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Multi-Objective Weather Routing Algorithm for Ships Based on Hybrid Particle Swarm Optimization

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Abstract Maritime transportation has become an important part of the international trade system. To promote its sustainable development, it is necessary to reduce the fuel consumption of ships, decrease navigation risks, and shorten the navigation time. Accordingly, planning a multi-objective route for ships is an effective way to achieve these goals. In this paper, we propose a multi-objective optimal ship weather routing system framework. Based on this framework, a ship route model, ship fuel consumption model, and navigation risk model are established, and a non-dominated sorting and multi-objective ship weather routing algorithm based on particle swarm optimization is proposed. To fasten the convergence of the algorithm and improve the diversity of route solutions, a mutation operation and an elite selection operation are introduced in the algorithm. Based on the Pareto optimal front and Pareto optimal solution set obtained by the algorithm, a recommended route selection criterion is designed. Finally, two sets of simulated navigation simulation experiments on a container ship are conducted. The experimental results show that the proposed multi-objective optimal weather routing system can be used to plan a ship route with low navigation risk, short navigation time, and low fuel consumption, fulfilling the safety, efficiency, and economic goals.

Key words weather routing; particle swarm optimization; route planning; multi-objective optimization

1 Introduction

The maritime transportation environment is complex and dynamic. Severe weather conditions threaten the navigation safety of ships, and shipwrecks are common. Such conditions can not only cause damage to ships but also seriously threaten the lives of crewmembers. In addition, the rapid development of the maritime industry has resulted in large amounts of greenhouse gas emissions, which have severely affected the global climate. In 2018, the International Maritime Organization (IMO) adopted the Initial IMO Strategy on the Reduction of Greenhouse Gas Emissions from Ships (Chircop, 2019). For the first time in the global maritime community, greenhouse gas emission targets have been formulated in response to shipping greenhouse gas emissions. Accordingly, in this study, we propose a multi-target ship route planning algorithm for weather routing to reduce ship fuel consumption and greenhouse gas emissions, improve ship navigation safety, and shorten ship navigation time.

The core of weather routing is the method used to design the best ship route. This method is based on short- and medium-term weather and marine forecasts and combines the ship performance, technical conditions, and navigation tasks to select the best route for ship navigation. The objectives of determining the best route generally include the following aspects: safety, efficiency, and economy (Zyczkowski *et al.*, 2019). With the increasingly significant role of weather routing in the maritime navigation of ships, many traditional and intelligent algorithms for the design of weather routing for ships have been proposed. Among them, the earliest traditional algorithm is the isochronous method (James, 1957). However, this method is unsuitable for computer calculations. To solve such shortcomings, the modified isochrone method (Hagiwara and Spans, 1987) was proposed, which is mainly used to calculate the shortest navigation time and least fuel consumption route, but it encounters the ‘isochronic loop’ problem. Accordingly, a three-dimensional (3D) modified isochrone method (Lin *et al.*, 2013; Fang and Lin, 2015) was proposed, which achieves the optimal minimum fuel consumption and expected arrival time. Traditional dynamic programming methods have been applied to weather routing (Wit, 1990). Shao *et al.* (2012) proposed a forward 3D dynamic programming method to optimize routes while minimizing fuel consumption. The Dijkstra algorithm (Panigrahi *et al.*, 2012; Sen and Padhy, 2015; Mannarini *et al.*, 2016) and

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A* algorithm (Xie *et al*., 2019) have also been applied to the weather routing problem, aiming to obtain the shortest voyage route, least time route, and lowest fuel consumption route. Zyczkowski *et al*. (2018) proposed a deterministic algorithm aid to determine the route of a sailing vessel and reduce the navigation time and number of turns. With the continuous development of intelligent heuristic optimization algorithms, swarm intelligence algorithms, such as the ant colony algorithms, genetic algorithms, and particle swarms, have also been applied to the optimal weather routing design problem. For example, Tsou and Cheng (2013) used the ant colony algorithm to plan the route of ships with minimum fuel consumption. Maki *et al*. (2011) applied the real-coded genetic algorithm to search the trade-off ship route and achieve economic and safety goals. Kang *et al*. (2012) developed a metaheuristic algorithm based on a genetic algorithm to reduce transportation costs. Wang *et al*. (2018) presented a real-coded genetic algorithm to determine the minimum voyage route time for point-to-point problems in a dynamic environment. Vettor and Guedes Soares (2012) presented a robust multi-objective evolutionary algorithm to approximate the most favorable set of solutions. Joanna (2015) presented a weather routing algorithm utilizing a multi-objective evolutionary to determine Pareto-optimal transoceanic ship routes. Szlapczynski and Ghaemi (2019) applied an evolutionary multi-objective optimization approach to pursue three objectives: minimization of collision risk, minimization of fuel consumption, and minimization of navigation time. Tagliaferri and Viola (2017) applied a neural network to produce a short-term wind forecast and obtain the route closest to the shortest voyage. In this study, we propose combining the multi-objective particle swarm optimization (MPSO) algorithm with the genetic algorithm to solve the optimal weather routing problem. The research content and structure of this article are as follows:

First, a mathematical model for the ship route design is established, including a route mathematical model, fuel consumption mathematical model, and navigation risk mathematical model. Second, a hybrid non-dominated sorting MPSO (HNDS-MPSO) algorithm is proposed to solve the route planning problem in consideration of static obstacle constraints (*i.e.*, coastlines, islands, reefs, and shoals) and dynamic obstacle constraints (*i.e.*, high-wind and wild-wave areas) at sea. The proposed algorithm is used to plan an optimal route while ensuring safety, being economical, and saving time. Third, to improve the diversity of solutions and avoid premature convergence of the algorithm, elite selection and mutation operations are added. Finally, based on the Pareto optimal front and Pareto optimal solution set obtained by the algorithm, a recommended route selection criterion is proposed, and a simulation experiment is designed for a container ship. The experimental results show that the algorithm is feasible and effective.

2 Multi-Objective Weather Routing System Framework

The weather routing system proposed in this paper consists of six interconnected parts: parameter input, environment construction, ship route model, multi-objective weather route planning algorithm, route evaluation, and route recommendation. The overall structural framework of the weather routing system and the relationship among the six parts are shown in Fig.1 and detailed as follows.

First, the parameter input includes the ship's departure port position, arrival port position, preset speed, and full-load displacement. The parameter values are provided by the operator according to the navigation task and requirements. Second, the environment construction includes the navigation area map obtained from the electronic chart and the meteorological forecast information obtained by the meteorological center. In this part, the system analyzes the static and dynamic obstacle areas of the naviga-

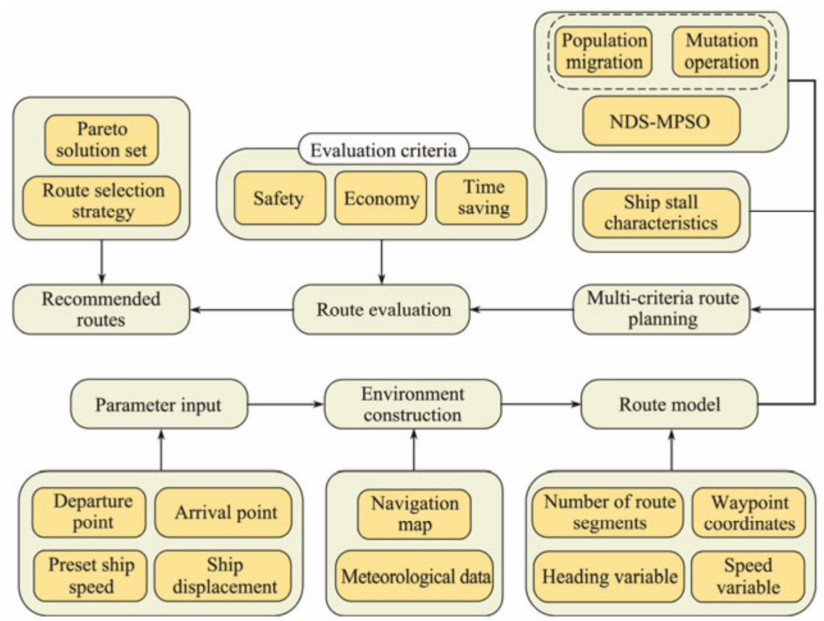

Fig.1 Multi-objective weather routing system framework.

tion area to identify the non-navigable and high-risk areas and to lay the foundation for the risk assessment of the best weather routing plan. Third, the ship route model is based on the particle swarm algorithm and the characteristics of the ship route. The routing model not only conforms to the characteristics of the actual ship route but also conveniently calculates the ship's sailing time, navigation risk, and fuel consumption. The non-dominated sorting multi-objective particle swarm algorithm is applied to solve the ship's weather routes. Fourth, the proposed algorithm is a multi-objective weather route planning algorithm based on the theory of particle swarm optimization, which combines the mutation operation and elite selection operation. Fifth, the route evaluation aims to obtain the Pareto optimal solution set and Pareto optimal front and achieve the shortest sailing time, lowest navigation risk, and least fuel consumption. Lastly, based on the obtained Pareto solution set data, the route recommendation is performed based on the idea that the total expected error is the smallest.

2.1 Ship Route Model

A ship route is defined by the following adjustable variables: the number of route segments, latitude and longitude of each waypoint, heading angle information of each route segment, and ship's hydrostatic speed in each route segment. In this study, we consider that the shipping route is composed of multiple route segments and that every two waypoints are connected by a rhumb line. As shown in Fig.2, S and E are the starting point and target point, respectively; N_i ($i \in N^+$) is the ith waypoint of the ship's route, where $N_0=S$, $N_n=E$; λ_i is the latitude coordinate of waypoint N_i; l_i is the longitude coordinate of waypoint N_i; V_i represents the set water speed of the vessel in the ith section of the route; φ_i represents the heading information of the ith section of the route; and the direction of north is 0°, which increases in the clockwise direction.

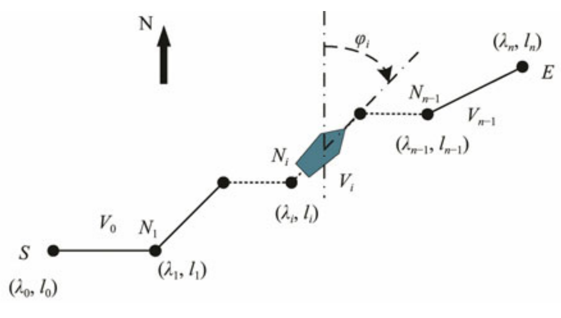

Fig.2 Ship route diagram.

The number of route segments n in the route model is determined according to the ship's hydrostatic speed and great circle route. In this study, the preset initial value of n is determined by Eq. (1), where L_{se} (n mile) is the great circle route distance between the departure point and destination, V (kn) is the hydrostatic speed, the voyage of a ship sailing for H (h) is a route segment in which the ship sails along the rhumb line, and the ceil function requires rounding to positive infinity.

$$n = \mathrm{ceil}\left(\frac{L_{se}}{H \times V}\right). \tag{1}$$

The position information of waypoints can be represented by a structure ***STR***. The position information of each waypoint in a route is shown in Eq. (2).

$$\boldsymbol{STR}=\{(\lambda_0, l_0) \cdots (\lambda_i, l_i) \cdots (\lambda_n, l_n)\}. \tag{2}$$

A ship route consists of multiple route segments. To characterize the course and speed of a ship in different route segments, the vector $\boldsymbol{\varphi}$ is used to represent the direction of the ship on each route segment, and the vector $\boldsymbol{v}$ is used to represent the ship's hydrostatic speed on each route segment, as shown in Eqs. (3) and (4):

$$\boldsymbol{\varphi} = [\varphi_0 \ \cdots \ \varphi_i \ \cdots \ \varphi_{n-1}], \tag{3}$$

$$\boldsymbol{v} = [v_0 \ \cdots \ v_i \ \cdots \ v_{n-1}], \tag{4}$$

where φ_i represents the heading of the ship in the ith route segment, the value of which can be determined by the latitude and longitude coordinates of the ith waypoint and the latitude-longitude coordinates of the $i+1$ waypoint, $\varphi_i \in [0°, 360°)$, and v_i represents the hydrostatic speed of the ship in the ith route segment.

2.2 Ship Stall Characteristics

The ship's stall will affect the ship's sailing time and fuel consumption and will have an important impact on the results of the ship's best weather routing plan. Therefore, speed loss is an important factor that must be considered in the design of ship weather routes. In this study, we use the ship stall calculation formula proposed by Liu (1992), which takes into account the effects of the sense wave height, wave direction, wind speed, and wind direction on the ship speed. Based on real ship observation data, the iterative method is used to obtain the ship stall equation based on the least-squares method:

$$\begin{aligned} V_a &= V_0 - (1.08h - 0.126qh + 2.77\times10^{-3} \times F\cos\alpha) \\ &\quad \times (1 - 2.33\times10^{-7} DV_0), \end{aligned} \tag{5}$$

where V_a (kn) is the actual speed of the ship against the wind and waves, V_0 (kn) is the hydrostatic speed of the ship, F (kn) is the wind speed, D (t) is the actual displacement of the ship, h (m) is the significant wave height, q (rad) is the relative angle between the ship's heading and the wave direction, and α (rad) is the relative angle between the ship's heading and the wind direction. This formula can be used for various types of ships with a hydrostatic speed between 9 kn and 20 kn and a ship displacement between 5000 t and 25000 t.

2.3 Ship Sailing Time

According to the established ship routing model, the length of a ship route can be obtained by adding up the lengths of all route segments:

$$L = \sum_{0}^{n-1} L_i \ , \tag{6}$$

where L is the total route length, n is the total number of route segments, and L_i is the length of the rhumb line for each segment. If the earth is regarded as an ellipsoid, then the formula for calculating the distance (length) between any two points on the Mercator projection map is as follows (Snyder, 1984):

$$\frac{l_2 - l_1}{\tan\varphi_{\mathrm{rh}}} = \ln\left[\tan\left(\frac{\pi}{4}+\frac{\lambda_2}{2}\right)\left(\frac{1-e\sin\lambda_2}{1+e\sin\lambda_2}\right)^{\frac{e}{2}}\right] - \ln\left[\tan\left(\frac{\pi}{4}+\frac{\lambda_1}{2}\right)\left(\frac{1-e\sin\lambda_1}{1+e\sin\lambda_1}\right)^{\frac{e}{2}}\right], \tag{7}$$

$$L_{\mathrm{rh}} = (\lambda_2 - \lambda_1)\times\sec\varphi_{\mathrm{rh}} \ , \tag{8}$$

where λ_1 and l_1 are the latitude and longitude coordinates of the first point, respectively; λ_2 and l_2 are the latitude and longitude coordinates of the second point, respectively; φ_{rh} is the direction of the rhumb line; L_{rh} is the distance between the two points (in radians); and $e=3.355\times10^{-3}$ is the eccentricity of the earth. The above formula applies to ships sailing along non-iso-latitude lines, whereas for iso-latitude lines, that is, when the ship's heading is 90˚ or 270˚, the following equation can be used:

$$L_{\mathrm{rh}} = (l_2 - l_1)\times\cos\lambda_1 \ . \tag{9}$$

Thus, the total time a ship sails along a route can be obtained by summing the time consumed for all route segments, as shown in Eq. (10):

$$T_{\mathrm{voyage}} = \sum_{i=0}^{n-1} t_i \ , \ t_i = \frac{L_i}{V_a^i} \ , \tag{10}$$

where T_{voyage} is the total sailing time of the ship, t_i is the sailing time of the ship on each route section, and V_a^i is the actual speed of the ship on the ith route segment.

2.4 Ship Navigation Risk

This study considers the wave height and wind speed in view of the second type of risk factor and establishes a risk assessment formula for ship routes:

$$\begin{cases} R = \dfrac{1}{n}\displaystyle\sum_{i=1}^{n}\left(\alpha\times\frac{h_{i\mathrm{wave}}}{h_{\mathrm{maxwave}}}+\beta\times\frac{v_{i\mathrm{wind}}}{v_{\mathrm{maxwind}}}\right) \\ \alpha+\beta=1 \end{cases}, \tag{11}$$

$$r_{\mathrm{risk}} = \left[1+\frac{1-2\wedge(-0.1\times T_{\mathrm{alarm}})}{1+2\wedge(-0.1\times T_{\mathrm{alarm}})}\right]\times R \ , \tag{12}$$

where r_{risk} is the risk value of the ship route; n is the total number of route sections of the ship route; $h_{i\mathrm{wave}}$ is the wave height of the ith section of the ship route; h_{maxwave} is the maximum alert wave height, the default value of which is 5 m; $v_{i\mathrm{wind}}$ is the wind speed of the ith section of the ship's route; v_{maxwind} is the maximum warning wind speed, the default value of which is 15 m s^{-1}; α and β are the coefficients of influence of the wave height and wind speed on the navigation risk of the ship, respectively; and T_{alarm} is the alarm time, which represents the accumulated time of the ship sailing in the high-risk area. In high-risk areas, the wave height is greater than the maximum warning wave height, or the wind speed is greater than the warning wind speed. According to the formula, the risk of a ship sailing along a route will change with the wave height and wind speed. Eq. (11) indicates that when the average cumulative wave height and cumulative wind speed are larger, the navigation risk value is larger, and Eq. (12) indicates that the longer the navigation time in the warning area, the larger the navigation risk value. Here, when the risk value of a route is greater than 0.6, the route is not acceptable. When the risk value is less than 0.6, although it is within an acceptable range, the risk value is expected to be as small as possible to reduce the risk of navigation.

2.5 Ship Fuel Consumption

Each ship route consists of multiple route segments. The intersection of each route segment and the integer latitude and longitude is called the sub-waypoint. Fig.3 shows a navigation area map with a resolution of 1˚×1˚. The red square point are the waypoints optimized in the algorithm; the black round-point are the sub-waypoints; S and E are the starting and ending points, respectively; and N_1 and N_2 are the waypoints. The resolution of the meteorological data in this study is selected as 1˚×1˚. Thus, the total sailing time and total fuel consumption of the ship are the cumulative sum of the sailing time and fuel consumption between the two adjacent points (diamond and circle) in the figure.

The total fuel consumption can be determined by the following formula:

$$f_{\mathrm{fuel}} = \sum_{i=1}^{m-1}\left(t_i\times FCPH_i\right), \tag{13}$$

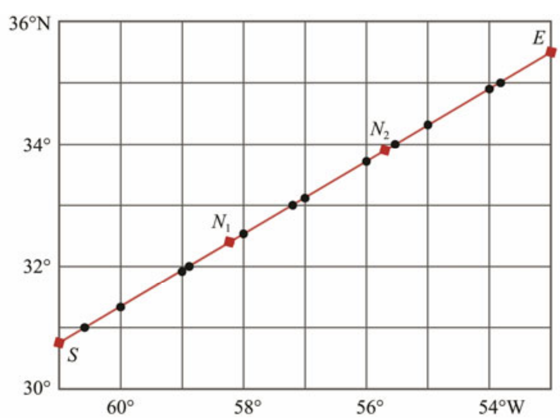

Fig.3 Ship route decomposition diagram.

where f_{fuel} is the total fuel consumption of the ship's route, m is the total number of waypoints (diamond and circle), t_i is the ship's sailing time along the ith route segment, and $FCPH_i$ is the average fuel consumption per unit hour of the ship along the ith route segment.

A search conducted by Du *et al*. (2011) and Kontovas (2014) showed that the relationship between the sailing speed and bunker consumption is nonlinear and that the daily bunker consumption is approximately proportional to the sailing speed cubed. Therefore, based on the fuel consumption data obtained from the actual sailing of the S-175 ship, this study uses the least-squares fitting method to obtain the curve relationship between the actual fuel consumption and speed of the ship, as shown in Eq. (14):

$$FCPH_i = 0.0273\times V_{a,i}{}^3 - 0.9169\times V_{a,i}{}^2 + 10.67\times V_{a,i} - 40.92,\ 10 \le V_{a,i} \le 20, \quad (14)$$

where $v_{a,\,i}$ represents the actual speed of the ship along the ith route segment. To ensure that the fuel consumption results are as practical as possible, only the data with a speed of 10 kn to 20 kn are fitted.

3 Weather Routing Algorithm Based on Non-dominated Sorting Multi-object Particle Swarm Optimization

3.1 Ship Navigation Area Initialization

In this study, the space for ship route optimization is limited to a local sea area that includes the starting point and ending point. By taking the fixed route as the reference line and expanding a certain length in the direction of the angle bisector of the angle formed by two adjacent equal course lines, the space of the ship's sailing area designed for the best weather route is established. This study uses the rhumb line between the starting point and ending point as the reference line. Fig.4 depicts an established navigation area.

The light-blue area represents land, the light-gray area represents the route optimization area, the dark-blue line represents the reference route, the dark-blue dots represent the ship waypoints, the green dotted lines represent the direction of the route optimization area expansion, and the red line represents the upper and lower boundaries of the route optimization area.

3.2 Particle Population Initialization

This study encodes the waypoint position information of the route control variable into a vector $\boldsymbol{X}$ to characterize particles, as shown in the following equation:

$$\boldsymbol{X} = [\boldsymbol{X}_0 \ \cdots \ \boldsymbol{X}_i \ \cdots \ \boldsymbol{X}_n]. \quad (15)$$

The positions of the red upper and lower borders in Fig.4 can be calculated from the reference route and extended distance. The two structures ***UpperBound*** and ***LowerBound*** are used to represent the upper and lower boundaries, respectively, which are expressed in Eqs. (16) and (17):

$$\boldsymbol{UpperBound} = \{\boldsymbol{Upper}_0 \ \cdots \ \boldsymbol{Upper}_i \ \cdots \ \boldsymbol{Upper}_n\}, \quad (16)$$

$$\boldsymbol{LowerBound} = \{\boldsymbol{Lower}_0 \ \cdots \ \boldsymbol{Lower}_i \ \cdots \ \boldsymbol{Lower}_n\}. \quad (17)$$

$\boldsymbol{X}_i$ represents the position information of the ith waypoint, $\boldsymbol{Upper}_i$ represents the position information of the ith upper boundary point, and $\boldsymbol{Lower}_i$ represents the position information of the ith lower boundary point.

To improve the diversity of the population, the initial particle swarm should be distributed as evenly as possible throughout the solution space. Therefore, this study uses a randomly generated, uniformly distributed random number within the upper and lower boundaries of each waypoint to generate a route. According to Eq. (18), an initial value of one particle can be randomly generated. If the generated route passes through islands or land, then a new route is regenerated. If the route generated for five consecutive times passes through the land, the objective function values of the route are all set to infinity, and the subsequent crossover and mutation operations are performed.

$$\boldsymbol{X}' = rand \times \{\boldsymbol{UpperBound} - \boldsymbol{LowerBound}\} + \boldsymbol{LowerBound}. \quad (18)$$

When the number of particle swarms is 50, the distribution of the initial particle swarms in the entire navigation area is as shown in Fig.5, and the initial particle swarms are uniformly distributed throughout the entire optimization region.

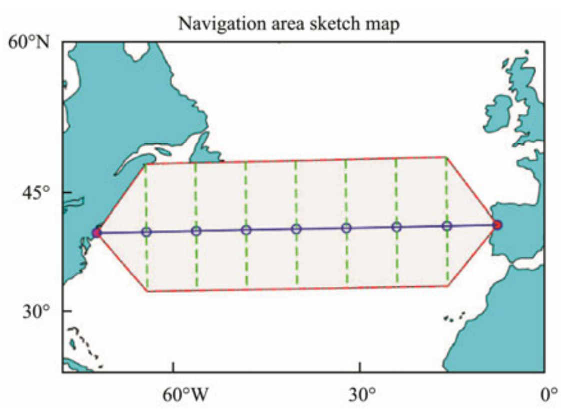

Fig.4 Schematic diagram of the ship navigation area.

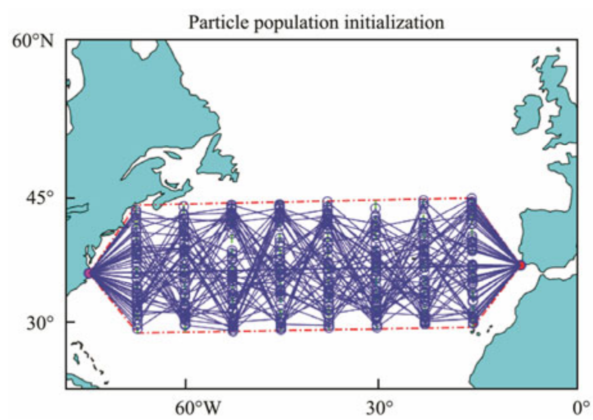

Fig.5 Route position with 50 particle populations.

3.3 Method of Designing the Ship's Best Weather Route Based on HNDS-MPSO

A particle swarm optimization algorithm is a random search algorithm based on swarm cooperation, which is developed through the foraging behavior of bird swarms (Vettor and Sobieszczanski-Sobieski, 2003). The basic particle swarm algorithm has a better effect when solving single-objective problems, but it cannot optimize multiple targets at the same time. Therefore, this study combines multi-objective optimization with particle swarm optimization and introduces elite selection and mutation operations in the genetic algorithms. An HNDS-MPSO algorithm is proposed to solve the problem of optimal weather navigation for ships.

The steps of the algorithm are shown in Table 1. To introduce the operation steps of the algorithm more clearly, the process of the route optimization algorithm is herein analyzed in detail:

In step 1, the particle swarm is initialized. The particle speed and position are represented by the position information of the waypoints along the route, where the particle speed determines the direction and distance of the current particle movement.

Table 1 HNDS-MPSO steps

Step	HNDS-MPSO algorithm
1	Initialize particle position and speed to obtain population POP1.
2	Calculate the initial particle swarm objective function, and select the individual optimal and global optimal particles according to the non-dominated ranking results.
3	While the maximum number of iterations or minimum error criteria is less than the set value, do: I. Update the particle speed and position to obtain new population POP2. II. Calculate the objective function value of each particle and update the individual optimal particles. III. Perform the mutation operation on population POP1 to obtain POP2, and calculate the objective function value of each particle. IV. Combine POP1, POP2, and POP3 for non-dominated sorting, and select *M* particles as the next generation according to the dominance level and crowding degree. V. Calculate the dominance level and congestion for *M* particles, perform non-dominated sorting, and update the globally optimal particles. VI. Obtain a new offspring population POP1 and increase the number of iterations by 1.
4	Analyze the results and give the recommended route based on the Pareto solution set.

In step 2, there are three optimization goals: the minimum ship navigation risk, minimum ship navigation time, and minimum ship fuel consumption. The smaller the three target values of the ship route are, the better the route. However, in the optimal weather navigation problem for ships under multiple constraints, it is almost impossible to simultaneously find three routes with the smallest target value. This study introduces the Pareto idea. According to the three target values of the particles, the domination level of each particle is calculated, and the crowding distance of the particles in each domination level is calculated. The definitions of dominance and non-dominance are as follows:

$$u = F\left(p'\right) = \min\left\{f_1\left(p'\right), f_2\left(p'\right), \cdots, f_{n_0}\left(p'\right)\right\}, \quad (19)$$

$$u' = F\left(q'\right) = \min\left\{f_1\left(q'\right), f_2\left(q'\right), \cdots, f_{n_0}\left(q'\right)\right\}, \quad (20)$$

$$ff\left[\forall i \in \left\{1, \cdots, n_0\right\}, u_i \le u_i'\right] \wedge \left[\exists i \in \left\{1, \cdots, n_0\right\}, u_i < u_i'\right], \quad (21)$$

where p' ($p' = \{p_1, p_2, \cdots, p_{m_d}\}$) and q' ($q' = \{q_1, q_2, \cdots, q_{m_d}\}$) are the decision variable vectors and the position information of the two particles is represented in the algorithm. u ($u = \{u_1, u_2, \cdots, u_{n_0}\}$) and u' ($u' = \{u'_1, u'_2, \cdots, u'_{n_0}\}$) are the optimization target vectors of two particles p' and q', respectively. Because there are three optimization targets in this study, $n = 3$. If the performance vectors u and u' satisfy Eq. (21), then particle p' dominates q'. If a particle neither dominates nor is dominated by other particles, then the particle is called a non-dominated solution, and the set of all particles that satisfy the non-dominated solution is called a non-dominated solution set. The division of dominance levels in the particle swarm is determined according to the following steps:

a) Perform non-dominated sorting of the initial particle swarm to obtain a set of Pareto optimal frontiers and Pareto optimal solutions. The particles in the solution set have the first domination level, that is, the highest domination level. Set $i = 2$.

b) Exclude particles in the population that have been assigned a dominance level, and then perform non-dominated sorting among the remaining particles to obtain the Pareto optimal solution set, which has the ith dominance level. Set $i = i + 1$.

c) Repeat step b) until all particles have been assigned a dominance level.

To further evaluate the performance of the particles in each domination level, the crowding distance between the particles at each domination level is defined according to Eq. (22):

$$Crowd\left(m\right) = \sum_{j=1}^{n_0} \frac{f_j\left(m+1\right) - f_j\left(m-1\right)}{f_{j\text{Max}} - f_{j\text{Min}}}, \quad (22)$$

where $Crowd(m)$ is the crowding distance of the mth particle ($m = 2, 3, \cdots, N' - 1$); f_j is the jth objective function value; $f_{j\text{Max}}$ and $f_{j\text{Min}}$ are the maximum and minimum values of the *j*th optimization target, respectively; N' is the number of particles at the same dominance level; and the crowding distance for edge particles is set to infinity.

Then, among the particles with the highest domination level and a crowding distance not equal to infinity, a particle is randomly selected as the global optimal particle.

Step 3 is a process of iterative optimization. In step I, the speed of the particles is updated according to Eq. (23), and the position of the particles is updated according to Eq. (24). In step III, the particle population is uniformly mutated at the mutation probability P, and the mutated population is taken as POP3. In step IV, the three populations are merged, and M particles are selected as the next generation through non-dominated sorting based on the domination level and the crowding distance. The purpose is to retain the superior particles of the parent. In step V, the global optimal particle position is updated. In step VI, the new population POP1 is used as the parent population, and the next iteration is performed until the conditions for exiting the iteration are satisfied.

$$v_{id}^{k+1} = \omega \times v_{id}^{k} + c_1 \times rand \times \left(p_{p\text{Best}} - x_{id}^{k} \right) + c_2 \times rand \times \left(p_{g\text{Best}} - x_{id}^{k} \right), \quad (23)$$

$$x_{id}^{k+1} = \frac{1}{2} \times \left(x_{id}^{k} + v_{id}^{k+1} \right), \; i = 1, 2, \cdots, m; \; d = 1, 2, \cdots, D, \quad (24)$$

where v_{id}^{k} is the particle velocity of the *d*th dimension of the *m*th particle in the *k*th iteration; x_{id}^{k} is the particle position of the *d*th dimension of the *m*th particle in the *k*th iteration; ω, c_1, c_2 are the coefficients; and *rand* is a uniform random number in the range (0, 1).

Finally, based on the Pareto optimal front and Pareto optimal solution set obtained by the algorithm, a recommended route is given according to Eq. (25):

$$Z = \min\left(\left(\sum_{j=1}^{N} \left| c_{ij} - y_j \right|^2 \right)^{0.5} \right), \; (i = 1, 2, \cdots, M), \quad (25)$$

where N is the number of optimization targets, c_{ij} is the *j*th objective function value of the *i*th particle after normalization, y_j is the normalized expected target function value, M is the number of particles in the Pareto solution, min is a function for selecting recommended routes in the Pareto solution set and the route in the solution set corresponding to the minimum value in parentheses is obtained, and Z is the recommended route that satisfies the conditions on the right side of the equation.

4 Results and Discussion

4.1 Algorithm Parameter Initialization

The experimental ship in this study is an S-175 container ship. The ship parameters are given in Table 2.

Table 2 Parameters of the S-175 container ship

Length	Width	Molded depth	Draft	Displacement
175 m	25.4 m	15.4 m	9.5 m	24742 m^3

The starting point is near the port of New York, and the destination is near the port of Porto, Portugal. The sailing time of the ship is 00:00 on July 1, 2016. The navigation area is obtained by expanding by 8 degrees along the angle bisector of the reference line. The ship's still water speed is set at 16 kn.

In Table 3, *Gen* indicates the number of iterations of the algorithm, and *Pop* indicates the number of particle populations. c_1, c_2, and ω are the parameters in the particle swarm algorithm, and P is the uniform mutation probability.

Table 3 MPSO algorithm parameters

Gen	*Pop*	c_1	c_2	ω	P
100	40	2	2	1	0.2

4.2 Acquisition and Analysis of Meteorological Data

In this study, we obtained the meteorological weather data for a period of time in advance from the European Centre for Medium-Range Weather Forecasts. The meteorological data considered in this experiment mainly include wind and wave information, which change over time. The meteorological data files used in this article are of the Network Common Data Format (NetCDF). The meteorological data used include the '10 meter U wind component', '10 meter V wind component', 'mean wave direction', and 'significant height of combined wind waves and swell'. The accuracy of the selected meteorological data is 1°×1°, and the meteorological data update interval is 6 hours, which corresponds to the meteorological data at 00:00, 06:00, 12:00, and 18:00 every day. Fig.6 shows the visual information diagrams of the waves and wind at two moments in a certain area of the Atlantic Ocean on July 8, 2016.

4.3 Experimental Results and Analysis

This study sets up two experiments: one is planning the optimal route under good sea conditions and the other is planning the optimal route under severe sea conditions.

4.3.1 Good sea conditions

According to the meteorological forecast, from July 1 to 7, 2016, the sea conditions in the ship's navigation area were good, and there were no extreme winds or waves. In this case, after applying the non-dominated sorting MPSO algorithm for ship route planning, the Pareto optimal solution set for the ship weather route is shown in Fig.7, and the Pareto optimal frontier is shown in Fig.8. Therefore, by sorting the objective function values of the ship routes in the Pareto solution, the minimum sailing time route, minimum safety risk route, and minimum fuel consumption route can be obtained. We set $y_1=200.0$, $y_2=0.30$ and $y_3=900$, which respectively indicate the expected sailing time, navigation risk, and fuel consumption of the ship. The recommended route can be obtained according to Eq. (22). The trajectories of the four ship routes are shown in Fig.9. In Fig.8, the green point D indicates the route with the lowest navigation risk, the black point B indicates the route with the shortest sailing time, the magenta point A indicates the route with the lowest fuel consumption, and the red point C indicates the recommended route. The recommended ship route is shown in Fig.10, and the specific performance of the route is shown in Table 4.

As shown in Table 4, although the route with the shortest sailing time is shorter than the recommended route, the navigation risk of the recommended route is lower. The safest route has the lowest safety risk, but the ship sailing time is too long. The route with the lowest fuel consumption consumes the least amount of fuel, but the ship is at

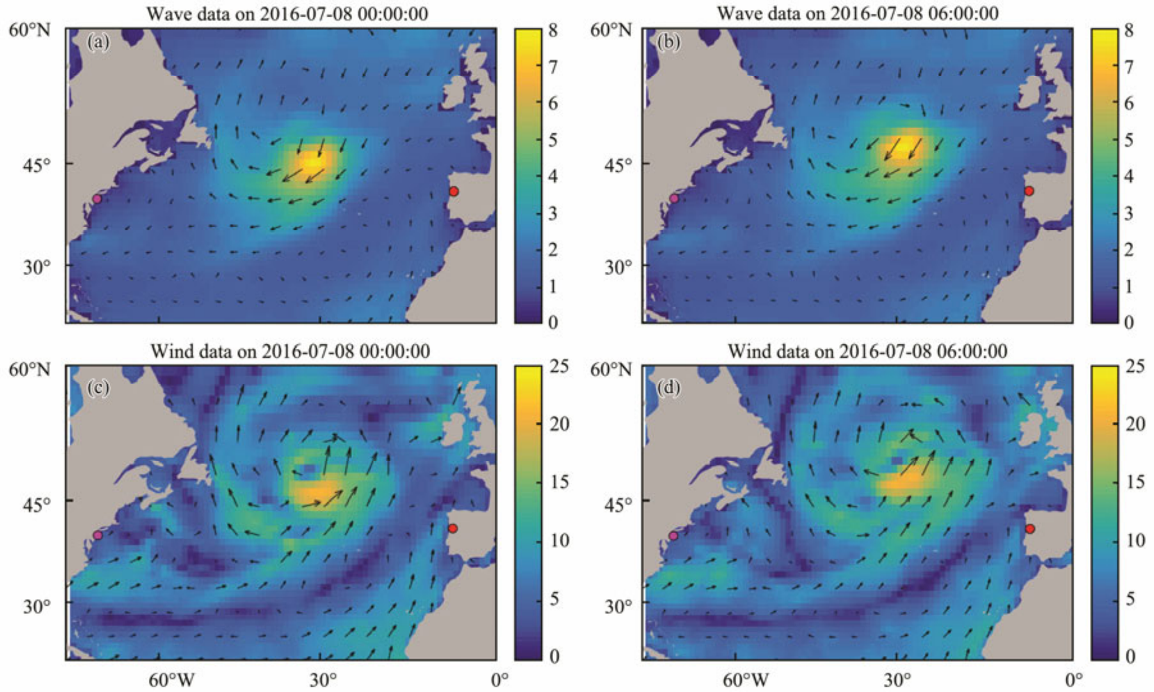

Fig.6 Wave and wind data at two different times.

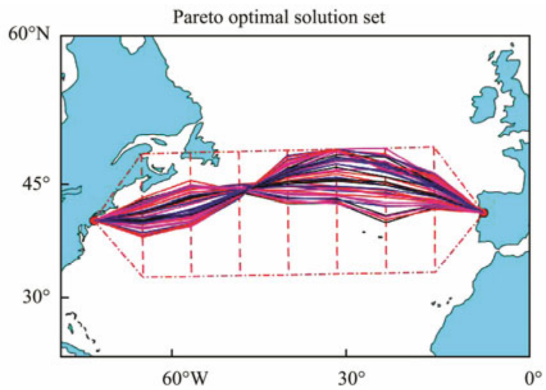

Fig.7 Schematic diagram of all routes.

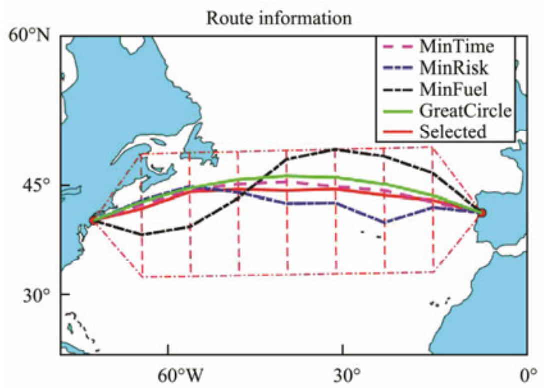

Fig.9 Schematic diagram of four ship routes.

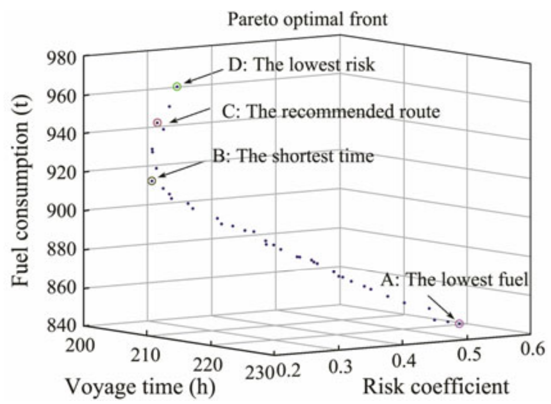

Fig.8 Pareto optimal front.

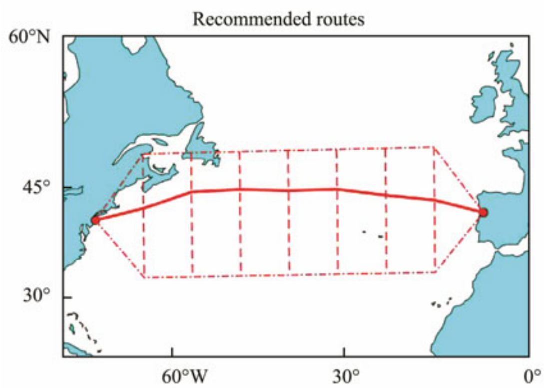

Fig.10 Recommended route.

high risk. In addition, we compared the great circle route with the recommended route. Although the great circle route has a shorter sailing distance, it is the route with the highest risk. The recommended route proposed in this paper can combine the three goals according to the expected target value to obtain an optimal weather route that meets the requirements. For the recommended route, the sailing positions of the ship at four different sailing moments are as shown in Fig.11. The figure shows that under good sea conditions, the ship can sail along the recommended route with less navigation risk, lower fuel consumption, and a shorter sailing time.

Table 4 Objective function values for the four routes under good sea conditions

Route	Distance (n miles)	Time (h)	Risk	Fuel (t)
Min time route	2944.92	200.301	0.314	914.039
Safest route	3046.50	206.066	0.272	962.090
Min fuel route	3165.89	226.391	0.505	844.868
Selected route	2952.46	200.775	0.299	915.318
The great circle	2939.57	200.321	0.334	907.773

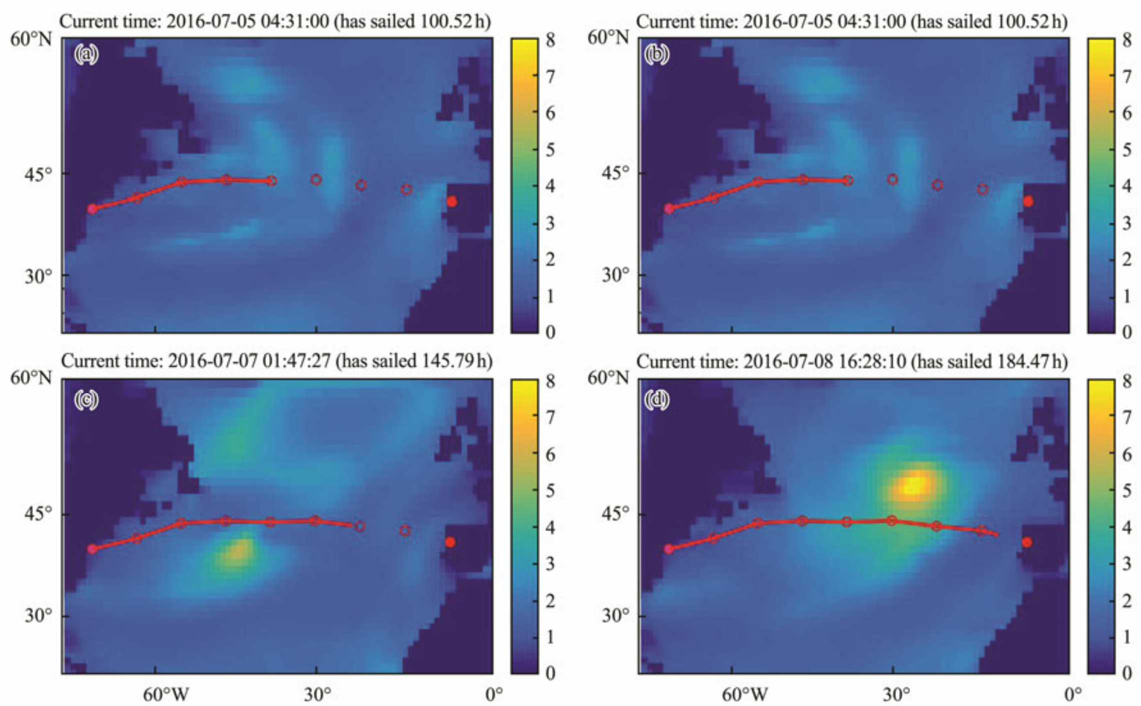

Fig.11 Ship's trajectory along the recommended route at four different times.

4.3.2 Severe sea conditions

To further illustrate the effectiveness of the algorithm, the best weather route under severe weather conditions in the ship's navigation area was also designed. According to the meteorological forecasts from July 3 to 10, 2016, the sea conditions in the ship's navigation area were severe. As shown in Fig.12, under severe sea conditions, the algorithm was applied to obtain the Pareto optimal solution set. By sorting the objective function values of the ship routes in the Pareto solution, the minimum sailing time route, minimum safety risk route, and minimum fuel consumption route can be obtained. We set $y_1=225.0$, $y_2=0.32$ and $y_3=950$, which respectively indicate the expected sailing time, navigation risk, and fuel consumption of the ship. The recommended route can be obtained according to Eq. (24). The Pareto optimal frontier is shown in Fig.13, the trajectories of the four ship routes are shown in Fig.14, and the specific performance of the route is shown in Table 5. The recommended ship route is shown in Fig.15. For the recommended route, the sailing positions of the ship at four different sailing moments are shown in Fig.16.

As shown in Fig.12, most of the routes in the Pareto optimal solution set can avoid high-risk areas near (37˚N, 35˚W). In the design of the best weather route, there are almost no ship routes with the characteristics of the shortest sailing time, lowest sailing risk, and least fuel consumption. Therefore, in this study, based on the expected target value, a comprehensive optimization was performed among the three targets. The selected route can meet the requirements of shorter sailing time and less fuel consumption *via* safe navigation of the ship. As shown in Fig.12 and Table 5, the recommended route can avoid dangerous sea areas with large winds and waves and reach its destination safely.

Table 5 Objective function values for the four routes under severe sea conditions

Route	Distance (n miles)	Time (h)	Risk	Fuel (t)
Min time route	2979.76	214.367	0.414	816.970
Safest route	3474.28	237.336	0.266	1058.550
Min fuel route	2946.06	216.699	0.463	774.741
Selected route	3257.01	225.424	0.313	955.602
The great circle	2939.56	246.441	0.466	778.471

Based on the above experiments, the routes in the Pareto solution set provide the captain with the possibility of choosing routes to meet different needs. To meet the safety, efficiency, and economy requirements in ship navigation, this paper presents a recommended route that has the shortest sailing time, lowest fuel consumption, and lowered navigation risk. The results show that the route has good performance.

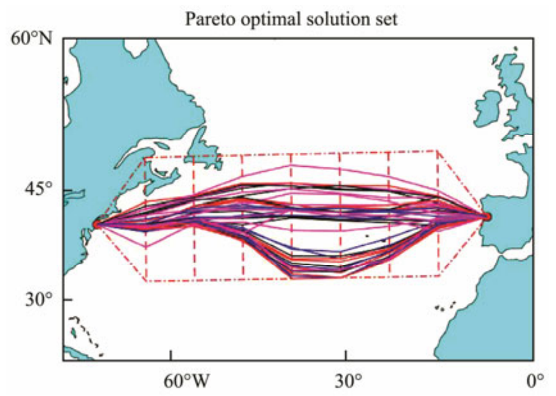

Fig.12 Schematic diagram of all routes.

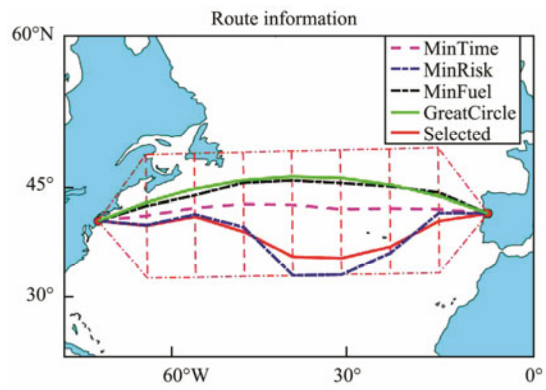

Fig.14 Schematic diagram of four ship routes.

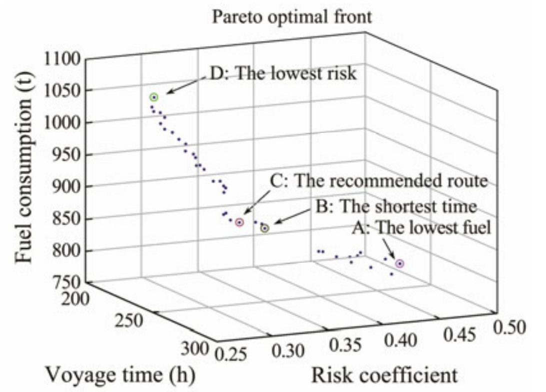

Fig.13 Pareto optimal front.

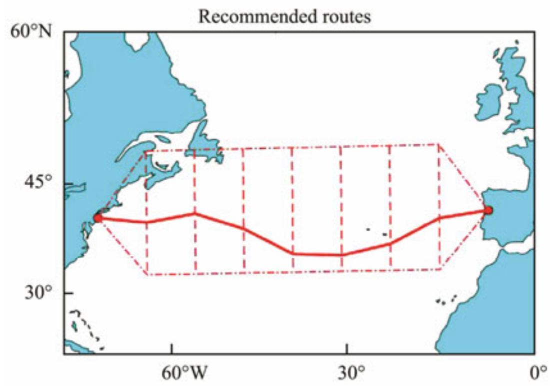

Fig.15 Recommended route.

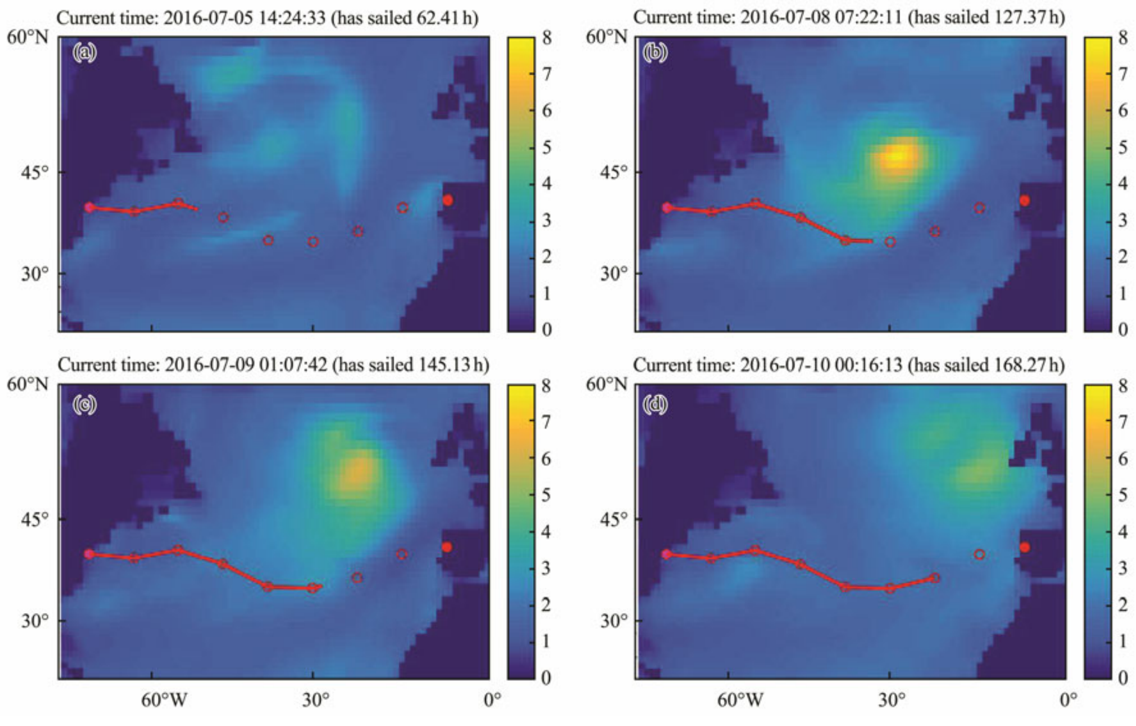

Fig.16 Ship's trajectory along the recommended route at four different times.

5 Conclusions

This study establishes a system framework for ship multi-objective weather routing based on the characteristics of a ship's ocean voyage. The system consists of the parameter input, environment construction, route model, multi-objective optimization algorithm, route evaluation, and route recommendation. Based on the system framework, this paper proposes a non-dominated sorting and multi-objective ship weather routing algorithm based on particle swarm optimization. This algorithm combines mutations and elite selection operations in genetic algorithms. Such an algorithm can obtain the lowest sailing risk, shortest sailing time, and lowest fuel consumption of ships and provide the best weather routes for ocean voyages, guaranteeing that ships can sail safely, efficiently, and economically. According to the experimental results, the recommended route can integrate three types of optimization objectives, avoiding high-risk sea areas and ensuring as little ship sailing time and fuel consumption as possible. Therefore, the multi-objective weather routing system and non-dominated multi-objective route planning algorithm proposed in this paper are feasible and effective when applied to ship weather routing problems. Although the results show that the algorithm is effective, some shortcomings need to be resolved. First, visibility and other ships are not considered when calculating the navigation risk. Second, the fuel consumption calculation is not accurate enough.

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The evolution of the port network along the Maritime Silk Road: From a sustainable development perspective

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ABSTRACT

This paper explores the evolution of the port network along the Maritime Silk Road (MSR) motivated by the need for sustainable development. First, considering the influence of sustainable development on the attraction of ports, we optimize the AB model, a generator based on connectivity. After this the evolution simulation is carried out based on the data of 55 major ports along the MSR. The results of evolution simulation show that, due to sustainable development, ports in Southeast Asia and South Asia are expected to become the core nodes in the network while the status of China's ports in the network will decline significantly. The results further show that the frequency of nodes close to the mid-value increases significantly and that ports currently under construction, such as Melaka Gateway, Hambantota and Gwadar, will have an important impact on the network structure. This study serves as a useful reference for port development along the MSR from a sustainable development perspective.

1. Introduction

In the context of the global energy crisis and environmental degradation, sustainable development has become the main strategic direction for the port industry. Sustainable development impacts port production, construction and operations management from three aspects of economic prosperity, environmental quality and social welfare [1]. In terms of the economy, ports are required to continuously improve production efficiency, technical capacity and management level to enhance their sustainable competitiveness. In terms of the environment, the ports are required to save energy and reduce emissions, and ensure that natural resources and the environment are not damaged. In social terms, it is necessary to strengthen resource integration and any complementary advantages with surrounding ports to achieve regional development [2]. Therefore, in order to adapt to these requirements, many world-famous ports and shipping companies, such as those found in Shanghai and the Mediterranean, have begun to make efforts in sustainable development [3,4]. Thus, considering the requirements for sustainable development, it is an important task for the realization of the long-term development strategy for ports to investigate the development trends and propose countermeasures for their future development.

Sustainable development will also significantly influence the evolution of the port network along the Maritime Silk Road (MSR). The 21st Century MSR Initiative, proposed by China, is an important regional cooperation project for the world. At present, countries along the MSR have carried out extensive cooperation with China in the fields of investment, trade and security [5-7]. Under the guidance of sustainable development, the breadth and depth of cooperation will be further strengthened. In terms of economic and social sustainable development, China has invested in, and constructed, many ports along the MSR including the Melaka Gateway, Kyaukpyu, Gwadar, Hambantota, Kuantan and Haifa [8], further deepening infrastructure interconnection. The construction and use of these ports will change the number of nodes in the MSR port network, thus affecting the evolution of port networks. In the context of environmental sustainable development, the Chinese Ministry of Environmental Protection issued the "Ecological and Environmental Protection Cooperation Plan of the 'Belt and Road." This comprehensively improved the following: safety standards; pollution control; scientific and technological innovation; information services; and other key cooperation areas of the MSR, which will change the status of some nodes in the MSR port network and also affect the evolution of port networks. In addition, the global COVID-19 pandemic has

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restricted the movement of people and logistics [9], which has brought new requirements for the sustainable development of ports. Thus, safe ports and smart ports have become the new trends in port development. Against the backdrop of this complex situation, this research addresses the following question: *How will the sustainable development concept affect the evolution of the port network along the MSR?*

Currently, the BA model is widely used in the evolution research of ports and other networks. In order to explain the mechanism of power-law distribution, Barabasi and Albert [10] proposed the BA scale-free model, which has two characteristics: growth and preferential attachment. The AB model is an extension of the BA model proposed by Albert and Barabasi [11], which was applied to the topological modeling of the Internet. The network will grow and expand by adding node, edge, and re-configuring edge. Compared with the BA model, the AB model is more consistent with the characteristics of port network evolution. The probability of connection between ports in the evolution of the port network is related to the degree of the port, in the BA scale-free network, and the older the node, the higher the degree [12]. In the AB model, the connection probability between ports is not only proportional to the degree of nodes but also to the product of degree and attractiveness of nodes. Thus, this paper applies the AB model to construct the port network along the MSR and explores the influence of a sustainable development concept.

There are two main aspects in this paper. First, it discusses the role of sustainable development within the process of port development. Second, based on the complex network method, it forecasts the evolution of the port network and individual ports along the MSR as a result of the drive toward of sustainable development. The contribution of this paper is that the simulation results reveal the evolution trend of the port network along the MSR under the requirements of sustainable development, and therefore provide an important reference for each port in order to adjust its own development strategy and further improve its position in the network.

The remaining sections of this paper are organized as follows: in section two, we review the literature on the MSR port network from the aspects of network construction and priority connectivity determination; section three describes the data and methodology we use to investigate the influence of sustainable development on the evolution of the MSR port network; section four presents the evolution results based on the collected data and conducts a discussion of the MSR port network; finally, the implications of the research findings and conclusions are drawn in section five.

2. Literature review

The fifth generation ports (5GP) consist of five aspects: service, technology, sustainable development, cluster and hub [13]. From these, sustainable development and clustering are contemporary aspects that are newly evolved in the 5GP concept. Contemporary port development is facing multiple pressures in order to address sustainable development issues, such as blind expansion of port scale, inefficient utilization of resources, and increasingly serious environmental pollution [14]. The increasingly prominent issue of sustainable development in recent years has become an essential consideration in determining competition and cooperation between ports [15]. However, the evaluation standard of port sustainability is a controversial issue, and many scholars have proposed their own frameworks.

From the perspective of port operations, Kang and Kim [16] integrated environmental technology, process and quality improvement, monitoring and upgrading, communication and cooperation, active participation and other related issues. Furthermore, they constructed a five-factor model of port sustainable development. Lu et al. [17] focused on port sustainable supply chain management and concluded that the external sustainable cooperation and internal sustainable management of ports can have a positive impact on the performance of port sustainable development. Schipper et al. [18] reviewed various long-term port plans and port improvement documents. They evaluated the sustainable development planning of ports and port cities, and concluded that the formulation of comprehensive plans, measures and regulations is helpful to promote the sustainable development of ports. Based on the survey of Taiwan's major international ports, Lu et al. [19] found that the social issues of employees' job security and safety are the most important assessment criteria for sustainable development. Hua et al. [20] paid more attention to the environment, and proposed that the sustainable development of ports should focus on energy consumption, pollutant emission monitoring, scientific research, technological innovation and green port construction. In summary, although scholars put forward the evaluation framework of port sustainable development from differing angles, the core aspects are economic prosperity, social welfare and environmental quality.

From an environmental perspective, the most vulnerable ecosystem at the interface between sea and land is air pollution which seriously limits the sustainable development of ports, particularly the large emissions of CO_2 [21]. From the perspective of social development, the quality of port infrastructure determines the efficiency of port operation. Efficient port operation not only brings about greater economic benefits, but can also improve the utilization rate of resources, which in turn brings higher environmental benefits. In addition, the quality of the environmental protection infrastructure will also affect the sustainable development of ports [22]. From the perspective of economic development, the logistics performance, such as the efficiency of the customs clearance processes will have a long-term effect on the trade volume of the port [23]. Higher customs clearance efficiency means better port logistics performance, which is conducive to the increase of port trade volume, and thus improves the sustainable development capacity of the port. Therefore, this paper takes CO_2 emission per unit of GDP, port infrastructure quality, and customs clearance efficiency as three indicators to measure the sustainable development of ports within the port network evolution model, in order to investigate the impact of sustainable development on port network evolution.

Regionalization represents a new phase in the development of port systems [24], which means the Complex Network Theory is increasingly used in port system research. The typical complex network is composed of a large number of nodes and edge-connecting nodes, which coincides with the port network composed of ports and shipping routes. Increasingly, scholars are analyzing and simulating the port network using the idea and method of the complex network by regarding the port as the node of the network and the connection between ports as the connection between nodes in the network [25-27].

At present, the research on the port network based on Complex Network Theory mainly focusses on the following aspects: the first is to study the structural characteristics of the shipping network, analyze and demonstrate the vulnerability [28], the robustness [29] and the small-world property [30] of the global shipping network and the spatial heterogeneity of ports [31]. The second is to study the evolution process of the shipping network, which not only discusses the centralized or decentralized development of global shipping routes and ports as a whole [32], but also analyzes the unequal development of regional status in the process of port evolution from a regional perspective [33]. Third, the status of ports in the maritime transport network is assessed. Most of these are analyzed by the centrality index [34,35] and connectivity index [25]. Table 1 summarizes the major research on the port network based on Complex Network Theory. However, it is worth noting that these analyzes only focus on the changes to the current status of the port compared with the past, and do not carry on empirical prediction analysis on the evolution of the future status. Therefore, there is a research gap to propose an appropriate model to predict the future evolution of port status.

In the construction of the port evolutionary network, most of the network models adopt the BA scale-free model. Even if some improvements are made, the weights of the characteristic indicators are changed only on the basis of the BA model [36,37]. The BA model has two

Table 1
Major research on the port network based on Complex Network Theory.

Aspects	Main findings	Author
Structural characteristics	This article reveals the strong relationship between local port policies and the evolution of shipping network design.	[28]
	The paper reveals a certain level of robustness in the global shipping network.	[29]
	This article finds that the values of the degree of ports follow power-law distribution, which indicates that the global marine network is scale-free; that is, there are a few well-connected ports, while the majority are less connected ports.	[31]
	Based on complex networks, the statistical characteristics of the MSR are investigated, and numerical analysis shows its small-world effects and scale-free properties. Additionally, the MSR highly depends on its hubs, which is likely to lead to network vulnerability.	[30]
Evolution process	This paper demonstrates that there is no contradiction between the two models of approaches to the provision of maritime services, one based on direct port to port services, the other characterized by a hub and spoke network. In fact they are complementary.	[32]
	This paper investigates the evolution of regional inequality in the global shipping network and finds that the East Asian, Northwest European and European (including the Mediterranean) regions have consistently held the highest positions, while East African and North African regions have held the lowest positions.	[33]
Port status	The results show that the average path length of the sea transportation network decreases after the Arctic route is open to traffic, the port degree value increases obviously in some Northeast Asia and Northwest Europe ports, and the port nuclear degree tends to be more polarized.	[34]
	This paper introduces an analysis framework for port connectivity from a global container liner shipping network perspective: it is defined in terms of the impact on the transportation network when the transshipment service is not available at the evaluated port.	[25]
	The results first indicate that the degree centrality in the throughput flow is changing from the Busan port in Korea to the Shanghai or Qingdao ports in China. Second, the export volume of Korea is decreasing. Third, as for the major ports in Korea and China, China may be in a more favorable position compared to Korea.	[35]

important characteristics. One is scale growth; that is, the number of ports keeps increasing. The other is preferential attachment, which means that newly emerged ports are more likely to connect with those ports with higher connectivity [12]. However, with the rapid development of global shipping and the full exploitation of geographical and natural resources, the total number of ports has become saturated and this makes it very difficult for new ports to emerge. In fact, there is no contradiction between the development of large ports and the survival of smaller ports because, alongside the development of large ports, smaller ports will exist in the form of feeder or feeding ports [38,39]. As a result, ports are connected not by old and new ports, but by changes in existing ports, or by new connections resulting from existing port strategies or political diplomacy, or by reconfigured ports resulting from resource allocation or the development of environmental protection initiatives. Therefore, it can be seen that the basic characteristics of the BA model are not suitable for today's global shipping network. However, the AB model, an expansion of the BA model, assumes that the growth and expansion of the network are mainly realized through the addition and reconfiguration of edges, and that overcoming the weakness of the BA model in simulating network growth can explain and predict the evolution process of the port network more objectively [11].

As a topological modeling model, the AB model is widely used in the evolution of the railway express consolidation network [40], novel email network [41], overlapping community networks [42], and other aspects. The attractiveness of ports is composed of many factors affecting the connection of port nodes. Before containerization, location factors profoundly affected the evolution of port systems. In the development stage of containerization, shipping market factors and technological progress factors had a more obvious impact on the evolution of port systems. For example, Yap and Lam [43] attributed the evolution and development of ports in Hong Kong, Busan and Kaohsiung to the development of the regional economy. Lee et al. [44] postulated that traffic congestion and land restrictions are important factors affecting the ranking of both the Singapore and Hong Kong ports in the port system. Based on the above views, some scholars take the container throughput of ports, GDP of the cities where ports are located, and the sea distance between ports as the determinants affecting the connection of port nodes in the network. After weighting and quantifying, the attractiveness formula of port nodes can be formed [34,45].

Finally, in terms of the research scope, the vast majority of current literature on the evolution of port networks focusses on the discussion of the global shipping network or regional port networks based on the division of countries and continents, while little attention is paid to the emerging sub-regional network. The MSR is a new regional cooperation initiative introduced by China in 2013. Only very limited literature focused on the description of the overall structure and pattern of the network. For example, Jiang et al. [46] determined the network type by constructing the network feature set, demonstrated that the shipping network of the MSR belongs to the scale network, and analyzed its topological characteristics. Mou et al. [47] explored the spatial pattern and current situation of regional trade associations of the MSR shipping network.

To conclude, there are three obvious gaps in the research that we aim to address in this paper. First, we explore the development trend of ports under the influence of the sustainable development concept. Second, we analyze the evolution characteristics of the port network along the MSR. Third, we reveal the evolution law of port network under the new situation of the global economy and trade with the AB model.

3. Methodology and data description

3.1. Data description

According to the geographical scope of the Maritime Silk Road (MSR) [48] and the ranking of the world's top 100 container ports in 2018 published by Lloyd's list [49], we selected 49 major ports along the MSR. As the proponent and important participant of the MSR initiative, China's overseas ports invested in and constructed along the route have a great impact on the MSR port network, we included another six major ports along the MSR, which are Melaka Gateway, Kuantan, Gwadar, Hambantota, Kyaukpyu and Haifa [50]. Table 2 lists the 55 ports from 21 countries (regions) along the MSR.

The impacts on each port are influenced by the economic growth rate, export and import trade volume, port location and cost, and economic development policy [35]. Consequently, we calculated the container throughput of each port, the distance between ports, and the economic growth trend of port hinterland, which is calculated by the growth rate of GDP and total international trade volume (see Appendix A). We also collected the quality of port infrastructure, the CO_2 emission per unit GDP, and the clearance efficiency. It should be noted that the data for these were mainly from Lloyd's list [49], World Bank Open Data [51], United Nations Conference on Trade and Development Statistics [52-54]. Table 3 provides the definition and data source of each factor.

The significance of liner shipping to global trade can be inferred from the fact that over 70% of seaborne trade, in terms of value, is transported by container ships [33]. Therefore, it is reasonable to construct the port

Table 2
Major ports in the Maritime Silk Road area in 2018.

No.	Port	Country/ Region	No.	Port	Country/ Region
1	Shanghai	China	29	Tanjung Perak	Indonesia
2	Singapore	Singapore	30	Cai Mep	Vietnam
3	Ningbo-Zhoushan	China	31	Dongguan	China
4	Shenzhen	China	32	Fuzhou	China
5	Guangzhou	China	33	Salalah	Oman
6	Hong Kong	Hong Kong	34	Nanjing	China
7	Qingdao	China	35	Ambarli	Turkey
8	Tianjin	China	36	Port Said	Egypt
9	Dubai	United Arab Emirates	37	Yantai	China
10	Hambantota	Sir Lanka	38	Tangshan	China
11	Port Klang	Malaysia	39	Chittagong	Bangladesh
12	Xiamen	China	40	Quanzhou	China
13	Kaohsiung	Taiwan	41	Zhuhai	China
14	Dalian	China	42	King Abdullah	Saudi Arabia
15	Tanjung Pelepas	Malaysia	43	Karachi	Pakistan
16	Laem Chabang	Thailand	44	Bandar Abbas	Iran
17	Tanjung Priok	Indonesia	45	Khorfakkan	United Arab Emirates
18	Colombo	Sir Lanka	46	Haikou	China
19	Ho Chi Minh City	Vietnam	47	Taichung	Taiwan
20	Yingkou	China	48	Abu Dhabi	United Arab Emirates
21	Jawaharlal Nehru	India	49	Jiaxing	China
22	Manila	Philippines	50	Mersin	Turkey
23	Taicang	China	51	Taipei	Taiwan
24	Kyaukpyu	Myanmar	52	Haifa	Israel
25	Lianyungang	China	53	Melaka Gateway	Malaysia
26	Mundra	India	54	Kuantan	Malaysia
27	Jeddah	Saudi Arabia	55	Gwadar	Pakistan
28	Rizhao	China			

network with the global container liner data. We constructed the actual MSR port network based on the global route network announced by the top 10 liner companies, whose total capacity published by Alphaliner [55] account for more than 80% of the world market share (as in Table 4). The actual network takes the port as the node and the route between ports as the edge and establishes a 0–1 adjacency matrix of 55 × 55. UCINET software is used to generate a simple indirect and unauthorized network and calculate the node degree, that is, number of nodes connected to the node, of each port in the network.

According to the number of shipping companies operating on each route (the standard is three or more shipping companies) we obtained the simplified actual maritime network of the MSR as shown in Fig. 1.

3.2. Methodology

Considering that the development of the existing ports of the MSR is relatively mature, we removed the step of adding new port nodes from the optimized AB model and adopted two evolution types for the MSR port network – these were *adding edge* and *re-configuring edge*. Specifically, adding edge refers to adding several new connections between existing port nodes in the network. Edge reconfiguration requires deleting the existing connection between two nodes, then adding a new connection between the third node and the initial first node. According to the actual situation, the route adjustment between ports will occur over a long period of time. Therefore, we use the AB model to predict the evolution of port network along MSR based on a long period of time in the future. In addition, the evolution process, connection-deleting-connection, is not only in line with the actual port network evolution law in theory, but the rationality has also been empirically tested [42]. The construction process of the model is as follows:

There are m_0 initial isolated nodes in the port network $\Omega = 1, 2, \ldots, m_0$. Each evolutionary process performs one of the following two steps with equal probability.

Adding $m(m \leq m_0 - 1)$ new internal connections with probability $q(0 < q < 1)$, which means adding new edges between existing nodes; randomly selecting a node as the starting point of the new edge, and the other end point of the edge is determined by the probability $\pi(k_i)$,

$$\pi(k_i) = \frac{k_i + 1}{\sum (k_i + 1)}, \tag{1}$$

Where $\boldsymbol{k_i}$ represents the degree of node $\boldsymbol{i}$ and $\sum (\boldsymbol{k_i} + \boldsymbol{1})$ is the sum of the degree of all nodes in the network. In order to ensure that the probability of establishing new connections of isolated nodes is non-zero, $\boldsymbol{k_i} + \boldsymbol{1}$ is used instead of $\boldsymbol{k_i}$ in the formula.

Re-configuring $m(m \leq m_0 - 1)$ edges with a probability of $1 - q$. Randomly selecting node i and an edge l_{ij} which are connected to i, deleting the edge and replacing it with a new edge $l_{ij'}$ that connects node i and node j'. The choice of node j' is determined by the probability $\pi(k_i)$.

In the AB model, it is known from Eq. (1) that nodes with longer existence time have higher degree value. However, in the real MSR port

Table 4
Transport capacity and market share of top 10 liner companies.

Ranking	Operator	TEU	Share
1	APM-Maersk	4180,805	17.8%
2	Mediterranean Shg Co	3670,049	15.6%
3	COSCO Group	2959,346	12.6%
4	CMA CGM Group	2660,149	11.3%
5	Hapag-Lloyd	1694,463	7.2%
6	ONE (Ocean Network Express)	1586,978	6.8%
7	Evergreen Line	1299,033	5.5%
8	Yang Ming Marine Transport Crop.	649,165	2.8%
9	PIL (Pacific Int. Line)	393,498	1.7%
10	Hyundai M.M.	367,317	1.6%

Data sources: [55]

Table 3
Definition and data source of factors.

Aspects	Features	Factors	Definition	Data source
Conventional factors	Capacity	Throughput	Annual container throughput of the port	[49]
	Potential	Economic growth trend	The economic growth trend of port hinterland	[51,53]
	Cost	Distance	The transport distance between two ports calculated according to the opened route	[52]
Sustainable development factors	Social	Quality of port infrastructure	The infrastructure's quality of the liner shipping connectivity and efficiency of seaport services of ports	[54]
	Economy	Efficiency of customs clearance process	The efficiency of customs clearance processes (i.e. speed, simplicity and predictability of formalities) of the country where the port is located	[51]
	Environment	Reciprocal of CO_2 emissions	The carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring of the country where the port is located	[51]

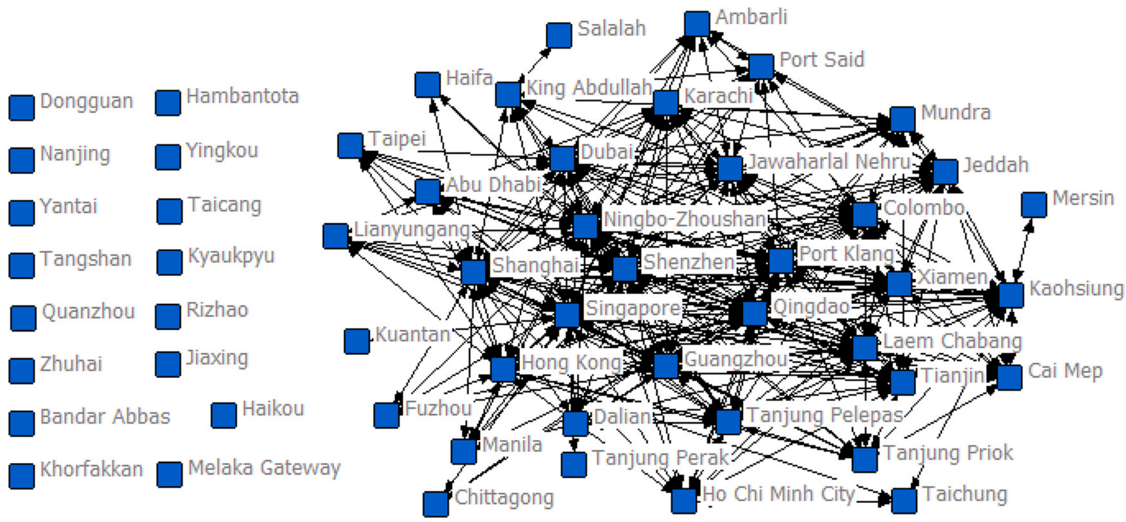

Fig. 1. Simplified actual shipping network.

network, due to the competition and cooperation between the nodes, the optimal connection probability will change. The degree value of the final node is not only related to the existence time of the node, but also related to the factors such as politics, economy, transportation, geography, industrial structure and shipping policy. Based on the reality, we express the adaptive functions r_{ij} of the port node and get the attractiveness p_{ij} of node i to node j.

$$p_{ij} = \pi(k_i) r_{ij} \tag{2}$$

Compared with the AB model, the optimal connection in the optimized model is determined by the overall attractiveness, not only in direct proportion to the degree value of nodes. In the optimized model, if a node has a higher fitness, it may get more edges in the evolution process of the node network. If the fitness of each node is the same, then the probability of adding edges in the network is completely determined by the probability $\pi(k_i)$.

In this model, we introduced six indices to measure the attractiveness of port nodes in the network, namely: (i) container throughput (Q), (ii) economic growth trend (Z), (iii) distance between ports (D), (iv) port infrastructure quality (S), (v) customs clearance efficiency of each port country (E), and (vi) CO_2 emissions per unit of GDP (C). Among them, the economic growth trend is calculated by the growth rate of GDP and total international trade volume. The faster the development speed of the port hinterland economy is, the stronger the port's external economic connection will be in the future, the more transportation demand will be generated, and the greater the attraction of establishing connection to other ports will be. The container throughput represents the throughput capacity of the port. The larger the port scale, the higher the handling efficiency, and the greater the attraction to other ports to establish connections. The distance between ports is the current shipping distance between ports. Considering the cost of route opening, the greater the distance between ports is, the greater the resistance to the new route opening becomes. The quality of port infrastructure [22], CO_2 emissions per unit of GDP [21], and customs clearance efficiency [23], respectively, measure the economic, environmental and social standards of sustainable port development. The higher the quality of port infrastructure and customs clearance efficiency, the stronger the sustainable development of the economy and social are, and the greater the attraction of the port becomes. Conversely, the higher the CO_2 emission per unit of GDP, the weaker the sustainable development is, and the smaller the attraction of the port becomes.

In order to eliminate the dimensional differences between different indicators, each indicator is standardized as:

$$X_{st} = \frac{X_i - X_{min}}{X_{max} - X_{min}}. \tag{3}$$

According to the positive and negative correlations between each index and attractiveness, the attractiveness of each network node can be obtained by using the index construction formula after weighted quantification:

$$r_{ij} = \frac{\frac{1}{\alpha}\exp(\alpha Z_i) + \frac{1}{\beta}\exp(\beta Q_i) + \frac{1}{\zeta}\exp(\zeta S_i) + \frac{1}{\epsilon}\exp(\epsilon E_i) - \frac{1}{\eta}\exp\boxed{f()}(\eta C_i)}{\frac{1}{\delta}\exp\boxed{f()}(\delta D_{ij})}, \tag{4}$$

Where α, β, ζ, ϵ, η, δ are the parameters, which are calculated by the maximum likelihood estimation method.

$$f(i,j,\alpha,\beta,\zeta,\varepsilon,\eta,\delta) = \frac{\frac{1}{\alpha}\exp(\alpha Z_i) + \frac{1}{\beta}\exp(\beta Q_i) + \frac{1}{\zeta}\exp(\zeta S_i) + \frac{1}{\epsilon}\exp(\epsilon E_i) - \frac{1}{\eta}\exp\boxed{f()}(\eta C_i)}{\frac{1}{\delta}\exp\boxed{f()}(\delta D_{ij})}. \tag{5}$$

$$L(n) = \prod_{i=1,j=1}^{n} \frac{\frac{1}{\alpha}\exp(\alpha Z_i) + \frac{1}{\beta}\exp(\beta Q_i) + \frac{1}{\zeta}\exp(\zeta S_i) + \frac{1}{\epsilon}\exp(\epsilon E_i) - \frac{1}{\eta}\exp\boxed{f()}(\eta C_i)}{\frac{1}{\delta}\exp\boxed{f()}(\delta D_{ij})}. \tag{6}$$

Eq. (6) is the likelihood function. Take a logarithm of it, calculate the partial derivative of $\alpha, \beta, \zeta, \varepsilon, \eta, \delta$, and make it equal to 0.

$$\frac{\partial InL}{\partial \alpha} = \frac{\partial InL}{\partial \beta} = \frac{\partial InL}{\partial \zeta} = \frac{\partial InL}{\partial \varepsilon} = \frac{\partial InL}{\partial \eta} = \frac{\partial InL}{\partial \delta} = 0. \tag{7}$$

Finally, calculate the parameter value by MATLAB.

After considering the effect of node degree and node influence factors, we substitute Eq. (4) into Eq. (2), and the attractiveness function of nodes in the network is obtained as follows:

$$p_{ij} = \frac{[\frac{1}{\alpha}\exp(\alpha Z_i) + \frac{1}{\beta}\exp(\beta Q_i) + \frac{1}{\zeta}\exp(\zeta S_i) + \frac{1}{\epsilon}\exp(\epsilon E_i) - \frac{1}{\eta}\exp(\eta C_i)](k_i+1)}{\frac{1}{\delta}\exp\boxed{f0}(\delta D_{ij})\sum(k_i+1)}. \quad (8)$$

Based on the data of 55 ports along the MSR, taking the attractiveness p_{ij} as the decisive factor of the connection between nodes, the evolution simulation process is as follows:

- Step 1: Initialize the parameters according to the data. Determine the value of nodesm_0, set the parameter values α, β, ζ, ε, η, δ, set the probability q, evolution times and total execution times of the model.
- Step 2: The edge-adding operation is performed once at first, and then the edge-adding and re-configuring operations are performed with probability q and $(1-q)$ as follows: In the edge-adding operation, selecting a node A1 randomly, and then selecting another node A2 of the edge according to the attractiveness p_{ij} of other nodes to A1. In the reconfiguration operation, selecting a node B1 randomly, finding all nodes connected with it, then deleting the connection between B1 and one of the nodes randomly. According to the attractiveness p_{ij} of other nodes to B1, another node B2 with edge is selected.
- Step 3: Reporting results. The average node degree of the final network is calculated according to the total number of execution times of the model.

4. Results and discussion

4.1. Simulation results

The optimized AB model is used to simulate the evolution of 55 major ports along the MSR. The parameter values obtained by the maximum likelihood estimation method are $\alpha = 2.6$, $\beta = 1.48$, $\zeta = 1.76$, $\varepsilon = 1.85$, $\eta = 1.24$, $\delta = 3.1$, respectively. The AB model is set to perform the edge-adding and edge reconfiguration operations with equal probability. The total number of execution times is 2000 (see Appendix B). Finally, in order to show the evolution results and characteristics of the port network more clearly, we take the average value of 1000 evolution results, and the ranking (RAN) and degrees (DEG) of each node are shown in Table 5.

The degree distribution of nodes in the network can be expressed by degree distribution function. In order to clearly compare the actual network and the evolutionary network, we log the degree distribution of the two networks and obtain the result as shown in Fig. 2.

Compared with the actual MSR port network, the evolution simulation results mainly differ in the following five aspects:

(1) The network density has increased and the isolated nodes have disappeared. The average degree of the actual network is 10, and 17 nodes are isolated nodes. The average degree of evolution simulation is 22.24, and the minimum degree is 2.
(2) Compared with the actual network, the frequency of nodes with the maximum and minimum degrees decreases in the evolutionary network, while the frequency of nodes close to the mid-value increases significantly. The frequency of nodes with the maximum and minimum degrees of the actual network are 0.07 and 0.31 respectively, while they are only 0.02 and 0.04, respectively, in the evolutionary network. Besides, the frequency of nodes close to the mid-value, 24, are 0.13, 0.07, and 0.05 in the evolutionary network, which are much higher than the actual network. This distribution means that the status gap between ports will narrow, showing a trend of coordinated development.
(3) Most of the core nodes in the network are ports in Southeast Asia and South Asia, and the status of ports in China has generally declined. Among the top 10 ports in the evolution result, except for Shanghai port, other ports are located in Southeast Asia and South Asia. China's ports, including Ningbo-Zhoushan, Qingdao and Tianjin, have generally declined in the network in the simulation results.
(4) According to the results of evolutionary simulation, the ports under construction that are not yet fully operational will be at the core of the MSR port network in the future. The main ports with obvious performance are Melaka Gateway, Kyaukpyu,

Table 5
Evolution results of network of Maritime Silk Road ports.

Port	Actual network		Evolution network		Port	Actual network		Evolution network	
	RAN	DEG	RAN	DEG		RAN	DEG	RAN	DEG
Shanghai	1	31	6	32	Manila	29	7	14	28
Singapore	2	31	4	34	Taipei	30	7	39	20
Ningbo-Zhoushan	3	31	42	18	Fuzhou	31	6	40	19
Shenzhen	4	31	17	26	Chittagong	32	3	11	30
Port Klang	5	25	1	36	Taichung	33	3	32	23
Hong Kong	6	23	15	27	Haifa	34	3	41	19
Qingdao	7	23	48	8	Tanjung Perak	35	1	21	26
Guangzhou	8	22	24	25	Salalah	36	1	29	24
Dubai	9	22	30	23	Mersin	37	1	43	18
Colombo	10	21	9	30	Kuantan	38	1	5	33
Jawaharlal Nehru	11	21	19	26	Hambantota	39	0	8	31
Kaohsiung	12	20	28	24	Yingkou	40	0	46	9
Laem Chabang	13	20	18	26	Taicang	41	0	54	2
Jeddah	14	19	33	22	Kyaukpyu	42	0	7	32
Xiamen	15	18	31	23	Rizhao	43	0	47	9
Tanjung Pelepas	16	18	2	35	Dongguan	44	0	25	25
Tianjin	17	16	49	8	Nanjing	45	0	55	2
Mundra	18	15	20	26	Yantai	46	0	52	8
Cai Mep	19	14	34	22	Tangshan	47	0	53	8
Karachi	20	14	22	26	Quanzhou	48	0	35	22
Tanjung Priok	21	12	12	29	Zhuhai	49	0	16	27
Ho Chi Minh City	22	12	10	30	Bandar Abbas	50	0	26	25
Abu Dhabi	23	12	36	22	Khorfakkan	51	0	27	25
Port Said	24	10	38	20	Haikou	52	0	13	29
King Abdullah	25	10	37	21	Jiaxing	53	0	45	16
Lianyungang	26	9	51	8	Melaka Gateway	54	0	3	35
Ambarli	27	9	44	17	Gwadar	55	0	23	26
Dalian	28	8	50	8					

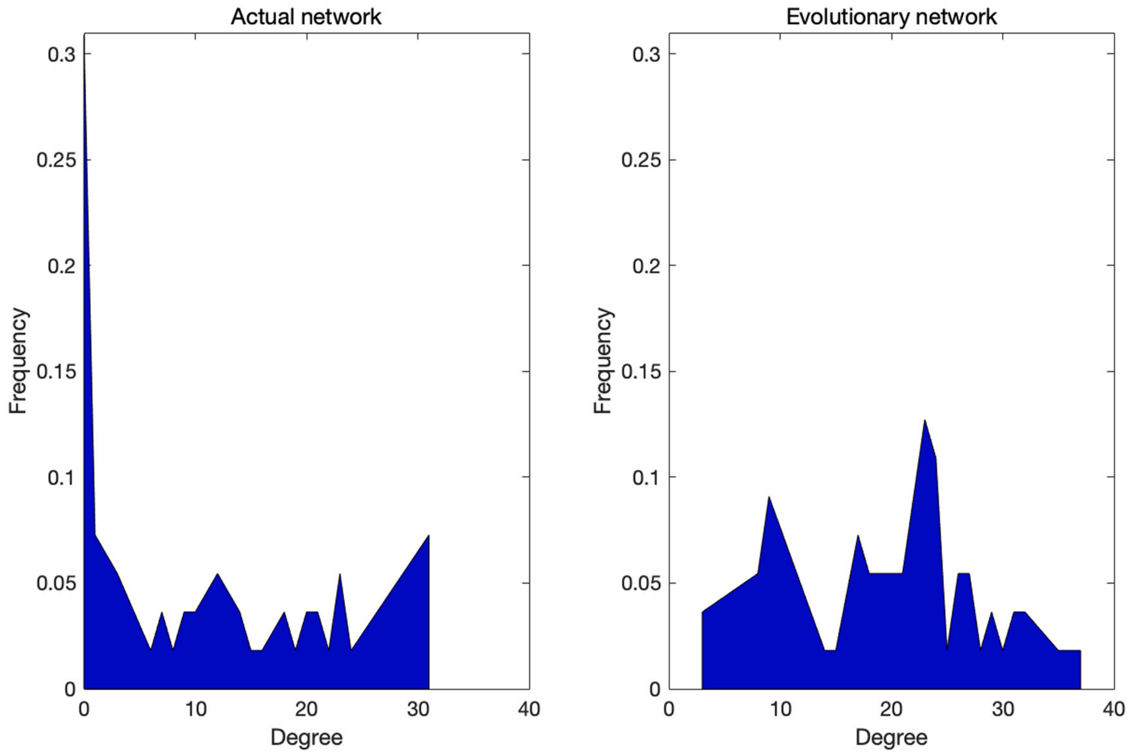

Fig. 2. Comparison of degree distribution between actual network and evolutionary network.

Hambantota and Gwadar. At present, these ports are not fully in use, so they are isolated nodes in the actual network. The simulation results suggest that these ports will evolve into important core nodes in the MSR port network in the future.

(5) The simulation results show that the central positions of ports in the south and north of China are significantly differentiated in the network. Haikou, Zhuhai, Shenzhen and other southern ports are significantly higher than Dalian, Yantai, Qingdao, Tianjin and other northern ports.

4.2. Discussion

Based on the data of 55 major ports along the MSR, the evolutionary simulation results show that the degree distribution of ports is consistent with the research results that ports are developing towards regional integration [24,38] and that the development of large ports and the survival of smaller ports are not contradictory. Affected by the adaptive functions, the status of each port node in the MSR port network has changed significantly, and the overall density of the network has increased. When the attractiveness determines the generation of a network connection, the attribute-value of each node is the main factor determining its position in the network. Because of the differences of throughput, economic growth trend, geographical location and level of sustainable development, the status of ports in the evolutionary network undergoes many different changes compared to the actual network. With the continuous progress of the construction of the MSR, it is bound to promote the economic exchanges and growth in this region. The ports in this region will further enhance their own reputation due to an increase in communication with other ports. Additionally, the vision of facility connectivity will be further realized.

Unlike the research of Mou et al. [47], we found that ports in Southeast Asia and South Asia, although having have a higher position in the network, under the influence of sustainable development factors, were lower in the network than those ports in East Asia. According to the current indicators of sustainable development, Southeast Asian and South Asian ports are expected to move to the center of the MSR port network, while the status of Chinese ports will gradually decline. This result is mainly attributed to the following two aspects: first, the evolution of port status was only limited along the MSR, so the geographical location had a greater impact on the evolution result; second, in addition to geographical location, the main reason for this phenomenon is the impact of sustainable development level. In the past few decades, China has had many resource and energy consuming industries that have resulted in higher CO_2 emissions per unit of GDP, and the current measured level of sustainable development is very low. Compared with the ports in northern China, ports such as Dubai and Jeddah whose shipping distances to Southeast Asia are shorter, their position in the evolution network is much higher due to the advantages of sustainable development. Therefore, in order to improve the status of ports within the network, China must accelerate the transformation of the mode of its economic development and reduce the proportion of industries with high energy consumption and high pollution levels. Furthermore, it should strengthen the construction of port sustainable development capacity, and use the opportunity of global value chain adjustment to improve the quality of economic development.

Based on the evolution simulation of the port network along the MSR, total traffic volume, a widely used indicator, is proved to be inaccurate in reflecting the actual development of ports [33]. Environmental pollution, infrastructure quality, customs clearance efficiency and other sustainable development factors play an important role in the development of a port [21,15,22,23]. The major ports under construction along the MSR are mostly located in Southeast Asia and South Asia, with superior geographical locations. Moreover, the infrastructure quality and customs clearance efficiency of these ports are relatively high, and affected by the economic structure of these ports' hinterland, so the CO_2 emissions per unit GDP in these areas are lower. Therefore, considering the influence of various factors on the evolution of port network, the ports under construction, such as Melaka Gateway, Kyaukpyu, Hambantota and Gwadar, are expected to become important nodes in the network and have an important impact on the overall network structure.

The difference in the position of ports in the network between the north and the south of China is mainly affected by three aspects: economic growth trend of the hinterland, geographical location, and the conditions for distribution and upgrading of the industrial chain. First, considering the rapid development of the Yangtze River Delta, Pearl River Delta and Guangdong-Hong Kong-Macao Bay area in recent years, compared with those ports in northern China, the hinterland economic growth trend of Haikou, Zhuhai, Shenzhen and other southern ports in China is stronger. This provides much better conditions for them to achieve an advantage in the future of network evolution. Second, compared with the ports in northern China, ports in southern China are closer to the two economic centers, ASEAN and EU, which means they will have better economic resources and shipping convenience. This report finding is aligned with Yap and Lam's [43] analysis of the evolution of Hong Kong, Busan and Kaohsiung ports. Moreover, due to the geographical location, the evolution results of ports in southern China are more optimistic. Third, in the process of the fourth global industrial migration, China (particularly the southern region) attracted the transfer of labor-intensive industries from all over the world with low land cost and surplus labor force, which promoted the rapid development of the economy. With the technological catchup in some fields, China has begun to transform to capital-intensive industries and establish its entire industrial chain system and manufacturing system. Due to this new process, the southern region undoubtedly has better industrial foundations and upgrading conditions, which means that it will have more economic influence in the future port network.

5. Conclusions

Sustainable development has become a global governance issue. In response, this paper has explored the evolution of the port network along the MSR from the perspective of sustainable development. We have selected the corresponding indicators from three aspects of sustainable development, namely: environment, economy and social. Furthermore, we have introduced them into the calculation of attractiveness in order to optimize the AB model, which is based on our established MSR port network evolution model. The results of evolution simulation show that, under the influence of sustainable development and other factors, ports in Southeast Asia and South Asia are expected to become the core nodes in the network while the status of China's ports in the network will decline significantly. The results further show that the frequency of nodes close to the mid-value increases significantly and that the ports under construction, such as Melaka Gateway, Hambantota and Gwadar, will have an important impact on the network structure. This paper provides a useful reference to study the port network evolution in other regions. Additionally, this paper also provides an important reference for ports along the MSR to adjust their own development strategy from the perspective of sustainable development.

Due to the limitations of data availability, the details on the quality of port infrastructure, efficiency of customs clearance process and CO_2 emissions are all based on the data of the country where the port is located, rather than the data of each specific port. However, this does not affect the outcome of our research motivation. This article is exploratory in that it only focusses on the impact of sustainable development on the evolution of the port network along the MSR. The major limitation of this paper is that our research on port evolution is geographically limited to the scope of the MSR, without considering the impact of other routes in the world, such as the Ice Silk Road [56,57]. In addition, in terms of model construction, we have ignored the role of some influencing factors and the dynamic future changes of the factors, which may have a great impact on the attractiveness of the model, and may show certain interference with and influence on the prediction. Finally, in future research, a more comprehensive index framework could be established to reflect the impact of port evolution to improve the model's prediction and interpretation ability.

CRediT authorship contribution statement

Changping Zhao, Yu Gong: Conceptualization, Methodology, Supervision. **Yecheng Wang**: Data curation, Writing - original draft. **Steve Brown**, **Rui Li**: Writing - reviewing & editing.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2021.104426.

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Analyzing the spatial-temporal characteristics of the marine economic efficiency of countries along the Maritime Silk Road and the influencing factors

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ABSTRACT

The 21st-century Maritime Silk Road (MSR) initiative provides a new direction for the high-quality development of China and the marine economy along the route. Studying the marine economy of the countries along the MSR will contribute to its sustainable development. This study used a slacks-based model (SBM) and considered undesired output to estimate the marine economic efficiency of 20 countries along the MSR from 2007 to 2017. The Malmquist-Luenberger productivity index model was applied to analyze the dynamic changes in and decomposition efficiency of marine economic efficiency. A dynamic panel model was employed to analyze the factors affecting efficiency. The results revealed that the overall marine economic efficiency of countries along the MSR trended upward from 2007 to 2017. The overall efficiency of the ocean at both ends of the MSR was greater than that in the middle and there was a clear difference in the marine economic efficiency of developed and developing countries. Moreover, as per the Malmquist-Luenberger productivity index model, the overall index demonstrated a fluctuating trend with the growth in the economic efficiency of countries along the MSR, which depend more on improvements in scale efficiency, and not on pure technical efficiency. Also, as shown by a dynamic panel model, degrees of resource dependence and levels of opening up have positive impacts on marine economic efficiency, while levels of economic development and the industrial structures have a negative impact. Therefore, countries along the MSR should actively adjust their industrial structures and attach importance to exchanges and cooperation that lead to maritime economic development.

1. Introduction

Ideas from the “21st-century Maritime Silk Road (MSR)” initiative proposed in 2013 by China are powerful means to create a cooperative, peaceful, and harmonious environment for foreign cooperation, which provides a new direction for a high-quality blue economy (Liu et al., 2018; Zheng et al., 2018). According to data from the Organization for Economic Co-operation and Development, the total value of the global marine economy accounted for approximately 2.5% of the total added value of the global economy in 2010, and it is expected to exceed USD 3 trillion by 2030. The marine economy will become a new growth point in the global economy. However, due to the difference between the marine resources and economic development levels of the countries along the MSR, their quality of marine economic development is varied, and a greener and more efficient development method should be developed. Therefore, studying the marine economic efficiency of the countries along the MSR and the influencing factors will help provide an understanding of trends in the marine economic development.

Improving the efficiency of the marine economy is conducive to the development of the blue economy and bringing new economic growth points to countries along the MSR. Marine economic efficiency is defined as the ratio of inputs to outputs within the production process of the marine economy (Morrissey and O’Donoghue, 2012). Currently, research perspectives on marine economic efficiency are divided into two categories. The first focuses on the efficiency of the marine industry. For example, Fisheries efficiency: Sun et al. (2017a) used a slacks-based model (SBM) to study the economic efficiency of marine fisheries. On this basis, kernel density and a tobit model were adopted to analyze the temporal and spatial evolution pattern of the economic efficiency of marine fisheries. Tingley et al. (2005) used the Stochastic Production Frontier (SPF) and Data Envelopment Analysis (DEA) models to calculate the efficiency of fisheries in the English Channel and used a tobit

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regression model analysis of factors affecting efficiency. Maritime transport efficiency: Sun et al. (2017b) proposed a nonradial DEA preference model to evaluate and analyze the efficiency of Chinese ports. Wang et al. (2019a) used a super-slack-based measure model and the Malmquist-Luenberger (ML) productivity index to calculate the marine environmental efficiency of a cruise shipping company. The second focuses on the overall efficiency of the marine economy. For example, Ding et al. (2020) used the improved cross-efficiency model to evaluate the green efficiency of the marine economy in 11 coastal areas from 2002 to 2016. A kernel density model was used to analyze the impact of China's environmental policies. Wang et al. (2019b) evaluated the utilization efficiency of marine resources in China and revealed a trend in regional differences. Ren et al. (2018) introduced undesired output into the measurement of total factor productivity in order to evaluate the green efficiency of the marine economy in 11 provinces and cities along China's coast from 2006 to 2014 and suggested relevant policy recommendations.

A longitudinal literature review found that domestic and foreign scholars have made great contributions to the study of marine economic efficiency. However, there is a lack of global-scale research on the efficiency of the marine economy. In addition, methods for researching this topic predominantly use data envelopment analysis and stochastic frontier analysis, but most scholars do not perform a dynamic analysis of the factors influencing it. Therefore, to bridge the gaps in the existing research, this study will build an index system for the marine economic efficiency of countries along the MSR using information from international databases, and will explore the characteristics of its spatiotemporal distribution. This study uses 20 countries along the MSR as research objects and applies an SBM, a ML index model, and a dynamic panel measurement model to analyze their marine economic efficiency and the influencing factors. The main goals are to (1) extend the scale of research on marine economic efficiency to the global level, and (2) use a dynamic panel measurement model to filter out disturbances in information on the explained variables and analyze the factors affecting the marine economic efficiency of countries along the MSR.

2. Materials and methods

2.1. Overview of MSR

The MSR is a platform that involves a wide range of countries (Blanchard and Flint, 2017), and it has no specific geographical area (Liu, 2015). This study uses 20 countries located along its main route to aid research on the efficiency of marine economy and divides them into four major regions (Table 1). This study uses overall national data; however, China is excluded because relevant data are only available for 11 provinces and cities on its east coast. At present, the countries along the MSR are located on three continents: Europe, Asia, and Africa. The eastern and western MSR connects East Asia and Europe, respectively, while the middle section consists of a vast economic hinterland. The countries along the MSR are rich in marine resources, such as fisheries resources, energy sources, and ports. In 2017, marine fish production in these 20 countries accounted for 30% of the global total, while the terminal throughput accounted for 29% of this amount.

However, challenges and opportunities exist side by side. The Maritime Silk Road also faces some challenges, such as a complex ocean environment (Zheng et al., 2016), trade friction, political and cultural differences, and renewable energy utilization (Zheng et al., 2013, 2020a), which have a significant impact on ocean development. Therefore, it is necessary to analyze the development status of the marine economy along the MSR, which is important to the improvement of marine economic efficiency.

Table 1
General situation of resources in countries along MSR.

Region	Country	Marine fish production (10,000 tons)	Primary energy production (Giga British Thermal Unit)	Terminal throughput (TEU)
East Asia	Japan, Korea	392	1.88	4.93E+07
Southeast Asia	Indonesia, Malaysia, Philippines, Cambodia, Brunei, Thailand, Singapore, Vietnam	1186	26.02	1.04E+08
South Asia	India, Sri Lanka	344	16.58	1.93E+07
West Asia	Turkey, Saudi Arabia, Iran	117	48.16	2.14E+07
East Africa	Egypt, Tanzania, Kenya	16	3.37	9.35E+06
Europe	Italy, Greece	31	4.06	1.52E+07

Note: Fishery output and terminal throughput use 2017 data, and primary energy production uses 2016 data.

2.2. Data sources

The marine economy refers to the sum of all economic activities related to the ocean, and it is an input–output system (Lin et al., 2016). Hence, this study uses the factors of resources, capital, labor, etc. to construct indicators. The indicators selected to establish the marine economic efficiency indicator system (Table 2) are as follows: The land and sea sides of the coastline are the space carriers of marine economy, which is a scarce space resource. To a certain extent, the variable of coastline length affects the size of exclusive economic zones, the number of ports, and the resources available for coastal tourism while also providing the possibility for developing a marine economy. The quality of port infrastructure and throughput also reflect the level of port infrastructure and trade. The number of tourists can indicate the condition of tourism resources and related supporting facilities in a country.

Table 2
The input-output index system of countries along MSR.

Input and output	Variable	Data Sources	Unit
Marine resources input	Length of continental coastline	Wikipedia	(km)
	International tourist arrivals	World Bank	(person)
	Primary energy consumption	BP World Energy Statistical Yearbook	(quadrillion Btu)
	Quality of port infrastructure	World Bank	(1 = underdeveloped,7 = developed and efficient)
	Container terminal throughput	World Bank	(TEU: 20 foot equivalent unit)
Labor input	Number of labor force	World Bank	(person)
Capital input	Gross fixed capital formation	World Bank	(2010 constant price USD)
Desirable output	GDP	World Bank	(2010 constant price USD)
Undesirable output	CO2	BP World Energy Statistical Yearbook	emissions (million tons)

Note: World Bank data were used for environmental output in Tanzania, Kenya, Brunei and Cambodia. Linear prediction was used to interpolate the missing values.

2.3. Slacks-based model

DEA is a nonparametric econometric method to evaluate the relative efficiency of the decision-making unit (DMU) (Charnes et al., 1997). This was originally proposed by Charnes and Cooper (1978), wherein a CCR model was created with constant rewards for scale. Then, Banker et al. (1984) developed the BCC model of variable scale compensation. However, the traditional DEA model does not consider undesired output. Measuring undesirable outputs can be traced back to two types: indirect and direct (Ramli and Munisamy, 2013). Although indirect methods are often used to measure efficiency with undesired outputs (Cherchye et al., 2014), there are still many limitations (Lucio et al., 2018). An SBM model was developed to overcome the defects of a traditional DEA (Tone, 2001). The SBM-DEA (Zhou et al., 2006) technique considers undesired output accounting for a slack in the input and economic output of marine resources, while also considering marine pollution an undesired output. This study applies the SBM-DEA technique to measure marine economic efficiency, as follows:

$$
\begin{aligned}
p^* = \min & \frac{1-\frac{1}{M}\sum_{m=1}^{M}\frac{s_m^x}{x_{k'm}^t}}{1+\frac{1}{N+I}\left(\sum_{n=1}^{N}\frac{s_n^y}{y_{k'n}^t}+\sum_{i=1}^{I}\frac{s_i^b}{b_{k'i}^t}\right)} \\
s.t. \quad & \sum_{k=1}^{k} z_k^t x_{km}^t + s_m^x = x_{k'm}^t, m = 1,\cdots,M \\
& \sum_{k=1}^{k} z_k^t y_{kn}^t - s_n^y = y_{k'n}^t, n = 1,\cdots,N \\
& \sum_{k=1}^{k} z_k^t b_{ki}^t + s_i^b = b_{k'i}^t, i = 1,\cdots,I \\
& z_k^t \geq 0, s_n^x \geq 0, s_m^y \geq 0, s_i^b \geq 0, k = 1,\cdots,\mathrm{K}
\end{aligned} \tag{1}
$$

In Model (1),$(x_{k'm}^t, y_{k'n}^t, b_{k'i}^t)$ represents marine resource-related inputs, marine economic expected output, and the environmental output of the *k*-th country in period *t*; (s_m^x, s_n^y, s_i^b)represents the slack vector of marine resource-related inputs, expected marine economic output, and environmental output. Owing to the redundant marine-related resource input, insufficient marine economic output, and excessive pollution discharge, the slack vector under constraint conditions is greater than 0. The objective function $\rho*$decreases monotonically with respect to s_m^x, s_n^y, s_i^b, and $0 < \rho* \leq 1$. For the DMU evaluated, the input and output are valid when $\rho* = 1$; that is, $s_m^x = 0$, $s_n^y = 0$, and $s_i^b = 0$. When $\rho^* < 1$, the efficiency of the marine economy in the country evaluated can be improved through optimization.

2.4. Dynamic panel econometric model

The dynamic panel model introduces the lag term of an explanatory variable into the model. This model can therefore reflect the characteristics of dynamic change in the factors affecting the efficiency of the marine economy. The following dynamic panel model was used in this study:

$$Y_{it} = a + \beta_0 Y_{it-1} + \beta_1 \ln X_{it} + \beta_2 \ln X_{it} + \beta_3 \ln X_{it} + \beta_4 \ln X_{it} + u_i + \varepsilon_{it} \tag{2}$$

where *i* and *t* represent a given country and time, respectively; *Y* is the efficiency of the marine economy described as the explained variable; *Yit-1* is the term for time lag; and *Xit* is the factor that influences the marine economic efficiency of each country described as an explanatory variable. To stabilize the variables, this study uses logarithm processing for all variables, where *ui* is the individual effect of the nonobserved cross section, β is the model parameter to be estimated, and *εit* is a random interference item. However, the inclusion of the lag term of the explained variable in Model (2) causes endogenous problems. Therefore, traditional ordinary least-squares estimation cannot be applied in this instance. To overcome this, the differential generalized method of moments (GMM) (Arellano and Bond, 1991) technique was applied to estimate the model coefficients effectively. However, differential GMM estimation tends to cause the problem of weak instrumental variables. To avoid this problem, the system GMM combined differential and level equations to improve the effectiveness of the model coefficient estimation.

Hayakawa’s derivation shows that the error of the differential GMM estimator is positive and the error of the level GMM estimator is negative. The error of the system GMM estimator is the weighted average of the difference GMM estimator and the level GMM estimator, which can offset the error of the two signs (Hayakawa, 2007). Therefore, system GMM estimation improves the effectiveness of the model coefficient estimation. Thus, this study used the system GMM to analyze the results of estimates of the factors affecting marine economic efficiency.

Many factors affect the efficiency of the marine economy. This study uses the latter as an explained variable based on data availability from the World Bank, while the level of economic development (X1; per capita GDP; 2010 USD at a constant price), degree of resource dependence (X2; the ratio of the total rent of the natural resources of a country to its GDP; %), level of opening up (X3; the ratio of goods and services imported to and exported from a country to its GDP; %), and industrial structure (X4; industrial value added, expressed in terms of GDP; %) are used as the explanatory variables.

3. Results

The efficiency of the marine economy of 20 countries along the MSR was calculated based on panel data from 2007 to 2017 and using the SBM model that considered undesired output. The results are shown in Table 3.

3.1. Temporal characteristics of marine economic efficiency

The overall average efficiency level (Table 3) of the efficiency of the marine economy in 20 countries along the MSR showed a fluctuating upward trend, moving from 0.431 in 2007 to 0.511 in 2017. From 2008 to 2012, however, this figure declined from 0.481 to 0.468 due to a negative impact of the global financial crisis of 2008. Then, from 2012 to

Table 3
Efficiency of the marine economy of countries along MSR during the period 2007–2017.

Country	2008	2010	2012	2014	2016	Mean	Rank
Korea	1.000	1.000	1.000	1.000	1.000	1.000	1
Japan	1.000	1.000	1.000	1.000	1.000	1.000	2
Italy	1.000	1.000	1.000	1.000	1.000	1.000	3
Greece	1.000	1.000	1.000	1.000	0.914	0.983	4
Singapore	0.821	1.000	0.903	1.000	1.000	0.945	5
Iran	1.000	0.483	0.416	0.457	1.000	0.671	6
India	0.387	0.535	0.714	0.706	0.916	0.652	7
Egypt	0.198	0.218	0.236	1.000	0.293	0.389	8
Saudi Arabia	0.363	0.359	0.378	0.385	0.418	0.381	9
Turkey	0.359	0.353	0.360	0.384	0.404	0.372	10
Kenya	0.331	0.296	0.301	0.297	0.357	0.316	11
Brunei	0.320	0.336	0.290	0.284	0.268	0.300	12
Sri Lanka	0.286	0.303	0.292	0.328	0.285	0.299	13
Tanzania	0.290	0.287	0.245	0.240	0.232	0.259	14
Philippines	0.294	0.255	0.269	0.238	0.201	0.251	15
Thailand	0.211	0.219	0.218	0.225	0.230	0.221	16
Indonesia	0.209	0.201	0.203	0.216	0.226	0.211	17
Cambodia	0.226	0.248	0.210	0.188	0.179	0.210	18
Malaysia	0.197	0.195	0.193	0.197	0.212	0.199	19
Vietnam	0.129	0.123	0.136	0.135	0.131	0.131	20
Mean	0.481	0.471	0.468	0.514	0.513	0.489	

Note: Due to limited space reasons, select even-numbered year efficiency values.

2016, the trend increased again, from 0.468 to 0.513, as these marine economies began gradually to recover from the impact of the financial crisis. Since then, the efficiency of these marine economies improved steadily again and continued on an upward trend thereafter. However, the average values of this efficiency were 0.481, 0.468, and 0.513 in 2007, 2012, and 2017, respectively. This demonstrates that the overall efficiency was at a low level.

In terms of regional changes (Fig. 1), the trends in the efficiency of marine economies along the MSR can be classified as stable, fluctuating, or rising. From 2007 to 2017, the marine economic efficiency in East Asia is highly efficient and stable. In contrast, the efficiency of the marine economy of Southeast Asian countries is relatively low and stable. Japan and South Korea had an early start in marine economy and a sound industrial structure (Dong, 2006). In contrast, Southeast Asia is rich in resources, but it cannot make full use of the advantages of marine resources.

The efficiency of the marine economy of South and West Asia is rising. The Indian economy is very large, with the service industry accounting for a relatively high proportion, which promotes economic development. Following the financial crisis in South Asia, the efficiency of the marine economy declined slowly; however, it has shown an upward trend in recent years. The West Asia region is rich in oil resources and has a beneficial geographical location at the hub of two oceans and five seas. Based on these advantages, the efficiency of the marine economy in this region is demonstrating an upward trend.

The efficiency of marine economies in Europe and East Africa is fluctuating, first rising and then falling. The efficiency values from Greece and Italy indicate that the main reason for this fluctuation is the influence of the Greek economy. In the African region along the MSR, the efficiency of the marine economy showed a slow decline after the global financial crisis. With the recovery of the economy, the marine economic growth rate picked up from 2012 to 2014. However, in 2014 the African region was affected by a marked decrease in international oil prices and the impact of the Ebola virus, which caused a chain reaction that severely affected mineral and agricultural products. This resulted in serious losses to countries dependent on resource exports; therefore, the efficiency of the marine economy in this region fell significantly in 2015.

3.2. Spatial characteristics of marine economic efficiency

Overall, countries with a high marine economic efficiency are mainly concentrated at the two ends of the MSR, namely in East Asia (efficiency value of 1.000) and Europe (0.950). The values for South Asia and West Asia (median areas) were 0.487 and 0.452, respectively, and other regions had low values. Countries at both ends of the MSR are economically developed (Fig. 2) and the high-value areas are concentrated in developed countries, including Greece, Italy, South Korea, Japan, and Singapore. Countries such as Iran, India, Egypt, and Saudi Arabia are in the median areas. Brunei, Sri Lanka, Tanzania, and the remaining countries are in the low-value areas. This indicates that there is a large gap in the efficiency of the marine economies of countries along the MSR. The efficiency of this type of economy is affected by the level of development and resource endowment of particular countries (Gai and Zhan, 2019). The developed countries along the MSR have few resources but rely on their industrial structures and science and technology to utilize the ocean in order to develop an export-oriented economy. Therefore, the Marine economic efficiency of these developed countries is high. Although countries in Southeast Asia and East Africa are rich in marine resources, their level of technology is low enough that they cannot use this to form a unique marine economic advantage. Instead, they focus on extensive resource development and mainly export large quantities of marine resources. Thus, their added value is low and the efficiency of their marine economies remains relatively inefficient.

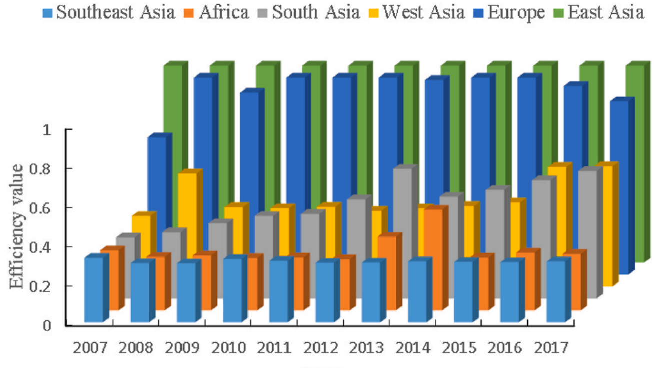

Fig. 1. Regional evolution of marine economy efficiency along MSR.

3.3. Analysis of the ML index and decomposition results

This study employs the ML index model to dynamically analyze changes in marine economic efficiency (Table 4) and determine which decomposition efficiency is most affected.

Table 4 reveals that the value of most of the ML index is above 1, indicating that overall marine economic efficiency is in a rising state. This is consistent with the results shown in Table 3. The trend in the index of the change in the efficiency of marine economies was volatile and declined from 2008 to 2012. This can be mainly attributed to the impact of the 2008 global financial crisis. The marine economy is a highly open economic system that is vulnerable to external economic shocks, which caused the ML index to drop from 1.150 to 0.993 from 2008 to 2012. Yet there was a small peak in the index from 2012 to 2013. As the global economy gradually recovered, the advantages of the macroeconomic policies of various countries promoted the development of the marine economy and caused an increase in the short-term efficiency of the marine economy. However, the index then decreased again, possibly due to the negative impact of the same short-term economic stimulus. The ML model decomposes comprehensive technical efficiency data into a pure technical efficiency index and a scale efficiency index (Table 4). The improvement of marine economic efficiency along the MSR relies more on scale efficiency than on pure technical portions.

3.4. Analysis of factors affecting marine economic efficiency

A dynamic panel model reflects the dynamic hysteresis effect by introducing hysteresis-explained variables into the static panel model. Adding a lag term to a model can reflect this inertial relationship and help filter disturbance information from the explained variable. Therefore, the lag terms for the marine economic efficiencies of each country are included in the measurement model, and the dynamic panel measurement model is used to analyze the factors affecting the marine economic efficiency. Y and X2 are unstable variables; however, both passed the Levin, Lin, and Chu test after the first-order difference. All variables with first-order differences were stationary. The results of the dynamic panel model estimation for the countries along the MSR are shown in Table 5. Both models passed the Wald, AR (2), and Sargan tests (Arellano and Bover, 1995; Blundell and Bond, 1998), thereby verifying that the dynamic panel is reasonable.

The systematic GMM estimation results of influencing factors of marine economic efficiency are shown in Table 5. The result of model estimation shows that the four influencing factors have significant influence. Levels of economic development have a significant negative impact on marine economic efficiency. For every unit increase in per capita GDP, the marine economic efficiency of the MSR decreases by 0.054 units.

The degree of resource dependence studied here is the ratio of natural resource rent to GDP. The degree of resource dependence has a significant positive impact on the efficiency of the marine economy.

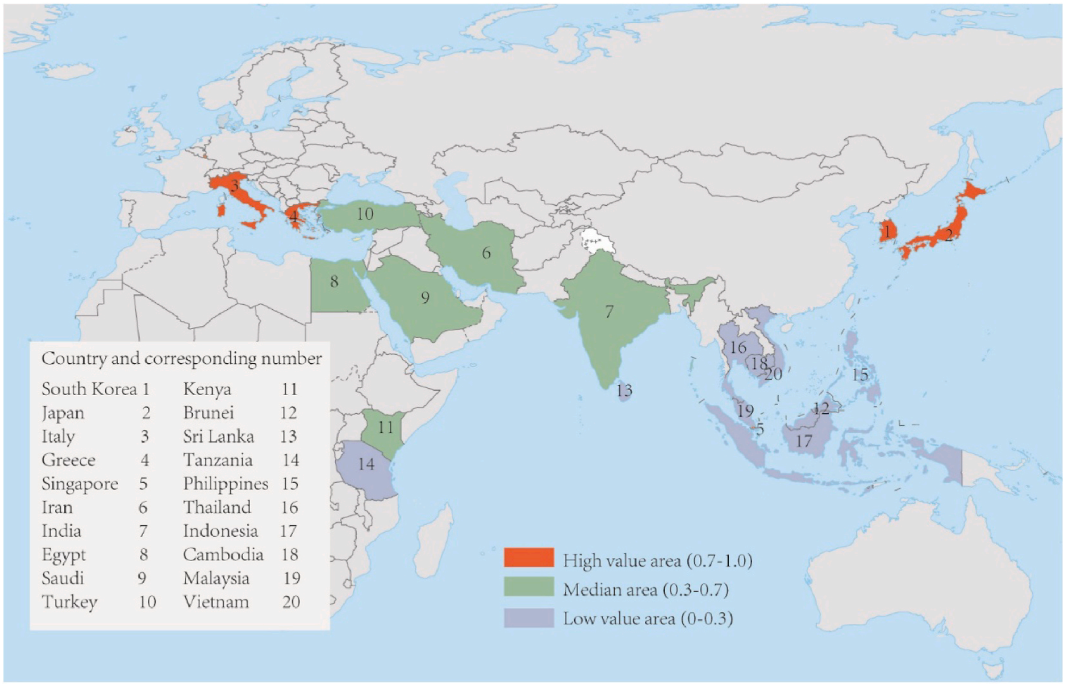

Fig. 2. Spatial distribution of Marine economic efficiency of MSR.

Table 4
ML index and decomposition results for the marine economic efficiency of 20 countries along MSR.

Year	Pure technical efficiency	Scale efficiency	ML index
2007–2008	1.053	1.202	1.150
2008–2009	1.008	0.996	0.988
2009–2010	0.979	1.050	1.018
2010–2011	0.959	1.082	1.004
2011–2012	0.974	1.024	0.993
2012–2013	1.064	1.026	1.097
2013–2014	1.006	1.017	1.029
2014–2015	0.960	1.007	0.968
2015–2016	1.030	1.028	1.066
2016–2017	0.999	1.006	1.005
Mean	1.003	1.044	1.032

Table 5
Estimation results of the influencing factors of Marine economic efficiency.

Variables	Coefficient	Standard deviation
Yt-1	0.607***	0.015
X1(the level of economic development)	−0.054***	0.017
X2(degree of resource dependence)	0.015***	0.036
X3(level of opening up)	0.096***	0.017
X4(the industrial structure)	−0.356***	0.004
constant	1.481***	0.184

Note:* is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

However, although the regression coefficient value is not high and its positive effect is limited, the relationship between resources and GDP can still be determined. Between 2007 and 2017, natural resource rents in Iran, Saudi Arabia, and Brunei averaged 24%, 39%, and 25% of their GDP, respectively, reflecting not only the degree of a region's resource endowment but also its resource dependence.

Import and export trade have a significant positive impact on the efficiency of the marine economy. They indicate that the level to which an economy is opened up has a positive effect on the efficiency of countries along the MSR. For every 1% increase in GDP based on the import and export of goods and services, the marine economic efficiency increases by 0.096%. This may be a result of import and export trade enabling countries with rich natural resources to transform resource advantages into economic advantages, while also permitting them to receive industrial and technological transfers from developed regions. For the economically developed areas along the MSR, import and export trade can provide the resources needed for economic development, thereby allowing them to rely on the ocean to develop export-oriented economies and expand their markets. This would be beneficial to improving the overall efficiency of the MSR.

The structure of a country has a significant negative impact on the efficiency of its marine economy. The main manifestation of this is that for every 1% increase in the proportion of industrial added value that makes up GDP, the efficiency of the marine economy decreases by 0.356%. As most of the countries along MSR are developing countries, the rest developed at a late industrial level. To some extent, it is an extensive economic development mode, which causes resource pollution and environmental waste. Therefore, the unreasonable industrial structure has a significant negative impact on the efficiency of marine economy.

4. Discussion

Compared with previous studies that focused on the efficiency of a certain region and country (Wang et al., 2019c), this paper studied the efficiency of the marine economy of the Maritime Silk Road, providing reference for countries along the MSR to develop a marine economy.

First, the results show that marine economic efficiency is vulnerable to external influences. The overall efficiency of the marine economy was significantly affected by the financial crisis. At a regional level, the Greek debt crisis, the Ebola virus, and fluctuations in energy prices all had an impact on economic efficiency. Trade was one of the transmission mechanisms of the financial crisis, which further affected the marine economy by affecting exports (Luo and Meng, 2020; Shikimi and Yamada, 2019). In addition, frequent marine disasters, such as typhoons, cold snaps, and storm surges, also threatened the development of the marine economy (Zheng et al., 2019). The Maritime Silk Road provides a new platform for the development of China's marine economy and countries along the route, but at the same time, one should pay attention to the construction of security mechanisms to enhance economic resilience.

Second, the results show that the regional development level has a significant negative impact on the efficiency of the marine economy, which reflects the current state of economic development along the route. The results of the ML index model show that the marine economic efficiency of the countries along the MSR relies mainly on scale efficiency rather than pure technical efficiency, which indicates that the countries along the MSR mainly rely on the input of resources and capital. This extensive mode of development will lead to problems such as resource waste and environmental pollution (Kumar, 2006; Han et al., 2017). In this paper, an SBM model, which takes environmental factors into consideration, was adopted to calculate marine economic efficiency. At present, the economic development level and environmental pollution of the countries along the Maritime Silk Road have not reached an equilibrium state. Marine environmental pollution is deteriorating with the economic growth. As a result, the economic benefits are smaller than the environmental costs (Gai et al., 2016).

Third, the efficiency of the marine economy along the route varies greatly, but the resource endowment of countries along the Maritime Silk Road is complementary. Southeast and West Asia are rich in oil and gas reserves and undiscovered oil and gas resources (Kong et al., 2017), while East Africa and Southeast Asia have abundant metal mineral resources. South Korea, Japan, Italy, Greece, and Singapore had an early start in the marine economy but are relatively short on energy and mineral resources (Liang and Liu, 2020). Countries in West Asia are rich in oil and gas resources but are relatively lacking in other resources, such as water resources. Finally, Eastern African nations have underdeveloped economies but are rich in mineral resources. The MSR initiative has created a development strategy for countries along this route to connect in order to allow the advantages of each country's marine resources to complement each other and enable common development (Tao et al., 2019).

5. Conclusions and suggestions

Based on the SBM model that considers undesired outputs, this study calculated the marine economic efficiency of countries along the MSR for the period of 2007–2017 and drew the following main conclusions:

(1) In terms of temporal trends, the marine economic efficiency of the countries along the MSR showed an overall upward pattern, from 0.431 in 2007 to 0.511 in 2017. However, from 2008 to 2012, this trend decreased from 0.481 to 0.468. This increased steadily again from 2012 to 2016, with the values moving from 0.468 to 0.513. The marine economy is more open than the terrestrial economy and is significantly impacted by external factors. The temporal changes of marine economic efficiency along the MSR can be classified as fluctuating, stable, or rising.

(2) In terms of spatial distribution characteristics, there are clear differences among the efficiencies of the marine economies of countries along the MSR. The developed countries in East Asia and Europe at both ends of MSR have efficient marine economies, while those in the middle region are less efficient. The overall efficiency of the marine economy is currently improving in West and South Asia, and the spatial pattern of the efficiency of the marine economy along the MSR has gradually changed from a bipolar pattern to a tri-polar pattern.

(3) Decomposing the efficiencies of the marine economies using the ML model shows that although the pure technical and scale efficiencies of marine economies fluctuate, the overall trend is slowly increasing. The overall change in this index presents a "W"-shaped trend, and the overall index along the MSR was generally greater than 1. This indicates that the marine economic efficiency of the region is on an upward trend. In terms of the scale and pure technical efficiencies, the former improves overall efficiency significantly. This confirms that growing the efficiency of the countries along the MSR route depends on the latter more than the former. Most countries along the MSR focus on the scale of resource development.

(4) Analysis of the influencing factors using the dynamic panel model, based on the results of system GMM estimations, showed that the degree of dependence on marine resources and the level of external development have a positive impact on the efficiency of marine economies. The economic development level and industrial structure of countries along the MSR negatively affect the efficiency of their marine economies.

Based on the empirical research described above, the following recommendations are made against the background of the continuous deepening of cooperation among countries along the MSR. The development of the marine economy along the MSR is uneven, and the marine economy at the two ends is more developed than that in the middle. All countries along the MSR should use this as a platform for cooperation to work actively on achieving complementary advantages. Countries along the Maritime Silk Road should rely more on marine technology and industrial structure optimization to improve marine economic efficiency (Fan et al., 2020). Europe and East Asia should continue to develop leading marine industries to maintain their own advantages. West and South and Southeast Asia are actively taking advantage of their location and resource endowments while also focusing on optimizing their industrial structures and actively learning from models of marine economic development in developed countries. East Africa should extend its industrial chain and transform its resource advantages into economic advantages. In addition, the relationship between environmental protection and economic development needs to be addressed. Developing marine economies should actively change modes of industrial development, prevent the use of a single economic model to develop the marine economy, and ultimately enhance their resilience.

These suggestions provide a theoretical basis for developing the marine economy of the countries along the Maritime Silk Road. However, due to the limitation of data, this paper only determined the influence of economic factors on the efficiency of the marine economy. Future studies should include external influencing factors into the research scope, such as the analysis of the impact on the marine economy of the ocean environment (Zheng et al., 2017, 2020b), trade friction, geographical location, and other factors.

Authors' contributions

All authors contributed equally to the writing of this paper. All authors read and approved the final manuscript.

Declaration of competing interest

The authors declare that they have no competing interests.

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How can the maritime industry meet Sustainable Development Goals? An analysis of sustainability reports from the social entrepreneurship perspective

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A R T I C L E I N F O

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A B S T R A C T

Sustainability Development Goals (SDGs) are a comprehensive agenda agreed upon globally that aims to stimulate actions towards economic, environmental and social sustainability. Being one of the key stakeholders, the international maritime industry plays an important role in contributing to global sustainability. By applying the concept of social entrepreneurship (SE), this study aims to examine (1) the basic and extended responsibilities (SDG 1–SDG 16) and (2) the potential collaborations within the value chain (SDG 17) concerning SDG implementation in maritime industry. To achieve these, we conduct a content analysis of sustainability reports published by container shipping liners and terminal operators from 2016 to 2019. More specifically, manual text classification is adopted to categorise the text content of sustainability reports based on 17 SDGs, and automatic text mining is employed to further identify the key roles of maritime industry related to each SDG. A unified framework is proposed, which points to varied motives and levels of comprehensiveness of the sustainability efforts by the maritime industry. This framework reveals the theoretic process of maritime industry's transitional involvement in sustainability from the SE perspective. It also creates managerial implications regarding the resource allocation strategies by maritime industry in meeting SDGs.

1. Introduction

In 2015, the United Nations (UN) released the influential document entitled ‘Transforming our world: the 2030 agenda for sustainable development’, in which 17 Sustainable Development Goals (SDGs) along with 169 targets were announced. The document aims to address a broad range of sustainable development issues such as poverty, hunger, health and well-being, and education (https://sustainabledevelopment.un.org). For the first time, a comprehensive agenda is agreed upon globally that could stimulate actions towards economic, environmental and social sustainability (UN, 2015). The 17 SDGs collectively serve as a shared normative framework that entails actors at all levels including governments, civil societies and private sectors (Ntona and Morgera, 2018; Recuero Virto, 2018).

The international maritime industry plays an important role in global sustainability as one of the key stakeholders (Benamara et al., 2019; Yuen et al., 2018a). By supporting world trade and facilitating global economy, maritime industry is associated with each

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SDG. Firstly, maritime industry may make a primary contribution to SDG 14, a dedicated goal to conservation and sustainable use of oceans, seas and marine resources (Cormier and Elliott, 2017; Recuero Virto, 2018). However, the responsibility of maritime industry goes far beyond SDG 14 such as reducing port-related pollutions in coastal regions, which contributes to the health and well-being of coastal residents (SDG 3); ensuring decent working conditions of seafarers, which is an important component of SDG 8; and sustainable development of cities and communities (SDG 11) that depends on secure global logistics systems (see Appendix A for details). To this end, the inherent development of maritime industry is highly relevant to the implementation of the UN's 2030 agenda and the associated SDGs, by way that a sustainable maritime industry contributes directly to achieving the SDGs, whereas the SDGs act as the universal framework that effectively guides the sustainable development of the maritime industry (Benamara et al., 2019; IMO, 2017).

Given the significant importance of the maritime industry in achieving SDGs, it is surprising to note the lack of research on SDGs in maritime-related studies. Some researchers attributed the lack of study to the slow response of the International Maritime Organisation (IMO) in implementing SDGs, as no particular SDG is explicitly addressing the maritime sector (Sciberras and Silva, 2018). Consequently, the maritime industry is uncertain about its role in connection with the SDGs, and the visibility of SDGs within the industry remains generally low (Fleming et al., 2017; Sciberras and Silva, 2018). Notably, certain research efforts have been devoted to SDG 14 (Islam and Shamsuddoha, 2018; Okafor-Yarwood, 2019), yet a comprehensive assessment of *all 17 SDGs* on their collective implications on the sustainable development of the maritime industry is lacking. A comprehensive assessment is essential to avoid the 'silo' risk that undermines the internal consistency (co-benefits and trade-offs) of the SDGs (Ntona and Morgera, 2018; Singh et al., 2018). In addition, the restricted focus on certain SDGs may also suffer the risk of 'cherry-picking' by maritime firms, where SDGs with short-term benefits are unduly prioritised over the long-term goals (Stafford-Smith et al., 2017). Against this backdrop, we argue that comprehensively establishing the relevancy of the SDGs to the maritime industry is urgently needed. In particular, the following question needs to be answered: How can the maritime industry meet the 17 SDGs?

On a theoretical premise, the concept of corporate social entrepreneurship (SE) is introduced whereby the implementation of SDGs is regarded as an entrepreneurial opportunity that addresses economic, social and environmental challenges to create shared values (Littlewood and Holt, 2018; Rahdari et al., 2016). In particular, SE posits that business enterprises undergo multiple transition stages before reaching a maturity level of sustainable business model: on the one hand, business enterprises may scale up their sustainability practices from seeking minimal compliance in the core business area to shouldering extended responsibility; on the other hand, business enterprises may establish partnership with their upstream and downstream value chain members to collaborate in sustainability matters (Littlewood and Holt, 2018; Stenn, 2017). Applying the concept in maritime industry, this study intends to answer the following specific research questions (RQs):

RQ1: What are the basic or extended sustainability practices that can be adopted by the maritime industry to meet SDGs?
RQ2: What forms of collaboration with value chain partners can be adopted by the maritime industry to meet SDGs?

Methodology-wise, a content analysis is conducted which examines text-based data and provides synthesised insights that lead to the construction of reality grounded in the data (Flick, 2009; Sciberras and Silva, 2018). As companies are increasingly disclosing their sustainability performance to gain legitimacy and create goodwill in society, we make use of their sustainability or corporate social responsibility reports. These reports are the official channels for companies to communicate with their shareholders, clients, investors and the general public. More specifically, manual text classification is adopted to categorise the text content of the reports based on 17 SDGs, and automatic text mining is employed to further identify the key roles of maritime industry related to each SDG. Based on the analysis results, we provide a comprehensive assessment regarding the sustainability efforts of the maritime industry to meet the SDGs.

The contributions of this study are multi-fold. Theoretically, this study integrates the concept of SE in the implementation of SDGs within the maritime industry. Based on the comprehensiveness (basic or extended) of sustainability efforts and level of value chain collaboration, a unified framework is proposed, revealing the maritime industry's transitional involvement in sustainability from the SE perspective. Practically, our study provides a comprehensive assessment of the maritime industry's sustainability efforts towards SDGs. The research findings pinpoint the specific SDGs that are currently overlooked and thus require more collective efforts from the industry. The proposed framework also serves as a self-assessment tool for an individual maritime company regarding its current sustainable development stage and creates implications for future SDG implementation strategies. The remainder of this paper is structured as follows. Firstly, the relevant literature is reviewed, emphasising on applying the concept of SE and the current implementation status of SDGs. Next, the research methodology is elaborated which discusses the process of data collection, manual text classification and automatic text mining in detail. Illustrations and interpretations of the data analysis results are then presented, indicating differentiated responsibilities of maritime industry in relation to different SDGs. Finally, a unified framework is provided in the conclusion section followed by a discussion on research implications and contributions.

2. Literature review

As a set of goals for global sustainability, the inception of the SDGs is a remarkable achievement with a universal agreement for human development (Stafford-Smith et al., 2017). Unlike its precedent Millennium Development Goals (MDGs), SDGs actively encourage the involvement of private sectors as both an addressee and a partner in shaping the sustainable development agenda (Poddar et al., 2019; Schönherr et al., 2017). Indeed, private sectors may be a critical component in realising SDGs, while SDGs provide abundant business opportunities for the private sectors (Moratis and Melissen, 2019). In this section, we theorise SDG implementation as an SE process where the interlink between SDGs and an entrepreneurial perspective of sustainability is established (Section 2.1). Subsequently, we review the current status of SDG implementation in the business context, leading to the identification of major research gaps in this field (Section 2.2). In particular, the maritime industry is regarded as a supporting industry for world trade, a major employer with a global reach and an energy-extensive business. Hence, it plays an incomparable role in global sustainable development and thus selected as the representative business context in our study.

2.1. Theoretical premise: An application of SE to SDG implementation

Social entrepreneurship is a prominent concept that originates from the interdisciplinary field of sustainability and entrepreneurship (Belz and Binder, 2017). Unlike the conventional view that suggests trade-offs between economic and social/environmental goals of business activities, SE studies focus on identifying opportunities for creating shared values (Rahdari et al., 2016). In this regard, SE shares great similarities with the concept of sustainable entrepreneurship, which views entrepreneurial activities as a tool to reduce environmental degradation (Cohen and Winn, 2007; Dean and McMullen, 2007). Due to the interconnection of social and environmental matters, we do not differentiate these two terms and referred them as SE in this study. Although no single definition has been agreed upon, SE is often understood as the process of exploiting the enterprise's full potential through innovative use of resources within the enterprise and across the value chain in pursuant of triple-bottom-line solutions (Belz and Binder, 2017; Rahdari et al., 2016). Taking such a view, we can apply the SE concept to a variety of organisations, large or small, non-profit or for-profit, with a social mission (Belz and Binder, 2017). To this end, the SDG implementation process can be theorised as an entrepreneurial process with innovative use of sustainability resources to create economic, social and environmental goals as specified in the 17 SDGs. Herein, by viewing SDG implementation as entrepreneurial opportunities that create shared values, SE serves as the theoretical premise of SDG implementation by business enterprises.

Furthermore, the SE concept suggests that business enterprises experience multiple dimensions of transition before entering a mature stage of sustainable business (Apostolopoulos et al., 2018; Schönherr et al., 2017). On the one hand, the business enterprises may start from practising restricted sustainability activities to ultimately shouldering extended sustainability responsibilities (Littlewood and Holt, 2018; Rahdari et al., 2016). They may start by focusing only on their core business area in seeking for minimal compliance, while gradually shifting to a broad range of sustainability efforts which create internal and external values. In this regard, the SDGs supply the SE process with a comprehensive range of specific goals for the enterprises to focus on, fulfilling restricted or extended sustainability responsibilities.

On the other hand, some researchers evaluate the maturity level of an enterprise towards sustainability by differentiating the micro- and meso-level SDGs and macro-level SDGs, suggesting that some SDGs can be achieved at the individual and organisational level whereas some SDGs require wider participation and collaboration (Rahdari et al., 2016; Yuen et al., 2018b). This view is shared by Littlewood and Holt (2018) who showed that some enterprises scale up their contribution by collaborating with their value chain members. Herein, the collaborated sustainability efforts in the SE process are a direct reflection of SDG 17 which calls for collaboration among different business sectors (and non-business sectors) towards the common sustainability goals. Given the extensive connection between the SE concept and the SDG implementation process, the SDGs serve as a reference framework that guides the SE process, whereas the SE process simultaneously contributes to the implementation of the SDGs.

2.2. Current status of SDG implementation

Despite the potential contribution of SDGs to enhance business sustainability, the awareness of SDGs within the private sector is generally low (Sciberras and Silva, 2018). Recent studies show that less than half of the companies globally have integrated SDGs into their sustainability target-setting, and even fewer have identified specific tools for their implementation (Moratis and Melissen, 2019; Poddar et al., 2019; WBCSD and DNV GL, 2018). Reviewing the extant literature, we have identified two challenges that are associated with the SDG implementation in the private sectors and likewise for the maritime industry.

Firstly, to ensure comprehensive coverage of sustainability issues, SDGs consist of diversified goals whose relevancies vary depending on the business contexts (Schönherr et al., 2017). Although companies can use SDGs as a comprehensive reference framework to broaden their scope of sustainability practices, the broad-based SDGs do not provide sufficient grounds that operationalise the general goals and targets by considering the varied relevancies to different contexts (Gupta and Vegelin, 2016; Pineda-Escobar, 2019). As pointed out by Pineda-Escobar (2019), the question on how businesses may relate with and implement SDGs requires further investigation.

Secondly, SDGs contain a coherent set of goals which are characterised by trade-offs and co-benefits, wherein the 17 goals are mutually dependent or even somewhat indivisible (Moratis and Melissen, 2019). However, at the individual organisational level, companies often do not adequately recognise the interconnections among the goals and integrate only those goals that best align with their sustainability strategies. As a result, companies may unduly prioritise goals with immediate benefits without truly weaving SDGs into their business (Moratis and Melissen, 2019). This is especially true given that companies are often more concerned on gaining legitimacy by engaging in corporate responsibility rather than genuinely embracing the big picture of sustainability (Montecchia et al., 2016; Siew, 2015; Yuen et al., 2019). Consequently, SDGs may be used merely as an instrumental tool for companies to 'cherry-pick' (Stafford-Smith et al., 2017), whereby certain goals, such as ending poverty, that require urgent participation from the private sectors are overlooked. As critically pointed out by Moratis and Melissen (2019), 'adoption of SDG framework' may eventually lead to nothing but 'rainbow-washing'.

Such is the case of the maritime industry, where the relevancy of SDGs to the maritime industry remains largely under-rated and the focus is primarily on 'easy' goals. Extant maritime studies seem to be rather restricted, linking only SDG14 with the sustainability of maritime industry (or the broader ocean industry) (Recuero Virto, 2018; Visbeck et al., 2014). For example, Neumann et al. (2017) provided a conceptual interpretation of SDG14 advocating strong sustainability in coastal areas; Cormier and Elliott (2017) assessed the targets of SDG14 and suggested SMART-based indicators for marine management. Some studies did recognise the interconnections between SDG14 and other sustainability goals, but the primary research focus was still on SDG14 where the ocean industry was concerned (Ntona and Morgera, 2018; Singh et al., 2018). To the best of the authors' knowledge, Kronfeld-Goharani (2018) seems to be the only study that assessed the relevancy of SDGs beyond the narrow focus on SDG14, yet the emphasis was on selected sustainability goals that relate only to the core business of maritime industry.

Of note, IMO recently provides the initial conceptualisation on the potential contributions of maritime industry to each SDG (see Appendix A). However, the specified contributions are largely basic and general. The extent to which the maritime industry can truly weave all SDGs into its operations and benefit from implementing SDGs as value-laden opportunities remains unknown. Thus, a comprehensive examination of SDGs in the maritime industry is still lacking. In this respect, the SE process suggests that business enterprises need to broaden their scope of corporate responsibility to include sustainability issues about extended business areas to reach a sustainable social model (Rahdari et al., 2016). In addition, as a critical part in the global value chain, maritime industry may further collaborate with the value chain members and contribute to the broader agenda of sustainability. Therefore, this study intends to address the research gap by examining 1) basic and extended responsibilities (RQ1) and 2) potential collaborations within the value chain (RQ2) in relation to SDG implementation in maritime industry. Ultimately, this study contributes to the literature by providing an assessment framework regarding the maturity level of sustainable development of maritime industry using SDGs as a reference.

3. Research method

This study aims to extract and data mine the sustainability-related contents as disclosed by companies of the maritime industry (see Appendix B for an illustration of research method). The top container liner companies (Alphaliner, 2019) and container terminal operators (Lloyd's List, 2018) are selected as the research target because they are considered as the most influential players in the industry. Moreover, these companies are under the highest pressure to disclose their sustainability efforts to the shareholders and the public regularly (Ashrafi et al., 2019; Fleming et al., 2017; Lawer, 2019). Thus, we firstly locate their sustainability reports, or reports otherwise termed, such as *corporate social responsibility report* and *sustainable development report*. Some companies disclose their sustainability performance in an *integrated report* or designate a special section in the *annual report* for sustainability issues. Relevant contents of these reports are also included in our study. Despite the different report names and reporting forms, these are essentially voluntary disclosures on sustainability performances by respective companies which are publicly available. In addition, we restrict to reports that were published from 2016 onwards, which contain companies' sustainability efforts in response to UN SDGs (announced in 2015).

3.1. Data extraction

As shown in Table 1, a total of 56 reports are identified, the majority of which are from container liner companies (40). The total number of reports is smaller than expected because many of the targeted companies are not listed in the stock exchanges and are not obliged to publish sustainability reports. In addition, some terminals are operated by one leading group, and thus, only one sustainability report is published that also covers their subsidiaries. Nonetheless, the average length of the reports is about 50–60 pages, which contain abundant information for further analysis. In this study, 'paragraph' is used as the unit of analysis as one paragraph is likely to address one single key theme related to SDGs (Hearst, 1997; Spens and Kovács, 2006). Accordingly, relevant contents are extracted from the identified reports which are compiled into a list. A total of 6,903 paragraphs are obtained, forming a text corpus dataset for further processing.

3.2. Manual text classification

A text classification process is conducted manually to assign each paragraph with one SDG. During this process, materials published by the official website of UN SDGs are firstly referenced (https://sustainabledevelopment.un.org), where keywords associated with each SDG are identified and used as indicators for classification. For example, paragraphs containing keywords such as *poor*, *poverty* and *low-income* were assigned to SDG 1. Next, the assigned paragraphs are read in full, and additional keywords are again identified and used as indicators. For example, keywords such as *life difficulties* and *unable to afford* were found to be effective indicators for paragraphs related to SDG 1. With several rounds of 'snowballing', we can assign most of the paragraphs with one SDG. For the remaining paragraphs, a group of three researchers in the relevant field were invited to read the content and offer their opinions. The paragraphs are then assigned with one SDG upon agreement of the three researchers.

3.3. Automatic text mining

Paragraphs assigned to each SDG are further analysed by applying automatic text mining (ATM). The software RapidMiner is used for the association-based text mining process (Hofmann and Klinkenberg, 2013), and the tool of Vosviewer is used for visualising the analytical results (van Eck and Waltman, 2010). More specifically, after inputting the text data, a standard process was applied for

Table 1
Sample statistics.

Source	2016*	2017*	2018*	2019*	Sum
Antwerp			1		1
Bremen	1				1
Chennai (Krishnapatnam Ports)	1				1
COSCO (operator of various ports in China)		1			1
Hamburg	1				1
Hutchison Ports (Hong Kong and Yantian Ports)			1		1
Kaohsiung		1			1
Mundra (Adani Port)	1	1	1		3
Singapore		1	1		2
Vancouver		1			1
Virginia			1	1	2
Westports (Port Klang)			1		1
Subtotal (Port)	4	5	6	1	16
CMA CGM			1		1
China Navigation (CNCO) – Swire Shipping	1	1	1		3
COSCO Group		1	1		2
Emirates Shipping Line	1		1		2
Evergreen Line	1		1		2
Grimaldi			1		1
Hapag-Lloyd			1		1
Hyundai Merchant Marine (HMM)	1	1	1	1	4
A.P Moller – Maersk (Maersk)	1	1	1	1	4
Matson	1	1	1		3
Mediterranean Shg Co. (MSC)		1	1		2
Ocean Network Express (ONE)				1	1
Seaboard Marine			1		1
Sinotrans	1		1	1	3
SITC	1	1	1		3
Wan Hai Lines	1	1	1		3
Yang Ming Maine Transport Corp.	1	1	1	1	4
Subtotal (shipping company)	10	9	16	5	40
Total	14	14	22	6	56

* Year of publishing, for example, reports published in 2016 cover the companies' sustainability efforts of 2015.

creating association rules using RapidMiner, which consisted of tokenisation, case transform, removal of default stop word (English), stemming, frequency calculation (FP-growth) and association rule creation (García et al., 2011). By doing so, the keywords and key terms with high frequencies are identified (see Appendix C), and their associations are analysed based on frequency support and statistical confidence. In line with the general practice, a confidence level of 0.80 was adopted as a cut-off point. The purpose of this study is to explore all potential areas that the maritime industry may contribute to sustainability; hence, we do not filter out association rules with a low level of frequency support. The generated rules were then inputted into Vosviewer to form the final clustering results.

4. Results and discussion

By assigning each paragraph of the main contents in the sustainability reports with one primary SDG, we profile the SDG implementation status in the shipping industry with each SDG. The classification results (Fig. 1) reveal that the primary contribution of maritime industry is to SDG 8 (27%), followed by SDG 9 (12%) and SDG 11 (12%). Relatively fewer sustainability efforts are put on areas related to SDG 13 (8%), SDG 16 (7%) and SDG 12 (6%). It is worth noting that the maritime industry's contribution to SDG 14 is surprisingly small (3%) based on the percentage of paragraphs in sustainability reports. This might be due to the interconnection between SDG 14 and other goals, which shall be further elaborated in the following sections. In addition, the current implementation status seems to suggest that the remaining goals are of less relevance to the maritime industry, with less than 3% of the contents devoted to each SDG.

Furthermore, the paragraphs assigned with SDG 17 (partnerships for the goals) are further analysed to identify the specific goals that the partnership strategies are intended to achieve. As shown in the secondary pie chart, more than 50% of the contents are linked with climate change (SDG 13), industry, innovation and infrastructure (SDG 9), and decent work and economic growth (SDG 8), which are priority agendas that call for collaborated sustainability efforts from industrial partners.

The remainder of this section discusses the results of ATM in detail. We answer RQ1 by differentiating SDGs that maritime industry should take responsibility for (Section 4.1), SDGs that the industry can facilitate to achieve (Section 4.2) and SDGs that fall under the extended responsibility of the maritime industry (Section 4.3). The findings on collaborated implementation strategies (SDG 17) are discussed in Section 4.4, which provides answers to RQ2.

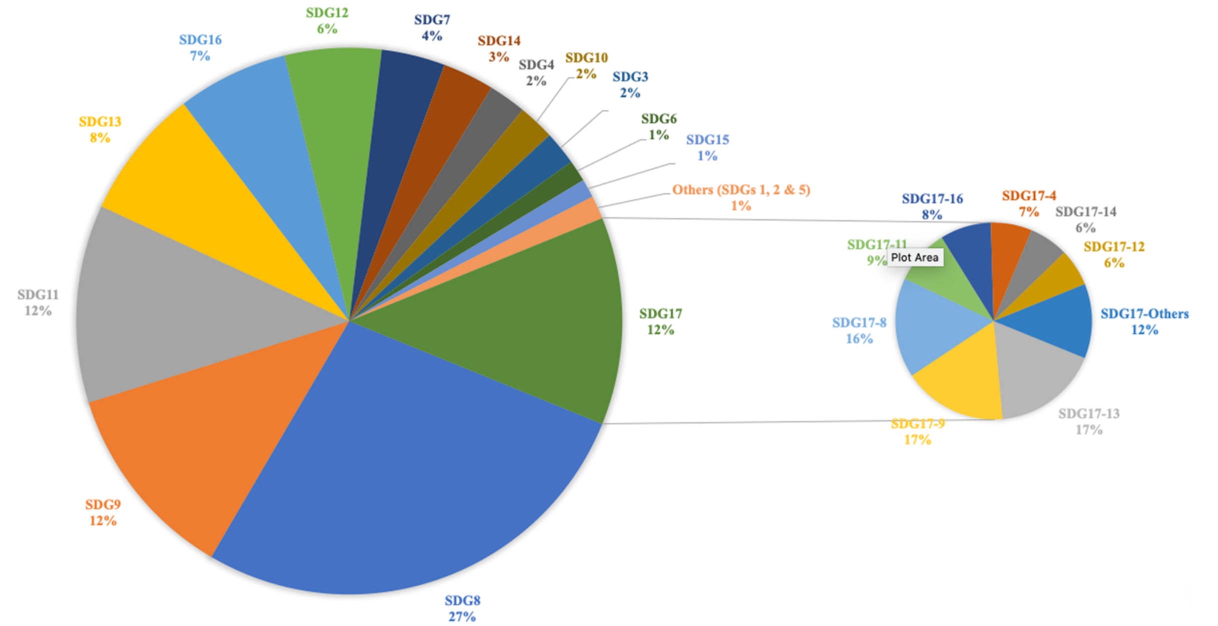


Fig. 1. Percentage of paragraphs in sustainability report related to each SDG.

4.1. *Core responsibilities of maritime industry towards sustainability*

The SE theory suggests that the initial step towards a mature model of sustainability and responsibility is to understand and accept the sustainability goals, to commit to the goals that are aligned with the core business (Rahdari et al., 2016). To a certain extent, this stage corresponds to limited corporate citizenship, where companies exhibit socially and environmentally responsible behaviours mainly due to economic and legal considerations (Carrol, 2016; Matten and Crane, 2005). Nonetheless, the initial step forms the basis for the companies in pursuit of sustainability by embedding sustainability goals into the corporate strategies wherever there is an alignment. In the context of this study, four sustainability goals, that is, SDGs 8, 9, 12 and 14, are found to be most aligned with the core business of maritime industry, representing its core responsibility towards sustainability. The ATM results are presented in Fig. 2. The sizes of the circle and the label reflected the total links that the keyword established with the conjugate ones; the thickness of the curved lines reflected the link strength between any two connected keywords.

4.1.1. *SDG 8: Occupational health and safety in support of decent work and economic growth*

Occupational risks associated with seafarers' health (physical or psychological) and safety (due to human factors or contextual factors) have been some of the major challenges of maritime industry (Fasoulis and Kurt, 2019; Lu and Tsai, 2008; McVeigh and MacLachlan, 2019; Sarvari et al., 2019; Zhou et al., 2019). The concern on such issues is frequently raised in the sustainability reports, which shows the industry's determination to safeguard employees' interests by ensuring safe and decent working environment. In this regard, the ATM result reveals three major focuses of maritime industry related to SDG 8 (Fig. 2 (upper left)).

Firstly, the safety concern forms the largest cluster (red cluster in the middle). Revolving on the keyword of ***safety***, it shows that maritime companies demonstrate commitments in raising ***safety awareness*** and ***safety culture*** within the organisation and the association ***contractors*** and subsidiary group. For a preventive purpose, periodical ***inspections*** and ***risk assessments*** are scheduled to identify potential safety ***hazards***. Although ***zero incident*** is always the ultimate goal, every ***accident*** is thoroughly investigated and documented to prevent future happening. Secondly, concerning the green cluster regarding concerns on ***occupational health***, maritime companies are actively seeking ***compliance*** with internationally recognised labour conventions, labour standards of local unions and internal code of conduct of the individual company. This is to ensure that all employees are treated fairly in a healthy working environment. Meanwhile, the companies dedicate efforts in ***caring*** for the employees' mental needs by increasing on-board connectivity which mitigates the seafarers' loneliness and positively impacts their psychological health. Finally, adequate training is essential to ensure workplace safety, which is revealed in the blue cluster. It is shown that ***training courses*** and seminars are organised to update the employees with the latest ***equipment*** and enhance employees' ***skills*** (see Table 2 for key quotes related to SDG 8).

4.1.2. *SDG 9: Green technology and transport infrastructure in support of industrial development based on technology and innovation*

In line with SDG 9, the development of the maritime industry is dependent on massive infrastructure building (Li et al., 2018; Wang and Yau, 2018) coupled by radical innovations (Halff et al., 2019; Hogström and Ringsberg, 2013). In this connection, our analysis suggests that maritime industry can contribute to building a sustainable maritime ecosystem by investing in logistics infrastructure to alleviate transportation barriers and, at the same time, devoting efforts in innovative ship or terminal designs and

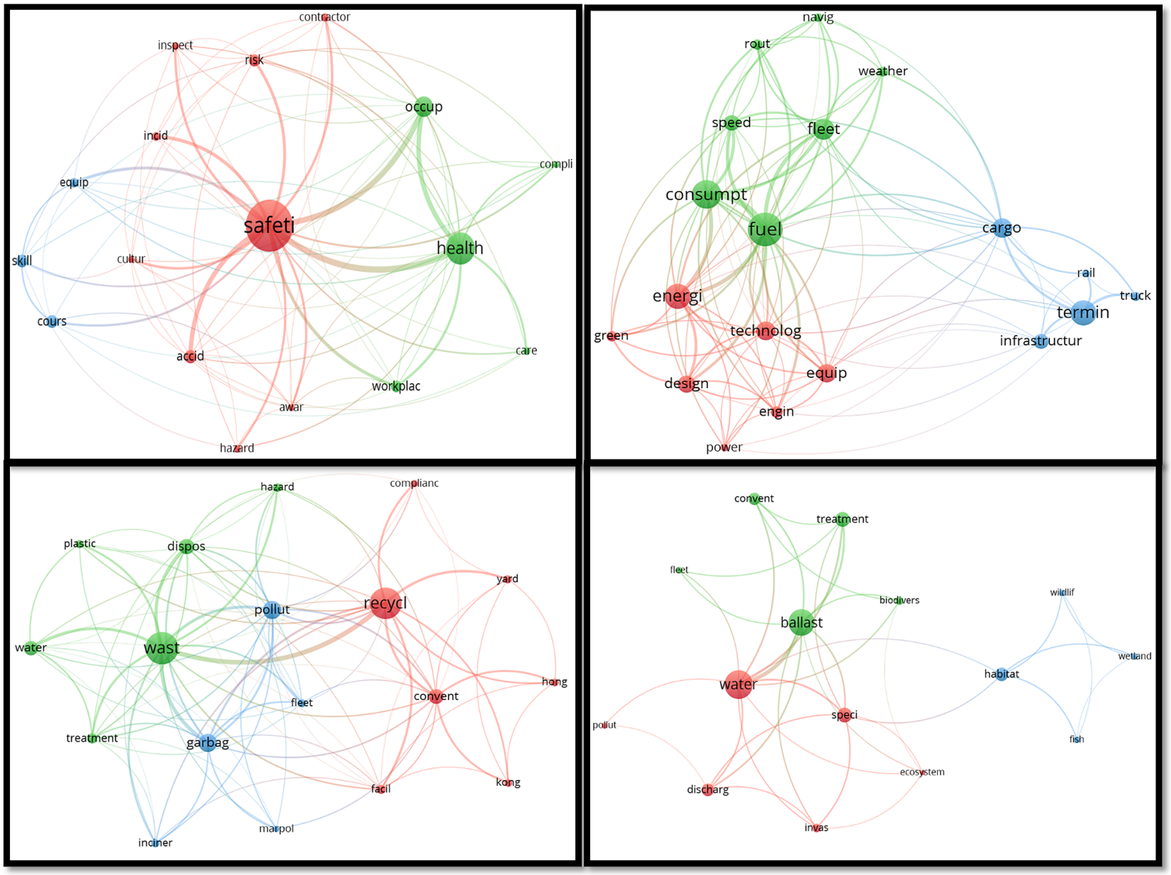


Fig. 2. SDGs that are related to the core business of maritime industry. (SDG 8-upper left, SDG 9-upper right, SDG 12-lower left & SDG 14-lower right).

Table 2
Key quotes related to SDG 8.

Key theme	Quote from sustainability report	Source
SDG 8-safety	*In 2017, we conducted 1179 safety inspections to track owned vessels 832 times with navigational risks …*	COSCO Shipping (2018)
SDG 8-health	*All our employees will be treated fairly in a safe and healthy working environment … (by) ensur(ing) compliance with … internationally recognised labour standards.*	Maersk (2019)
SDG 8-training	*The Seaman Dept … organise training courses that improve their familiarity in professional areas such as navigation safety … to continue enhancing the competency of foreign deck officers.*	Evergreen (2018)

operating systems to further advance the operational efficiency (Fig. 2 (upper right)).

For the maritime industry's contribution to infrastructure building (blue), it is found that both ***container terminals*** and container maritime companies are investing extensively in ***transportation infrastructure*** in searching for more efficient and greener solutions. This includes renewing ***trucking fleet***, strengthening ***road and rail connections***, modernising ***cargo operational facilities***, etc. Furthermore, ***green ship design*** has also been found to be a recurrent theme in sustainability reports (red cluster). The modern container ships have been designed to be increasingly more ***energy-efficient*** and environmentally friendly. Closely associated with the red cluster is the green cluster. This cluster concerns the use of innovative operation systems that process real-time ***navigational data*** to optimise the ***shipping routes*** for the fleet. For sustainability efforts related to all three clusters, latest energy-saving technologies are applied in designing ultra-efficient fleets or terminals that lead to economic saving for the companies and ensure legal compliance of emission standards (see Table 3 for key quotes related to SDG 9).

4.1.3. SDG 12: Waste management and responsible ship recycling in support of responsible consumption and production

A significant amount of wastes is generated from shipping activities on-board and shore-based activity from terminals and supporting offices. Proper waste management is an essential aspect that maritime industry should take responsibility for and thus contribute to the goal of responsible consumption and production (SDG 12) (Löhr et al., 2017). Furthermore, from a life cycle

Table 3
Key quotes related to SDG 9.

Key theme	Quote from sustainability report	Source
SDG 9-green ship design	*These mega-ships will be propelled by ultra-efficient G-type engines and will include the latest energy-saving technologies in line with the IMO's Energy Efficiency Design Index (EEDI) standards.*	MSC (2018)
SDG 9-innovative operation system	*MSC has also extensively invested in a state-of-the-art automatic data acquisition and monitoring system to better evaluate the optimisation of energy consumption of its fleet.*	MSC (2017)
SDG 9-infrastructure building	*Our task is to develop the infrastructure in the port region so that the port experiences healthy growth in both national and international contexts and is able to compete at a high level.*	Hamburg Port (2016)

perspective, the end-of-life ship recycling activity is also a critical component of SDG 12 (Rahman et al., 2016). The traditional ship recycling activity is often held to be a major safety hazard to the yard workers and an environmental threat to the coastal ecosystem (Abdullah et al., 2013; Choi et al., 2016; Du et al., 2018). In this regard, sustainable and responsible ship recycling practices form another important aspect that should be integrated into the sustainability strategy of maritime industry.

Indeed, these two aspects are well reflected in the sustainability reports under examination (Fig. 2 (lower left)). As shown in the green and blue clusters, maritime companies have stressed the importance of the proper management for both non-hazardous wastes, such as ***waste paper, waste plastic*** and ***garbage***, and ***hazardous wastes*** such as ***oily water***. Under the ***MARPOL*** Convention (International Convention for the Prevention of Pollution from Ships), maritime companies have formulated a Waste Management Plan detailing the standard procedures for waste receiving, storage, ***treatment***, ***disposal,*** etc. In addition, although ***incineration*** on board is not specifically prohibited by MARPOL convention, some companies forbid such a practice that may lead to air pollution. Furthermore, concerning the ship recycling practices (see red cluster), maritime companies are seeking ***compliance*** with the ***Hong Kong Convention*** by using ship recycling facilities that are ratified by the convention. However, it is worth noting that the convention has not yet come into force despite a strong devotion by some responsible companies, and about 90% of ships were still dismantled in sub-standard facilities (Maersk, 2019) (see Table 4 for relevant quotes related to SDG 12).

4.1.4. SDG 14: Responsible ballast water management in support of life below water

As discussed in the earlier section, SDG 14 has been the primary focus of the extant literature concerning marine ecology (Neumann et al., 2017; Ntona and Morgera, 2018). However, when the perspective of maritime industry is adopted, the situation seems to turn out differently. Our finding suggests that only about 3% of the content (by paragraph) in sustainability reports is primarily associated with SDG 14. This is probably due to the difference between the concepts of marine and maritime, where marine concerns substances or lives *of seas*, whereas maritime refers to things *associated with seas.* In addition, other goals such as SDG 12 (e.g. waste management) also play an important role in protecting life below water, which also explains the relatively less focus on SDG 14 by the maritime industry.

The clustering result suggests a predominant focus on protecting biodiversity in relation to SDG 14 (Fig. 2 (lower right)). More specifically, some companies acknowledge the consequences of ***alien species invasion*** associated with illegal ballast water discharge, which may cause serious damage to the whole ecosystem (red cluster). The green cluster illustrates the sustainability efforts of the maritime industry devoted to biodiversity in compliance with the ***Ballast Water Management Convention***. With the recent entry into force of the convention, maritime companies are required to equip their ships with standard ***ballast water treatment system*** to avoid discharge of harmful organisms and pathogens. This represents a strong commitment to protecting marine lives by the maritime industry. Additionally, the container terminals also demonstrate efforts towards protecting the ***coastal ecosystem*** as shown in the blue cluster. Particular efforts are made in restoring ***tidal wetlands*** which are a ***natural habitat*** for diverse ***wildlife and fish*** (see Table 5 for relevant quotes related to SDG 14).

4.2. Maritime industry as a facilitator in achieving sustainability

Apart from SDGs that are aligned well with the core business, the maritime industry can move one step further to facilitate achieving other sustainability goals. Unlike sustainable behaviours that are out of economic and legal considerations, the maritime industry can commit to create social benefits when an overlap occurs between their business activities and some SDGs to a certain

Table 4
Key quotes related to SDG 12.

Key theme	Quote from sustainability report	Source
SDG 12-waste management (on-board and ashore)	• *Hyundai Glovis safely treats wastes generated in operation of its logistics or Logistics Centers by developing 'Convention Guidelines for Waste Treatment'.* • *Incinerating plastic waste causes emissions of dioxins and toxic gases, and therefore Yang Ming strictly forbids our crew to incinerate plastic waste on board.*	HMM (2016); Yang Ming (2017)
SDG 12-responsible ship recycling	*We pre-audited four Ship Recycling Facilities (SRF) in India … This enabled us to be assured that the selected SRF are operating in/ beyond basic compliance with the Hong Kong International Convention …*	CNCO (2016)

Table 5
Key quotes related to SDG 14.

Key theme	Quote from sustainability report	Source
SDG 14-biodiversity (ballast water management)	• *The purpose of the Convention is to minimise … transmigration … of harmful aquatic micro-organisms and pathogens… a phenomenon that damages … biodiversity ….* • *Our fleet management team will work with ship owners to select the appropriate ballast water treatment system … to protect biodiversity …*	Grimaldi (2018); ONE (2019)
SDG 14-biodiversity (coastline restoration)	*We began construction on the New Brighton Park Shoreline Habitat Restoration Project. This project is an opportunity to restore coastal wetland habitat to provide productive habitat for juvenile fish and wildlife…*	Vancouver Port (2017)

extent. From the SE perspective, sustainability efforts at this level may correspond to an equivalent view of corporate citizenship where companies participate in a broad range of entrepreneurial activities in search for both economic and social returns (Rahdari et al., 2016). In a sense, companies are facilitating in achieving sustainable goals while fulfilling their entrepreneurial motives. Based on the ATM result, our study identifies four SDGs that the maritime industry can facilitate to achieve, namely SDGs 2, 7, 13 and 16 (Fig. 3).

SDG 2 calls attention on the issue of global food security. Although maritime industry is not directly involved in the food production stage, a considerable proportion of ***food loss*** occurs during the journey from ***producer to market***, citing inadequate infrastructure and technology for storing and transporting goods as the key restrictions. Although ensuring food security is by no means the priority of maritime industry, it can partner with the chain members to ***develop solutions*** for more efficient global ***food chains***. Thus, the issue of food loss is rightly positioned in the nexus of maritime industry's economic and social agendas.

SDGs 7 and 13 represent two synergistic goals that the maritime industry can participate to achieve. As shown in Fig. 3 (upper right and lower left), companies respond to both goals by switching to ***clean energies*** (mainly for shore-based offices and terminals) such as ***electricity*** and ***natural gas***. They are also committed to developing ***energy-saving technologies*** that decrease the ***energy consumption*** level. Consequently, companies can alleviate the industry's reliance on fossil fuel and reduce their ***carbon footprint*** simultaneously, which ultimately leads to economic benefits for the companies.

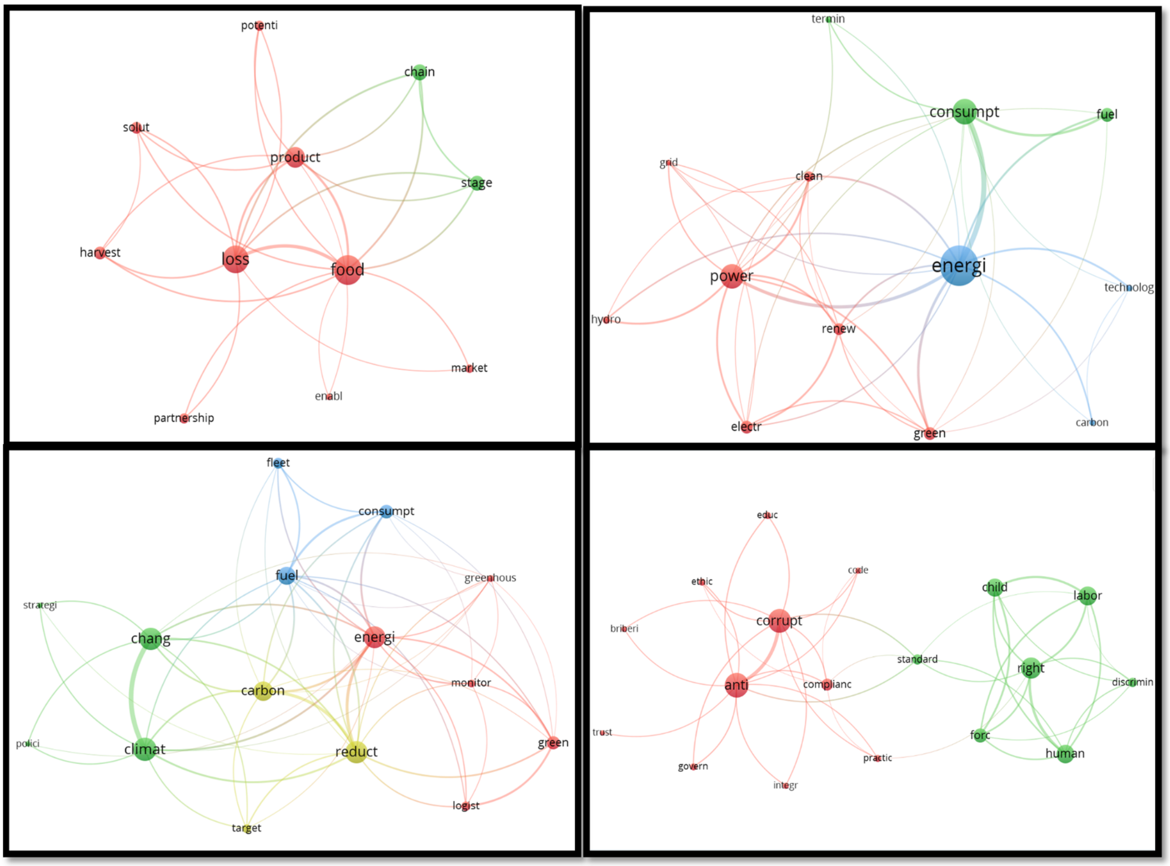


Fig. 3. SDGs that maritime industry facilitates to achieve. (SDG2-upper left, SDG7-upper right, SDG13- lower left & SDG16-lower right).

Table 6
Key quotes related to SDGs 2, 7, 13 and 16.

Key theme	Quote from sustainability report	Source
SDG 2-global food chain	*Our commitment to help halve food loss by 2030 is a new area in our sustainability strategy established in 2017. We are currently shaping our activities and growing our insights and understanding of the issue.*	Maersk (2019)
SDG 7-clean energy	*Over the last two years, we have purchased a total of 2.7 million kWh of green power, making valid contributions towards a cleaner future.*	Wan Hai Lines (2018)
SDG 13-control greenhouse gas emission	*Increasing the proportion of green electricity … feeding the electricity into the grid and a solar heating system … have enabled us to reduce our CO2 emissions steadily.*	Bremen Port (2016)
SDG 16 anti-corruptionand human right	• *Operations assessed for risks related to corruption… communication and training about anti-corruption policies and procedures…* • *We have created human rights clauses in agreements with our external stakeholders. Contractors … have to address human rights … as part of the agreement, violations of which incur penalties.*	Singapore Port (2018) Krishnapatnam Port (2016)

Finally, the ATM results of SDG 16 reveal two relatively under-noticed issues by academic researchers: ***anti-corruption*** and ***human rights***. The problem associated with ***bribery*** or 'facilitation costs' at ports is widely acknowledged in the maritime industry (Sequeira and Djankov, 2014). In response, the industry is found to have formed a partnership-based Maritime Anti-Corruption Network intending to combat corruption and end facilitation payment in ports. Meanwhile, companies are trying to foster ***ethical conduct*** and honest culture at all levels through conversations, campaigns and ***education***. Regarding human rights, companies express strong devotions to human rights which include the prohibition of ***child labour***, compulsory labour, ***sexual harassment and discrimination***. Thus, by addressing the issues of corruption and human rights, the maritime industry facilitates in building a more transparent business model and a more inclusive workforce which contribute to achieving SDG 16 (see Table 6 for related quotes).

4.3. Extended responsibility of maritime industry towards sustainability

Some SDGs are not ideally aligned nor even overlapped with the core business of maritime industry. However, as employers and major value creators, the industry can still contribute to these SDGs by extending their responsibilities towards sustainability. By doing so, the industry further evolves along the SE process and becomes one step closer to a mature sustainability model (Rahdari et al., 2016). This stage is similar to an extended view of corporate citizenship, and companies' sustainable behaviours are mostly explained by social and philanthropic motives. In this study, eight SDGs are identified as belonging to this category (Fig. 4).

The findings suggest that maritime companies can be involved in a wide range of voluntary activities that benefit the local community and society at large. For example, companies can establish ***philanthropic foundations*** to help the poor families with ***medical***, ***educational*** and ***employment needs*** (SDGs 1, 3 and 4). They can also make ***donations*** to the local community to help ***disadvantaged people*** or provide scholarship for students from low-income families (SDGs 4 and 11). Furthermore, as an employer, companies can offer ***internship opportunities*** to local university students (SDGs 4 and 11). They can also enforce strict ***labour standards*** to promote ***equal employment opportunities*** regardless of gender, religion, race and cultural background (SDGs 5 and 10). Table 7 provides a summary of key quotes from the sustainability reports that address each of the eight SDGs. It is found that although these SDGs are only remotely related to the maritime industry, companies are voluntarily extending their responsibilities and engaging in diverse sustainable behaviours with varying degrees of involvement.

4.4. Partnerships for sustainability

SDG 17 calls for global partnerships and cooperation for successful implementation of the goals. As a critical component in the global supply chain, the maritime industry is also actively collaborating with chain members to achieve sustainability goals. With reference to Fig. 5, the text analysis result shows that the industry has established partnerships for economic, environmental and social purposes. For partnerships on economic considerations, the leading companies are found to pursue shared growth and mutual benefits with their ***suppliers and customers***, to enhance the overall ***competitiveness of the supply chain*** in the market (yellow and orange clusters). They also support the ***Fair Trading*** Voluntary Compliance Program which promotes fair practices and avoid unhealthy competitions within the industry (blue cluster). For partnering efforts on environmental protection, the primary focus is on the ***prevention of pollution*** from ships by ensuring compliance with various international ***conventions, codes and guidelines*** (red cluster). In particular, the companies are working with internationally recognised organisations such as IMO and ISO (International Organisation for Standardisation) for standard-setting and promoting best practices. In addition, by collaborating with the energy sector, sustainability efforts are also committed on investing in ***clean energies*** and other energy-saving technologies that further enhance the energy-efficiency and reduce the ***environmental impact*** of maritime industry (green cluster). Finally, the companies partner with various social organisations and charity groups to promote ***labour standards*** (brown cluster), ***decent working conditions*** (purple cluster) and ***social welfare*** (sky-blue cluster).

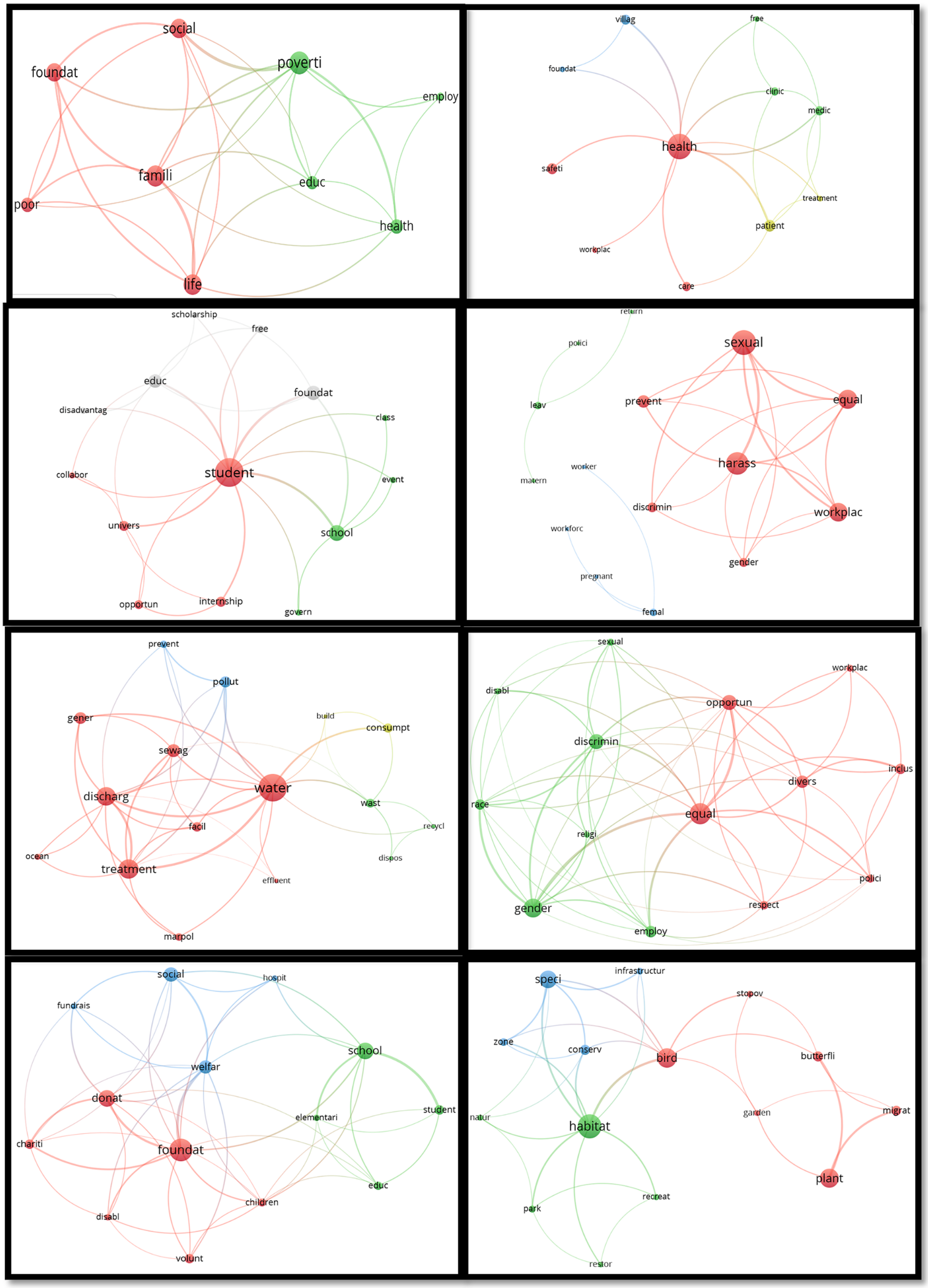


Fig. 4. SDGs that are related to extended responsibility of maritime industry. SDG1-1st row left, SDG3-1st row right, SDG4-2nd row left, SDG 5-2nd row right, SDG6-3rd row left, SDG10-3rd row right, SDG 11-4th row left & SDG15-4th row right.

Table 7
Key quotes related to SDGs 1, 2, 4, 5, 6, 10, 11 and 15.

Key theme	Quote from sustainability report	Source
SDG 1 – end poverty	*The organisation works with children and their families to challenge poverty … Each year, Seaboard Marine employees elect to sponsor a child, providing them with clothes, food ….*	Seaboard Marine (2018)
SDG 3 – good health and well-being	*We offer health and wellness incentives that reward colleagues and their spouses financially for things including getting annual physical exams, taking an online wellness evaluation …*	Virginia Port (2018)
SDG 4 – quality education	*SPO also sponsors the annual Swire Pacific Offshore Bursary at Nanyang Technological University in perpetuity. This SGD 250,000 bursary supports two students with disabilities …*	Swire (2017)
SDG 5 – gender equality	*While the proportion of men has fallen slightly in favour of a limited rise in the number of women employed in industry … there are still a lot more men than women working in the port of Antwerp …*	Antwerp Port (2018)
SDG 6 – clean water and sanitation	*Dry Wash Project completed its second year … reaching a turnover of about 55%. This enabled them to provide 31,659,615 L of water…*	Emirates (2016)
SDG 10 – reduce inequality	*We aspire to create an inclusive culture … we will be in a prime position to attract people from the widest talent pool, specifically increasing the gender and nationality diversity at our senior levels.*	Maersk (2019)
SDG 11 – sustainable cities and communities	*The Group will … adopt a more active way to acquire a deeper understanding of community needs, ensure the process of business operation takes into account community interests …*	Sinotrans (2016)
SDG 15 – life on land	*In this way … Antwerp Port Authority and the Left Bank Development Corporation seeks to achieve correct conservation of the protected bird species and habitats …….*	Antwerp Port (2018)

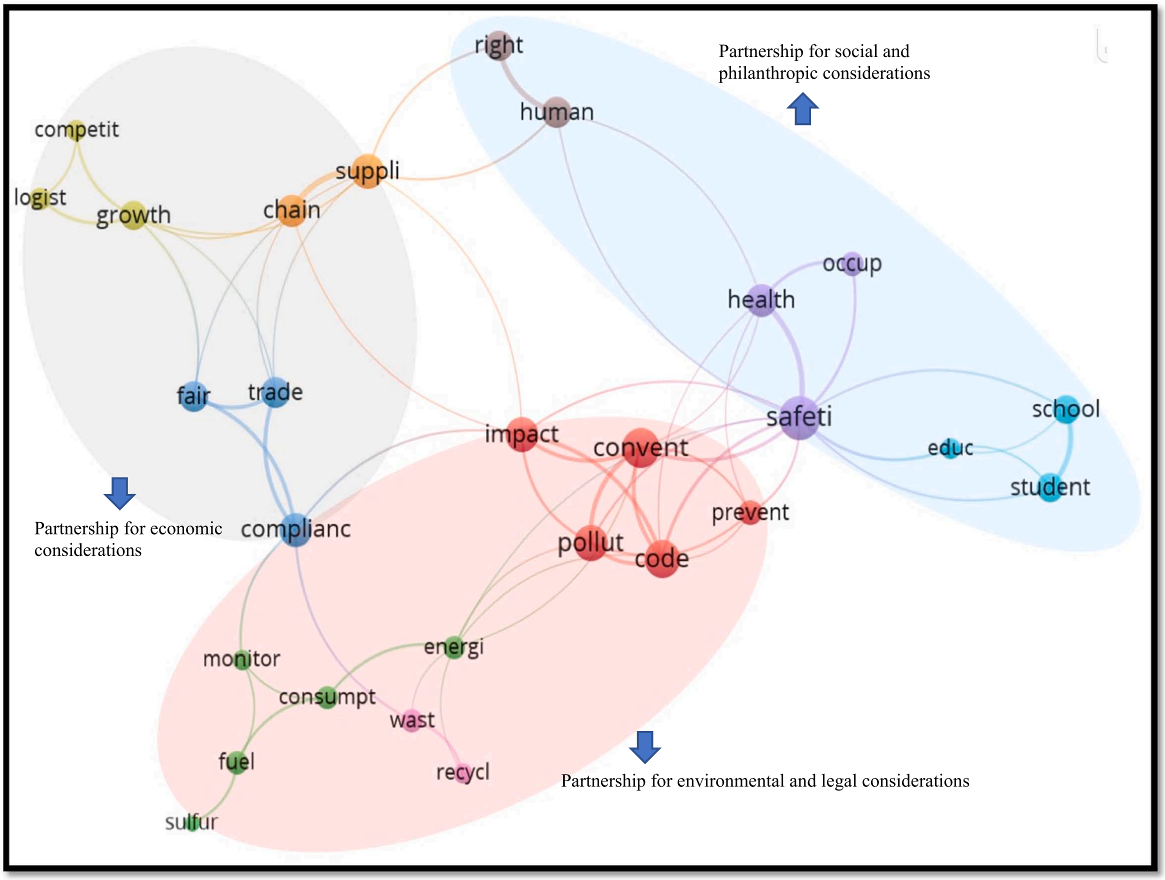


Fig. 5. Clustering analysis of SDG 17 (keywords 'partner' and 'partnership' are removed for analysis due to high occurrence).

5. Conclusion

By applying the text mining technique, this study conceptualises the relevancy of the 17 SDGs in the context of the maritime industry. The differentiated roles played by the industry concerning sustainability goals are presented, leading to a transitional process of social or sustainable entrepreneurship.

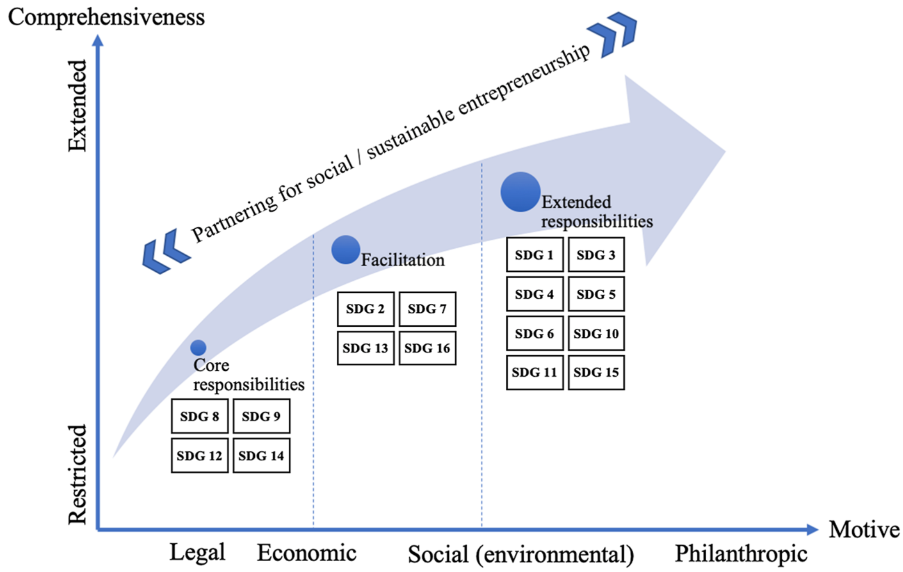


Fig. 6. A unified framework.

5.1. A unified framework and practical implications

Based on the motives and comprehensiveness of sustainability efforts, a unified framework is proposed in Fig. 6, which serves as an assessment framework of the SDG implementation status in the maritime industry. More specifically, it is found that the core responsibilities of the maritime industry lie in the goals concerning provision of safe and healthy working environment (SDG 8), development of green technologies and transport infrastructure (SDG 9), responsible waste management and ship recycling (SDG 12), and proper ballast water management and coastal ecosystem protection (SDG 14). Maritime companies can go one step further to facilitate the achievement of SDGs 2, 7, 13 and 16 by developing secure global food chains, investing in energy efficiency, and promoting anti-corruption practices and human rights. Finally, the industry can fully embrace all SDGs by extending its responsibilities beyond the business agenda. In this regard, companies' sustainability efforts can be put in a wide range of activities that address the needs of their employees, the local communities, and the less fortunate groups in the society, ensuring no one is left behind in pursuing sustainability. Along the process, maritime companies can partner with chain members and leading organisations in seeking for shared values that lead to economic, environmental and social benefits (SDG 17). By doing this, the industry can evolve from behaving out of legal and economic motives to truly weaving social and philanthropic goals into the entrepreneurial endeavours.

This study strongly advocates the relevancy and criticality of SDGs in developing a sustainable maritime industry. By providing detailed illustrations and a unified framework, we pinpoint various priorities, partnership strategies and future directions that the industry may consider for sustainability planning. Thus, we contribute to promote the visibility of the global sustainability initiative within the maritime industry and provide guidance on its implementation, which in turn elevates the sustainability profile of the maritime industry.

5.2. Theoretical contributions

This study makes several theoretical contributions. Firstly, our study integrates the insights of SE into the sustainable development process in the maritime industry. Therefore, we contribute to the maritime literature with an entrepreneurial perspective of SDG implementation. Such a perspective not only points to a series of opportunities for shared value creation but also provides a roadmap of SDG implementation that may guide the sustainable transition of the maritime industry.

Secondly, we synthesise the maritime industry's contributions to all SDGs, which extends the previous literature that restricted to the industry's involvement in SDG 14 or a few SDGs (Kronfeld-Goharani, 2018; Neumann et al., 2017; Ntona and Morgera, 2018). In addition, this study presents a transitional view of sustainability goals by differentiating core responsibilities, facilitator roles and extended responsibilities of the maritime industry. While the prior research focuses heavily on the internal connections among the SDGs (i.e. co-benefits and trade-offs) (Moratis and Melissen, 2019; Singh et al., 2018), we suggest that more attention should be paid to the external context of the industry's sustainable development stage (i.e. the maturity stage of sustainability along the transitional process). Therefore, this study not only broadens the scope of SDGs research by comprehensively establishing the relevancy of 17 SDGs to the maritime industry but also supplies a new transitional perspective of maritime sustainability research as anchored on the SDGs scheme.

Finally, it is worth pointing out that the extant sustainability literature (maritime-related or in general) is often considered segmented, focusing on the different aspects of economic (Darousos et al., 2019), environmental (Di Vaio et al., 2018; Rahim et al.,

2016) and social dimensions (Fasoulis and Kurt, 2019; Yuen and Lim, 2016). In this regard, SDGs which are essentially an all-encompassing sustainability scheme becomes an effective framework that may unify the scattered focuses of sustainability literature. Herein, along with a few pilot attempts (Benamara et al., 2019; Kronfeld-Goharani, 2018), our study represents one of the few works that adopts the SDG scheme to comprehensively examine sustainability issues in the maritime industry. We encourage future researchers to extend our study to the wider service contexts.

Methodology-wise, this study proposes a text processing technique that combines a snowballing-based classification process (manual) with an association-based clustering analysis (automatic). The proposed method is proven to be effective in mining a massive amount of text data and visualising complex patterns hidden within. While this study is conducted under the context of the maritime industry, the method can be well adapted to other contexts, which represents our contribution to methodology.

5.3. Limitations

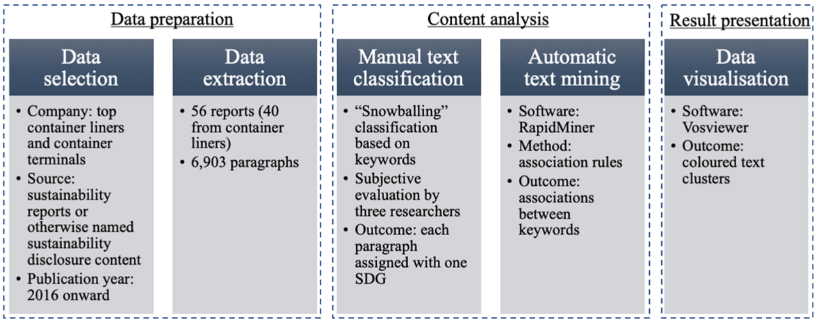
Finally, the findings of our study have to be interpreted considering its limitations. Firstly, the majority amount of text data is from top container liner companies. Although they are the main players of maritime industry, they represent only a single voice from the industry. However, many maritime companies are family-based businesses; hence, not much information is available publicly, let alone their sustainable contributions. Therefore, the predominant focus on liner companies (and to a less extent, on container terminal operators) is a potential limitation of this study. Thus, we encourage future research to identify other appropriate research contexts in the maritime industry where abundant information can be extracted and rich insights can be generated. Secondly, SDG 10 of 'reduce inequality within and among countries' may be subject to different interpretations. In line with most maritime companies, it is interpreted as a prohibition of discrimination against race, religion and culture, which is considered an extended responsibility of the maritime industry. However, the industry may play an essential role in enhancing logistics efficiency and increasing accessibility of less developed countries, which contributes to reducing inequality at the national level. Nonetheless, this aspect is seldom mentioned in the sustainability report. Future studies may further investigate SDG 10 from this direction.

Appendix A. Role of maritime industry in UN's Sustainable Development Goals (SDGs)

No.	SDG	Role of maritime industry in achieving SDGs
1	No poverty	Ensure shipping is safe, secure and clean-creating prosperity and sustainable growth in a green and blue economy
2	Zero hunger	Ensure efficient and economical supply chains for global food distribution; Safeguard a major source of nutrition by tackling illegal, unreported and unregulated fishing
3	Good health and well-being	Contribute to the reduction of shipping-related pollution in oceans, ports and coastal regions
4	Quality education	Safety, security and environmental protection at sea depend on seafarer education and training.
5	Gender quality	Support gender equality and empowers women in the maritime section through a global programme and targeted activities
6	Clean water and sanitation	Minimise dumping and waste disposal at sea, which is a key component of the overall waste-management cycle
7	Affordable and clean energy	Promote funding, research and development of clean energy technology for the maritime sector
8	Decent work and economic growth	Seafaring is an important source of work, especially in developing countries. Issues surrounding seafarers' health and welfare are a central theme of shipping industry.
9	Industry, innovation and infrastructure	More efficient shipping, working in partnership with the port sector, will be a major driver towards global stability and sustainable development for the good of all people
10	Reduced inequalities	Enhance capacity in countries which lack the technical knowledge and resources to operate a safe and efficient shipping industry
11	Sustainable cities and communities	Sustainable cities and communities rely on a secure supply chain. Shipping industry helps to enhance maritime safety and security which protects the global logistics infrastructure
12	Responsible consumption and production	Reduce waste generation, both operational waste from ships and dumping of wastes at sea
13	Climate action	Control emissions from the shipping sector and solutions to minimise shipping's contribution to air pollution and its impact on climate change
14	Life below water	Shipping industry is responsible for global measures to improve the safety and security of international shipping and to prevent pollution from ships
15	Life on land	Shipping industry is responsible for security in ports and is part of global efforts to halt illegal wildlife trafficking
16	Peace, justice and strong institutions	Shipping industry promotes effective institutions to ensure the safe, secure and environmentally protective flow of maritime commerce
17	Partnerships for the goals	IMO currently has partnership arrangements with more than 60 IGOs and more than 70 NGOs, including major global environmental organisations and bodies

Source: Adapted from IMO and the sustainable development goals (http://www.imo.org/en/MediaCentre/HotTopics/Pages/SustainableDevelopmentGoals.aspx)

Appendix B. Illustration of research method



Appendix C. Keywords or key terms of each SDG based on frequency count

SGD1	Support	SDG2	Support	SDG3	Support	SDG4	Support
Poverti(y)	0.40	Food + loss	0.50	Health	0.44	Student	0.33
Famili(es)	0.32	Food + product(ion)	0.31	Safeti(y)	0.28	Educ(ation)	0.29
Foundat(ion)	0.24	Food + market	0.31	Emerg (ency)	0.16	School	0.20
Life	0.24	Enabl(e) + food	0.25	Medic (ation)	0.15	Foundat(ion)	0.16
Poor	0.24	Food + partnership	0.25	Procedur(e)	0.15	Opportun(ity)	0.16
SGD5	Support	SDG6	Support	SDG7	Support	SDG8	Support
Women	0.46	Water + consumpt(ion)	0.21	Fuel	0.30	Safeti(y)	0.26
Femal(e)	0.39	Water + treat(ment)	0.19	Energi + consumpt(ion)	0.26	Health	0.13
Equal	0.33	Water + discharg(e)	0.18	Power	0.24	Cours(e)	0.09
Leav(e)	0.20	Water + pollut(ion)	0.16	Electr(icity)	0.19	Risk	0.08
Harass(ment)	0.19	Wast(e) + water	0.16	Green	0.16	Skill	0.07
SGD9	Support	SDG10	Support	SDG11	Support	SDG12	Support
Fuel + consumpt(ion)	0.06	Equal(ity)	0.36	Foundat (ion)	0.18	Wast(e) + recycl(ing)	0.18
Fuel + speed	0.03	Gender	0.36	School	0.15	Wast(e) + dispos(al)	0.11
Termin(al) + infrastructur(e)	0.03	Divers(ity)	0.34	Donat(ion)	0.14	Wast(e) + water	0.08
Technolog(y) + energi	0.03	Discrimin(ation)	0.22	Educ(ation)	0.13	Wast(e) + pollut(ion)	0.07
Suppli(y) + chain	0.03	employ(ment) + opportun(ity)	0.21	Volunt(ary)	0.10	Recycl(ing) + convent(ion)	0.06
SGD13	Support	SDG14	Support	SDG15	Support	SDG16	Support
Climat(e) + chang(e)	0.14	ballast + water + treatment	0.08	Habitat	0.37	Anti + corrupt(ion)	0.15
Carbon + reduct(ion)	0.08	natur(al) + habitat	0.07	Speci(es)	0.29	Human + right	0.11
Energi(y) + consump(ion)	0.08	water + biodivers(ity)	0.06	Bird	0.25	Labour + right	0.05
Reduct(ion) + target	0.06	ballst + water + convent(ion)	0.06	Plant	0.22	Child + labour	0.05
Fuel + fleet	0.06	water + pollut(ion)	0.06	Natur(e)	0.20	Forc(e) + child	0.05

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Embracing Sustainability in Shipping: Assessing Industry's Adaptations Incited by the, Newly, Introduced '*triple bottom line*' Approach to Sustainable Maritime Development

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Abstract: Increasing environmental, social and economic problems, born by unceasing economic growth, have transformed our approach to the development concept. The 1980s saw the appearance of the sustainable development term and, during the 1990s, sustainability notion was implicitly framed as an integrated concept, frequently, termed as the 'triple bottom line' approach. Among several initiatives and efforts to balance our economic and societal pursuits with environmental challenges the, lately, introduced United Nations (UN) Sustainable Development Goals (SDGs) refer to a remarkable evolution, which came to strengthen and establish sustainability conception as an integrated social, economic and environmental triptych. International shipping, as the major carrier of world trade and significant contributor to environmental degradation has, definitely, a vital role to play in facilitating the UN's sustainability venture. Although there is a great amount of legislative instruments, codes and guidance to address sustainability in shipping, though, limited research has been devoted to identify how the tanker and dry bulk maritime sector has responded to such recent cohesive attitude to sustainable maritime development. Through a quantitative research approach this empirical study aimed to investigate maritime industry's insights and attitudes in relation to the, newly, introduced triple bottom line approach to global sustainable development. Research data were collected via a questionnaire survey conducted to 50 tanker and/or dry bulk shipping companies. Pearson's chi-square test of independence and Spearman's correlation coefficient measures were utilized to test our three formulated hypotheses. Findings highlighted increasing awareness and adaptation of the maritime sector to the triple bottom line approach and, subsequent, sustainability absorption under the auspices of a corporate social responsibility (CSR) business model. Introduction of sustainable development in an integrated manner appears to have influenced the extent that statutory maritime regulations occupy to the formulation of marine safety management systems. To sum up, the integrated management system model turned out to be the most rated tactic to manage sustainability and, as such, a conceptual CSR framework was proposed to facilitate such an objective.

Keywords: triple bottom line approach; world development; sustainable shipping; corporate social responsibility; marine management systems

1. Introduction

Development is a broad concept that has been, sporadically, manipulated by several social, political, economic and academic disciplines and actors. Its multi-dimensional nature has allowed, all the way through the earliest times of our civilization the creation of a variety of approximations and studies with the aim to realize and define the real meaning of development in our world (Edwards

1993). In an attempt to contextualize and conceptualize its meaning, a review of the several definitions of the development notion shows that it has been, primarily, considered as a process, which aims to establish a better life for humans and society (Gran 1983). Further to that, Todaro and Smith (2012) regard development as a physical and mental state where society has been provided with all essential resources to achieve a better quality of life. Historically, the end of World War II signified a new era, where development was treated, synonymously, to economic growth (Turner 1997). Thereby, in the 1950s and the 1960s, such economic dimension of development was further strengthened and accompanied with the desire to increase industrialization and productivity. In that sense, development was, mainly, identified with bigger production rates to the satisfaction of society needs (Bryant and White 1982). However, in the mid-1960s onwards an amalgam of societal and environmental problems appeared in the global scene, which significantly transformed our thinking on the development meaning. Accordingly, the sustainable development concept was introduced and encompassed the world's objectives to reverse environmental impacts caused by unceasing economic development. Since then, concern has been, obviously, shifted on preserving our planet's natural resources, while securing society's welfare, rather than focusing on mere economic growth (United Nations 2013).

The introduction and implementation of United Nations 2030 Agenda and Sustainable Development Goals, in 2015, bears clear implications for the private sector, which is called to collaborate with governments and demonstrate commitment in preserving our ecosystem (Pedersen 2018). It is evident that the shipping industry has a significant role to play to such global sustainability mandates. The strategic economic and social importance of maritime transport, along with its recognized efficiency and effectiveness as major transport mode (estimated in tonne-miles) has acknowledged shipping as a critical facilitator and contributor to global sustainable development requirements (Psaraftis 2019). Additionally, shipping is responsible for generating negative environmental and climate change impacts through CO_2, NOx and SOx emissions, oil pollution, transfer of ballast water sediments, ships recycling activities, etc. It is, therefore, imperative under UN's 2030 Agenda to adopt and implement a wide spectrum of measures to deal with such issues (Allal et al. 2018). As a response, the International Maritime Organization (IMO) has welcomed UN's initiative and committed itself in, continuously, improving the industry's image and contribution to sustainable development requirements. Moreover, the Organization has urged the maritime community to consider a wide range of subjects and challenges that may contribute to shipping sustainability (energy efficiency, technology, maritime education, safety culture, maritime security, cooperation and know-how exchange, etc.) and highlighted, for the first time, corporate social responsibility as a strategic tool to place shipping on a sustainable track (Sekimizu 2012). From a European perspective, the European Union (EU), through the establishment of the European Sustainable Shipping Forum (ESSF) and White Paper adoption, has demonstrated its harmonization and commitment to improve shipping industry's contribution to the latest sustainability trends (Ringbom 2018).

Further to the above challenges, this study seeks to contribute to the existing maritime sustainability framework by addressing the gaps and suggesting a conceptual process to facilitate implementation of sustainable development in the maritime industry, as an integrated notion. In the following sections, the study continues with a review of the theoretical framework for sustainable development and summarizes relevant sustainability research, regulatory developments and critical factors that urged the application of the triple bottom line approach in shipping. Thereafter, the rationale for the development of research hypotheses and selection of methodology is discussed. Next, results from a questionnaire survey and quantitative analysis are presented and analyzed, along with hypotheses testing outcome. Following, deductions and conclusions from this study are drawn and complemented by implications, limitations and opportunities for future research.

2. Literature Review

Further to our introduction, during the 1980s, the progressive and evolving process of the development concept shifted towards environmental affairs and the need to combine development without harming the environment. The formation of United Nations World Commission on Environment and Development (WCED), in 1983, aimed at introducing and establishing a new approach to development that would, principally, raise awareness on the catastrophic consequences of socio-economic development on natural resources and the environment as a whole (Mebratu 1998). However, continuous degradation of world's natural resources and publicity of disastrous environmental effects, as a result of unbridled economic development, accelerated and increased public sensitivity for environmental affairs (Vitousek et al. 1997). In 1987, the United Nations World Commission on Environment and Development (WCED), known also as the Brundtland Commission, through the report *Our Common Future*, highlighted the need to balance social and economic pursuits with environmental preservation (WCED 1987). Though, a remarkable point of the Brundtland report was the introduction of the sustainable development concept, which meant to set new directions and shape our way of thinking on the global development process (Helming et al. 2008). As such, the emergence of sustainable development term was a reality and defined as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (WCED 1987, p. 43).

Since the Brundtland Commission, in 1987, an abundance of theoretical reviews and interpretations of the sustainable development concept have been taking place. According to Hotelling (1931) the scarcity of natural resources and the essence to use non-renewable natural resources with care and diligence has constituted the core of sustainability. In that respect, Holdgate (1993) emphasized the need to consider the limitations of the earth's natural resources and, as such, any productivity increases and technological advances should be taking into account such scarcity. However, there is a general consensus that sustainable development refers to a multidimensional issue that can be approached by several angles, which complicates somehow its uniform interpretation (Radermacher 1999). In that respect, it is obvious that the sustainable development term contains two fundamental concepts: Sustainable and development (Sharpley 2000). As such, from an economic perspective, development seeks to achieve capital maximization and growth. In sociology, development is more concerned with societal relationships and human rights. Ecology treats development from the angle of preservation of biological species and natural environments (Rios Osorio et al. 2005). In terms of the sustainability notion, the contribution of the Brundtland Commission report underlies that the idea of sustainable development refers to a complementary, mutual and unified concept, incorporating economic, social and environmental dimensions (Kuhlman and Farrington 2010). However, in the 1990s, John Elkington (1997) was the first who, deliberately, coined and launched the sustainability concept as a unified term, the so called triple bottom line approach, which integrated the existing scattered social, environmental and economic aspects and approximations. Since then, and despite the several distinctions and intellectual approaches, the triple bottom line approach has prevailed and is, gradually, used synonymously to sustainable development (Hammer and Pivo 2017). Moreover, despite the several academic and political debates on its exact definition, the integrated triptych of environmental, social and economic values has dominated the business world and, as such, every effort to measure and frame an organization's performance has been motivated by the essence to balance business economic targets with social and environmental impacts (Goel 2010).

The use of oceans, covering almost three quarters of our planet, constitute a vital source of income, nutrition and climate stability and their preservation is, therefore, imperative for the sustenance of our economic, ecological and societal systems. Protecting, therefore, our oceans and safeguarding the life of seafarers is by definition a matter of maintaining our planet's continuity and society's welfare (Spalding 2016). Such value of the oceans has been, primarily, identified and safeguarded by the United Nations Convention on the Law of the Sea (UNCLOS), which amongst others, aims to establish an international framework and governing rules that ensure the sustainable use of the oceans (Pyć 2016). Due to the crucial role that shipping has to play to the facilitation of world trade, its indisputable contribution to the global economy and its obvious impact to several stakeholders (i.e., seafarers, local communities, fisheries, environmental and non-governmental organizations, shippers, etc.), there is an imperative necessity to maintain and promote the sustainable character of the maritime industry (O'Brien 2002). Although, shipping is considered as the most environmental friendly and efficient transport mode, however, the growing use of the oceans increases negative externalities (i.e., ship's emission and subsequent greenhouse effects, loss of life at sea, cargo and ship damage, etc.; Gilbert and Bows 2012).

Shipping is an, inherently, international industry that has been, justifiably, given the attribute of the most efficient transport mode. Indeed, efficiency and low cost of transporting large quantities of bulk or containerized cargo by sea have established maritime transport as the dominant carrier of world trade, with, approximately, 90% of goods to be carried by sea (Mitropoulos 2005). However, despite its efficiency, seaborne transport generates negative impacts. Actually, the shipping industry has direct impacts to the environment, through CO_2 emissions and accidental or operational marine pollution (i.e., oil spills, release of harmful ballast water sediments, sewage, cargo residues release, etc.; Chang and Danao 2017). Moreover, the shipping profession is a risky occupation and the 'safety at sea' term is an imperative for maritime industry viability. As such, there are numerous sources of risks that may threaten the safety of people on board and ship's structural integrity, with some of them being attributed to human error, poor weather conditions, equipment failure, etc. (Galić et al. 2014). Furthermore, security of merchant shipping refers to a recent and growing area of concern that threatens the industry. Seafarers and ships are easy targets and highly exposed to several security threats, such as piracy, smuggling, terrorist attacks, etc. (Bueger 2015). Therefore, reduction of CO_2 emissions, along with energy efficiency measures and protection of life at sea has been, thoroughly, placed at the forefront of strategies and initiatives of organizations and other maritime stakeholders (Chatzinikolaou and Ventikos 2011). In 1948, in an attempt to regulate and eliminate aforementioned perils and challenges at sea, the International Maritime Organization (IMO) was created. Through the IMO Convention 1948, the Organization, which is comprised by approximately 170 Member States, acts as the United Nations specialized Agency to ensure safety of life at sea and protection of the marine environment, and has been, actively, involved in the law-making process and generation of internationally applicable maritime statutory legislation (Karim 2016).

Coming to the sustainability issue, on September 2015, our world came up with a historic decision, which meant to change our approach to sustainable development and, additionally, bear a significant impact to the shipping industry. The 2030 Agenda on Sustainable Development, adopted at the United Nations Headquarters, in New York, set global goals and targets in order to achieve sustainable development in its three dimensions (economic, social and environmental; United Nations 2015). The 2030 Agenda, comprised by 17 goals, 169 targets and 230 indicators, refers to a comprehensive instrument that urges the international community to focus and act on critical to our planet challenges including, poverty eradication, resource use efficiency and waste reduction, human rights, creation of decent work genetic resource sharing, etc. (Hambrey 2017). Although such undertaking was not the first initiative assumed by the United Nations, however, a revolutionary idea and underlying key for the success of such movement refers to the profound integrated approach to sustainable development (Hong 2017).

In the outcome of such regulatory and policy evolutions, the concept of a sustainable maritime industry is a subject that has, over time, generated various interpretations and definitions, in terms of its theoretical and practical consideration and implementation. Comparing to land-based industries, the issue of sustainability in shipping has been, traditionally, treated as synonymous to the elimination of environmental impacts generated by maritime operations (Cabezas-Basurko et al. 2008). Traditionally, environmental sensitivity and elimination of environmental risks has been laid in the forefront of companies' strategy (Progoulaki and Roe 2011). Moreover, safety performance and eradication of risks related to navigation, occupational health and safety, ergonomics, ship operations and maintenance and crew welfare matters have always been a top priority for ship and shore personnel (Boisson 1999). Lun et al. (2014) notes that shipping companies consider environmental issues to be more critical for their business, comparing to social matters. At the operational level, commitment towards sustainability was more seen as an attempt to ensure compliance with applicable environmental and safety regulations, rather than as a notion integrated into company's policy (Pawlik et al. 2012). Similarly, stakeholders interest in shipping has, habitually, concentrated to environmental and safety matters, which were, mainly, seen as an obligatory and legally binding endeavor (Tzannatos and Stournaras 2015). However, no matter the angle that someone approaches such a notion, the 2030 Agenda and Sustainable Development Goals (SDGs) attained to mainstream specific goals and objectives across the maritime sector and, thus, frame quantitative and measurable targets that the shipping industry has to achieve and demonstrate its contribution to global sustainability efforts (Parry et al. 2018). It would be worth mentioning though that, recently, the container and cruise shipping sector has raised the issue of sustainability in an integrated manner (Pawlik et al. 2012). As such, along with safety and environmental issues, economic transparency and social welfare have constituted a meaningful factor to liner shipping companies' strategy (Pruzan-Jorgensen and Farrag 2010).

At the policy and regulatory level, the International Maritime Organization has, at present, recognized and mapped shipping industry's contribution to the 2030 Agenda and SDGs. The development of the Organizations' Strategic Plan, for the six-year period 2016 to 2021, aimed, specifically, at setting strategic directions (SD) and measurable targets (Sciberras and Silva 2018). Thus, specific goals have been set by the Organization in areas such as, safety culture promotion, technology innovation, energy efficiency, maritime security enhancement, education and training of seafarers, etc. However, it is worth underlining that, at the policy level, and for the first time in its history, IMO has conceptualized and acted towards the achievement of a sustainable maritime transportation system, which is founded on the integrated principles of the triple bottom line to sustainable development (Sekimizu 2012). In this line, and within the European Union framework, the European Maritime Safety Agency (EMSA) has further emphasized the need to strengthen sustainable maritime development on the three pillars of environmental, social and economic integration. On September 2013, the European Sustainable Shipping Forum (ESSF) was established with the aim to contribute to recent sustainability challenges. Furthermore, inclusion and understanding of maritime stakeholders' interests and processes was highlighted as a vital point in supporting such sustainable shipping initiatives (EMSA 2019). Additionally, several industry's Associations, such as the Norwegian Shipowners Association emphasized the need to foster a sustainable shipping industry on the principles of the triple bottom line approach, contributing, thus, to global sustainability targets (Norwegian Shipowners Association 2019). In this line, major classification societies have addressed the impact of SDGs in shipping, the opportunities they create and the imperative to consider sustainability in an integrated and not fragmented manner (Gjølberg et al. 2017).

Bearing in mind the recent introduction of UN 2030 Agenda and SDGs in shipping, and reviewing relevant studies, it is assumed that, with the exception of a few shipping segments (i.e., container and passenger industry), no significant empirical research has been undertaken to identify tanker and dry bulk sector perceptions and practices, in relation to the introduction of the triple bottom line approach to sustainable maritime development. Such stimulated global interest to address sustainability in shipping in an integrated manner (triple bottom line) and not through fragmented and retrospective polices or regulatory treaties have constituted a critical motivator for this study. It would be beneficial, though, to identify how the shipping industry has reacted and adapted to such trends with the objective to correct irregularities and propose effective management regimes. It is reasonable that effective implementation and achievement of Sustainable Development Goals requires, primarily, adequate understanding of the three sustainability pillars (environmental, social, economic). It would be, therefore, of great value to assess theoretical and practical comprehension and implementation of such a notion within the maritime context and identify any potential influences in the functions and processes of shipping companies. Hence, the aim of this study is to investigate and illuminate the shipping industry's (tanker and dry bulk sector) insights and adaptation to the application of the, recently, urged triple bottom line approach to sustainable maritime development.

3. Theoretical Foundations and Hypotheses

3.1. Triple Bottom Line Approach to Sustainability and CSR Correlations

The term of corporate social responsibility, as a theoretical concept and tactical issue, has, nowadays, been brought to the forefront of a company's business strategy and corporate objectives. Globalization trends, liberalization of trade and stakeholders' unrestricted access to information have transformed perceptions of business towards society and vice versa (Kiran and Sharma 2011). Since the 1960s and 1970s, corporate social responsibility has gained growing importance and recognition in business practices. Despite the abundant literature and academic approaches and research on that term, it has been, mainly, rooted in the social contract theory and depicts society's expectations from corporations and business actors (Carroll 1999). According to Davies (1973) such expectations extend beyond the mere compliance and fulfillment of a firm's regulatory duties and financial obligations and, thus, incorporate several other aspects that interrelate with business activities (i.e., social, ethical, moral environmental, etc.). There are several global corporate social responsibility (CSR) Standards (i.e., Global Reporting Initiative, ISO26001, SA8000, etc.) that provide guidance and aim to set universally adopted principles on CSR. Though, they all maintain a voluntary and consultative character (Ganescu 2012).

Developments in international legislation, along with increasing stakeholders' pressure, have urged companies to focus and manage multilateral and complex environmental, social and economic issues (Doz and Kosonen 2010). Although engagement with such subjects is not new, however, United Nations 2030 Agenda and SDGs have set the legal framework for private business to engage and demonstrate compliance and achievements towards measurable sustainability objectives (Yakovleva et al. 2017). Under such regulatory and business evolution, CSR can constitute a strategic management tool that could assist companies to integrate and achieve their sustainability performance. Given the fact that a fundamental role and obligation of business is to eliminate negative impacts and operate responsibly, it goes without saying that sustainability objectives should form part of corporate strategy (Baumgartner 2014). As stressed previously, shipping is a large, international and diversified industry and, as such, utilization of seaborne trade has a significant impact on society, economy and the environment. Increasing statutory maritime legislation aims at regulating the hazardous and detrimental aspects of shipping activities, reducing, thus, its negative health, safety, social and environmental impacts (Lai et al. 2011). What can be deduced at this point is that sustainable development, as currently attempted under the triple bottom line approach, intersects and is embedded in the CSR notion. Therefore, CSR can constitute the framework and strategic corporate initiative to integrate sustainability triple bottom line principles (Epstein and Wisner 2001). Aligned with such consideration, IMO's latest stance visualizes that a sustainable maritime industry should be achieved by "*inter alia, anchoring the vision of sustainable development into "Corporate Social Responsibility" (CSR) related activities*" (Sekimizu 2012, p. 22). Thus, it is believed that understanding sustainability under the triple bottom line approach (social, economic and environmental) will, successively, shape sustainability as a notion that lies under the spectrum of the CSR strategy. It is, therefore, hypothesized that:

H1. *Considering sustainability as part of a company's CSR policy is closely related to sustainable development perception under the triple bottom line approach.*

3.2. Marine Safety Management Systems and Interactions with the Triple Bottom Line Approach

The purpose of a safety management system (SMS) is to establish a systematic approach, through which an organization will be able to effectively manage its risks. Depending on the business scope, an organization may face several risks including, health, safety, environmental, corporate, stakeholders, etc. (Cooper 2000). However, such requirement for organizations to establish and operate under an SMS is not something new. A historical flashback shows that development of safety management systems has, primarily, appeared in the outcome of catastrophic events. In 1974, the explosion of the

Nypro Ltd caprolactam production facility, in the UK, resulted to the formation of the Health and Safety at Work Act, which incorporated the first requirement to develop a safety management system (Gallagher et al. 2001). Introduction of the SMS, as a regulatory requirement, in the shipping industry became mandatory in 1998, when IMO's Resolution A741 (18) entered into force. Such progress appeared in the maritime arena in the aftermath of serious maritime disasters, such as the Exxon Valdez, Herald of Free Enterprise, Scandinavian Star and Estonia (Jedral 2000). Next, the International Safety Management (ISM) Code raised the requirement for management companies to develop a safety management system that would take into account applicable maritime legislation, relevant to the ship type, with the aim to ensure a safe, healthy, environmental friendly and, generally, risk free operation of their ships (El Ashmawy 2009).

Almost 20 years since the implementation of the ISM Code, the maritime industry is faced with multidimensional and critical issues. Amongst others, the introduction of the United Nations 2030 Agenda and 17 Sustainable Development Goals, call for systematic action with the aim to protect the planet, safeguard the life of seafarers, maintain efficient and affordable shipping services and ensure dignified living and working conditions for those working on board. Shipping has to transform its overall approach and, therefore, act and provide solutions to vital planet challenges, as embedded in the modern triple bottom line approach to sustainable development (Gjølberg et al. 2017). However, consideration and formulation of processes and practices in the shipping industry has been, mostly, governed and motivated by the attempt of shipping companies to comply with statutory maritime legislation (Acciaro 2012). Safety, environmental protection and energy efficiency initiatives have been, highly, recognized and pursued by shipping companies as a mean to secure industry's sustainability, reduce business risks and promote company's image to stakeholders (Smith 2016). However, such pursuits have been, mainly, triggered by the need to comply with statutory maritime legislation and do not refer to a systematic approach to manage sustainability in an integrated manner (Kunnaala et al. 2013). Moreover, according to Yuen and Lim (2016), although the influence from newest sustainability developments in shipping is sensible, however, existing overloaded maritime regulatory regime is considered by shipping companies as a highly deterring factor in undertaking further voluntary, and beyond regulation, sustainability initiatives. Hence, it is assumed that the recent introduction of the triple bottom line approach in shipping will not transform such attitude and shipping companies will keep maintaining their traditional approach to SMS formulation (mainly, driven by statutory maritime legislation). As such, it was hypothesized that:

H2. *Companies' conventional approach to SMS formulation is unimportantly influenced by sustainable development introduction under the triple bottom line approach.*

3.3. Consolidated Management Systems and Sustainability Management

Development of a regime that stimulates involvement of private entities in philanthropic, environmental, social and anti-corruption activities has long been encountered in the international regulatory setting. However, SDGs envisage integration of social, economic and environmental objectives into a business strategy (Nilsson et al. 2016). The integrated management system (IMS) approach to sustainable development is a notion that seeks to consolidate the dimensions of the triple bottom line approach into operating practices of corporations (Searcy 2012). Having set the policy and management objectives, then, economic, social and environmental aspects of company's operations need to be addressed into detailed processes that prescribe specific directions, roles and responsibilities for every department and company's employee (Sroufe and Joseph 2017). Elements of commonly known Standards, such as ISO 9001 (quality management), ISO 14001 (environmental management), ISM Code requirements, along with requirement of other applicable maritime Conventions and Codes need to be brought together and balanced in an integrated management system (Oskarsson and Malmborg 2005).

Managing sustainability in an integrated manner lends the company with a unique advantage to manage its resources effectively (i.e., personnel, time and money), avoiding, thus, bureaucracy and procedure duplication (Asif et al. 2013). Furthermore, a critical for the company value, that of stakeholders, can be effectively considered by taking into account their particular interests and business aspects (Sealy et al. 2010). The triple bottom line approach to sustainability is by definition a multi-dimensional concept that, indirectly, sets the foundations for an integrated approach in managing and measuring sustainability. Such approach forms a dynamic managerial process that continuously takes into consideration a company's needs and challenges within the multifaceted business environment (Fauzi et al. 2010). At the strategic and corporate level, such an approach to sustainability is also identified and embedded in a corporate social responsibility business operating model (Dey and Sircar 2012). In line with such considerations, and within the maritime context, Poulovassilis and Meidanis (2013) suggest that current sustainability mandates require broadening the scope of conventional marine management systems so as to incorporate economic, social and environmental concerns, along with stakeholders' expectations. Accordingly, it should be expected that sustainability awareness under the triple bottom line principles will, subsequently, motivate adoption of the integrated management system model, as the preferred tool to achieve sustainability. Under such consideration, it was hypothesized that:

H3. *Adoption of an integrated management system model as a mean to achieve sustainability is positively stimulated by sustainable development perception under the triple bottom line approach.*

4. Methodology

4.1. Research Strategy and Data Collection

Data gathering was done via an electronic questionnaire survey that was carried out among 50 shipping companies, based worldwide, and operating in the tanker and/or dry bulk maritime sector. The questionnaire was distributed to the email addresses of maritime personnel working in various departments, such as health, safety and environmental, technical, accounting/management, human resources and operations. The respondents were given the option to maintain their anonymity and at the end of the questionnaire they were provided with the space to share any personal experiences and thoughts. Data group is based on the collection of the type of data that will better inform our hypotheses and be appropriate to the research variables type (Johnson 2005). Given the fact that our study is concerned with the testing of developed hypotheses, our research follows a quantitative research approach and strategy. As such, the use of a questionnaire survey has been selected as the identical data collection method. Self-administered questionnaires allow us to collect quantifiable and measurable data from our drawn population sample, relatively quickly and cost effectively (Creswell and Creswell 2017). Both independent and dependent variables, concerned with hypotheses testing, relate to statements. Hence, participants were asked to state their level of agreement on such particular statements measured on a five point Likert (Strongly Agree to Strongly Disagree) and Guttman (Yes/I am not sure/No) scale. Moreover, descriptive statistics are employed to discuss demographics and provide general inferences of our collected data. Some indicant examples of questions used to test hypotheses refer to:

- Which topics should be part of a company's Corporate Social Responsibility (CSR) policy/program?
- Shipping operations are executed based on company's Safety Management System, which includes policies, objectives, plans, procedures, responsibilities and other measures. Taking into consideration your company's Safety Management System (SMS), please rate the importance of the provided elements (statutory regulations, CSR/sustainability standards, other industry standards i.e., ISO9001, ISO14001, etc.) to the formulation of your company's Safety Management System (SMS)? Please rank your preference.

- To what extent do you agree with the following statement: Sustainable shipping operations can be effectively achieved by adopting an integrated management system approach that consolidates and balances the requirements of various voluntary standards (i.e., ISO9001, ISO14001, OHSAS18001, etc.) and statutory regulations (i.e., ISM, ISPS, MLC, etc.) into business operations.
- To what extent do you agree with the following statement: Sustainable development is understood as the conduct of business in a way that a company's economic, social and environmental impacts are considered and, as such, business activities are performed transparently and with the aim to eliminate social and environmental risks.

A summary of dependent and independent variables are presented in Table 1.

Table 1. Independent and dependent variables and corresponding hypotheses.

Alternative Hypothesis	Independent Variable	Dependent Variable	Test
$H_{1:}$ Considering sustainability as part of a company's CSR policy is closely related to sustainable development perception under the triple bottom line approach.	Sustainable development perception under the triple bottom line approach. (ordinal)	Considering sustainability as part of a company's CSR policy. (nominal)	Chi-square test of independence
$H_{2:}$ Companies' conventional approach to SMS formulation is unimportantly influenced by sustainable development introduction under the triple bottom line approach.	Sustainable development introduction under the triple bottom line approach. (ordinal)	Companies' conventional approach to SMS formulation. (ordinal)	Spearman's correlation coefficient
$H_{3:}$ Adoption of an integrated management system model as a mean to achieve sustainability is positively stimulated by sustainable development perception under the triple bottom line approach.	Sustainable development perception under the triple bottom line approach. (ordinal)	Adoption of an integrated management system model to achieve sustainability. (ordinal)	Spearman's correlation coefficient

4.2. Data Analysis Method

Both descriptive and inferential statistics methods were employed to summarize results and verify hypotheses. The type of variables and collected data was used as a criterion for the selection of the most appropriate hypothesis testing method. In particular, Hypothesis 1(H1) was tested using a chi-square test of independence. Chi-square test of independence, or Pearson chi-square test, is a non-parametric test, suitable for the testing of hypotheses, which include at least one variable measured on a nominal scale (McHugh 2013). A chi-square test provides evidence on whether there is a statistically significant relationship between groups or variables. Therefore, depending on the test results, at the level of significance $a = 0.05$, we reject the null hypothesis if the p-value is less than a ($p < 0.05$; Rana and Singhal 2015). Further, a chi-square test of independence is coupled with a contingency coefficient (C) measure. Contingency coefficient (C) is termed as a measure of association that is used to determine the strength of relationship between our variables. Values close to −1 indicate a strong negative association, while values close to 1 show a perfect positive association. Values of 0 imply no relationship between variables (Tan et al. 2004). Hypotheses 2 (H2) and 3 (H3) were tested using Spearman's correlation coefficient measure. The nature of our selected variables, which were categorical measured on an ordinal scale, allowed us to use such a statistical measure to verify the statistical significance between our variables. As per Spearman, a statistical significant relationship between variables exists when the p-value is less than 0.05 (where a, the level of significance) and, therefore, the null hypothesis is rejected (Myers and Sirois 2004). Spearman's correlation coefficient (Rs) also enables us to determine the strength of association between selected variables. Rs values range between $-1 < \text{Rs} < 1$. Values close to −1 imply a strong negative association, while values close to 1 inform us for the existence of a strong positive relationship between variables. A value close to 0 implies no relationship between variables (Rebekić et al. 2015). The Statistical Package for Social Sciences (SPSS) version 25 for windows was used for the elaboration of collected data. Summarized hypothesis, dependent and independent variables, along with specific statistical measures employed in this study are presented in Table 1.

5. Results

5.1. Demographic Data

Out of the 50 respondents, 38 (76%) were males, with the remaining 12 (24%) of the sample population being females. Most of the personnel belonged in the age groups of 41–50 and 51+, accounting for 34% and 32% respectively. The majority of companies' fleet size ranged between 1–20 and 61+ vessels corresponding to 42% and 34% respectively. Participating companies' size, in terms of employee number, was 251+ (58%) and 51–150 (20%), while the remaining accounted 151–250 (14%) and 1–50 (8%). Among all the respondents, 32 (64%) held positions in the QHSE department, six (12%) hold positions in the human resources department, while five (10%) and two (4%) work in the technical and accounting/management division respectively. Forty-one (82%) declared to have incorporated into the company's policy CSR principles, while five (10%) answered that no CSR principles were embedded into their organization. Surprisingly though, only 2% found to be officially certified against a CSR/sustainability standard, while the majority inclined towards environmental, quality and health management standards certification (73%). Similarly, the majority of respondents (72%) employed an integrated health, safety and environmental report as a mean to measure and communicate business performance, while 16% opted to generate a dedicated annual sustainability report. With regards to the companies' nationality, 11 (22%) were based in Norway, 10 (20%) in Greece, seven (14%) in Denmark, four (8%) in Germany, four (8%) Cyprus, three in Finland (6%), two in Canada (4%), two in Switzerland (4%), two in The Netherlands (4%), while the remaining five were based in countries such as Monaco, Turkey, Sweden, Belgium and Italy. Review of such results provides a clear indication that a sizable number of participants occupied positions in departments that exposed them directly to sustainability matters and, moreover, they came from diversified backgrounds and had acquired sufficient work experience. Furthermore, participating companies were large in size, in terms of vessels number under management and employee number, and were based in a variety of countries, a fact that did not constrain our conclusions to the findings of a single country.

5.2. Hypothesis Testing Results

The statistical significance of hypothesis 1 variables was tested. Further to the application of chi-square test of independence, obtained p-value was $0.022 < a$. A statistically significant relationship between variables had been identified, with $a = 0.05$ being the level of significance. Therefore, the null hypothesis was rejected (X^2 (8) = 17,859, p-value = 0.022). As such, on the basis of the data, it was found that perceiving sustainable development under the triple bottom line approach was significantly related to the consideration of sustainability as part of a company's CSR policy and management strategy. Furthermore, according to the application of the contingency coefficient measure, the estimated C value was 0.513. Such a result suggests the existence of a quite positive association between selected variables. More precisely, it was implied that the more we understand sustainable development under the triple bottom line approach, the more we consider sustainability as being part of a company's CSR policy and management strategy. Table 2 presents a summary of results from testing hypothesis 1.

Table 2. Hypotheses 1 Testing: Chi-square test of independence and contingency coefficient measure.

Null Hypothesis	*p*-Value	X^2	Contingency Coefficient (C)	H_0 Rejected (a < 0.05)
H_0: Considering sustainability as part of a company's CSR policy is not closely related to sustainable development perception under the triple bottom line approach.	0.022 *	17,859	0.513 **	Yes

Notes: * H_0 rejected at significance level $p < 0.05$ ** $-1 \leq C \leq 1$, −1 = perfect negative relationship, 0 = No relationship, 1 = perfect positive relationship.

On the basis of the analyzed data, we did not find support for Hypothesis 2, which assumes that the recent introduction of sustainable maritime development under the triple bottom line approach, is not expected to have altered companies' conventional approach to SMS formulation. From the application of Spearman's correlation measure, the obtained *p*-value was 0.343 > 0.05 (at level of significance a), which shows the non-existence of a statistically significant relationship between variables. As such, the null hypothesis was retained. Moreover, the estimated *Rs* value was 0.137, which indicates the almost absent association between variables. Further to that, introducing sustainable development under the triple bottom line approach was expected to have influenced the degree that statutory maritime regulations occupy to the formulation of company's SMS raising, thus, incorporation of further sustainability provisions and standards. Results from testing hypotheses 2 are presented in Table 3.

Table 3. Hypothesis 2 Testing: Spearman's correlation measure.

Null Hypothesis	*p*-Value	Spearman's Correlation Coefficient (R_s)	H_0 Rejected (a < 0.05)
H_0: Companies' conventional approach to SMS formulation is not unimportantly influenced by sustainable development introduction under the triple bottom line approach.	0.343 *	0.137 **	No

Notes: * H_0 rejected at significance level $p < 0.05$ ** $-1 \leq (Rs) \leq 1$, −1 = perfect negative relationship, 0 = No relationship, 1 = perfect positive relationship.

On the basis of obtained data, we found support for hypothesis 3. Hence, perceiving sustainable development under the triple bottom line approach was significantly related to the adoption of the integrated management system model as a mean to achieve sustainability. Therefore, testing of hypothesis 3 implies a statistically significant relationship between variables. Accordingly, obtained values from the application of Spearman's correlation measure generated a *p*-value of 0.000 < 0.05 (at level of significance a). In view of that result, the null hypothesis was rejected. Moreover, a quite positive association had been identified, as indicated by the obtained *Rs* value of 0.519. In that sense, raising companies understanding of sustainable development under the triple bottom line approach positively increased their inclination towards the integrated management system model, as the best mean to achieve sustainability. Results from testing hypotheses 3 are presented in Table 4.

Table 4. Hypothesis 3 Testing: Spearman's correlation measure.

Null Hypothesis	p-Value	Spearman's Correlation Coefficient (R_s)	H_0 Rejected ($a < 0.05$)
H_0: Adoption of an integrated management system model as a mean to achieve sustainability is not positively stimulated by sustainable development perception under the triple bottom line approach.	0.000 *	0.519 **	Yes

Notes: * H_0 rejected at significance level $p < 0.05$, ** $-1 \leq (Rs) \leq 1$, -1 = perfect negative relationship, 0 = No relationship, 1 = perfect positive relationship.

6. Discussion

Overall, data analysis implied verification of hypotheses 1 and 3, while hypothesis 2 was rejected. The triple bottom line approach to sustainable development is highly diffused in the shipping industry and is considered as being part of a company's wider CSR policy. In that sense, the integrated management system was indicated as the preferred model to achieve sustainability. However, perceiving sustainability in an integrated manner (environmental, social and economic) does not necessarily constitute statutory maritime legislation as the sole determinant source to marine safety management systems formulation. Deductions and inferences are discussed below.

6.1. Triple Bottom Line Approach to Sustainability and CSR Correlations

Confirmation of hypothesis 1 found to be in line with previous research findings. Thereby, it was affirmed that supporting a sustainability mindset as an integrated triptych will promote awareness of sustainability as a notion anchored and achieved through a wider CSR management strategy. Such deduction is in accordance with existing research which, mostly, regards CSR as a business management model set at strategic level that aims to integrate environmental, social and economic pursuits within the organization (Saha and Dahiya 2015). It is worth noting at this point that the sustainability notion has been frequently termed as corporate sustainability reflecting, thus, a company's strategic approach and commitment to sustainable development (Dyllick and Hockerts 2002). However, despite such diverse employed terminology, confirmation of hypothesis 1 showed that the more companies deal with sustainability as an integrated notion, the more they perceive it as being part of a wider CSR corporate strategy (Aras and Crowther 2008). Latest industry's regulatory and policy efforts to address sustainability in its three dimensions and embrace it under the 'umbrella' of a CSR business model seem to have shaped shipping sustainability perception. Consequently, shipping industry has recognized that the multifaceted challenges of sustainable development today require a strategic approach. Such understanding has, possibly, driven companies to realize that sustainability initiatives within an organization should be placed under a CSR policy (Gjølberg et al. 2017; Poulovassilis and Meidanis 2013). Further reviewing the latest IMO's inherent policy stance in conjunction with study findings, it was ascertained a harmonization of maritime companies' CSR and sustainability attitude with such IMO's inspiration. Indeed, as discussed above, contemporary sustainability developments and, specifically, UN's 2030 Agenda and SDGs, have introduced an integrated approach in sustainability management for private corporations. Actually, the integrated term of the sustainability concept does not refer to a recent discovery since it has been identified long before, by Elkington, during the 1990's, and has been commonly acknowledged as the triple bottom line approach (Purvis et al. 2018). However, today, and keeping up with recent policy and regulatory changes, the study findings supported shipping companies' wide sustainability perception as an integrated notion (triple bottom line approach) embedded into CSR, an assumption fully aligned with contemporary IMO's viewpoint (namely that every sustainability action should be framed into a CSR policy framework; Sekimizu 2012).

6.2. Marine Safety Management Systems and Interactions with the Triple Bottom Line Approach

Hypothesis 2 explored the association between sustainable development perception under the triple bottom line approach and how likely it was to affect the extent that provisions of statutory maritime legislation occupy in the formulation of companies' SMS. Understanding sustainability in an integrated manner is definitely a reality in shipping. Literature review and empirical investigation supported that the maritime sector had acknowledged sustainable development in its three dimensions, which was, furthermore, in line with UN's and IMO latest regulatory developments (Sekimizu 2012). However, we found no support between the association of sustainable development understanding in its three dimensions and deployment of the provisions of statutory maritime legislation as the principal regulatory source to SMS formulation. As such, hypothesis 2 was not confirmed. Interpreting further such a finding, we have to admit that the issue of quality, safety and environmental protection in merchant shipping has been, customarily, identified with compliance against minimum statutory maritime legislation, such as SOLAS, MARPOL, ISM Code, etc. (Kunnaala et al. 2013). As a matter of fact, and on a general level, the foundation and structure of marine safety management systems has been, mainly governed by statutory maritime legislation, reflecting, thus, the industry's overall culture and approach to the whole issue (Ships 1994). Initially, evolutions in the field of sustainable development and current promulgation of such a notion in an integrated manner were believed not to have affected the traditional approach of maritime companies to SMS formulation. However, and contrary to hypothesis 2's initial assumption, empirical results debated such reasoning. A sensible explanation of this would stem from the fact that shipping companies, operating in an international and changing environment, have sought to adapt their traditional approach to SMS formulation. In that way, they have moved one step forward and realized that effective sustainability management, nowadays, requires integration into SMS of several social, environmental and economic elements and principles that up to now had been, possibly, out of the scope of shipping business. Thus, dissemination of the sustainable development concept in an integrated manner has, without doubt, altered their conventional approach to SMS formulation. Hence, shipping companies, driven by current sustainability challenges and awareness, seem to have renovated their safety management system approach by incorporating sustainability elements, apart from customary maritime legislation (Gjølberg et al. 2017).

6.3. Consolidated Management Systems and Sustainability Management

A positive relationship was hypothesized to exist between sustainable development understanding, under the triple bottom line approach, and the adoption of the integrated management system model as a mean to achieve sustainability. Further to that, hypothesis 3 was confirmed. Moreover such an association was found to be quite strong. Further to the introduction of UN's 2030 Agenda, in 2015, the sustainable development concept has been obviously introduced in an integrated manner (Griggs et al. 2013). The literature review confirmed the profound diffusion of such an approach in shipping, which was found to be in line with our empirical investigation results. Identification of the integrated management system approach to manage sustainability management has been previously identified as an effective and strategic tool for organizations (Azapagic 2003). In that sense, combination of several aspects and elements from various standards and statutory regulations and their later integration into company's safety management system, has proved to be a flexible and cost-effective tactic to manage business risks, stakeholders' relations and, thus, contribute to a company's overall sustainability (Başaran 2018). Similarly, study results implied that the integrated management system approach was highly rated by shipping companies as a mean to manage sustainability challenges, with such being attitude reinforced by the growing sustainability perception under the triple bottom line approach. This is, potentially, explained by the fact that up-to-date multilateral and multidimensional aspects of the sustainable development concept require homogenous, well-structured and integrated solutions to be achieved. Therefore, the integrated management system model turns out to be a tested and reliable solution to avoid duplication, ensure flexibility, eliminate process fragmentation and increase organization's overall efficiency (Hong 2017). Hence, shipping companies, appreciating the ever increasing and complex social, environmental and economic challenges, at the international and regional level, indicate IMS as the most effective mean. Further to the identification of a strong enough association between hypothesis 3 variables, it is supported that the more complicated and demanding sustainability challenges will become, the more shipping companies will be tending to the choice of the IMS solution.

7. Study Implications

The aim of this study was to explore the concept of the triple bottom line approach to sustainability, in the aftermath of the recent introduction of UN's 2030 Agenda and Sustainable Development Goals in shipping. Therefore, identified gaps, along with growing dissemination of sustainable development under its three dimensions, has motivated us to assess tanker and dry bulk sector's adaptation to such newly hosted tendencies. In summary, literature review conclusions, coupled by empirical research results, suggest two major implications.

Firstly, the theoretical added value of this paper has made it possible to enrich our knowledge and reach a deeper understanding on sustainable development configuration in the maritime sector, in the light of the lately promoted triple bottom line approach and UN's Sustainable Development Goals in shipping. Findings suggest that sustainability is broadly understood as an integrated element (environmental, social and economic), which is embedded into a company's broader CSR policy and management strategy. Regulatory and policy level developments have shaped sustainability in shipping under the triple bottom line notion, which, additionally, has urged shipping companies to consider CSR as the vehicle to achieve sustainability throughout their operations. Furthermore, such a tendency has affected their 'traditional' safety management system approach, which was initially based on the provisions of statutory maritime legislation. Under this new reality and mindset on sustainable development, it is also implied that shipping companies have well started adapting their traditional SMS approach, by integrating elements of other environmental, social and economic Standards. Moreover, another implication to knowledge suggests that identification of sustainability under the triple bottom line approach has obviously stimulated the acknowledgement and dissemination of the integrated management system model as the most effective management pattern to achieve sustainable maritime operations.

Secondly, this study may provide useful input to regulators and policy makers in designing and prioritizing their regulatory chases and focus areas. Research findings suggest that corporate social responsibility may serve as a key contributor and vehicle to the achievement of sustainable development. Such a fact signalizes a clear indication to regulators and policy makers with regards to their future areas of concern and action. Thus, understanding sustainability as part of a CSR policy and strategy demonstrates that UN Sustainable Development Goals could be better achieved by further circulating CSR principles in the shipping sector. Practically, such a deduction should be translated to the diffusion and promotion of integrated CSR business models in shipping so as to address current sustainability challenges. However, the fact that the shipping industry appears not so keen to the adoption of official CSR/sustainability standards certification, measuring and reporting systems should constitute a concern area for regulators and policy makers, which are urged to consider and promulgate the integrated management system model as the most effective mean to achieve sustainable operations. Such advancement though, should maintain a voluntary character without necessarily being accompanied by the establishment of a mandatory CSR and sustainability regime for the maritime sector. Further awareness, training and guidance on CSR and sustainability instruments and aspects should, therefore, constitute the principal focus areas and action field for regulators and policy makers.

8. Conclusions: A Conceptual CSR Framework for the Achievement of a Sustainable Maritime Industry

Bearing in mind the literature review assumptions and coupled by the study findings, it was assumed that CSR could lend shipping companies with a strategic management tool to contribute to the fulfillment of United Nations' Sustainable Development Goals and subsequent IMO's Strategic Directions for the achievement of a sustainable shipping industry. CSR should be, primarily, seen as the vehicle to deal with sustainable development requirements and fulfill stakeholders' demands. In that respect, CSR requires deep knowledge, broad interpretation and extensive integration of SDGs, IMO's strategic directions, Flag Administration rules and other industry requirements into a company's processes. Moreover, key stakeholders' expectations (employees, suppliers, charterers, labor unions, local community) should be analyzed and their concerns be integrated into business processes. Equally important is the integration of principles and requirements of individual management systems and industry standards to facilitate company's goals. As a matter of fact, multiple systems and standards exist to deal with efficiency, environment, social accountability and occupational safety. In such a plethora of regulations and management standards, the use of fragmentary and isolated management systems would compromise efficiency and, additionally, would bring confusion at the employee and operational level. Therefore, a company's SMS needs to be filtered and relevant requirements to be integrated and adjusted to company's objectives, business profile, management culture, and overall commercial potential. Practically, job manuals, procedures, processes and instructions need to be written and communicated to employees in a manner that avoids duplication and confusion, promote efficiency, address stakeholders and sustainability needs and, moreover, can be measurable and auditable at any time (Asif et al. 2013).

In the light of such argumentation, the below proposed conceptual CSR framework depicted in Figure 1, suggests a structured pathway on how CSR can be structured into business operations. Such conceptual approach commences at the top management level with the dissemination of CSR into the strategic management objectives and processes (Matten and Moon 2008). Firstly, it is imperative the creation of a CSR strategy that places sustainability at the core of business. Secondly, it is vital the integration of CSR principles into a company's business activities, through the appropriate transformation of the safety management system, in such a way that a company's economic objectives are balanced with stakeholders' expectations, societal anticipations and environmental challenges (Zwetsloot 2003). Thereafter, CSR implementation will continue with the integration of existing management systems to meet stakeholders' requirements. The whole process will be concluded, thereupon, at the operational level by setting work instructions and procedures that promote efficiency, ensure a safe workplace, respect the environment, consider the society and manage stakeholders' requirements (Asif et al. 2013). However, in order such an attempt to be productive it has to be systematic, measurable and clearly defined into core business strategy, processes and objectives (Burke and Logsdon 1996).

Figure 1 summarizes the foremost phases, as described above, to be passing through in order to create and integrate CSR into a company's shipping operations.

It is worth reminding at this point that as per obtained study results, dedicated CSR measuring and reporting has not been a practice widely followed by shipping companies. In contrast, shipping companies, customarily, generate an integrated health, safety and environmental report, mainly for internal use. However, ship managers can benefit from CSR measuring and reporting in many forms, one of which is the increased trust and improved company's image and relationships with stakeholders (i.e., Charterers, local communities, Port State Controls, Flag Administrations, etc.). Hence, in order for CSR to be fruitful, it should be practically addressed through quantifiable and defined indicators, tailored to the requirements of sustainable development (economic, social and environmental) and stakeholder pursuits (Schaltegger and Wagner 2006). The Global Reporting Initiative framework can provide a suggestive example of CSR measuring and reporting standards. However, selection of CSR measurement indicators is a decision that should be taken according the individual characteristics of each company and measurement of CSR performance should be followed by CSR measurement and reporting (Toppinen et al. 2012). Measuring and reporting CSR performance can provide ship managers with an overview of the success of their CSR and sustainability initiatives, highlight areas of improvement and assist in the reassessment and orientation of a company's strategy. Ultimately, according to Figure 1, CSR audit is a valuable tool that provides a snapshot of the implementation state of company's corporate mandates and strategic objectives. Audit results can be later evaluated and decisions taken on where an improvement effort should be undertaken (Asif et al. 2013).

Figure 1. A conceptual corporate social responsibility (CSR) framework for a sustainable maritime industry.

9. Limitations and Future Research

Limitations to this study were primarily concerned with the employment of a questionnaire survey. Specifically, the use of this data collection method did not give the space for open-ended questions and might cause misinterpretations of the answers. Moreover, our research approach and design did not allow us to examine policies, procedures and processes of shipping companies with regards to CSR and sustainability. Thus, such a fact bears some subjectivity to the interpretation of the results. To that end, future studies are recommended with the aim to collect and provide more qualitative information and insights on current perceptions and practices employed by companies in their attempt to operate sustainably. A future qualitative approach and research, possibly through case studies, interviews, observations and document review is recommended as a mean to overcome identified limitations and propose CSR and sustainability best practices.

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Has China's Belt and Road Initiative promoted its green total factor productivity ? ——Evidence from primary provinces along the route

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ABSTRACT

Because nearly five years have passed since China's Belt and Road Initiative (BRI) was implemented, there is an urgent need to explore whether it has significantly promoted provincial green economy development. Focusing on the primary provinces along its route, this study uses a GML index based on SBM directional distance function to evaluate provincial green total factor productivity (GTFP) and quantitatively analyses the BRI's net effect on provincial GTFP. The results indicate that provincial GTFP development is relatively good, with technological progress being its main driving force, there are significant differences between the regional GTFP development along the Silk Road Economic Belt (SREB) and the Maritime Silk Road (MSR), and the BRI has played a significant role in promoting provincial and two regional GTFP. R&D investment inhibits provincial GTFP development while it is not significant. There is a U-shaped relationship between economic development and GTFP, a negative correlation between the current provincial economic level and GTFP. Trade between provinces and countries along the route has a negative effect on GTFP. To promote GTFP development, the provinces should value foreign trade, improve innovation mechanism, cultivate talents and actively embed in the BRI construction.

1. Introduction

In April 2017, the ‘Guiding Opinions on Promoting the Construction of the Green Belt and Road’ was issued by the Ministry of Environmental Protection of China, and it stated that Belt and Road Initiative (BRI) construction should incorporate sustainable development requirements and integrate ecological concepts. A report given during the 19th National Congress of the Communist Party of China emphasised once again that ‘green’ is the major element of BRI construction, meaning that all the involved societies should promote participation in environmental preservation and pursue total factor production. Green BRI construction would effectively meet the needs of China's current economic transformation, which aims to shift from an input-driven economy to an innovation-driven one with the promotion of green total factor productivity (GTFP) as its foothold (Ji and Zhang, 2019). As a source of economic growth, GTFP comprehensively considers resource and environmental constraints as well as the input constraints of traditional TFP. Therefore, GTFP can effectively reflect the sustainability of economic development.

As the main forces in BRI implementation, primary provinces along its route can fully reap the developmental benefits brought by their extensive involvement in its construction, and their effective supports are related to BRI construction progress. Consequently, these provinces should not only take full advantage of the BRI development platform, accelerate technological innovation and pursue high-quality economic development, but also they should improve the quality and efficiency of economic development to build strong frontiers of green BRI construction.

However, current research rarely focuses on China's provinces along the BRI route, analyses their GTFP development or isolates the steps that they should take to pursue high efficiency economies, which are crucial to the effective construction and progress of the BRI itself. Moreover, because nearly five years have passed since the BRI was implemented, there is an urgent need to explore whether it has significantly promoted the development of China's provincial green economy. Doing so may provide policy makers with valuable references for further integrating BRI construction into local construction and improving BRI implementation. However, there is currently no relevant research that quantitatively analyses the net effect of BRI construction on national or provincial economic development. As a result, estimating the impact of the BRI on economic development is an important endeavour.

This study is the first to focus on China's primary provinces along the BRI route, analyse their provincial GTFP development and

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quantitatively estimate the BRI's net effect on provincial GTFP. Moreover, ways for accelerating provincial GTFP development are discussed, forming a reference for how these provinces can pursue high-quality economic development while also building powerful supports for green BRI construction. This study has three major contributions: 1) An evaluation and analysis of the GTFP development of China's primary provinces along the BRI route that employs a cutting-edge GML index based on SBM directional distance function. 2) A quantitative estimate of BRI's net effect on provincial and regional GTFP that uses regression discontinuity analysis, which is considered to be the closest method to natural experiments and superior to other causal inference methods. 3) An in-depth discussion of the practical steps that provinces can take to improve GTFP development and integrate BRI construction into local construction.

2. Literature review

Recent related research focus on the GTFP measurement and its influencing factors. Regarding GTFP measurement, Pittman (1983) applied data envelopment analysis (DEA) to take into account undesirable output for the first time. Chung et al. (1997) and Fare et al. (2001) further expanded on this by forming a directional distance function and proposing a ML (Malmquist Luenberger) index, which was more compatible with environmental concepts. Many follow-up scholars applied this method in subsequent studies. Bampatsou and Halkos (2018) estimated the GTFP of 28 EU countries. Chen and Golley (2014) estimated the changing patterns of GTFP growth in 38 China's industrial sectors. Li and Lin (2017) found that China's provincial GTFP shows an overall improving trend from 1997 to 2010 while the absolute efficiency is still at a low level. However, these studies were mostly limited to radial and oriented methods, which cannot effectively overcome the measurement bias caused by radial or oriented selection. To this end, Fukuyama and Weber (2009) formulated a more general SBM directional distance function following the non-radial and non-oriented basis proposed by Tone (2001), which is highly favoured by scholars, Song et al. (2018) analysed the GTFP of 11 provinces in the Yangtze River Economic Belt, he found that the trend of provincial GTFP development presented a U shape. Long et al. (2015) found that China's cement manufactures is facing a dilemma between economic and ecological benefits. Yao et al. (2018) found that the green total factor water efficiency of China's provinces has different development status, among which Tianjin has the best development. Given no solution of linear programming and non-transitivity usually exist in the ML index, Oh (2010) constructed a global production possibility set and presented the GML index. Since then, several scholars have evaluated GTFP with the GML index. Ren et al. (2018) found that after taking into account undesirable output, the GTFP of China's marine economy has significantly decreased, and there are great differences between coastal regional GTFP. Chen et al. (2018) measured the GTFP development of China's industrial sectors, and found that the industrial GTFP decreased by 0.02% after considering energy and environmental constraints.

Although the SBM directional distance function and the GML index can each compensate for deficiencies in previous methods, some problems remain with their individual uses. SBM directional distance function fails to effectively deal with the inconsistency of production frontier in each production unit stage, which influences the comparability of inter-temporal results. Furthermore, the absolute GML index cannot diminish the measurement deviation caused by radial and oriented problems. In contrast, the GML index based on SBM directional distance function can both effectively deal with radial and oriented problems and achieve global comparability in the production frontier. Therefore, many recent scholars have measured GTFP using a GML index based on SBM directional distance function. Lin and Chen (2018) measured the GTFP development status of 30 China's provinces, he found that the provincial GTFP development is not optimistic while there are 17 provinces whose average GTFP is less than 1. Wang et al. (2018) found that the GTFP of China's provinces presents an overall upward trend from 2004 to 2008. The above research not only effectively improved the GTFP estimation methods, but also carried on rich beneficial discussions to the GTFP. However, the existing research has not extended its perspective to China's provinces along the BRI to analyse their GTFP development, which is of great significance for promoting the effective integration of the BRI into China's local construction.

Regarding GTFP influencing factors, most scholars carry out analysis from the traditional perspective. Some scholars explored the role of environmental regulation, Zhao et al. (2018) found that there is a nonlinear relationship between environmental regulation and GTFP. Long et al. (2013) found that China's entry into the WTO did not lead to adequate improvements in environmental conditions even if the government adopted strict environmental regulations. Some scholars have recently taken carbon emissions into consideration when studying economic growth. Ahmed (2012) asserted that CO_2 emission intensity impacted productivity growth by influencing GTFP. Some scholars also considered the relationship between foreign direct investment (FDI) and GTFP, Zhang et al. (2016) indicated that FDI has strong positive effect on GTFP growth. Some scholars analysed the influence of economic development on GTFP, Zhang et al. (2014) verified a U-shaped relationship between economic development and GTFP. Moreover, Long et al. (2018a) estimated how the 2008 Beijing Olympic Games influenced the GTFP of China's cities, he found that the impact of the Olympic Games on GTFP has regional heterogeneity, especially for Beijing and its neighbour cities. The above studies conducted rich discussions on the influencing factors of GTFP, however, none of them have discussed the influence of BRI construction on China's provincial GTFP, which has important reference significance for how to make full use of the BRI construction to promote provincial GTFP growth in the future.

As a higher-level open platform, the BRI can promote the development of an open world economic system by strengthening interregional cooperation (Duan et al., 2018), which may allow China to gain value in the international market. By expanding the external demand for Chinese products, the BRI may promote China's GTFP growth in a variety of ways. First, by strengthening comparative advantages and optimising resource allocation. Following traditional international trade theory, comparative advantage is an important basis for international trade. By frequently trading with countries along the BRI route, China's provinces can export products based on their own comparative advantages, form industrial labour divisions, accelerate factor flow to further strengthen these comparative advantages and improve resource allocation efficiency. Second, by achieving economies of scale and improving technical efficiency. Smith asserted that market scope expansion can promote social division of labour. The finer the social division of labour, the more favourable it is to form economies of scale, thus raising production efficiency. As a part of a broad international market, the BRI can greatly increase the external demand for Chinese products, expand market capacity, achieve economies of scale and enhance production efficiency. Third, by increasing competitive pressure and achieving technological progress (Ji et al., 2018). While the vast international market brings more development space for Chinese enterprises, it also raises the development requirements for effective survival. Namely, the diversification and high-end demand for products acts as a strong squeeze mechanism for enterprises that want to enter the international market. To be competitive, these enterprises must prioritise technological innovation and production. Finally, by promoting economic growth through technology spillover. Export enterprises participating in the BRI often horizontally correlate with non-export enterprises. This enables the latter to both imitate advanced export-based production technologies to accelerate their own development and use the facilities provided for export enterprises to obtain timely information on international market (Ji et al., 2019), reduce the sunk costs of exports, accelerate advancements into international markets and seek greater developmental benefits. Notably, because of vertical correlation, export enterprises can also promote the industrial technological progress of both upstream and downstream enterprises, reduce production costs, improve production efficiency, accelerate workforce improvement and ultimately raise the societal GTFP.

3. Methodology and data

3.1. Research setting and sample

After its entry into the WTO, China implemented a comprehensive globalisation policy reform in 2002. Because of this international engagement, China's economy improved significantly. Considering the economic effects of globalisation and the common lag phenomenon, a sample period from 2003 to 2016 was selected for this study. This study selected 17 provinces as research samples based on the references of existing scholars and the directories of primary provinces given in 'Vision and Action of Promoting the Construction of the Silk Road Economic Belt and the 21st Century Maritime Silk Road'. Because data for Tibet were largely missing, it was excluded from this study. The total trade volume between these 17 provinces and the countries along the BRI from 2003 to 2016 accounted for an estimated 70.5% of the total trade volume between China and these countries, which indicates that the 17 primary provinces chosen in this paper have certain representativeness. The basic data for trade between China's provinces and the countries along the BRI route are from the Korean trade association database (http://www.kita.net/). The data related to China are sourced from *China's General Administration of Customs*. Other basic data for each indicator are sourced from *China Statistical Yearbook*, *China Population and Employment Statistics Yearbook, China Science and Technology Statistical Yearbook* and the regional statistical yearbooks.

3.2. Methods

3.2.1. GTFP measurement

GTFP is an important index to measure economic vitality because it can reflect the engine and quality of economic development. To measure GTFP in this study, we adopt a GML index based on SBM directional distance function.

1) The global production possibility set. A province K is represented as DMU_K, and it uses N inputs: $x = (x_1, \cdots, x_n) \in R_N^+$ and produces M desirable outputs: $y = (y_1, \cdots, y_n) \in R_M^+$ and I undesirable outputs: $b = (b_1, \cdots, b_n) \in R_I^+$. Therefore, the current production possibility set $P^t(x)$ can be expressed as:

$$P^t(x) = \{(y^t, b^t)\colon \textstyle\sum_{k=1}^{K} z_k^t y_{km}^t \geq y_{km}^t, \forall m; \quad \sum_{k=1}^{K} z_k^t b_{ki}^t = b_{ki}^t, \forall i; \\ \textstyle\sum_{k=1}^{K} z_k^t x_{kn}^t \leq x_{kn}^t, \forall n; \sum_{k=1}^{K} Z_k^t = 1, z_k^t \geq 0, \forall k\} \tag{1}$$

where z_k^t denotes the weight of each cross-section. If $z_k^t \geq 0$ indicates constant returns to scale (CRS), then $\sum_{k=1}^{K} z_k^t = 1, z_k^t \geq 0$ indicates variable returns to scale (VRS). However, because technological retrogression may occur in $P^t(x)$, consequently, Oh (2010) constructed the global production possibilities set $P^G(x)$, emphasising the consistency and comparability of the production frontier:

$$P^G(x) = \{(y^t, b^t)\colon \textstyle\sum_{t=1}^{T}\sum_{k=1}^{K} z_k^t y_{km}^t \geq y_{km}^t, \forall m; \\ \textstyle\sum_{t=1}^{T}\sum_{k=1}^{K} z_k^t b_{ki}^t = b_{ki}^t, \forall i; \\ \textstyle\sum_{t=1}^{T}\sum_{k=1}^{K} z_k^t x_{kn}^t \leq x_{kn}^t, \forall n; \sum_{t=1}^{T}\sum_{k=1}^{K} z_k^t = 1, z_k^t \geq 0, \forall k\} \tag{2}$$

2) The SBM directional distance function. Drawing on the research of Fukuyama and Weber (2009), this study defines the current SBM directional distance function that covers undesired outputs as:

$$\vec{S}_v^t = (x^{t,k'}, y^{t,k'}, b^{t,k'}, g^x, g^y, g^b) \\ = \max_{s^x, s^y, s^b} \frac{\frac{1}{N}\sum_{n=1}^{N}\frac{s_n^x}{g_n^x} + \frac{1}{M+I}\left(\sum_{m=1}^{M}\frac{s_m^y}{g_m^y} + \sum_{i=1}^{I}\frac{s_i^b}{g_i^b}\right)}{2} \tag{3}$$

$$s.\ t. \quad \sum_{k=1}^{K} z_k^t x_{kn}^t + s_n^x = x_{k'n}^t, \forall n; \quad \sum_{k=1}^{K} z_k^t y_{km}^t - s_m^y = y_{k'm}^t, \forall m; \\ \sum_{k=1}^{K} z_k^t b_{ki}^t + s_i^b = b_{k'i}^t, \forall i; \sum_{k=1}^{K} z_k^t = 1, z_k^t \geq 0, \forall k; \quad s_m^y \geq 0, \forall m; \ s_i^b \geq 0, \forall i$$

where (g^x, g^y, g^b) denotes the direction vectors for decreasing inputs, increasing desirable outputs and decreasing undesirable outputs, respectively, and (s_n^x, s_m^y, s_i^b) denotes the slack vectors for redundant inputs, inadequate desirable outputs and redundant undesirable outputs, respectively. If the value is greater than 0, the actual inputs and undesirable outputs are greater than the boundary inputs and outputs while the desirable outputs are less than the boundary outputs. The global SBM directional distance function is given as follows:

$$\vec{S}_v^G (x^{t,k'}, y^{t,k'}, b^{t,k'}, g^x, g^y, g^b) \\ = \max_{s^x, s^y, s^b} \frac{\frac{1}{N}\sum_{n=1}^{N}\frac{s_n^x}{g_n^x} + \frac{1}{M+I}\left(\sum_{m=1}^{M}\frac{s_m^y}{g_m^y} + \sum_{i=1}^{I}\frac{s_i^b}{g_i^b}\right)}{2} \tag{4}$$

$$s.\ t. \quad \sum_{t=1}^{T}\sum_{k=1}^{K} z_k^t x_{kn}^t + s_n^x = x_{k'n}^t, \forall n; \quad \sum_{t=1}^{T}\sum_{k=1}^{K} z_k^t y_{km}^t - s_m^y = y_{k'm}^t, \forall m; \\ \sum_{t=1}^{T}\sum_{k=1}^{K} z_k^t b_{ki}^t + s_i^b = b_{k'i}^t, \forall i; \quad \sum_{k=1}^{K} z_k^t = 1, z_k^t \geq 0, \forall k; s_m^y \geq 0, \forall m; s_i^b \geq 0, \forall i$$

3) GML index. With reference to Oh (2010), this study constructs a GML index based on SBM directional distance function, which can also be derived as the technical efficiency change index GEC and the technological progress change index GTC. GEC refers to the improvement of management systems and resource allocation methods. GTC mainly refers to the improvement of production technologies and manufacturing skills. The details are as follows:

$$GML_t^{t+1} = \frac{1 + \vec{S}_V^G (x^t, y^t, b^t; g^x, g^y, g^b)}{1 + \vec{S}_V^G (x^{t+1}, y^{t+1}, b^{t+1}; g^x, g^y, g^b)} = GEC_t^{t+1} \cdot GTC_t^{t+1} \tag{5}$$

$$GEC_t^{t+1} = \frac{1 + \vec{S}_V^t (x^t, y^t, b^t; g^x, g^y, g^b)}{1 + \vec{S}_V^{t+1} (x^{t+1}, y^{t+1}, b^{t+1}; g^x, g^y, g^b)} \tag{6}$$

$$GTC_t^{t+1} \\ = \frac{\left[1 + \vec{S}_V^G (x^t, y^t, b^t; g^x, g^y, g^b)\right] / \left[1 + \vec{S}_V^t (x^t, y^t, b^t; g^x, g^y, g^b)\right]}{\left[1 + \vec{S}_V^G (x^{t+1}, y^{t+1}, b^{t+1}; g^x, g^y, g^b)\right] / \left[1 + \vec{S}_V^{t+1} (x^{t+1}, y^{t+1}, b^{t+1}; g^x, g^y, g^b)\right]} \tag{7}$$

where $\vec{S}_V^t (x^t, y^t, b^t; g^x, g^y, g^b)$ and $\vec{S}_V^G (x^t, y^t, b^t; g^x, g^y, g^b)$ represent the current and global SBM directional distance functions based on non-radial and non-oriented measurements, respectively. The GML index denotes the change from period $t + 1$ to period t. If the index is greater than 1, it represents GTFP growth. If it is less than 1, it represents GTFP decline. If it is equal to 1, the GTFP is in a stable state, as are the GEC and the GTC.

3.2.2. Regression discontinuity analysis

In recent years, regression discontinuity (RD) has proven effective in the evaluation of policy effects. Thus, it can be used to measure the causal effect of the outcome variable affected by a certain discontinuous policy or external test. RD analysis was first introduced by Thistlethwaite and Campbell (1960). Based on the discontinuous fact that students will obtain a scholarship when their test scores reach a certain threshold, they analysed the scholarship's influence on these students' future academic achievements. In recent years, many scholars have applied RD analysis to policy effects (Abdulkadiroglu et al., 2017; Campello et al., 2017). Under the RD analytical framework, when the running variable x_i (time) is over a cut-off point c, individual i will either be treated or not treated, which means that there are two treatment stages $D_i = \begin{cases} 1 & x \geq c \\ 0 & x < c \end{cases}$ and two final outcomes $Y_i(1)$ and $Y_i(0)$. For our purposes, i is treated if it participates in BRI construction. Where $Y_i(1)$ represents the outcome variable affected by the policy, $Y_i(0)$ represents the outcome variable not affected by the policy. Thus, Y_i can be expressed as follows:

$$Y_i = Y_0(1 - D_i) + Y_1 D_i = Y_0 + (Y_1 - Y_0)D_i \tag{8}$$

Intuitively, the easiest way to measure a policy's effects is to calculate the difference between $Y_i(1)$ and $Y_i(0)$. However, as the provinces along the BRI route are either involved in its construction or not, it is impossible to observe both at the same time. RD analysis can effectively solve this problem by assuming that individuals distributed on both sides near the cut-off have no systematic difference except whether they accept treatment. Hence, the individuals on the left side near the cut-off can form the 'counterfactual group' on the right side.

RD analysis is divided into sharp regression discontinuity (SRD) analysis and fuzzy regression discontinuity (FRD) analysis. As primary provinces along the route did not immediately participate in its construction after the BRI was proposed, the FRD is the more suitable option. Under the local continuity hypothesis, suppose that the outcome variable GTFP exists in two states, $E(Y_0|X)$ and $E(Y_1|X)$, with the following characteristics:

$$\lim_{x\downarrow c} E(Y|X) - \lim_{x\uparrow c} E(Y|X) = \tau\left[\lim_{x\downarrow c} E(D|X) - \lim_{x\uparrow c} E(D|X)\right] + \lim_{x\downarrow c} E(Y_0|X) - \lim_{x\uparrow c} E(Y_0|X) \tag{9}$$

Because of its continuity, $\lim_{x\downarrow c} E(Y_0|X) - \lim_{x\uparrow c} E(Y_0|X) = 0$. If there is a jump in the GTFP at the cut-off point c, then $\lim_{x\downarrow c} E(D|X) - \lim_{x\uparrow c} E(D|X) \neq 0$, and the local average treatment effect of the BRI on provincial GTFP can be expressed as follows:

$$\tau = LATE = \frac{\lim_{x\downarrow c} E(Y|X) - \lim_{x\uparrow c} E(Y|X)}{\lim_{x\downarrow c} E(D|X) - \lim_{x\uparrow c} E(D|X)} \tag{10}$$

Considering the practical problems in this paper and drawing on the research of Lee and Lemieux (2009), this study sets the cut-off point in 2014. The main reason is that the BRI was officially proposed in October 2013, since policy implementation often has a reaction period and lag effect, and actually most relevant planning and promotion programs of BRI construction were officially started in 2014. For example, in order to effectively support the construction of BRI, China's government set up the Silk Road Fund in 2014, which aimed to provide investment and financing support for the BRI infrastructure construction, resource development, industrial and financial cooperation and other projects related to connectivity. Setting 2013 as the cut-off may have resulted in an underestimation of the policy's effect. Therefore, 2014 was chosen as the optimal cut-off point.

FRD estimation can be performed by non-parametric IV estimation or parameter 2SLS estimation, the two have equivalent results (Imbens and Lemieux, 2008). This study uses the latter and the estimation equation is given as follows:

$$Y_i = \alpha_0 + \alpha_1 D_i + \alpha_2(x_i - c) + \alpha_3 D_i(x_i - c) + \alpha_4 Z_i + u_i \tag{11}$$

where Y_i denotes the GTFP of primary provinces along the route (Ln$GTFP$), α_1 denotes the treatment effect, D_i denotes the treatment variable representing provinces' participation in BRI construction, S_i denotes the indicator variable used as its instrumental variable $S_i = 1(x_i \geq c)$ and Z_i denotes covariates. The interaction term $D_i(x_i - c)$ is introduced to allow the regression line to have different slopes on either side of the cut-off point.

3.3. Variables and measurements

3.3.1. Input indicators

In terms of evaluation indicators, most scholars use labour, capital and energy as input indicators (Feng et al., 2018; Chen et al., 2019). For labour input, we use the number of employed people at the end of year in each province. For capital investment, we use Goldsmith's perpetual inventory method (PIM) to measure the productive capital stock in each province. The formula is as follows:

$$K_t = K_{t-1}(1 - \delta_t) + I_t \tag{12}$$

where K_t, δ_t, I_t represent capital stock, depreciation rate and investment amount in year t, respectively. Compared with the fixed assets investment of the whole society, the total fixed capital formation is slightly better than the former when measuring capital stock. Therefore, this study uses the latter as its investment amount. Simultaneously, to ensure the continuity and comparability of the data, it is converted into the 2003 base period using the fixed asset investment index. The capital stock of the base period is measured using the revised initial capital stock growth rate method proposed by Reinsdorf. The formula is as follows:

$$K_0 = I_0(1 + g)/(g + \delta) \tag{13}$$

where K_0, I_0, g represent the initial capital stock growth rate, capital investment and constant price investment, respectively. Since the capital stock calculation is quite sensitive to the depreciation rate, we continue the practice of most scholars and adopt the value of 10.96%. For energy input, this study uses the equivalent energy consumption after the standard coal method conversion.

3.3.2. Output indicators

Output indicators include desirable output (Li et al., 2016; Long et al., 2018b) and undesirable output (Li et al., 2018; Wu et al., 2017). Reference to previous studies, the desirable output is characterised by the GDP of each province. To ensure the comparability of the data, it is converted based on the year 2003. Undesirable outputs generally have three forms: waste water, waste gas and solid waste. However, a single pollutant cannot fully reflect the environmental restraint mechanism. By combining the main control objects from the '13th Five-Year Plan for Energy Conservation and Emission Reduction', this study uses COD and ammonia nitrogen emissions to characterise waste water, SO_2 and smoke (powder) dust emissions to characterise waste gas and industrial solid waste emissions to characterise solid waste. Because of the limited number of indicators used in DEA evaluation, this study applies the principal component analysis method to convert the above indicators into a comprehensive pollution index.

3.3.3. Covariates of regression discontinuity

Reasonable R&D investment promotes industrial structure upgrading, this study uses R&D investment from industrial enterprises above a scale to represent (LnRD). Economic development affects

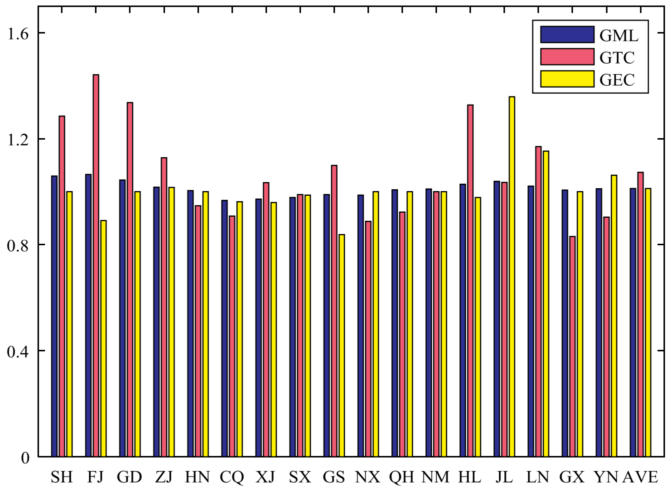

Fig. 1. GTFP development status in the primary provinces along the BRI route.

technological progress and production efficiency, given the possible non-linear relationship between it and environmental pollution, the value of per capita income (Ln*EL*) and its squared term ($\mathrm{Ln}^2 EL$) are introduced, respectively. To investigate BRI influence on provincial GTFP, the total amount of trade between these provinces and 64 countries along the route from 2003 to 2016 is used to represent provincial foreign trade (Ln*Trade*).

As the GML index represents the variation of period $t+1$ relative to period t, which is not comparable, this study transforms it into a cumulative index. Assuming that the GTFP in the first period is 1, the GTFP of the period $t+1$ is $GTFP_{t+1} = GML_t^{t+1} \cdot GTFP_t$.

4. Results

4.1. GTFP development status

4.1.1. Provincial GTFP development

As shown in Fig. 1, the GTFP development status of primary provinces along the BRI route is generally good. The average GML index during 2003–2016 is 1.012, average GTC index is 1.073 and average GEC index is 1.012. It means that during this period, provincial GTFP increased by an average of 1.2%, green technological progress by an average of 7.3% and green technical efficiency by an average of 1.2%. Meanwhile, the GTFP development varies greatly among the provinces, among which Fujian, Shanghai and Guangdong develop well while Chongqing and Xinjiang poorly developed.[1]

To deeply analyse the evolutionary characteristic of provincial GTFP and identify its driving force, this study also examines the general development trend and its GTFP decomposition from 2003 to 2016 (Fig. 2). In terms of growth trend, the provincial GTFP has a remarkable trend, especially the technological progress. In terms of driving forces behind GTFP development, technological progress and GTFP show great synchronization, while there is no strong correlation between technical efficiency and GTFP, and the green technical efficiency is generally lower than technological progress and GTFP. This indicates that technological progress is the main driving force of provincial GTFP growth, the involved provinces should not only continue to develop their technological progress, but also improve technical efficiency and release new development potential.

[1] SH, FJ, GD, ZJ, HN, CQ, XJ, SX, GS, NX, QH, NM, HL, JL, LN, GX, YN, AVE represent Shanghai, Fujian, Guangdong, Zhejiang, Hainan, Chongqing, Xinjiang, Shanxi, Gansu, Ningxia, Qinghai, Inner Mongolia, Heilongjiang, Jilin, Liaoning, Guangxi, Yunnan, Average respectively.

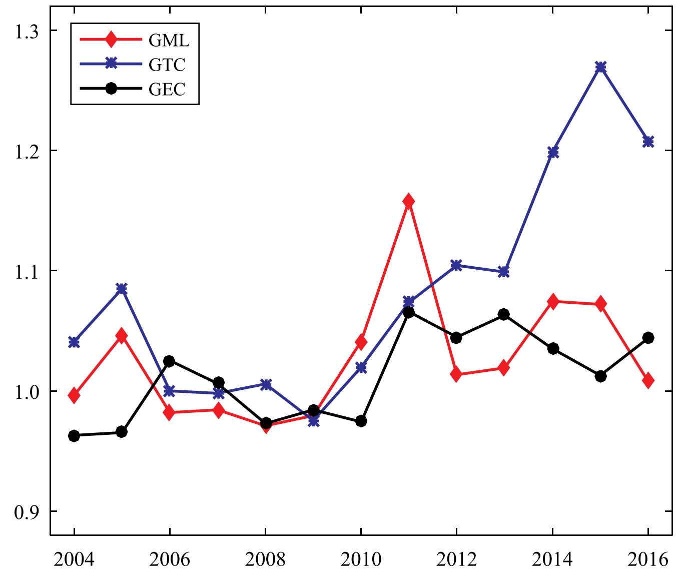

Fig. 2. Evolutionary characteristics of provincial GTFP along the BRI route.

4.1.2. Regional heterogeneity of GTFP development

In view of the great differences in economic level and trade pattern between provinces along the Silk Road Economic Belt (SREB) and the Maritime Silk Road (MSR), which indicate that the GTFP development may vary greatly between the two regions. Therefore, after dividing primary provinces into the SREB and MSR, this study makes a comparative analysis of regional heterogeneity of GTFP development. According to the functional orientation of the provinces along the BRI in 'Promoting the Vision and Action of the Joint Construction of the Silk Road Economic Belt and the 21st Century Maritime Silk Road', the geographical location, and the trade patterns between them and countries along the route, Xinjiang, Shanxi, Gansu, Ningxia, Qinghai, Inner Mongolia, Heilongjiang, Jilin, Liaoning and Chongqing are divided into provinces along the SREB; Guangdong, Fujian, Zhejiang, Shanghai, Hainan, Guangxi and Yunnan are divided into provinces along the MSR.

As is shown in Fig. 3a, the GTFP development of SREB route shows an overall downward trend. From 2003 to 2016, the average GML, GTC and GEC index is 1.000, 1.037 and 1.023 respectively, which means that during the sample period, GTFP development of the SREB is stable, green technological progress increased by 3.7%, and green technical efficiency increased by 2.3%. Both the green technological progress and green technical efficiency promote the regional GTFP development.

However, as shown in Fig. 3b, GTFP development of the MSR shows an overall upward trend. Its average GML, GTC and GEC index during the sample period is 1.029, 1.124 and 0.996 respectively, which means that the GTFP of MSR increased by 2.9%, the green technological progress increased by 12.4%, and the green technical efficiency decreased by 0.4%. Moreover, the green technological progress is a powerful driver of the regional GTFP development while the green technical efficiency mainly plays a restrictive role. In conclusion, the GTFP development status of the two regions is quite different, each region should improve its own GTFP development accordingly.

4.2. Influence of BRI on provincial GTFP

4.2.1. Graphic analysis

The basic idea of the FRD analysis is as follows: if provincial GTFP has a significant jump around 2014, then this change may have been caused by the BRI construction. Hence, before the formal FRD analysis, this paper demonstrates the relationship between GTFP and the running variables. This graphic analysis method is standard practice in RD analysis, and it helps us to intuitively comprehend the impact of BRI

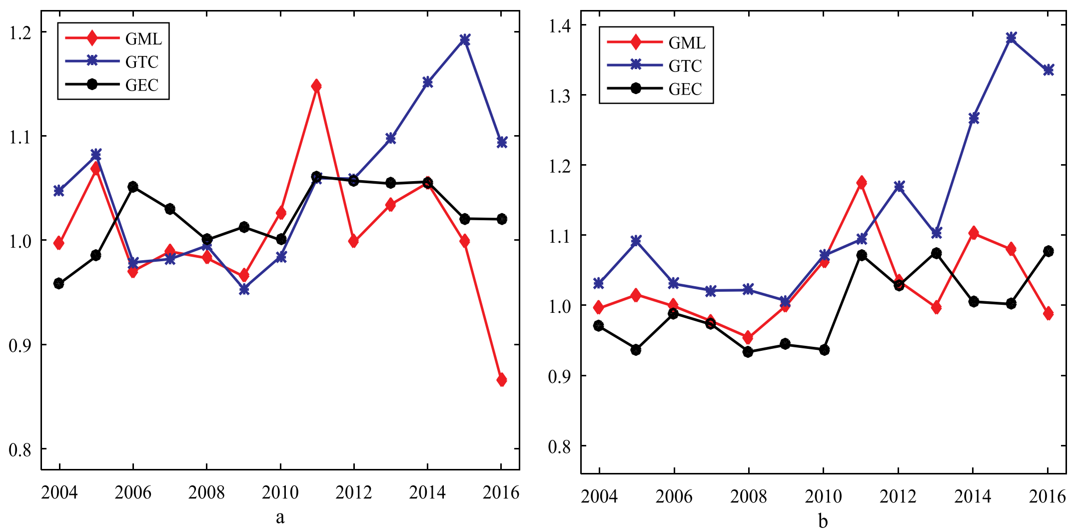

Fig. 3. Evolutionary characteristics of regional GTFP along the SREB and MSR.

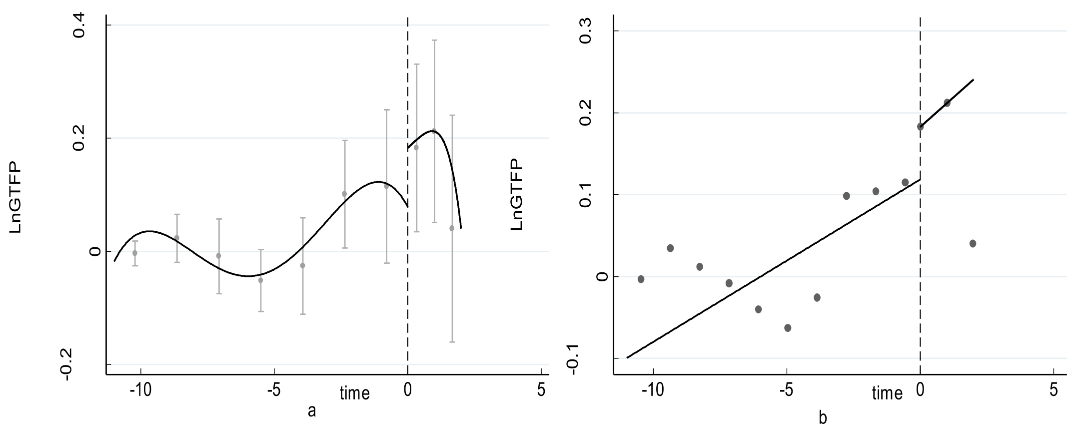

Fig. 4. Relationship between provincial GTFP and running variables.

Table 1
Effect of the BRI on provincial GTFP.

Variables	(1)	(2)	(3)	(4)	(5)
D	0.138***(3.20)	0.122*** (2.80)	0.101** (2.33)	0.090** (1.98)	0.092** (2.32)
Ln*RD*		−0.065* (−1.90)	−0.044 (−1.29)	−0.041 (−1.34)	−0.020 (−0.80)
Ln*EL*			−0.425*** (−2.86)	−4.105*** (−7.74)	−3.896*** (−7.39)
Ln^2EL				0.203*** (7.17)	0.206*** (7.78)
Ln*Trade*					−0.038* (−1.79)
cons	0.079*** (3.16)	0.393** (2.35)	4.736*** (3.10)	21.030*** (7.91)	18.463*** (6.93)
R^2	0.1518	0.1657	0.1961	0.3512	0.3551
Wald	59.46	63.80	74.06	142.72	119.36

Note: the z value in brackets, *, ** and *** indicate that the statistical value is significant at 10%, 5% and 1%, respectively.

Table 2
Effect of the BRI on regional GTFP along the SREB.

Variables	(1)	(2)	(3)	(4)	(5)
D	0.143*** (2.61)	0.107** (1.96)	0.105** (1.96)	0.085** (1.96)	0.079** (1.99)
Ln*RD*		−0.127*** (−2.78)	−0.125*** (−2.62)	−0.056 (−1.54)	−0.025 (−0.64)
Ln*EL*			−0.035 (−0.16)	−3.557*** (−3.75)	−3.081*** (−3.27)
Ln^2EL				0.189*** (4.06)	0.168*** (3.69)
Ln*Trade*					−0.088*** (−2.91)
cons	0.066*** (2.08)	0.637** (3.07)	0.992 (0.44)	16.909*** (3.42)	14.616*** (2.94)
R^2	0.1447	0.1942	0.1944	0.2695	0.3702
Wald	26.89	36.05	35.80	44.49	119.36

Note: the z value in brackets, *, ** and *** indicate that the statistical value is significant at 10%, 5% and 1%, respectively.

Table 3
Effect of the BRI on regional GTFP along the MSR.

Variables	(1)	(2)	(3)	(4)	(5)
D	0.130** (2.13)	0.120** (1.96)	0.105** (1.97)	0.099** (2.01)	0.091** (1.96)
Ln*RD*		−0.056 (−1.21)	−0.011 (−0.22)	−0.007 (−0.18)	−0.015 (−0.38)
Ln*EL*			−0.577** (−2.42)	−3.557*** (−7.16)	−3.906*** (−5.25)
Ln^2EL				0.260*** (6.58)	0.229*** (5.35)
Ln*Trade*					−0.105* (−1.82)
cons	0.097*** (2.74)	0.399 (1.59)	6.254*** (2.57)	19.794*** (6.91)	16.745*** (5.09)
R^2	0.3680	0.3785	0.4181	0.6143	0.6289
Wald	73.92	75.80	85.88	171.30	179.23

Note: the z value in brackets, *, ** and *** indicate that the statistical value is significant at 10%, 5% and 1%, respectively.

Table 4
Test of the conditional density function.

Variables	coefficient	standard error	z value	P value
LnRD	−0.015	0.807	−0.02	0.985
LnEL	−0.020	0.256	−0.08	0.938
Ln^2EL	−0.391	5.319	−0.07	0.941
LnTrade	0.053	1.086	0.05	0.961
lwald	0.073	0.158	0.46	0.646

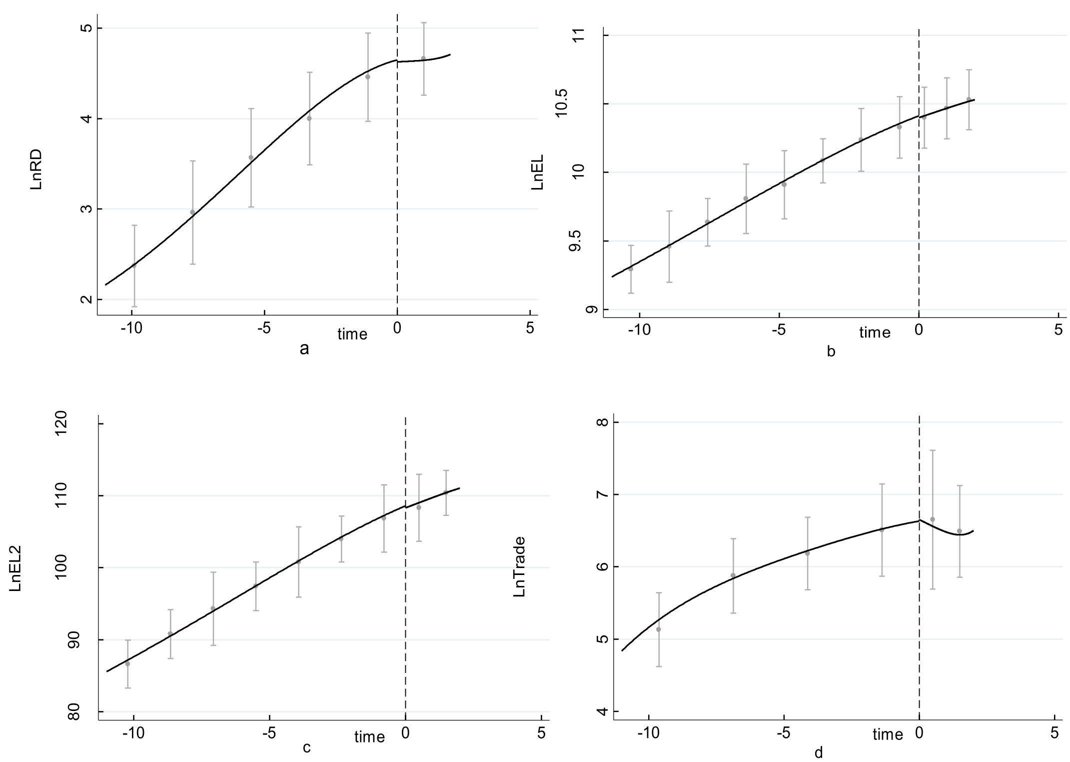

Fig. 5. Variation of the covariates with the running variable.

construction on provincial GTFP. As seen in Fig. 4a, provincial GTFP shows a significant jump in 2014, which indicates that BRI construction may have promoted provincial GTFP. Likewise, Fig. 4b also demonstrates the significant and positive effect of BRI construction on provincial GTFP.

4.2.2. Results of the regression discontinuity analysis

As seen in Fig. 4, the BRI construction has led to a discontinuous change in provincial GTFP, meaning that the BRI may have promoted provincial GTFP. To isolate the specific effect of this promotion, we first analyse the treatment of BRI construction on provincial GTFP and then introduce each covariate in turn, as introducing these covariates improves our estimation. The details are as follows:

As seen in Table 1, the coefficients of treatment variable D do not change significantly whether or not each covariate is added, and this reflects the robustness of model estimation. As seen in column (1), the BRI has significantly improved provincial GTFP with impact coefficient of 0.138. Among the covariates, R&D investment has a non-significant effect on provincial GTFP. Many recent studies have also obtained this peculiar result, the reason might be that the irrational and overlapping structure of provincial R&D funding leads to an ineffective ecological development. The current average structural ratio of provincial R&D funding (basic research + applied research): experimental development from 2009 to 2016[2] is 1:3.5, which is much lower than China's optimal funding structure 1: 2.23 (Song et al., 2012), too much R&D funding is overinvested into the experimental research while the funding for basic research is insufficient. The irrational structure of R&D expenditure restricts the efficiency of resource allocation and hinders the provincial GTFP growth.

[2] Before 2009, the specific expenditure structure of R&D expenditure in some provinces was seriously deficient, so the sample period of research was limited to 2009–2012.

Table 5
Effect of the BRI on GTFP with different bandwidths.

Variables	[−9,3]						[−8,3]					
	The BRI		the SREB		The MSR		The BRI		the SREB		The MSR	
D	0.123*** (2.78)	0.097** (2.33)	0.136** (2.44)	0.090* (1.73)	0.103** (1.99)	0.086* (1.91)	0.100** (2.23)	0.083** (1.96)	0.113** (2.01)	0.082** (1.98)	0.080* (1.91)	0.069* (1.95)
Ln*RD*		−0.035 (−1.15)		−0.080 (−1.27)		−0.021 (−0.45)		−0.037 (−1.10)		−0.071 (−1.02)		−0.049 (−0.81)
Ln*EL*		−4.162*** (−5.99)		−2.852** (−2.48)		−4.667*** (−4.56)		−4.307*** (−5.33)		−2.909** (−2.22)		−5.134*** (−4.21)
Ln^2EL		0.220*** (6.33)		0.166*** (3.00)		0.278*** (4.68)		0.228*** (5.65)		0.173*** (2.73)		0.315*** (4.51)
Ln*Trade*		−0.055** (−2.15)		−0.127*** (−3.71)		−0.073 (−0.95)		−0.058** (−2.15)		−0.136*** (−3.85)		−0.068 (−0.70)
cons	0.094*** (3.41)	0.393** (2.35)	0.073** (2.10)	12.927** (2.11)	0.123*** (3.24)	19.058*** (4.29)	0.117*** (4.03)	20.476*** (4.97)	0.096*** (2.63)	12.844* (1.85)	0.146*** (2.68)	19.951*** (3.76)
R^2	0.1702	0.3352	0.1677	0.4608	0.4189	0.6032	0.2069	0.3497	0.2072	0.1990	0.4573	0.6191
Wald	63.00	93.71	28.47	63.28	82.29	146.51	69.20	91.55	31.42	63.15	89.11	146.12

Note: the z value in brackets, *, ** and *** indicate that the statistical value is significant at 10%, 5% and 1%, respectively.

Economic development and GTFP have a U-shaped relationship, and current provincial economic development and GTFP show a negative correlation. The environmental Kuznets curve proposes that when economic development is at a low level, pollution will increase alongside economic development, which then will restrict GTFP growth. When economic development reaches a certain stage, pollution will slow down and environmental quality will improve, which is conducive to GTFP growth. During the research sample period, most provinces were left of the inflection point. A few exceptions included Shanghai, Guangdong and Zhejiang, which were always right of it. This indicates that the low economic development level of corresponding provinces restricted the GTFP development. To improve themselves, provinces along the BRI route should prioritise economic construction and development.

Notably, the arrival of inflection point does not imply immediate environmental quality improvement. This improvement requires not only a long accumulation period, but also a certain external pressure. Many studies (Grossman and Krueger, 1995) have stressed that economic growth does not automatically lead to increased environmental quality, which instead requires effective environmental policy intervention. Accordingly, these provinces should allow environmental policies to intervene in their operations, as this will bolster green economic development.

Trade between primary provinces and countries along the BRI had a negative effect on provincial GTFP. We purpose two possible reasons for this. First, the trade structure between primary provinces and these countries is still irrational. During the early stages of trade, the commodities exported from the primary provinces were primarily low-tech and labour-intensive products. Following the traditional static comparative advantage theory, this low-quality trade expansion undoubtedly led to a comparative advantage concentration in traditional sectors with limited technological growth, in turn hindering GTFP development. Second, the promotion of GTFP by foreign trade often has obvious 'threshold' characteristics. That is, when factors such as economic development and R&D reach certain levels, foreign trade will have clear positive effects on GTFP. Hence, the primary provinces with low economic development and R&D have not effectively supported sustainable green economy development, resulting in the negative effect of foreign trade on GTFP.

4.3. Regional heterogeneity analysis

The foregoing analysis has shown that there is obvious regional heterogeneity in the GTFP development between the SREB and the MSR, which means that the influence of the BRI on the two regional GTFP may be different. Therefore, this study makes a comparative analysis of the heterogeneous effect of the BRI on two regional GTFP.

As is shown Tables 2–3, the BRI has significantly promoted regional GTFP development along the SREB and the MSR. The influence coefficient of the BRI on two regional GTFP is 0.143 and 0.130 respectively, which indicates that the BRI construction has brought tangible development dividend to regions along the route, the regions have achieved their own development when actively participate in the BRI construction. This can further strengthen the confidence to promote the BRI construction. After adding the covariates in sequence, the coefficients of the treatment variable D do not change significantly, which reflects the validity and robustness of the estimation results. The influence of covariates on two regional GTFP is basically consistent with the overall situation along the BRI, which will not be repeated here.

4.4. Validity test

This study will now test the validity of previous estimations. The validity of RD estimation requires that the running variable not to be manipulated accurately by the individual. The running variable used in this study is the year. Because the chosen provinces were unable to

Table 6
Effect of the BRI on GTFP with 2013 as the cut-off point.

Variables	The BRI		the SREB		The MSR	
D	0.119*** (2.84)	0.072* (1.86)	0.138*** (2.74)	0.089* (1.71)	0.078 * (1.92)	0.043* (1.88)
Ln*RD*		−0.019 (−0.78)		−0.023 (−0.57)		−0.023 (−0.74)
Ln*EL*		−3.856*** (−7.10)		−3.023*** (−3.00)		−3.817*** (−6.32)
Ln^2EL		0.204*** (7.48)		0.166*** (3.39)		0.203*** (6.82)
Ln*Trade*		−0.033 (−1.57)		−0.080** (−2.57)		−0.033 (−0.76)
cons	0.047* (1.79)	18.263*** (6.66)	0.034 (1.00)	14.192*** (2.68)	0.066* (1.78)	17.910*** (5.88)
R^2	0.1363	0.3278	0.1071	0.3051	0.3687	0.6073
Wald	54.48	107.57	20.40	43.36	74.10	133.22

Note: the z value in brackets, *, ** and *** indicate that the statistical value is significant at 10%, 5% and 1%, respectively.

anticipate their roles in the BRI construction before it was announced, there is no self-selection problem to consider. Moreover, the validity of RD estimation also requires that the covariates not have a significant jump at the cut-off point. Otherwise, the treatment effect at the cut-off point cannot be attributed to the analysed policy. Therefore, this study tests the variation of each covariate with the running variable and its conditional density function.

As shown in Table 4 and Fig. 5, no covariate has a significant jump at the cut-off point, meaning that all covariates have the required smoothness.

The validity of RD estimation also requires for the consistency of the treatment effect not to be affected by whether or not the covariates are added, this has been shown above. In addition, the validity also specifies bandwidth selection parameters. Considering the requirements for RD estimation sample sizes, this study sets the bandwidths to [-9, 3] and [-8, 3], respectively. The details are as follows:

Table 5 demonstrates that the BRI construction has a significant positive effect on provincial and two regional GTFP, regardless of the bandwidth setting used. Moreover, the influence coefficients of the covariates were similar to those of the above estimation, which indicates that our results are valid once again.

Finally, to test whether the BRI construction has a lag affect, we used 2013 as the cut-off point and then tested the effect of BRI construction on provincial and two regional GTFP (Table 6). The results show that BRI construction still had significant positive effects on provincial and two regional GTFP while the promotion effect is lower than estimation using 2014 as cut-off point. This reflects that there is indeed a lag effect in the promotion of the BRI and 2014 remains a more appropriate cut-off point.

5. Conclusions and policy implications

5.1. Main conclusions

This study focuses on China's primary provinces along the BRI route, analyses the provincial GTFP development by the GML index based on SBM directional distance function and quantitatively estimates the net effect of BRI construction on provincial GTFP. The results of our study show that provincial GTFP development is generally good and define its main driving force as technological progress, there are significant differences in GTFP development between regions along the SREB and the MSR. Overall, the BRI construction has significantly promoted the growth of provincial and two regional GTFP. R&D investment inhibits provincial GTFP development while is not significant. Economic level and GTFP performance has a U-shaped relationship, and provincial economic development and GTFP have a negative correlation. Trade between these provinces and countries along the BRI route has a negative effect on the current provincial GTFP, and this may stem from the unreasonable trade structure as well as provincial economic and R&D constraints.

5.2. Policy implications

To speed up provincial GTFP development and effectively build the frontiers of BRI construction, following suggestions are given.

1) Leverage foreign trade, develop a green economy. The promotion of foreign trade to GTFP requires the support of a reasonable trade structure and advanced economy. Primary provinces should utilise BRI construction opportunities, improve their trade structures, produce energy-efficient and high-end trade commodities and internalise advanced production technologies to develop high-end value chains. Meanwhile, ecological economy development should be given the highest priority. These provinces ought to welcome environmental intervention measures, improve the quality and efficiency of their economic development and accelerate GTFP growth by harnessing the spillover effect of foreign trade.
2) Improve the innovation mechanism, value a talented workforce. Provincial governments should effectively utilise their innovative enterprises, strengthen ecological supervision, refine regulatory measures, improve the compensation mechanism, and provide technological and financial support to those enterprises that promote technological innovation with the BRI funding. Subsidies such as tax reductions and sewage charge refunds for environmental enterprises should be implemented to reduce technological innovation costs. Moreover, these provinces should recruit high-level individuals from overseas, effectively establishing a talent recruitment mechanism that increases human resource capital.
3) Emphasise technological innovation, optimise R&D structure. R&D intensity is important to the continuous innovation capability and development potential, primary provinces should increase their R&D investments. The government itself should increase its R&D investment and encourage enterprises, universities and other R&D institutions to do the same. Moreover, R&D distribution structure should remain rational, avoiding resource redundancy and overlapping waste, and improve factor utilisation. In particular, future policies should transfer more R&D investment to basic research.
4) Actively embed in the BRI construction, improve production efficiency. As the important implementers of the BRI construction, enterprises should further enhance their participation, expand overseas markets, improve international operation capacity, achieve economies of scale and improve technical efficiency. And they should also attach importance to scientific and technological innovation, promote industrial upgrading, strengthen the technical exchanges and cooperation with developed countries along the BRI, absorb their advanced production concepts and technologies to improve production efficiency.

5.3. Limitations and future research

This paper has several limitations and can be expanded by further research in plenty of ways. First, based on the overall perspective of economic development, this study analyse the impact of the BRI on provincial GTFP, however, different industries adopt distinct embedding mechanisms to participate in BRI construction because of the industrial heterogeneity. This means that the BRI may uniquely influence these industries. So further research can distinguish the effects of the BRI on various industries, analyse their distinctive influence mechanisms and explore how specific industries can use the BRI to promote their own development as well as improve BRI implementation.

Second, due to the data limitation, this study does not further analyse the impact of the BRI on the GTFP of Chinese enterprises. However, the enterprises are actually the main bodies and practical implementers of the BRI, which can not only benefit from the BRI construction, but also their own performance can exert important influence on the BRI construction. Therefore, further research could expand on the perspectives of these firms, evaluate their GTFP development, estimate the impact of the BRI on them and analyse how they can take advantage of the BRI to promote technological progress and accelerate the their pace of internationalization.

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ARTICLE

The UN's 2030 Agenda for sustainable development and the maritime transport domain: the role and challenges of IMO and its stakeholders through a grounded theory perspective

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Abstract In September 2015, the United Nations (UN) officially adopted the 2030 Agenda for Sustainable Development together with 17 sustainable development goals (SDGs) (UN, 2016). The attainment of the SDGs requires a strong commitment by all UN Member States, not least by the Member States at the International Maritime Organization (IMO). This empirical research aims to identify the role and challenges of stakeholders at IMO, when implementing the UN's 2030 Agenda in the international maritime transport domain using a grounded theory approach. This paper describes the methodology and the analytical process undertaken and presents the main findings based on empirical data. The results are presented as a set of six propositions. The first proposition presents the phenomena engulfing Member States at IMO stemming out from lack of knowledge and policy incoherency on the 2030 Agenda at national level. The other five propositions suggest how these challenges could potentially be best alleviated through an IMO-led strategy on sustainable development within the context of the 2030 Agenda, supported by an appropriate governance structure that sees the introduction of strategic actors for coordinating the implementation of the SDGs at national level. With the support of a Task Force, and by also making use of the IMO Member State Audit Scheme (IMSAS), to create more awareness and ownership, the strategic actors could work towards balancing the three dimensions of sustainable development—the economic, the environmental, and the social dimensions—which were found to be imbalanced in the international maritime transport domain.

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1 Introduction

According to the United Nations Conference on Trade and Development (UNCTAD), around 80% of global trade by volume and over 70% of global trade by value is carried by sea and is handled by ports worldwide. In developing countries, these percentages can be even higher. In 2015, world seaborne trade volumes were estimated to have surpassed 10 billion tons (UNCTAD 2016). Shipping is by far the most cost-effective and efficient mode of international transportation of raw material, manufactured goods, and other essential cargo (IMO 2017a). Therefore, shipping needs to remain sustainable—hence, sustainable development is paramount to international shipping, insofar as it has a great global impact. It is here where the United Nations' newly adopted Development Agenda "Transforming our World: The 2030 Agenda for Sustainable Development" and the 17 sustainable development goals (SDGs) fully come to play. While the SDGs neither refer directly to transport nor to maritime transport, the UN Interagency Expert Group on Sustainable Development Goal Indicators, considers shipping as a critical factor for the effective realization of eight goals and 11 targets, both directly and indirectly (UNCTAD 2016). So, the sustainable development of maritime transport raises major challenges not only for the sector but also in terms of global governance.

1.1 IMO as the global standard-setting authority for the maritime transport industry

The International Maritime Organization (IMO)[1], as the global standard-setting authority for the safety, security, and environmental performance of international shipping, has an important role to play in the attainment of the SDGs because it can create a more effective regulatory framework for the maritime transport industry (IMO 2017c). As stated by the IMO Secretariat during the last Assembly, "IMO is fully committed to achieving the 2030 Agenda and the SDGs, including aligning its programmes and initiatives to support Member States" (IMO (2017j, annex 1, p. 4). Therefore, IMO has the responsibility to play a full and active role in achieving the 2030 Agenda and the SDGs and to provide support to its Member States through, inter alia, policy advice, and technical cooperation, particularly when implementing the SDGs within Member States' national setup through their respective national sustainable development strategies.

1.2 A problem that needs to be addressed

Similar to what has happened with the Millennium Development Goals (MDGs), the United Nations' 2030 Agenda for Sustainable Development could also become an integral part of the work of IMO (IMO 2017j, annex 1, p. 4), not only in terms of

[1] (http://www.imo.org/en/Pages/Default.aspx).

technical cooperation but also across all other sectors that IMO caters for through its organs (IMO 2015). However, in order to do so, as the findings of this study based on empirical data will suggest, the main challenge that the 2030 Agenda poses to the IMO must be addressed, i.e., Member States must be more rigorously engaged and committed in coming forward with proposals on how IMO could achieve the 2030 Agenda and the SDGs in a balanced and integrated manner when embracing the three dimensions of sustainable development (economic, social, and environmental) within the context of its programs and initiatives. Although discussions on how IMO could potentially contribute towards the fulfillment of the SDGs have started, particularly in the Technical Cooperation Committee (TCC), the present list of outputs for the 2018–2019 biennium of the Strategic Plan of IMO for the 6-year period 2018–2023 contain only two outputs related to SDGs listed under two Strategic Directions out of seven Strategic Directions in total (IMO 2017k). In respect of the implementation of the 2030 Development Agenda and the SDGs, IMO is almost 2 years behind other United Nations System bodies; the latter are far ahead of IMO in linking their work to the SDGs (IMO 2017d). As IMO mainly depends on the input that its Member States put forward for discussion and agreement, there are several reasons why IMO Member States have been slow in reacting to the 2030 Agenda within the context of the work that IMO does.

Based on grounded data and using a constructivist approach, this paper aims to provide answers on why this delay has happened which, in most cases, are far beyond the IMO's Secretariat remit. This paper is structured in two parts. The first part, which comprises Sections 1 and 2, discusses elements within the literature on sustainable development and provides an overview of the current state of play on the implementation of the 2030 Agenda at IMO. Subsequently, the second part, in Sections 3 to 5, explains the methodological model applied and the analytical framework used and presents the analysis of the main findings of the empirical research and concludes by presenting the propositions which also provide the basis for further research.

2 Literature review on sustainable development

Literature on the importance of sustainable development for the international maritime transport domain is limited and much less on what the stakeholders, particularly those involved at policy decision making at IMO and at national levels, are doing in this respect. The essence of the 2030 Agenda is primarily based on sustainable development and there seems to be a clear understanding among researchers that both strategy and governance play a critical role in facilitating and putting in place a sustainable development program, particularly from a political commitment point of view (Jordan and Lenschow 2008; Lafferty 2004; UN 2016). Sustainable development seeks to balance the needs of the current generation with those of the future; the concept is essentially about the integration of a short-term and long-term timescales in policy making (Lafferty 2004). Swanson et al. (2004) suggest that despite the progress made, nations are only at the early stages of learning towards effective strategic and coordinated action for sustainable development, particularly at a global level. On the implementation of sustainable development, Rist (2008) submits that the big question is "how?" This question applies also very squarely to the international maritime transport domain. The stakeholders should agree on what needs to be done concretely to narrow down any identified gaps by setting clear SDG-related outputs in the IMO's Strategic Plan.

Turning on governance, Lafferty (2004) concluded that sustainable development faces clear challenges often inherent in the complexity of the concept. Jordan (2008) shares the same view and suggests that sustainable development does not just "happen" in an automatic or preordained way. Kemp and Parto (2005) describe governance as the process of decision making and the process by which decisions are implemented. They claim that the most significant challenge related to governance for sustainable development is to ensure that multi-player governance regimes embody capacity for sustainability-oriented coordination, direction, and re-direction. Adams and Luchsinger (2017) stated that the implementation of the 2030 Agenda is not just a matter of having better efficiency and effectiveness but is more on how the UN development system can meet the high demands of new commitments aimed at transforming the course of development with a view to be equitable and sustainable. In order to effectively implement a sustainable development policy, it would be desirable to have strong political commitments as Member States have the tendency to engage in a rather unstructured way in adopting and dropping administrative instruments. If aspects of sustainable development are not part of the mindset of leaders and members of the organization, it would affect the efficiency of the core business and its objectives would not be attained (Baumgartner 2009). Broadly speaking, it is a challenge for the maritime policy makers to adopt innovative government approaches in pursuit of sustainable development at national level and at international level.

2.1 Taking stock—what has been done so far at IMO on sustainability

The issues that have been raised in the preceding section could potentially be critical for policy makers representing their Member States at IMO when dealing with sustainable development matters. IMO, mainly as a Secretariat, was instrumental in proposing the concept for Sustainable Maritime Transport System (SMTS) in 2013 in a rather comprehensive way (IMO 2013a).[2] SMTS, as a concept, listed a number of imperatives or overall goals that IMO Member States particularly policy makers directly involved in shipping and maritime industries must aspire to in order to establish such a system. One of the three aims of SMTS was "to identify the various 'imperatives' or goals that must be met to implement a SMTS, and the activities that will need to be undertaken to achieve them—possibly requiring actions by the relevant bodies and the various maritime stakeholders. It should be borne in mind that the goals are not to be conceived as measurable results, but rather an expression of a desirable state" IMO (2013b, p. 5). Despite the effort that was made by the IMO Secretariat in coming up with the SMTS concept, the IMO's stakeholders were not so forthcoming in determining what should be done in concrete terms to meet the "imperatives" or "goals" as outlined by the SMTS concept. Through the SMTS, Member States could have championed sustainability and could have laid down the path towards putting measures in place to have

[2] The SMTS was launched on September 26, 2013 by IMO during a special 1-day symposium it hosted on a Sustainable Maritime Transportation System—it was the 36th celebration of World Maritime Day and the theme was "Sustainable Development: IMO's contribution beyond Rio+20" (IMO 2013a).

sustainable shipping on international scale—thus serving as a stepping stone, a point of entry on sustainability, that could have facilitated the responsiveness and the engagement of IMO's stakeholders on the advent of the 2030 Agenda and the associated SDGs. Fast forward to 2015, the former IMO Secretary-General Koji Sekimizu welcomed the adoption of the 2030 Agenda by the UN, saying that IMO "stands ready to support the further development and implementation of the SDGs and I am confident that all IMO Member States will engage in discussions on how best to realize them, through IMO's work, particularly through the IMO Integrated Technical Cooperation Programme" (IMO 2015b). It is evidently clear that IMO, as a Secretariat, expected the Member States to engage themselves in seeing how best to realize the SDGs through the TCC. The important role that IMO has towards the achievement of the 2030 Agenda and the SDGs and how the international shipping and the maritime community contributes to sustainable development in relation to SDGs is highlighted by a brochure the IMO Secretariat published (IMO 2017l). In order to see how IMO's Member States reacted strategically towards the 2030 Agenda to concretely contribute to the SDGs, the following section focuses on IMO's Strategic Plan.

2.2 IMO's strategic plan for the period 2016 to 2021—IMO's attempt to include reference to the 2030 Agenda for sustainable development

Since much of the IMO's work hinges on its Strategic Plan,[3] it was equally important for IMO to align its objectives and strategy with the 2030 Agenda (as most of the UN-specialized bodies had done prior to 2015). All United Nations system bodies were requested by the UN to align and link their work with the SDGs (IMO 2017d). This critical step did not really materialize at an early stage at IMO as its Member States did not react in good time. In order for IMO to achieve its vision and its objectives, it has a Strategic Plan covering a 6-year period and outputs (previously known as high-level action plan) spanning over a 2-year period (IMO 2017k). The IMO's Strategic Plan for 2016–2021 included 14 key Strategic Directions specifically formulated to enable IMO to achieve its mission objectives (IMO 2015c). While one would have expected that in 2015 the Member States of IMO would have aligned IMO's Strategic Directions (SD) with the UN's SDGs, in actual fact, it had only included a reference to SDGs in only two of its Strategic Direction, SD 1 and SD 3, and in one of the actions for SD 13. This meant that during 2016, none of the IMO Committees, bar for the TCC, were engaged towards working on the SDGs; only the TCC had the 2030 Agenda as a main agenda item under its wing (replacing the long-standing agenda item on the MDGs by the SDGs). During the TCC 66th session meeting in October 2016, the Committee discussed and agreed on how the TCC could link its technical assistance work, that of the Integrated Technical Cooperation Programme (ITCP) in particular, with the SDGs. Many concerns were raised by Member States as to how IMO is tackling the implementation of the SDGs, and this was reflected in the TCC report, "Many delegations observed that the linkage between the SDGs and IMO's Strategic Plan, Strategic Directions and High-level Action Plan should be identified first before linking them to the ITCP since the scope of the SDGs was much broader than the ITCP.

[3] The IMO Assembly, which meets once every 2 years, and the member Governments adopt the Strategic Plan which contains key strategic directions that will enable IMO to achieve its mission objectives.

However, given that many other United Nations System bodies were far ahead of IMO in linking their work to the SDGs, some delegations noted the urgency in addressing this matter sooner rather than later" (IMO 2017d, p. 8), and "the rest of the United Nations System had already either linked their work with the SDGs or were rapidly progressing the related work" (IMO 2017d, p. 9).

The 67th session of the TCC, held in July 2017, worked to identify the linkages[4] between IMO's technical assistance work and the SDGs and drafted two Assembly Resolutions[5] related to the 2030 Agenda and endorsed a draft Assembly Resolution on the guiding principles of IMO's ITCP in support of the 2030 Agenda (IMO 2017e). Later, the Assembly Resolutions were adopted by the 30th session of the IMO Assembly IMO (2017k). Indeed, considerable amount of work on the 2030 Agenda had been carried out by the TCC as it was seen as the natural Committee to engage in the transition of the MDGs to SDGs. IMO was already active through the ITCP within which it supported Member States in activities related to MDGs. It remains to be seen, however, how and when the other four IMO Committees will engage on the 2030 Agenda.

2.3 IMO's new strategic framework for 2018–2023—a more visible approach towards engaging with the 2030 Agenda

Of considerable importance was the outcome of IMO Council C117 held in December 2016, during which the new strategic framework for the 2018–2023 period was approved by the Member States forming part of the Council. With respect to the 2030 Agenda, the Council decided to include in the Vision Statement of IMO a direct reference to it and, as a result of this, the Vision Statement for the IMO for the period 2018–2023 reads:

(1) "IMO will uphold its leadership role as the global regulator of shipping, promote greater recognition of the sector's importance and enable the advancement of shipping, whilst addressing the challenges of continued developments in technology and world trade; and the need to meet the 2030 Agenda for Sustainable Development."

(2) "To achieve this, IMO will focus on review, development and implementation of and compliance with IMO instruments in its pursuit to proactively identify, analyse and address emerging issues and support Member States in their implementation of the 2030 Agenda for Sustainable Development" (IMO 2016, annex p. 1).

Apart from the Vision Statement, the Council also included in the overarching principles direct reference to the 2030 Agenda by emphasizing the important role IMO has to play in achieving the 2030 Agenda (IMO 2016). In addition, the approved new strategic framework for the 2018–2023 now contains seven SDs. Out of the seven

[4] The most relevant SDGs were found to be SDGs 4, 5, 6, 7, 9, 13, 14, and 17 (IMO 2017e, p. 12).

[5] Draft Assembly resolution "The linkages between IMO's Technical Assistance work and the 2030 Agenda for Sustainable Development" and draft Assembly resolution "Guiding Principles of IMO's Integrated Technical Cooperation Programme in support of the 2030 Agenda for Sustainable Development" (IMO 2017i, p. 8).

Strategic Directions, only SD 3 (respond to climate change) and SD 4 (engage in ocean governance) refer to the 2030 Agenda for Sustainable Development and the SDGs, respectively (IMO 2016). IMO, as a Secretariat, is doing its utmost to engage its Member States in coming forward with proposed actions. This can be seen by the efforts that the Secretary-General, Mr. Kitack Lim, is doing, particularly when addressing the Committees at IMO, in making IMO Member States more aware on IMO's goal of actively working towards the UN 2030 Agenda (Green4sea 2017). The outcome of the IMO Council C118, held in July 2017, has set the sails for IMO to start looking on how the linking of its own work with the SDGs can be done during biennial 2018–2019. The Council has approved the outputs for the 2018–2019 biennium,[6] which were aligned to the new SDs of the Strategic Plan for 2018–2023 and has decided that it recognizes the fact that IMO "has yet to fully define and agree on a process to integrate the SDGs into its work" (IMO 2017f, p. 2). To this effect, it was decided that in this particular phase, the IMO Secretariat will not be asked to lead a process for developing additional performance indicators relating to IMO's work but to prepare a document containing the draft alignment of the SDs and outputs to the SDGs for its consideration at the next IMO Council (IMO 2017f). One has also to see how IMO's SDG role within the UN system will continue to evolve particularly within the Inter-agency and Expert Group on SDG indicators (IAEG-SDGs) which is tasked to develop and implement the global indicator framework for the SDGs and targets of the 2030 Agenda (UN 2017). While the UN has put a requirement for all UN system bodies to align and link their work with the SDGs (IMO 2017a), particularly because IMO has "obligations and responsibilities to implement through its standard-setting work and its technical cooperation activities, the aims and objectives of the SDGs and its targets, and of the need to mobilize the means required to support with concrete actions the realization of the 2030 Agenda, including the Addis Ababa Action Agenda" (IMO 2017k, annex 6, p. 1), apart from the TCC, none of the other IMO Committees have as yet taken specifically on board the 2030 Agenda to deliver concrete SDG-related outputs as a parent organ. Such undertaking has a dependency on how Member States respond to the transition of the SDGs into IMO's work and more so at national level. On this, it is important to point out that, since the 2030 Agenda consist of universal goals and targets, it encourages all Member States to ramp up their national responses towards the implementation of the 2030 Agenda (UN 2015). Notwithstanding the above obligations at national level, work at international level has started at IMO within the TCC.

3 Objectives of the research

In view of the previous analysis, the objectives of the research are the following: (1) to identify the challenges related to strategy and governance of IMO and its stakeholders within the context of the 2030 Agenda for Sustainable Development in the maritime

[6] Out of 87 outputs to be delivered for the 2018–2019 biennium, there are only two outputs referring to the SDGs—under SD 4 (engage in ocean governance) output number 4.2 and under SD 5 (enhance global facilitation and security of internal trade) output number 5.5. Both have the TCC as the parent organ. Out of the 49 outputs related to other work (OW), there are none referring to the SDGs (IMO 2017h). Additionally, none of the Performance Indicators (42 in total) associated with the seven IMO SDs are linked to an SDG (IMO 2017g).

transport domain; (2) to determine if there is a need for an international strategic response for implementing the SDGs in the international maritime transport domain; and (3) to determine how best the IMO can strategically support its stakeholders in translating the 2030 Agenda into national policy.

3.1 Methodology

3.1.1 A grounded theory approach

The research methodology used in this study is based on a grounded theory approach. Grounded theory allows the use of all types of data when conducting the research and provides rich insights of organizational behavior and activities leading to the construction of reality that is grounded in data (Flick 2009). Grounded theory, as a general research methodology, is ontologically and epistemologically flexible as it provides the full package from data collection and analysis to the theoretical explanation of underlying patterns of social behavior (Holton and Walsh 2016). In the grounded theory approach, Glaser (1998) stated that all is data, with main qualitative methods being supported or enhanced with quantitative and observation data. Categories will emerge based on codes that will eventually form core concepts in the data to emerge until theoretical saturation is achieved, which allows for a model or a number of propositions to be established that are rigorously grounded in the data. Glaser and Strauss (1967) explain that grounded theory is a research method which provides the means to develop a theory that offers an explanation on the area of concern of the participants within the researcher's substantive area and further provides an explanation on how that concern is resolved or processed. Miles et al. (2014, p. 11) put forward that, "the strengths of qualitative data lie on naturally occurring, ordinary events in natural settings so that to have a strong handle on what real life is like." To be able to understand the complexity of implementing the 2030 Agenda and the SDGs in the international maritime transport domain, the authors chose IMO headquarters as the de facto natural setting for conducting the interviews with IMO's stakeholders. This helped the authors to further understand the role and challenges of IMO, as a specialized agency of the United Nations, and of its stakeholders in fulfilling the 2030 Agenda for Sustainable Development and the SDGs.

3.1.2 Method applied—a constructivist approach

As is normally done when using the constructivist approach in grounded theory, the authors of this paper conducted a literature review before they began collecting data and doing analysis. Such prior knowledge on issues related to sustainable development helped them to sensitize concepts within the context of the research method particularly for developing a deep understanding of the phenomena being investigated and issues associated to it when later analyzing empirical data to improve the groundedness of data (Bowen 2006; Charmaz 2001, 2006). When advocating grounded theory, Glaser (1998) also advised that before they embark on their research, researchers should do preliminary reading as this helps put the study into a context.

3.2 Research method: data collection and analytic rigor

Grounded theory allows researchers the freedom to use any data from any source, which is deemed to be useful, and by doing so, researchers can determine what is really going on (Holton and Walsh 2016). The quality and credibility of research start with the data and the depth and scope of the data make a difference (Charmaz 2006). For this research, the data were mainly primary but also secondary. Primary data were obtained from face-to-face, in-depth interviews with representatives attending IMO meetings over a period of 15 months and by observing ongoing debates at IMO Committees. All of this were done while using the grounded theory cycle of data collection during which, data collection, coding, conceptual abstraction of empirical data through constant comparative analysis, generation of concepts and categories, and elaboration of their properties and dimensions were carried out. The sampling strategy of the grounded theory cycle consisted of three waves of interviews, namely the convenience, purposeful and theoretical sampling (the latter aimed mainly to refine key categories). This led to theoretical saturation and theoretical integration. Figure 1 shows the process used in this research.

The analytic rigour was ensured through three stages of conceptual build up within the grounded theory cycle: the lower level of analytic rigour (stage 1), increased level of analytical rigour (stage 2), and the higher level of analytic rigour (stage 3) (see Fig. 1). Stage 1 was essential mainly for the identification of key interviewees that were versed with the ongoing discussions at IMO and who were also close to the shipping industry. Several face-to-face discussions took place with eight representatives of Member States at IMO. This was part of the first phase of the grounded theory cycle: the convenience sampling, which has helped in building preliminary concepts at a low level of rigour by means of sensing the environment surrounding the decision makers at IMO and to understand the political, economic, and social complexities in responding strategically

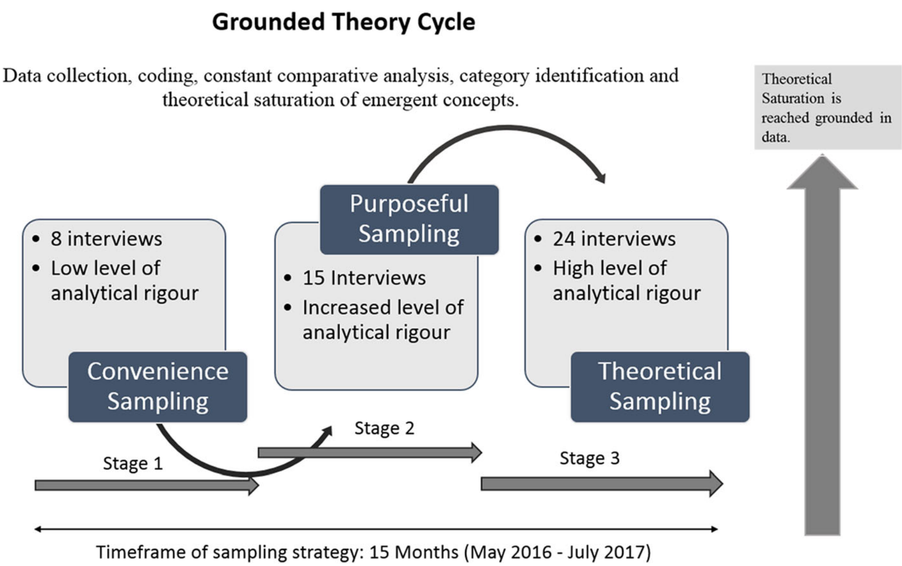

Fig. 1 The grounded theory process as applied to the research (self-designed)

towards implementing the 2030 Agenda. Stage 2 and stage 3 constituted of the remaining interviews, which were conducted during the two remaining cycles of the sampling strategy of grounded theory, namely the purposeful sampling (further elaboration of categories and sub-categories) during which 15 interviews were held, and the theoretical sampling (saturation of properties and dimensions of concepts) during which 24 interviews were held, bringing the total number of interviews to 47. Almost all of the face-to-face interviews were carried out at IMO, HQ in London during several field work sessions undertaken specifically for this research. Except for some cases, most of the interviews were all digitally taped and transcribed—the transcribed text generated more than 150,000 words of transcribed data.

3.2.1 Secondary data

Secondary data were acquired from the IMO's website, mainly the section that contains information on strategic and high-level action plans and trends, developments, and challenges for IMO's strategic framework. Numerous documents submitted to IMO meetings were reviewed; voluminous amounts of documents and sites held by the UN and other UN specialized agencies on matters related to the implementation of the 2030 Agenda and websites of administrations or entities of those that were interviewed were also reviewed. Our references largely show the use of these sources.

3.3 Data analysis as an iterative process—establishing the coding paradigm

Through the constructivist approach, the grounded theory allowed the authors to use their knowledge and experience and information gathered from literature review to analyze more in depth what was being noted and observed during the grounded theory cycle, while not being oblivious to other important elements and concepts that emerge, and therefore not being conditioned by what is already known. The data analysis was carried out until saturation was reached and no more properties and dimensions of categories emerged. The category schema that was developed was transposed into the conditional/consequential matrix, known as the "Conditional and Consequential Matrix" (Strauss and Corbin 1998, 2008), which consisted of three main features: contextual conditions, actions and reactions, and consequences or outcomes.

By virtue of this approach, the conditional/consequential matrix provided the platform for organizing and linking all concepts that explain the main concern in that particular area under study in a way of putting the analytic picture all together by keeping track of the complex relationships that emerged. Strauss and Corbin (2015, p. 158) highlight the importance of the matrix by emphasizing that the matrix "gives qualitative research its soul." The matrix provided the means to have a better understanding of the process of action-interaction of individuals or countries in how they respond and interact to changes, depending on the prevailing situation as a result of the conditions and consequences.

3.4 Data management and the coding exercise

The MAX Qualitative Data Analysis (MAXQDA) software, particularly MAXQDA 2012, was used for data management, storage, and analysis. MAXQDA is one of a range of qualitative data management tools that are designed for coding activities using four interactive screens as shown by Fig. 2. The coding exercise consisted of "dragging" text extracts from the transcribed interviews which were uploaded into the document system and displayed in the document browser of the code system's category and sub-categories and their respective properties and dimensions which emerged from the empirical data during the analysis. The MAXQDA code matrix browser provided an excellent possibility of seeing the coding intensity, where a repetitive focus on particular categories and their sub-categories, properties and dimensions, was being placed.

The main areas of concentrations (high coding intensity) became immediately visible once the coding of each interview was completed. Figure 3 provides an example. It shows a screen shot from the MAXQDA code matrix browser, showing the level of coding intensity per interview against the schema under one of the main constructs of the coding paradigm: consequences/outcome—sub-category: bridging the gap. The intensity of coding across a large spectrum of interviews for the properties of establishing a sustainable development strategy, governance framework in place for all organs, and IMO leadership on SDGs/setting up a Task Force, is very visible.

4 Results and discussion

The main results of the empirical research based on 47 interviews are presented in this section. They are grouped under the three components of the *Conditional and Consequential Matrix* of Strauss and Corbin (1998). The Matrix, as an analytic tool, helped the authors to understand: the issues within the *Context* (i.e., the elements that form up

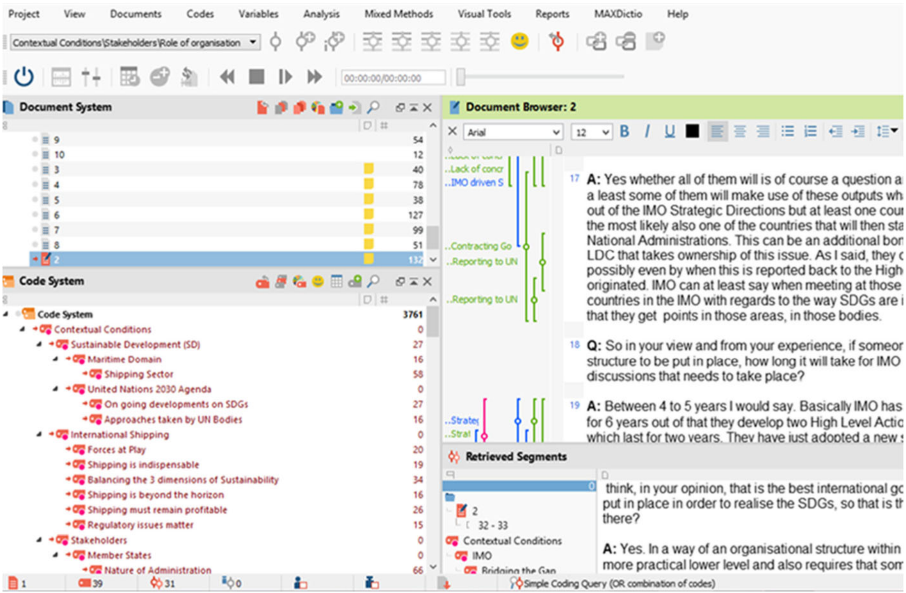

Fig. 2 A sample of the coding paradigm showing, the coding, the categories, sub-categories, and properties (part of the contextual conditions) in MAXQDA and the four interactive screens

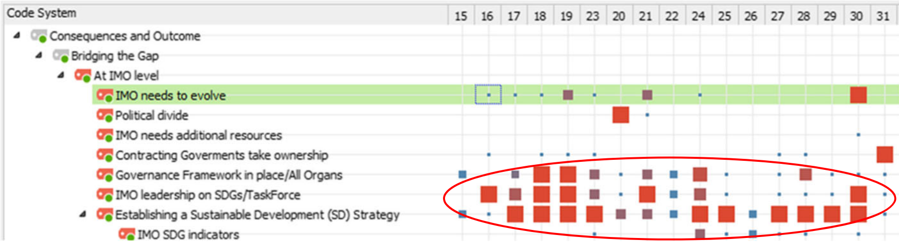

Fig. 3 Screen shot from the MAXQDA code matrix browser showing the level of coding intensity of the properties of particular sub-categories (bridging the gap) under Consequences/Outcomes

any situation and the interpretation given to them by the interviewees) that has a bearing on the *Conditions* (i.e., Member States must follow established IMO procedures) of the situation and the substantive area under study; the *Actions and Reactions* that takes place to attain the desired outcomes (i.e., how the Member States reacted at IMO towards the implementation of the 2030 Agenda); and the *Consequences and Outcomes* that follow as a result of the actions taken (i.e., alignment of IMO's Strategic Plan and concrete SDG-related outputs). The matrix provided the means for identifying the range of potential conditions of a given situation together within the consequences as a result from action-interaction (Strauss and Corbin 2015). As recommended by Glaser (2008), the authors let the data to "speak" and all data were treated as a one set under the matrix. Following a detailed coding exercise, based on constant comparison and conceptual abstraction of empirical data, the main findings that have emerged under the three main components of the matrix are described in this section. The findings capture and visualize the complex relationships for which the interviewees gave a detailed account on *context-actions-outcome* situations in dealing with the implementation of the 2030 Agenda at IMO and at national level. The following are the main constructs that emerged.

4.1 Contextual conditions—a need for galvanizing commitment towards sustainable development

The contextual conditions component is pivotal in understanding the context—the set of circumstances, within which the research study was conducted and the range of conditions that formed part of the issues/situations and the meaning given by the participants that were interviewed (Strauss and Corbin 2015).

The research found that, from a context point of view, the stakeholders at IMO, being the Members States, Intergovernmental Organizations (IGOs), and Non-Governmental Organizations (NGOs), have a central role to play to provide visibility of the SDGs within the shipping industry. An issue, which was apparent across the spectrum of the interviewees and which has an impact on the present conditions affecting the importance of shipping on international scale within the context of the 2030 Agenda, was that for the officials that have represented the national administrations or countries in the UN, when developing the SDGs, the maritime sector, precisely the shipping, was a very tiny element often not a priority at national level and which ended up being forgotten and not mentioned at all in the SDGs. So transport was not taken into consideration when the SDGs were being drafted and agreed upon at the UN.

The end result was that there is no particular SDG focusing solely to transport and yet transport is a major contributor to a number of SDGs. However, it emerged that the environmental aspect was predominately covered and well represented, which was indeed important, and was always high on the agenda of Member States. Nonetheless, maritime administrations were generally neither much consulted nor kept updated on how the 2030 Agenda could contribute towards shipping. Consequently, maritime administrations were finding it difficult to see how they could contribute towards achieving the SDGs and making the "shipping connection with SDGs" without clear directions from IMO. Similar issues were experienced by IGOs and NGOs as they were finding the entities within their domain were not much aware, if any, of the 2030 Agenda. It also became apparent that there was lack of knowledge and visibility on SDGs, often due to political and policy incoherency at national level. This was the main reason which conditioned most of the stakeholders attending IMO meetings in not being able to bring up the SDGs during their deliberations particularly between September 2015 and July 2017. This influenced IMO's working context in respect of the 2030 Agenda and to some extent, as a result, it had conditioned IMO in not having a clear SDG plan of action/outputs at the level of its Strategic Plan.

The research found that sustainable development is extremely important for maritime and shipping in particular not only because it provides the means for countries to continue developing and evolving their economy but also because shipping itself needs to remain sustainable in order to contribute towards sustainable development, hence the 2030 Agenda. One of the research findings indicated that the present international shipping conditions must be improved to better contribute towards the sustainable development of the world economy and more so for the developmental growth of each country. Participants in the research study claimed that this could be accomplished through more engagement by the international community, particularly the Member States attending IMO by taking a proactive approach in implementing the SDGs through concrete actions. One interviewee stated that shipping must remain sustainable because what "carries the freight needs to be sustainable." When interviewing representatives of the industry, it became clearly visible that at some point, the industry could turn around and, as an interviewee put it, "can't make a profit anymore" due to the increasing number of international regulations being put in place thus effecting the operating conditions. An interviewee well versed with the shipping industry insisted that "[when] people talk about sustainability—it is often from an environmental perspective and the same people would often then talk about the industry as if it has got some mission to destroy the environment which is clearly not in actual fact. The shipping industry is a business and unless the business model is sustainable, people will walk away from it." Another interviewee explained, "I mean I have heard of ship owners that they will just say the market is not profitable for the next 10 to 15 years—we will sell everything and come back in 15 years' time when the market is better. For them it is just a money-making scheme—so people will say shipping is my life but if there is no money in it why to remain in it?" This calls for more attention within the IMO for action to ensure that the right context and conditions are there for shipping and that efforts should be made to adequately balance the three dimensions of sustainable development. IMO's role in regulating the shipping industry is critical towards ensuring a sustainable maritime transportation particularly because shipping is considered as an important enabler for most of the SDGs and therefore it has a pivotal role in ensuring sustainable economic growth (IMO 2017l).

The findings suggest that more work should be done to further improve IMO's regulatory framework to ensure a better global maritime transportation system.

It was established that in terms of shipping, as a transport mode, it is unmatched. One interviewee claimed, "there is nothing that competes with it and is not like shipping will go away." Additionally, for Small Island Developing States (SIDS), shipping is the main trade driving force; these countries depend entirely on maritime transport. For the Caribbean SIDS, for instance, shipping is the main mode of transport as 95% of goods is imported by sea and the remaining by air transport. An overwhelming number of interviewees have stated that IMO is the de facto international regulatory authority for shipping. An interviewee explained, "IMO is an extremely important body; without it we will have chaos in the world." It also transpired that IMO is highly respected and the work it is doing is highly regarded. One interviewee insisted, "IMO has a strong element of pragmatism and has historically been at the very forefront of any new era in shipping so it is very natural for IMO to tackle the implementation of the SDGs." Several interviewees were of the opinion that provided that there was a Member States' agreement, thus setting the conditions right, IMO should eventually start its work on the SDGs across all organs and not just within TCC. In their view, the "SDG context" within IMO could soon be coming on board, provided that the right condition was there, i.e., engagement by Member States. One participant declared that "…we have lost some time but now is catch up time." Almost all the interviewees agreed that, at the end, IMO is all its members and therefore Member States should have been more proactive in bringing up 2030 Agenda at IMO in good time for discussion, just after it was adopted, thereby ensuring that the right context would be set within the IMO organs. IMO depends very much on the Member States' submission of the documents for consideration of new outputs. The research found that the IMO's Strategic Plans for 2016–2021 and 2018–2023 had very limited references to the SDGs in terms of Strategic Directions, SDG-related actions, and outputs. It was interesting to note that the responses from the interviewees were suggesting that in order to set the context right, IMO had to continue building on what had already been achieved by further formulation and elaboration of its strategy. As eloquently expressed by one interviewee, "IMO should harness what is already doing well and to profile that better and to make sure its articulation of its own strategy to implement the SDGs." Through this, the context would be set for generating better conditions that will assist IMO's Member States to come up with proposals for concrete action and improved SDG-related outputs in respect of the 2030 Agenda.

4.2 Actions and reactions—a need for Member States to come forward with input on the 2030 Agenda at IMO

The second largest paradigm of categories is the Actions and Reactions, which Strauss and Corbin (2015) describe as the actual responses of interviewees on the issues, events, or problematic situations for which people give meaning to them. The conditions and consequences do not stand in isolation but are the result of a rather complex movement between the two components which result in action and reaction. It provides an insight not only on what has happened in terms of action but also on what could be done to either manage or tackle better the responses (the actions within the context described in the previous sub-section).

The research found that in terms of actions during the period under study, IMO was behind in implementing the SDGs when compared with other UN Bodies, including the Food and Agriculture Organization[7] (FAO), the International Labour Organization[8] (ILO), and the International Civil Aviation Organization[9] (ICAO). Most of the other UN Bodies had a clear action plan in their work related to the 2030 Agenda, and in most cases, action had started prior to the entry into force of the SDGs. It transpired very clearly that although the SDGs had been agreed by all Member States of the UN at a level of Heads of State, and although all countries had expressed a commitment to implement the SDGs (which was a result of an extensive consultative process that took number of years to achieve), IMO did not feature as a custodian of any of the 230 indicators of the 169 targets of the 17 goals of the SDGs, which were set to put in action the SDGs. As to the development of the SDGs, the research established that from an action point of view, the IMO Secretariat was very much involved in the formation of SDG 14. One interviewee explained that "IMO was involved in chiseling out the exact nature of the SDG 14 on the Oceans" because the IMO Secretariat was part of the UN Technical Support Team developing this goal.

In terms of the actual actions that have been carried out within the context of IMO's work, it transpired that prior to the adoption of the 2030 Agenda, the IMO Secretariat and several Member States were seeing the 2030 Agenda from the lenses of IMO's Integrated Technical Cooperation Committee (ITCP) only as also indicated in Section 2.2. It was found that the IMO's Strategic Plan for 2016–2021 acknowledged the ITCP as the mechanism that will play a pivotal role in IMO activities to support the achievement of the SDGs as it was recognized that the ITCP contributes towards the economic, social, and environmental aspects of sustainable development that are particularly important in the case of SIDS. The TCC was the first Committee to have started action by linking its work towards the relevant SDGs. So far, in terms of action, none of the other Committees had started to link their work,[10] notwithstanding that their work is very much related to many SDGs. There was a general feeling among the interviewees that "the Organization should give direction to all Committees on what they should be doing on SDGs not just the TCC." The research findings demonstrated that as much as IMO was successful with the MDGs in assisting developing countries, the SDGs need to be seen differently as they are also intended for developed countries. The picture which this conjures is that in order to initiate action, all of the IMO organs need to first align and link their work to the SDGs and then identify the gap in terms of sustainability by also emphasizing on the SDGs so that appropriate outputs are agreed against concrete performance indicators once action is taken.

The research identified a common assertion among interviewees that what makes the IMO is actually its members; hence, the IMO Secretariat depends on the proposed and agreed actions by Member States performing the right reaction. One interviewee expressed this very elegantly, "IMO at the end of the day is the Member States that makes it, but IMO is always seen as the UN special Agency that regulates and provides

[7] http://www.fao.org/home/en/

[8] http://www.ilo.org/global/lang–en/index.htm

[9] https://www.icao.int/Pages/default.aspx

[10] The IMO Council C118, held in July 2017, decided to task the IMO Secretariat to prepare a document showing how the outputs and the IMO Strategic Directions can be linked with the SDGs. The document will be discussed in July 2018 at the IMO Council C120.

direction to the shipping industry, so if IMO embraces this (2030 Agenda), we are convinced… I am convinced, that the whole shipping industry then will follow suit." This suggests that if IMO was to be actively engaged on the SDGs and the 2030 Agenda when adopted, in terms of concrete actions, it had to be tasked directly by the Member States that constitute the Organization. One interviewee reflected, "IMO is actually a well-functioning UN agency and to be absolutely honest, this needs to be promoted as well through its work on the SDGs." The research found that in stark contrast to these submissions, input from Member States on the 2030 Agenda, particularly in terms of paper submissions on SDG-related matters to Committee meetings between September 2015 and July 2017, was almost inexistent. This reaction has affected IMO's actions towards the attainment of SDGs. The research pointed to a situation whereby in terms of actions, IMO's work is "silo-based" and very much often geared towards particular issues. There is a general consensus that IMO should now start working towards sustainability through an appropriate strategy with "concrete actions for concrete SDG related outputs with a holistic view rather that of addressing only current issues" as one interviewee recognized. The research also indicated that there was support for IMO to include reference in the IMO Member State Audit Scheme (IMSAS)[11], in some form or another (but not as mandatory text) to the SDGs as this could also help Member States to secure action from their Government in taking on board the 2030 Agenda and increase participation. An interviewee proposed that "IMO can expand the scope of IMSAS to embrace the SDGs by making sure there is an alliance with this in the national transport maritime strategy/policy or a national ocean policy." This, however, may be a complicated measure, which needs careful consideration if it is to be adopted.

The research findings suggest that action, in terms of debate within IMO Committees, on the 2030 Agenda and the SDGs at IMO has been somehow scarce and took place mainly from a TCC point of view and has not yet featured as an agenda item in the other Committees. During the IMO Council (C118), it was recognized that IMO has still to decide on what process is to be adopted for the implementation of the SDGs—likely to be agreed upon late 2018 beginning 2019. Results of this research have shown that the most apparent challenges that Member States are facing when it comes to action in respect of the 2030 Agenda are mainly due to policy incoherency as a result of fragmentation within government departments often due to poor coordination between Ministries notably between Ministries of foreign affairs and transport, leaving the latter to some extent unaware of the 2030 Agenda and the SDGs. One interviewee outlined that "the biggest challenge is the 'silo' mentality and one of the major challenges is that you find everywhere is—this is mine, this is not yours." This inactivity on the SDGs in terms of action has been mirrored at IMO as Member States did not push for the Strategic Plan of IMO to be aligned with the SDGs during 2015 when the Strategic Plan for 2016–2021 was being agreed. However, the research identified those representing SIDS as the most forthcoming on the SDGs; they had good knowledge of the 2030 Agenda and knew how the SDGs can assist in the development of their

[11] The IMO Member State Audit Scheme (IMSAS) aims to provide an audited Member State with a possibility of an assessment of how effectively it implements and administers the mandatory IMO instruments falling under the Scheme (IMO, 2017b).

nations and their respective region which depend mainly on maritime transport for trade, commerce, and mobility.

During the course of the empirical research, it became evidently clear that a number of elements had to be in place in order for the stakeholders to be in a position to provide the desired action-reaction effect on sustainable development both internationally and nationally. It was found that a governance structure for sustainability, with the appropriate mechanisms to steer and with a clear strategy for sustainable development must be put in place at IMO for better action. Such framework would enable IMO to be in a better position to implement the 2030 Agenda in the international maritime transport domain as it foresees through its Vision Statement. A large number of interviewees suggested that, for matters related to sustainability within the context of 2030 Agenda, a strategic actor should be appointed at a national level to coordinate action nationwide with a view to maximize synergy among different entities so that no one is left behind. An interviewee reflected that ideally "each country will have a champion or a strategic actor to coordinate across the Ministries who will be empowered to report directly to IMO and vice-versa and who provides or coordinates inputs to be reflected in the strategy of IMO."

4.3 Consequences and Outcomes—a need for strategizing towards the attainment of the 2030 Agenda and the SDGs

The conditions and consequences do not stand alone but are the result of a rather complex movement between the two components which result in action and reaction. Strauss and Corbin (2015, p. 161) posit *that* "since one event and the action that follows often leads to another and another, like links in a chain, it is often complex and difficult to sort through." Figure 4 shows the mapping exercise for the categories that constituted the consequences and the outcomes flanked by the sub-categories, properties, and dimensions. The findings are summarized below.

Most of the interviewees had not been active in engaging themselves on the 2030 Agenda at IMO because they lacked knowledge on the SDGs, and as a consequence, they were still in the process of digesting what the SDGs really are at national level. Even though their respective countries were engaging slowly on the incorporation of the SDGs in their national sustainable development plans, throughout the period of this research, they were not aware of any substantial SDG-related action, with a shipping perspective in their country.[12] For concrete outcomes, the participants emphasized the importance of adopting best practices for integration, communication, and coordination at national level, such as among different Ministries as very often they employ different institutional frameworks, and at international level, particularly at IMO, as the SDGs are multi-faceted. Input on SDGs by Member States in terms of proposed outcome

[12] Most of the Member States that were interviewed were oblivious of what their country is doing on the 2030 Agenda. In actual fact, they were never consulted back home on the SDGs and yet they were expected to engage at IMO on how the implementation of the SDGs is to be effected from an international shipping point of view. What was indeed surprising was that a good number of these countries had in fact ranked among the top performing countries in respect of UN SDG achievements and were listed in the "The SDG Index and Dashboards 2017 Report which was completed by the Sustainable Development Solutions Network and the Bertelsmann Stiftung (SDSN 2017). This report provides information on the performance of those countries that are actively implementing the UN's 2030 Agenda and its 17 SDGs and is currently listing 157 countries.

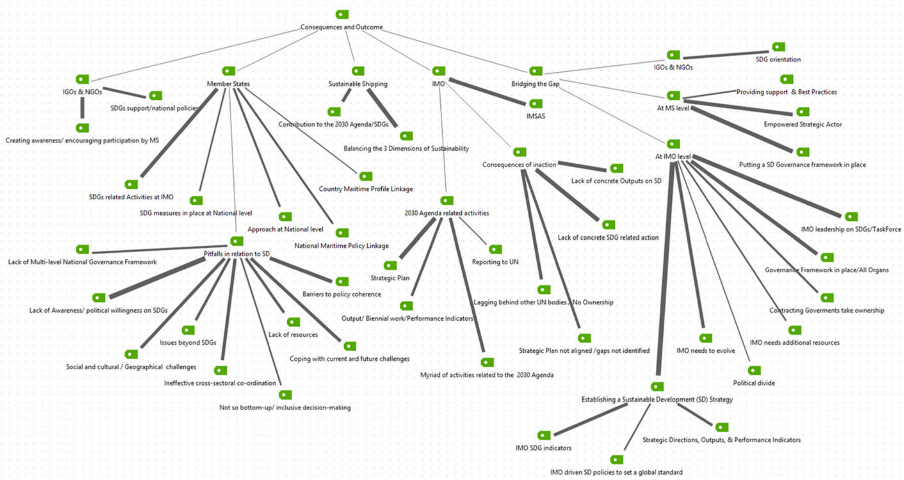

Fig. 4 Consequences and Outcomes—a need for strategizing towards the attainment of the 2030 Agenda and the SDGs

(outputs) for Strategic Plan for the 2018–2023 period was almost inexistent and consequently has affected the SDG-related outcome of IMO. There was general support by the interviewees to consider incorporating the SDGs from a shipping perspective into their national maritime policy and IMO Country Maritime Profile; however, more support on this is needed from IMO. The importance of NGOs' and IGOs' role in shaping the outcome at IMO and in ensuring coherence and coordination within their region or domain came out very clearly as they are the entrusted entities to represent their countries or their interest at national level and at IMO.[13] But ultimately, they need the support of Member States. An NGO recognized that "we are able to meet with the Ministers, talk the language, and we are able to meet with the Heads of the Government even the Head of the State and we are trusted. We are a catalyzer and a chemical reaction, if you know what I mean. However, ultimately, without the willingness of the Member States, IMO will not produce any concrete outcome." Another NGO made similar observations, "IMO alone cannot do anything. You have the Member States and they must be engaged. If the Member States are not engaged then IMO will move slowly." The need for policy coherency between IMO, its stakeholders, and within Member States emerged as prime prerequisite for the successful implementation of the SDGs particularly in achieving the desired outcome, considering that input for IMO outputs depends on Member States and therefore is a direct consequence of their level of engagement. The audits that are carried out by IMO within the framework of IMSAS were seen as a tool that could be used to contribute towards achieving the desired outcome also in terms of the SDGs at national level, mainly among the SIDs. One interviewee commented, "just a simple line in the audit saying something like this: To what extent your country is contributing towards the implementation of the SDGs? Is there a strategy or a national program in place?" IMSAS would certainly help Member

[13] The NGOs, in particular, were more concerned about the fact that the discussions on the 2030 Agenda at IMO took a considerable amount of time to start and as a result this has put IMO behind other UN bodies in terms of desired SDG outcome; however, the TCC has started to link its work activities with the SDGs.

States in pushing their Governments to act on the SDGs and to produce tangible outcomes that would be beneficial to the whole nation. The low level of engagement of most Member States, leading to almost no SDG-related outcome at IMO, was found to be a consequence of the very apparent lack of awareness on the 2030 Agenda and the SDGs; the lack of political willingness, commitment, and continuity (due to changing government cycles); lack of resources and funding; the fragmentation and dysfunctional entities or Ministries; the social and cultural differences that exists in a country compounded by geographical challenges; the lack of a multi-level national governmental framework that considers shipping as important sector (often “forgotten” and not included); the fact that some countries think more on the short term than on the long term (SDGs are seen as a long-term issue therefore are put aside); and the barriers to policy coherence within the government, all of which were found to be very common among the participants.

Issues that emerged and which need to be looked at by IMO to bridge the gap to maximize the outcome—basically IMOs’ outputs (which in turn brings about positive consequences in relation to the 2030 Agenda)—ranged from the need to narrowing down the imbalances and the political divide between the various maritime administrations around the world to improving IMO’s role on matters related the social aspect of seafarers by including more concrete outcomes through a dedicated Strategic Direction and from using the IMSAS, as an interviewee stated “to shaken up a little bit the governments on SDGs” to a need for balancing off the three dimensions of sustainability through its work, by putting equal emphasis on the social, environmental, and economical dimensions, since the latter was found to be not catered for within IMO.

It was established that generally speaking, IMO, as an institution, needs to clearly define what it aims to achieve in terms of outcome and outputs related to the SDGs—“identify where we want to go as we haven’t done that at Organizational level,” as an interviewee eloquently put it. In doing so, the IMO’s Secretariat is seen by a large number of those that have been interviewed as the de facto institution that could lead and guide Member States in the implementation of the 2030 Agenda within the international maritime transport domain, provided that resources are made available, and also likewise, Governments take also ownership. The research concluded that IMO still needs to agree by which means and by which process the SDGs are to be integrated into its work following which additional performance indicators may be developed for 2018–2023 (changes to the Strategic Plan, the performance indicators, and the outputs can be done every biennium). Discussing the importance of a clear process, another interviewee said, “I think they need to be more specific because the way it is right now it is going to be very difficult, if not impossible, for IMO to identify what kind of outputs need to be delivered by the IMO to meet the SDGs, it’s too vague.” The research identified a plausible way forward, i.e., devising a dedicated strategy on sustainable development flanked with a strong governance framework. Gaps that will be identified could be tackled through new outputs and performance indicators, thus providing a firm commitment and clarity on how shipping can contribute to the SDGs[14]

[14] An NGO stated, “I think part of the challenge for IMO is that because shipping doesn’t officially appear to connote to include the ocean, this is the big discussion that needs to have whether or not IMO has a mandate for the oceans but for me since all ships are crossing the oceans IMO has responsibilities vis-á-vis the oceans.”

through concrete SDG-related outcomes. The need for the IMO Secretariat to evolve and to improve its structures was also highlighted for better outcome particularly in establishing a Task Force that assumes a central role on sustainability by improving governance on sustainable development, provided that more effective mechanisms are put in place. The research concluded that, through a strategy on sustainable development, IMO would be more strategically oriented towards fulfilling the 2030 Agenda and SDGs with concrete outcomes. One interviewee sustained that "what IMO should have done was a Sustainable Development Strategy—so as to be able to say—ok this is what we have done, now let's define what do we want to focus on in the future—that is the whole purpose of the SDGs, it is not what we have done—it is what we have done so far but also what we are going to do." The importance of putting a sustainable development strategy for concrete outputs was also seen from the perspective of national engagement by Member States. Making this point, one interviewee said that "it would be a sustainable development strategy that can communicate down to Member States level and that there has to be feedback coming back". But a sustainable development strategy has to have a sound steering mechanism, a good governance framework for maximizing IMO's outputs, as an interviewee stated, "The governance structure must be clearly defined and delineated otherwise everybody will be stuck and everybody will be loose." The research further found that in addition to the linking of its current work with the SDGs, IMO needs also to identify where the gaps are and furthermore how these gaps can be narrowed by each organ of IMO and subsequently bridged thus contributing towards sustainability and the attainment of the SDGs. Numerous examples were communicated by the interviewees as to what IMO is doing exceptionally well in terms of outcome and outputs to ensure safe, secure, and efficient shipping through its regulatory framework—ranging from safety requirements (SOLAS Convention[15]) to environmental protection (MARPOL Convention[16]) and from training and competency of seafarers (STCW Convention[17]) and contribution to the legal framework governing the rights and responsibilities of nations in respect of ocean space (UNCLOS Convention[18]). References were made to SDG 14 (conserve and sustainably use the oceans, seas and marine resources for sustainable development), particularly in respect of the sterling work that IMO is doing on marine pollution, and the conservation and sustainable use of oceans, and SDG 13 on climate change (air pollution and greenhouse gas emissions from ships). Figure 4 shows an example of the resulting mapping exercise using MAXmap for the high-level framework's categories, sub-categories, properties, and dimensions of the Consequences and Outcomes of the matrix. The thickness of the connecting lines demonstrates the intensity of coding of each coded segment. As can be seen from the resulting map, Member States have been experiencing several challenges in relation to sustainable development and the 2030 Agenda. The most pressing ones are lack of awareness and political willingness, ineffective coordination, and policy incoherency, which have also been found to be present elsewhere when pursuing sustainable development, as the literature review suggest. Of significance importance, is that the findings suggest (see

[15] International Convention for the Safety of Life at Sea (SOLAS), 1974, as amended.
[16] International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of the 1978 relating thereto and by the Protocol of 1997 (MARPOL).
[17] International Convention on Standards of Training, Certificaiton and Watchkeeping for Seafarers (STCW).
[18] The United Nations Convention on the Law of the Sea (UNCLOS).

Bridging the Gap, *At IMO level*) that there is a need for establishing a sustainable development strategy at IMO as this can potentially leverage IMO's output on the SDGs which in turn will also engage and raise awareness among IMO's stakeholders.

5 Conclusion and propositions

This research explored the role and challenges of IMO and its stakeholders when implementing the 2030 Agenda for Sustainable Development in the international maritime transport domain. The research was based on the premise that IMO, and its Member States will continue to seek ways on how best to integrate the SDGs into IMO's work as presently such process is not in place as confirmed by the IMO Council held in July 2017 (IMO 2017f). On the basis of the empirical findings, this paper presents six propositions, which address the three objectives of this research and which were derived from the pattern in the data all of which also fit with the constructs found. The first proposition describes the phenomenon that has contributed to the factors that have delayed IMO in starting its work on the 2030 Agenda. It is complemented by five propositions, which were identified as essential elements for a potential solution to the main concern of the interviewees to better respond to the 2030 Agenda and the corresponding SDGs in a coherent way.

5.1 Propositions in relation to objective 1 of the research study

> Proposition 1: While Member States may be fully engaged in subscribing to international commitments, such as the UN 2030 Agenda, the effective implementation of such commitments may be too complex to handle, often due to lack of policy coherency, coordination at national level, and not so clear knowledge about the 2030 Agenda. This is often compounded by a lack of understating on what needs to be done at Member State/s level to achieve the desired results. This in turn will have an impact on the effectiveness of the internationally based institutions which are expected to be engaged by the same Member State/s to maximize the benefits of such commitment. As these institutions largely depend on the submissions of Member States to initiate action through their work program at international level (such as IMO), the end result will often be a soft start followed by low level of engagement which may often not reflect the amount of commitment that was originally envisaged. The degree by which an institution can quickly react to new developments has also a bearing on the type of institution—if it is program based there is a certain amount of flexibility unlike when this concerns a regulatory based institution such as IMO.
>
> Proposition 2: The importance of having a well-defined governance structure, possibly under the auspices of the office the Secretary General, such as a permanent Task Force as suggested by many interviewees, was manifested very clearly. The Task Force, as a steering mechanism for the implementation of the 2030 Agenda, should promote and oversee the fulfillment of the SDGs by also addressing the dire need for balancing the three dimensions of sustainable development within IMO's work through regular feedback from stakeholders.

5.2 Propositions in relation to objective 2 of the research study

Proposition 3: Member States often look at IMO as the institution that not only regulates international shipping but also to be the *best placed* and *trusted* institution to deal with cross-cutting shipping related issues which require an organization to internationally lead the realization of complex initiatives within the shipping domain. Member States that see IMO in this way want IMO's Secretariat to assume the much-needed critical role of taking a strategic lead in the implementation of the 2030 Agenda for Sustainable Development and the SDGs in the shipping domain. The research also established that there is no particular SDG focusing solely to transport, yet transport is a major contributor to a number of SDGs. It was found that there is a need for establishing an international platform among the UN's bodies, including program and funds, to cater for transport in the context of the 2030 Agenda (similar to existing ones for energy, water, and oceans) in which the IMO Secretariat can actively participate. This need was underscored by many interviewees as they believe this would ensure that Member States are always kept actively abreast on matters related to sustainable development stemming out from the 2030 Agenda, which, in turn, will enable them to be more engaged and committed to the accomplishment of the SDGs within their country.
Proposition 4: Member States that exhibit the properties described in propositions 1 and 2 suggest that there must be a Strategy for Sustainable Development in place at IMO, as part of its Strategic Plan The Strategy for Sustainable Development should provide clear strategic means for IMO to translate and integrate, with a certain degree of priority, the work of its Committees with the 2030 Agenda so that gaps, new actions, performance indicators and outputs will be identified and put in place.

5.3 Propositions in relation to objective 3 of the research study

Proposition 5: The success of a proper action and subsequently the fulfillment of the SDGs at national level were seen by a large number of Member States as having a dependency on the ability of who is responsible to coordinate and carry out the interaction among the various Ministries and bodies making up the Government. If there was a Strategic Actor on sustainable development in place at national level, acting as a focal point, who would interact with IMO regularly (i.e., with the proposed Task Force—proposition 2), issues related to lack of effective communication and coordination and policy incoherency at national level would be reduced significantly if not eliminated. Such interaction on the 2030 Agenda is even more necessary, insofar as to what concern maritime issues particularly at the level of oceans, as these issues have a global effect, far beyond national frontiers.
Proposition 6: A way of ensuring that Governments are kept *on check* on their commitment towards the SDGs was the proposal for the inclusion of a reference to the 2030 Agenda for Sustainable Development in IMO's IMSAS, as many interviewees suggested. While it was generally expressed that IMSAS cannot enforce the implementation of SDGs at national level, as the SDGs do not fall within any of IMO's instruments subjected to the audit, having a soft reference to the SDGs in

> IMSAS would help maritime administrations by no small means, such as SIDS, in seeking firm commitment from Governments on the 2030 Agenda for Sustainable Development.

Through this research, the authors have acquired deeper and broader knowledge on the type of challenges that may be encountered during the implementation of the 2030 Agenda for sustainable development in the maritime transport domain within the context of IMO. The propositions drawn by the authors, as presented in this paper, are based on the analysis of empirical data directly collected from where the international action is—at IMO, were validated and are widely applicable. However, the propositions must be seen as a part of a process of addressing the concerns of the participants attending IMO meetings. The authors of this paper believe that further research is required, particularly at national level, within maritime administrations and with cross-sectoral entities to further understand what is behind the issues that were identified during the research as described in Section 4. It is clear that the level of performance of Member States at IMO is not consistent among Member States and the degree of engagement varies depending where the prime interest of the Member State is—a stance very much common in other UN system bodies. The proposition of establishing a Task Force within IMO, as suggested by many respondents, may be the solution to have a better governance structure for facilitating the implementation of the 2030 Agenda. However, prior to the setting up of a Task Force, it must be first established how such Task Force should be set up to operate effectively so as not to replicate already existing structures within IMO, i.e., the role should be very well defined. Likewise, it must also be seen how the proposed strategy for sustainable development could form part of IMO's Strategic Pan under the Strategic Directions so that new SDG-related outputs will be identified and agreed upon.

In conclusion, it is suggested that more in-depth studies should be carried to further analyze how best the abovementioned propositions can be addressed. Such studies could further identify what is additionally needed to effectively implement the 2030 Agenda for Sustainable Development and the SDGs in the maritime transport domain in accordance with best practices in the field.

Compliance with ethical standards

Disclaimer The content of this paper does not necessarily reflect the official opinion of the European Maritime Safety Agency. Responsibility for the information and views expressed in this paper lie entirely with the authors.

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