}i = OPC_{i,j} + T_{i,j} * VoT_k \tag{1}$$

where:

$GC_{i,j}i$ = Generalized cost of container transport by ship size (i) traveling from port of origin (i) to the port of destination (j) [EUR/TEU].

$OPC_{i,j}$ = *Out-of-pocket cost [EUR/TEU].*

$T_{i,j}$ = *Total transport time from the point of origin (i) to the destination point (j) [h].*

VoT_k = *Value of time of product type k [EUR/TEU*h].*

As indicated in Eq. 1, the non-monetary part is monetized by multiplying the value of time and the total transport time. The total transport time includes all the time consumed in the chain segments from the origin to the destination.

The updated version of CCM

The updated version includes defining a new maritime route called West-Africa–West-Europe to the model as the study focuses on the trade route between West-Africa and West-Europe. In this regard, some additional ports are added: for Africa, the ports of Dakar, Abidjan, Tema, and Douala, and for Europe, the ports of Brest, Montoir de Bretagne, Vigo, and Marin.

The maritime access draught and all available container terminals are incorporated for each port. For each terminal, the following data are collected: (i) terminal infrastructure characteristics (quay wall length, terminal draught, etc.), (ii) terminal throughput (number of TEUs handled at the terminal), (iii) terminal equipment (number of container cranes, handling rate of the container cranes), (iv) port-entering cost parameters (port dues, pilotage, tug boats, (un)mooring and shifting and container handling cost), and (v) hinterland distance data, for each available hinterland transport mode, from each terminal to all the different European and African hinterland regions (250 respectively 15 regions).

Moreover, the African hinterland is developed and updated in the model. This hinterland consists of the following countries: Mauritania, Senegal, Gambia, Mali, Guinee, Sierra Leone, Ivory Coast, Ghana, Togo, Benin, Mali, Burkina Faso, Niger, Nigeria, and Cameroon. All these countries will be linked to the four African ports.

Last but not least, the reefer and dry container vessels with a loading capacity of 2000–3000 TEU nominal with 600 plugs minimum / min 1200 TEU reefer + 600 TEU dry capacity are added to the model.

Fig. 3 Five destinations in Europe. *Source*: authors' composition

Scenario development

Five different transport chains (defined from a production location in Africa to a warehouse in Europe) are included in the analysis. These transport chains are from a West-African origin to (i) Lille (France), (ii) Rennes (France), (iii) Chateaurenard (France), (iv) Gyal (Hungary), and (v) IJselmuiden (Netherlands) (see Fig. 3).

These chains are selected as these European destinations play an essential role in the reefer cargo in West-Africa–E.U. trade route based on the consultation with the classified company specializing in producing, transporting, and distributing fruit and vegetables. Moreover, the three European countries are diverse in terms of geographical location, namely France (West-Europe), The Netherlands (North-West-Europe), and Hungary (Central Europe). Hence, first, they are selected to have a comparative analysis of West-European countries (between The Netherlands and France) and second to have a competitive overview of a Central-European region with a conventional West-Africa-to-West-Europe trade route.

As the main port of call in the West-Europe region to be used as the central hub for the transshipment cargo from/to other ports, three candidates, namely the ports of Antwerp, Rotterdam, and Flushing, are considered. The reasons to consider these ports are in twofold. First, ports with the highest (un)loading cargo share need to be selected; hence, the port of Antwerp, by handling more than 50% of loading cargo in the West-Europe–West-Africa (return) leg, can be considered the main port of call for dry and reefer cargo in this trade route. Second, the ports need to be located in West-Europe.

Hub-port selection in West-Europe

The next step in the research is to select the transshipment port in West-Europe in order to develop the scenarios. The generalized chain cost is calculated by applying the CCM

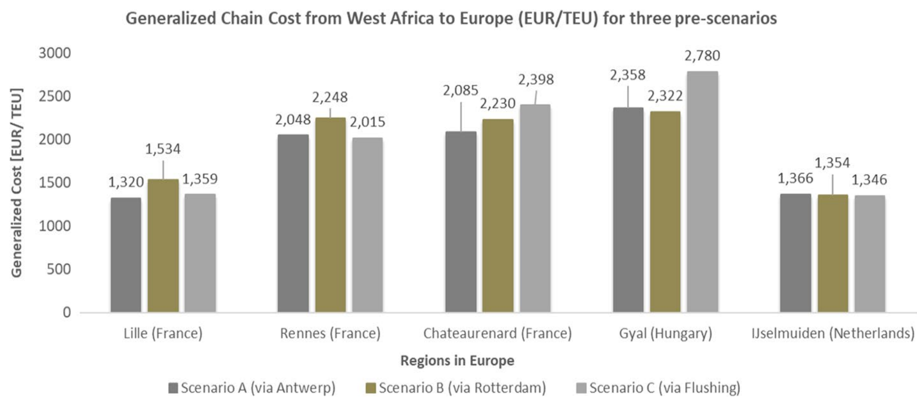

Fig. 4 Generalized chain cost—pre-scenarios A, B, C

to determine which port shows the best results regarding the lowest generalized chain costs. Three initial scenarios are considered: in scenario A (un)loading cargo share of only the port of Antwerp is selected, while in scenarios B and C (un)loading cargo share of ports of Rotterdam and Flushing are considered, respectively[6] (Fig. 4).

By comparing the results of the generalized chain cost, it is observed that the port of Antwerp has the lowest generalized chain cost for the routes from Africa to two regions in Europe, namely Lille (France) and Chateaurenard (France). Based on the results, the port of Antwerp is considered the best option for the central transshipment hub in the West-Europe region compared to Rotterdam and Flushing for the setting of this paper.

This case study considers two main scenarios for the calculation process:

- Scenario 1 discusses the non-transshipment cargo flow originating from the major European ports going back to four African ports, namely Dakar, Abidjan, Tema, and Douala.
- Scenario 2 considers non-transshipment cargoes from the major European ports and transshipment container flows originating from the Baltic, Ireland, and Kattegat regions and Russia transported via the port of Antwerp to all four African ports.

For each scenario, the maritime loop starts and ends with the port of Abidjan. In the return leg (West-Europe–West-Africa), the unloading cargo share in all African ports is computed precisely based on the actual handling of cargo originating in the European ports.

Scenario 1

In this scenario, non-transshipment cargo flows from London Gateway, Antwerp, Le Havre, and Montoir de Bretagne (these ports have the highest potential volumes for the return leg), going back to all four African ports, are taken into consideration. Figure 5 presents the order of calls in the loop and (un)loading cargo share at each port;

[6] In the calculation process, it is assumed that the unloading share is 20% for London Gateway and 80% for the port of Antwerp in the outbound leg. However, in this leg, the loading share is based on the obtained data of dry and reefer cargo types of non-transshipment cargo volume originating from Antwerp, Rotterdam and Flushing into the computation separately. See Appendix 2 for more information on the scenarios.

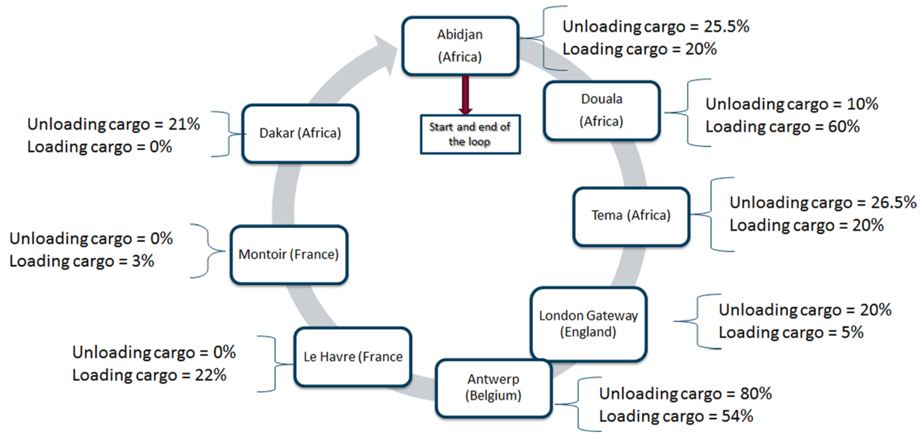

Fig. 5 Order of ports and (un)loading share (dry and reefer cargo)—scenario 1

Table 8 Loading cargo % of the vessel at European ports– scenario 1

Calling at port	Total loading %	Loading dry share %	Loading reefer share %
London Gateway	5	4	1
Antwerp	54	14	40
Le Havre	22	5.5	16.5
Montoir	3	1	2
Total	84	24.5	59.5

Table 9 Unloading cargo % of the vessel at African ports—scenario 1

Calling at port	Total unloading %	Unloading dry share %	Unloading reefer share %
Dakar	21	6	15
Tema	26.5	8.5	18
Douala	10	3	7
Abidjan	25.5	7	18.5
Total	84	24.5	59.5

while Tables 8 and 9 give an overview of the loading cargo % of the vessel at European ports and unloading cargo % of the vessels at African ports.

In scenario 1, the ship is (un)loaded with 84% of the ship's total capacity, of which 24.5% is dry cargo, and 59.5% is reefer cargo.

Scenario 2

In scenario 2, the non-transshipment cargo flow from scenario 1 is taken into account, together with transshipment cargo flow originating from the Baltic, Ireland, Kattegat, and Russia that are transshipped via the port of Antwerp, going back to the four

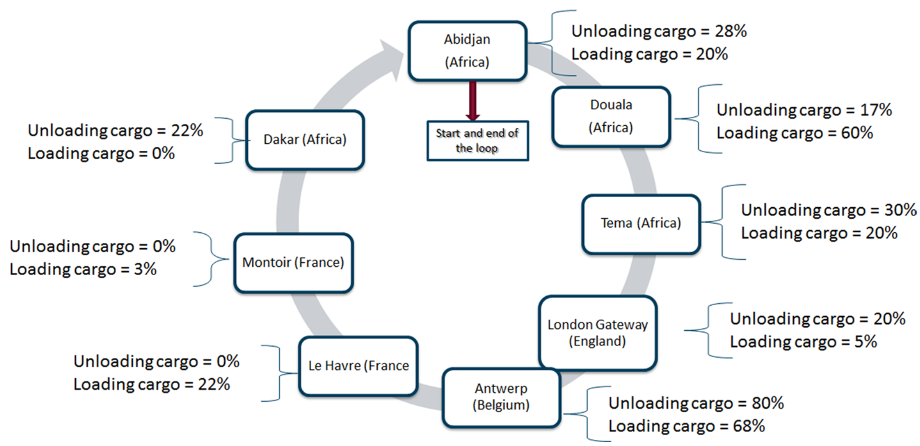

Fig. 6 Order of ports and (un)loading share (non-transshipment and transshipment cargo)—scenario 2

Table 10 Loading cargo % of the vessel at European ports—scenario 2

Calling at port	Total loading %	Loading dry share %	Loading reefer share %
London Gateway	5	4	1
Antwerp	68	14	54
Le Havre	22	5.5	16.5
Montoir	3	1	2
Total	98	24.5	73.5

Table 11 Unloading cargo % of the vessel at African ports—scenario 2

Calling at port	Total unloading %	Unloading dry share %	Unloading reefer share %
Dakar	22	6	16
Tema	30	8.5	22
Douala	17	3	14
Abidjan	28	7	20.5
Total	98	24.5	73.5

African ports. (see Fig. 6). The total (un)loading % accounts now for 98%; the (un) loading reefer share % amounts to 73.5%.

In this scenario, the ship is loaded with 98% of the ship's total capacity, of which 14% belongs to the transshipment cargo flow originating from the Baltic, Ireland Kattegat and Russia, transshipped via the port of Antwerp. In parallel, Tables 10 and 11 plot the (un)loading share of cargo at each port.

Economic assessment: results

The generalized chain cost is calculated by running the CCM. Successively, the results of the different scenarios are described and finally compared.

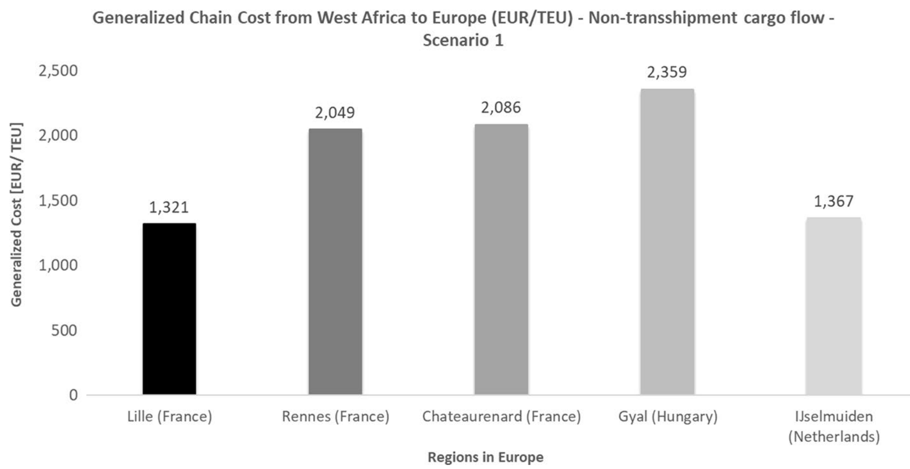

Fig. 7 Generalized chain cost for European regions in scenario 1

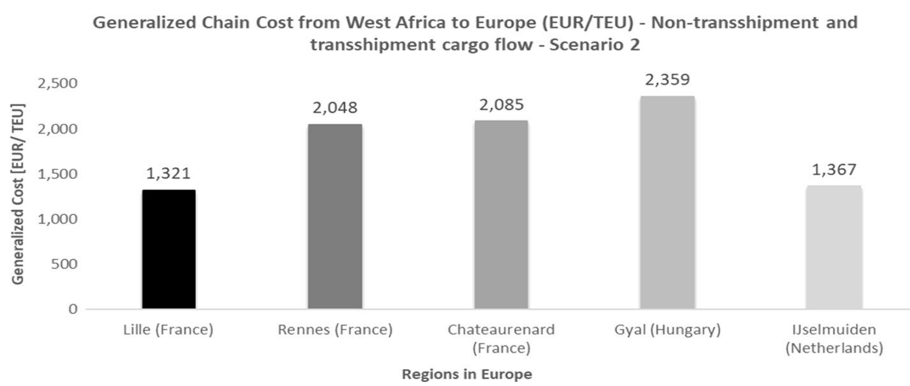

Fig. 8 Supply chain cost—scenario 2

Scenario 1

The generalized chain costs for reefer cargo from Africa to all five European regions in scenario 1 are presented in Fig. 7.

The lowest generalized chain cost is obtained for Lille and IJselmuiden, and these two regions show the same result approximately; while, the generalized chain cost from Africa to Gyal has the highest value. Chateaurenard and Rennes are the second and third most expensive regions in Europe, respectively.

In the generalized chain cost, the port and hinterland costs of the destination region are essential, but these costs at the origin area also significantly impact the generalized cost and the maritime shipping cost. By taking Lille as an example, the hinterland cost from the port of Antwerp has the lowest value compared to the hinterland cost from this port to Gyal, which leads to having a lower supply chain cost for Lille. Therefore, it is observed that the hinterland cost from the destination port to the final warehouse plays a significant role in the generalized chain cost.

Scenario 2

Parallel to the previous section, the generalized chain costs from Africa to all five European regions in scenario 2 are presented in Fig. 8.

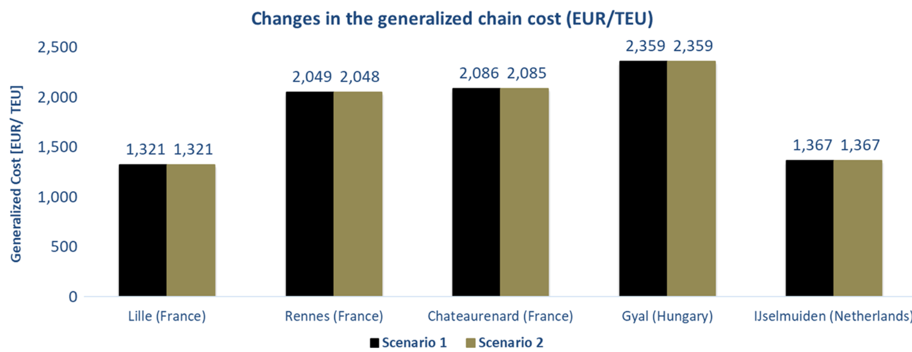

Fig. 9 Changes in supply chain costs between scenarios 1 and 2

Comparing both scenarios

Ultimately, it is interesting to compare both scenarios. Scenario 1 is considered the reference scenario.

As in scenario 1, the supply chain cost for Lille and IJselmuiden shows approximately the same result; while, the generalized chain cost from Africa to Gyal has the highest value. Chateaurenard and Rennes are the second and third most expensive regions in Europe, respectively.

By loading more cargo at the port of Antwerp due to the potential market in the Baltic, Ireland Kattegat, and Russia, the ship's total cost increases slightly as the port handling costs rise. By comparing the generalized chain cost between scenario 1 and 2, it is observed that the lowest generalized chain cost from Africa to the European regions Lille (France), Gyal (Hungary), and IJselmuiden (the Netherlands), does not differ, while for the regions Rennes (France) and Chateaurenard (France), the generalized chain cost in scenario 2 reduces slightly but the difference is insignificant.

Figure 9 shows that scenario 2 reduces the generalized chain cost by approximately 0.1%.

Conclusion

This paper concerns a case study on an efficient maritime supply chain of dry and reefer cargo on a specific trade route. This paper's primary goal was to assess the potential business benefits of choosing various ports of call for the Europe–West-Africa (reefer and dry) transport in the – Rotterdam–Gibraltar range.

Following the paper's objective, the addressed research question is: what are the possible benefits for a reefer shipping company of selecting different ports of call in the Rotterdam–Gibraltar range for West-Europe–West-Africa (reefer and dry) trade?

Based on the obtained results, it can be concluded that the port of Antwerp is the most appealing port in North-West Europe to employ as a central hub for the transshipment cargo in this paper's setting for two main reasons. Firstly, this port has much more loading cargo potential (54%) than the other ports. Secondly, it is observed that the port of Antwerp has the lowest generalized chain cost for the routes from Africa to three regions in Europe (all regions in France).

Moreover, it is observed that by adding more ports in the loop, the ship's total cost (vessel owner's cost) rises moderately, while this phenomenon has negligible impacts on the generalized cost (shipper's cost). It can be justified that port charges, cargo handling rate, cost and space availability play a significant role in this context. The total maritime cost will increase by calling at more ports and higher cargo loading.

However, the generalized chain cost follows a different pattern. In this cost, the port and hinterland costs of the destination region are essential. Still, these costs at the origin area also significantly impact on the generalized and ocean shipping costs. For example, as the selected West-European ports in this case study (Antwerp, Rotterdam, and Flushing) are in the same range, they face fierce competition to be the central hub for reefer cargo in West Europe. Thus, it is concluded that, although the supply chain cost should be considered in the supply chain optimization, this is not a decisive factor and the total maritime cost has a higher priority.

This paper contributes to the literature by evaluating the generalized chain cost from the shipper's perspective based on analyzing the transportation of dry and reefer cargo in a round maritime route between West-Africa and West-Europe. This study is novel as it considers the viewpoint of a shipping line specialized in producing and distributing refrigerated cargo and the cargo owner's standpoint by applying a generalized chain cost approach.

Other factors such as hinterland distance to the warehouse, cargo loading and unloading rate, space availability, congestion at the terminal, and competitiveness issues with neighboring ports play a crucial role in port selection analysis. Furthermore, this paper extends the existing CCM to the African regions by developing new ports and terminals.

Several stakeholders in the maritime industry, including policymakers and logistics service providers, benefit from the research outputs as it has consequences for stakeholders in terms of management and policy to advance their competitive position. The research outcomes will also benefit the shipping lines and shippers. By performing the port analysis regarding the import/export cargo volume and maritime and supply chain costs, these stakeholders can decide which ports are the best to call at on a specific route.

The limitations of the research are that the analysis is done for this specific case study (West Africa to the Rotterdam–Gibraltar range). This means that only ports in these regions are considers. Also, the hinterland coverage was limited to five specific regions in Western Europe. This means that more ports and regions have to added to the model to further generalize the results and to optimize the complete maritime supply chain.

Another element that needs further research is the problem of empty container repositioning of the high-cost equipment such as reefer containers. Edirisinghe et al. (2018) has indicated the importance of the container exchange to reduce these repositioning costs.

Appendix 1: Trade-based HS codes with description

(Table 12).

Table 12 H.S. codes for different types of commodities

H.S. code	Commodity description
70310	Onions or Shallots
303	Frozen fish excl Fillets
402	Processed milk and cream
401	Non-processed milk and cream
706	Carrots, turnips edible roots
701	Potatoes; fresh or chilled
407	Bird eggs in shell
405	Butter other fats
202	Frozen Bovine meat
406	Cheese and curd
80810	Apples fresh
805	Citrus; fresh or dried
80410	Dates; fresh or dried
806	Grapes; fresh or dried
81050	Kiwifruit, fresh
203	Frozen Swine meat
204	Frozen Sheep/Goat meat
206	Frozen offal of bovine
207	Frozen offal of poultry
208	Other offal meat
205	Frozen Horse meat
30462	Fish fillets; frozen, catfish
30469	Fish fillets; frozen, carp
30461	Fish fillets; frozen, tilapias
30463	Fish fillets; frozen, Nile Perch
30429	Fish fillets & other fish meat
30421	Swordfish, frozen fillets

Appendix 2

(Figs. 10, 11, 12).

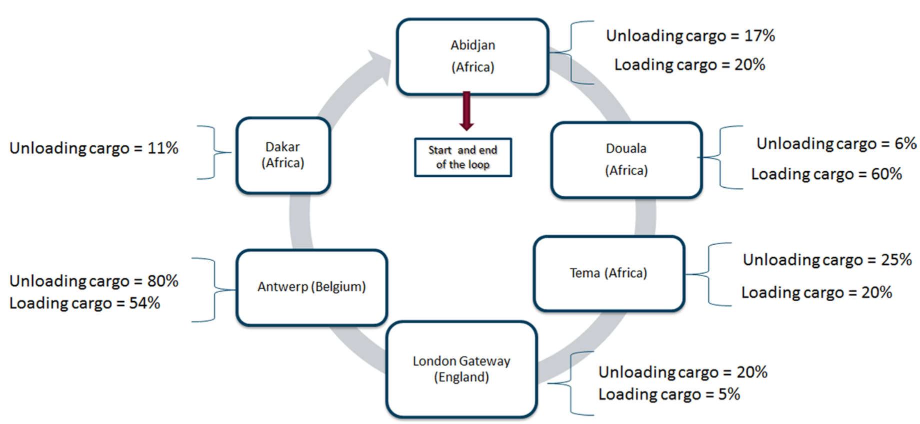

Fig. 10 Ports of call and loading and unloading cargo share in scenario A (Antwerp)

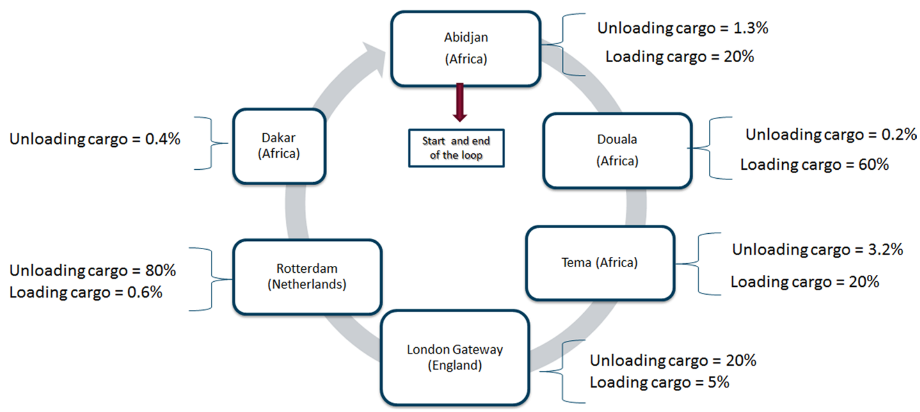

Fig. 11 Loading and unloading cargo share in scenario B (Rotterdam)

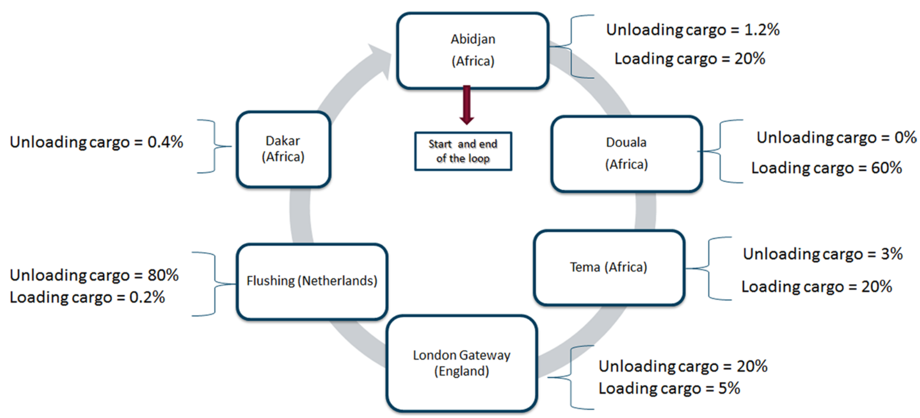

Fig. 12 Loading and unloading cargo share in scenario C (Flushing)

Abbreviations

EU	European Union
GC	Generalized cost
OPC	Out-of-pocket cost
VOT	Value of time
UK	United Kingdom

Acknowledgements
Not applicable

Author contributions
The main principle researcher was SAM. EvH developed and updated the used model and, provided input for the development of the model. EvH, TV and CS have supervised the work They also supported SAM with the interpretation of the results and he helped in structuring the paper. All authors read and approved the final manuscript.

Funding
Not applicable.

Availability of data and materials
The data used in this paper was collected open source data.

Declarations

Competing interests
The authors declare that they have no competing interests.

Received: 25 October 2022 Revised: 11 March 2023 Accepted: 16 March 2023
Published online: 23 March 2023

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