Sustainable port development: the role of Chinese seaports in the 21st century Maritime Silk Road

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Abstract: We evaluate the *respective roles*, *functions and prospects* of the 15 Chinese ports, intended to be the 'eastern end' of China's Belt and Road Initiative (BRI). To achieve this, and thus contribute to the future development of BRI, we introduce the concept of *sustainable development capability*. We employ principal component analysis and analytic hierarchy process to build a model which evaluates the (cooperative) sustainability of the ports, based on four dimensions: capacity of port operations; (ambient) economic conditions; environmental factors; and human intellect and technology (HIT). Sensitivity and cluster analysis are used, to classify the ports into four categories (respective roles): international hub ports, regional hub ports, node ports, and regional gate ports. We hope that the port system we present and assess here will provide guidance to ports and countries, especially in Europe, leading to the right 'port alliances', that could turn BRI into an efficient global transportation system.

Keywords: one belt-one road; OBOR; Belt and Road Initiative; BRI; China; sustainability; seaports; principal component analysis; PCA; analytic hierarchy process; sensitivity analysis; cluster analysis.

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Since 1992, Hercules Haralambides is a Professor of Maritime Economics and Logistics, having taught at nine universities (and in seven different countries), most prominent of which being Sorbonne University, Erasmus University Rotterdam, and National University of Singapore. Currently he is also Distinguished Chair Professor at Dalian Maritime University (China). He is the Founder of the Erasmus Center for Maritime Economics and Logistics (MEL) and the founding Editor-in-Chief of the quarterly journal *Maritime Economics & Logistics* (*MEL*). He has consulted governments, international organisations and private companies all over the world including, for a number of years, the European Commission.

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1 Introduction

In 2013, China proposed its strategic plan of building the New Silk Road Economic Belt and the 21st century Maritime Silk Road (MSR) (jointly referred to as the one belt-one road initiative or OBOR). Since then, the concept has garnered great attention and strong support from many countries and regions around the world, particularly in Europe and Central Asia. In March 2015, under the authorisation of the State Council of China; China's National Development and Reform Commission (NDRC); the Ministry of Foreign Affairs; and the Ministry of Commerce jointly released their *Visions and Actions on Jointly Building Silk Road Economic Belt and the 21st Century MSR* document. The document presented the 15 Chinese seaports, namely, Shanghai, Tianjin, Ningbo, Guangzhou, Shenzhen, Zhanjiang, Shantou, Qingdao, Yantai, Dalian, Fuzhou, Xiamen, Quanzhou, Haikou, and Sanya, whose construction and/or further development and modernisation should be prioritised in terms of strengthening and giving better form to the BRI[1] (Ministry of Commerce of China, 2015).

MSR is expected to impact trade and bring about structural changes in transportation systems, port networks, and international logistics (Haralambides and Merk, forthcoming;

Lee et al., 2018). As such, the ‘initiative’ is expected to reduce trade and transport costs and thus stimulate trade between China and the ASEAN countries, Africa, Europe and Central Asia. Ongoing albeit still unpublished research shows that a 10% improvement in connectivity between countries along the ‘MSR’ could deliver a 3% decrease in China’s trade costs, which would in turn boost the country’s imports and exports by around 6% and 9% respectively (Haralambides and Merk, forthcoming). Such effects would be expected to occur as a result of improved connectivity among countries that are currently badly connected, albeit possessing considerable consumer and commodity markets, or production capabilities. Since ports act as important logistics hubs in the development of BRI, their *sustainability*, as defined here, would in parallel benefit local economies, the development of human capital, and the protection of the natural environment in the wider port regions.

One might note at this point that, although studies on BRI abound, particularly on BRI’s impact on regional and global economies and trade development (Du and Zhang, 2018; Zhang, 2019), as well as on logistics services (Sheu and Kundu, 2018; Liu et al., 2018; Chan et al., 2019) and shipping (Schinas and von Westarp, 2018; Yang et al., 2018), an evaluation of the ports along the BRI as attempted here is noticeably lacking.

In recent years, research on the evaluation of the various aspects of port operations has been prolific (see http://www.porteconomics.eu). Wu et al. (2010) evaluated and classified the performances of 77 major international container ports from four aspects: cargo-handling capacity, number of berths, terminal area and storage capacity. Cabral and Ramos (2014) employed cluster analysis to classify 17 Brazilian container ports into three distinct groups, along three dimensions: number of containers handled, berth length, and number of berths. Tovar et al. (2015) investigated the connectivity and competitiveness of container ports in the Canary Islands using graph theory. Kim (2016) utilised the entropy weight (TOPSIS) method to analyse the competitiveness of ports in Korea and China, from the viewpoints of port throughput, infrastructure and financial criteria. He showed the ports of Shanghai, Shenzhen and Busan to be the three most competitive ports. Same as we, here, Ke and Wang (2017) combined hierarchical analysis, principal component analysis (PCA) and cluster analysis to classify the Chinese *maritime centres* of the main port cities, and rank the latter according to their *soft* and *hard* infrastructure.

With the increasing prominence of environmental problems, port research has lately refocused on the *joint* evaluation of economic, social, and environmental sustainability of ports. Asgari et al. (2015) used AHP to rank the sustainability of five major UK ports on the basis of economic *and* environmental dimensions. Schipper et al. (2017) assessed the sustainability performance of a mixed set of ports, through three dimensions: society, environment and economy. Laxe et al. (2017) evaluated the sustainable development of Spanish ports, using four dimensions of sustainable development, i.e., economic, institutional[2], environmental and social. Wan et al. (2017) evaluated the sustainable development level of major ports in China along five dimensions: drivers, pressures, states, impacts and responses. ‘Drivers’ are primarily used to describe the indices facilitating regional economic activities and industrial development, which may lead to environmental problems if over-demanded. ‘Pressures’ indicates the stress on the sustainable development of resources, environment and ecological systems, inflicted by daily port operations. ‘States’ concerns indices that reflect the current conditions prevailing in the port environment. ‘Impacts’ are selected to address not only the operational efficiency but also the safety degree of ports, since these two aspects have been widely studied in the development of green ports. Finally, ‘responses’ focuses on the actions taken by port authorities to pursue the sustainable development of their ports.

The above literature discussion is not meant to be exhaustive, being only a presentation of *some* works that have in a way inspired the development of our own ideas, the innovative objective of which is to assess the sustainability of *only those* ports of China representing the *eastern end* of BRI and, as a consequence, the sustainability of the BRI project by and large. To our view, this is the first time in literature that such an undertaking is attempted.

Based on earlier literature and the *characteristics* of BRI, we select 32 representative indicators of port sustainability and establish a comprehensive evaluation system, based on our four dimensions of sustainability, i.e., capacity of port operations; economic conditions; environmental factors; and human intellect and technology. The ports are sorted according to their sustainability score; subsequent cluster analysis suggests four different roles for them. These are

a international hub ports

b regional hub ports

c node ports

d regional gate ports.

Model results are tested through sensitivity analysis. Finally, we put forward related proposals to further enhance the sustainable development of the assessed ports, as well as bridge their possible gaps vis à vis the aspirations of BRI.

A few lines on the characteristics of our four ‘*port roles*’ might not be amiss here. Thus, an *international hub port* is assumed to have a superior location; dense international container trunk routes and regional branch routes; good infrastructure and nautical accessibility; ample space for future development and proximity to an international airport (Haralambides, 2017). The hinterland and foreland of an international hub port covers the whole area of BRI. *Regional hub ports* are ports with regional trunk and branch routes, served by much smaller ships which provide shuttle or cyclical feeding services to international hub ports (Haralambides, 2019). The hinterland of a regional hub port covers the BRI area adjacent to that port. We define *node ports* as those ports that provide cargo-handling services to port cities and their surrounding areas, as well as feeding services to regional hub ports. Finally, as regional *gate ports* we consider ports that provide cargo-handling services only to their cities.

Our research aims at determining the *respective roles* of the 15 Chinese ports intended to make part of China’s Belt and Road Initiative (BRI). We introduce the concept of *sustainable development capability*, and we combine *PCA* with *analytic hierarchy process* to build an assessment system which evaluates the sustainability of these ports on the basis of four *dimensions*: capacity of port operations, economic conditions, environmental factors, and human intellect and technology (HIT). We use sensitivity and cluster analysis to classify the 15 ports into four categories (respective roles): international hub ports, regional hub ports, node ports, and regional gate ports.

2 Data sources and methodology

2.1 The four dimensions

We consider *port sustainability* as involving the relationship between the port and its hinterland economy; society, environment; and human capital. More specifically, as mentioned above, we evaluate port sustainability along four dimensions:

a capacity of port operations

b economic conditions

c environmental factors

d HIT.

The relationship between these dimensions and *port sustainability* is briefly described below.

The *capacity of port operations* is a direct consequence of a port's level of development and it is thus an important dimension in measuring the (economic) sustainability of the port. Here, we measure the capacity of *port operations* by the port's total number of berths; total throughput; throughput growth rate; and seaborne trade (traffic) with foreign BRI ports.

The *economic conditions* dimension is mainly used to measure the economic rigor of the port-city. A strong *city economy* can provide a continuous supply of goods to be traded through the port and as such it constitutes a second important dimension in assessing the (economic) sustainability of the port. *Economic conditions* are here proxied by the GDP of the city; the value of the tertiary sector's output; government budget; and total foreign trade volume with countries along BRI.

The *environmental* dimension mainly evaluates the natural and ecological circumstances of the port-city. An *environmentally burdened* city will induce adverse social impacts, which, in their turn, could affect shippers' choice among competing ports. We evaluate environmental sustainability by air quality; rate of treatment of waste water; standard-reaching rate of nearshore water; green coverage rate in developed areas; and expenditure on energy-saving investments per capita (in the city).

The *HIT* dimension assesses the existence of talent, education and technology in the port city. Talent and *science and technology* are prerequisites for the long-term, healthy development of ports and their international competitiveness. We assess this dimension by the number of university students; the number of patents deposited; and the city's investment in scientific research.

2.2 Data sources

The ports considered here are the 15 Chinese ports mentioned by the Chinese Government in *Visions and Actions on Jointly Building Silk Road Economic Belt and 21st Century MSR* (Ministry of Commerce of China, 2015). Data was obtained from China Statistical Yearbook; China Statistical Yearbook of Relevant Provinces and Cities; China Yearbook of Cities; and the Statistical Bulletin of National Economy and Social Development of Relevant Cities in China. Details are shown in Table 1.

Table 1 Data sources

Data category	*Data source*
Port operation indicators	Statistical yearbooks of Shanghai, Tianjin, Zhejiang, Guangdong, Shandong, Liaoning, Fujian and Hainan in China, websites of the ports of Shanghai, Tianjin, Ningbo, Guangzhou, Shenzhen, Zhanjiang, Shantou, Qingdao, Yantai, Dalian, Fuzhou, Xiamen, Quanzhou, Haikou and Sanya
Port-city economic indicators	China Statistical Yearbook, Statistical yearbooks of Shanghai, Tianjin, Zhejiang, Guangdong, Shandong, Liaoning, Fujian and Hainan in China, urban economic yearbook, and statistical bulletin of national economy and social development in various cities
Environmental indicators	Statistical yearbooks of Shanghai, Tianjin, Zhejiang, Guangdong, Shandong, Liaoning, Fujian and Hainan in China, and various city environmental protection bureau websites
Human intellect and technology (HIT)	Statistical yearbooks of Shanghai, Tianjin, Zhejiang, Guangdong, Shandong, Liaoning, Fujian and Hainan in China, and various city bureau websites

2.3 Methodology

AHP can reasonably derive the weight of each indicator, based on expert opinions. However, when there are too many indicators, or when differences between indicators are not big enough (multicollinearity), the subjective judgment error of experts may be prevalent and the weight, calculated by the constructed judgment matrix, may not be reasonable. PCA is widely used in the field of evaluation. However, if the method is used alone, the irregularity of some data may lead to the phenomenon whereby unimportant indicators are highlighted. We therefore combine PCA and analytic hierarchy process to divide 32 indicators into 4 dimensions with large differences.

For indicators strongly correlated within a dimension, PCA is used to eliminate multicollinearity and calculate the final score of the dimension. Subsequently, AHP is used to construct *expert judgment matrix* to calculate the weights of the four dimensions. Compared to previous evaluation methods, our combined method can not only reduce the impact of the abnormal data on evaluation results, reduce the evaluation error caused by multicollinearity between indicators, but also make full use of expert experience to accurately calculate comprehensive scores of the four dimensions.

The following steps are taken to carry out the evaluation of the sustainability of our BRI seaports.

Step 1 Indicator selection

As discussed above, based on the concept of *sustainable development capability*; the evaluation indicators of port sustainability discussed in the literature (Asgari et al., 2015; Schipper et al., 2017; Laxe et al., 2017); and our survey administered to industry practitioners, 32 indicators are selected along our four dimensions: capacity of port operations, economic conditions, environmental factors, and HIT. The indicators are presented in Table B2 in Appendix B and Tables C1–C3 in Appendix C.

Step 2 Standardisation of data

In this stage we standardise the values of the indicators, to make them comparable across the 15 seaports. The normalised *Z*-scores are obtained by:

$$Z_{ij} = \frac{X_{ij} - \bar{X}_j}{\sigma x_j} \tag{1}$$

Z_{ij} normalised value of indicator *j* for port *i*

$\bar{X}_j$ mean of indicator *j* (for all ports)

X_{ij} value of indicator *j* for port *i*

σx_j standard deviation of indicator *j* distribution (for all ports).

Step 3 Comprehensive evaluation of the four dimensions

Once the calculations of the 32 indicators have been generated, it is necessary to evaluate the *Z*-scores of the dimensions, obtained as the means of the standardised values of the indicators. Given the number of indicators in each dimension, *PCA* has been used to eliminate multicollinearity.

Table 2 The *Z*-scores of the four dimensions

Seaport	*Capacity of port operations*		*Economic conditions*		*Environmental factors*		*Human intelligence and tech (HIT)*	
	Z-scores	*Rank*	*Z-scores*	*Rank*	*Z-scores*	*Rank*	*Z-scores*	*Rank*
Shanghai	2.23	1	2.77	1	–1.56	14	1.91	2
Tianjin	1.20	2	0.72	4	–1.75	15	1.30	3
Ningbo	0.98	3	0.05	5	–0.22	10	–0.06	7
Guangzhou	0.41	7	1.36	3	–0.36	11	2.04	1
Shenzhen	0.50	5	1.40	2	1.55	1	–0.04	5
Zhanjiang	–0.54	9	–0.88	14	–1.29	13	–0.94	13
Shantou	–1.05	13	–1.16	15	0.24	8	–1.18	15
Qingdao	0.45	6	0.01	6	–0.55	12	0.32	4
Yantai	–0.31	8	–0.56	9	0.25	7	–0.48	10
Dalian	0.51	4	–0.11	7	–0.19	9	–0.24	8
Fuzhou	–0.68	11	–0.62	11	0.31	6	–0.06	6
Xiamen	–0.56	10	–0.34	8	0.91	3	–0.42	9
Quanzhou	–0.76	12	–0.70	12	0.51	5	–0.62	12
Haikou	–1.07	14	–0.60	10	0.68	4	–0.54	11
Sanya	–1.32	15	–0.84	13	1.47	2	–0.98	14

The covariance matrices of the four dimensions are calculated first, deriving the eigenvectors and eigenvalues of the covariances. Eigenvalues are ranked from large to small. The main eigenvectors of the four dimensions are selected according to the eigenvalues of covariances. The Z-score of each dimension is derived from the standardised values of the indicators and eigenvectors. The results are shown in Table 2.

Step 4 Kolmogorov-Smirnov test

To verify whether the results obtained are meaningful and consistent, the Kolmogorov-Smirnov test is employed to test whether the standardised values of each of the four dimensions follow the normal distribution. Test results, after standardising the data with zero mean and one standard deviation are obtained and shown in Table 3. Their statistical significance affirms the null hypothesis that the dimensions follow a normal distribution.

Table 3 Kolmogorov-Smirnov test

		Capacity of port operations	*Economic conditions*	*Environmental factors*	*Human intellect and tech*
N		15	15	15	15
Normal Parameters[a,b]	Mean	0.000	0.000	0.000	0.000
	Std. deviation	1.000	1.000	1.000	1.000
Most extreme differences	Absolute	0.173	0.214	0.129	0.251
	Positive	0.173	0.214	0.102	0.251
	Negative	–0.127	–0.122	–0.129	–0.0119
Test statistic		0.173	0.214	0.129	0.251
Exact sig. (2-tailed)		0.696	0.435	0.937	0.256

Notes: [a]test distribution is normal.
[b]calculated from data.

Table 4 Weights obtained from judgment matrix

	Capacity of port operations	*Economic conditions*	*Environmental factors*	*Human intellect and tech*
Expert group 1	0.355952	0.271429	0.169643	0.202976
Expert group 2	0.485528	0.273121	0.134307	0.107044
Expert group 3	0.523133	0.196293	0.15165	0.128923
Expert group 4	0.380703	0.169385	0.10767	0.342242
Average weight	*0.436*	*0.227*	*0.141*	*0.195*

Step 5 Determining the weights of the four dimensions and calculating port sustainability

AHP is used to determine the weights of the four dimensions. The problem is modelled as a hierarchy, including the *port sustainability* goal and the four dimensions which evaluate it. Priorities among the four dimensions are established next, through a series of judgements based on their pairwise comparisons. By interviewing four groups of experts and scholars with long experience in ports and shipping (January 2019), four judgment matrices are constructed. The consistency of the judgements is evaluated by calculating the *consistency rate*. The consistency ratio (CR) values of the judgment matrix, constructed from the four groups of experts, were 0.0175, 0.0126, 0.0978, and 0.017, respectively. As all CRs were less than 0.1, conforming also to the consistency test, the weight distribution was feasible. Finally, the weights of the four dimensions were obtained by calculating the judgement matrix of each group of experts, and then calculating the average weights of the four groups.

Port sustainability is calculated from the weights of the four groups of judgment matrices. This is shown in equation (2) and the results in Table 5.

$$y_i = w_{1i} \times x_1 + w_{2i} \times x_2 + w_{3i} \times x_3 + w_{4i} \times x_4 \quad (2)$$

where y_i expresses the sustainability of the port calculated from the i^{th} expert's judgment matrix weight; w_{1i} is the weight of x_1 calculated after the i^{th} expert's matrix has passed the consistency test; and x is the standardised data of the scores of the four dimensions.

3 Cluster analysis and sensitivity analysis

3.1 Cluster analysis

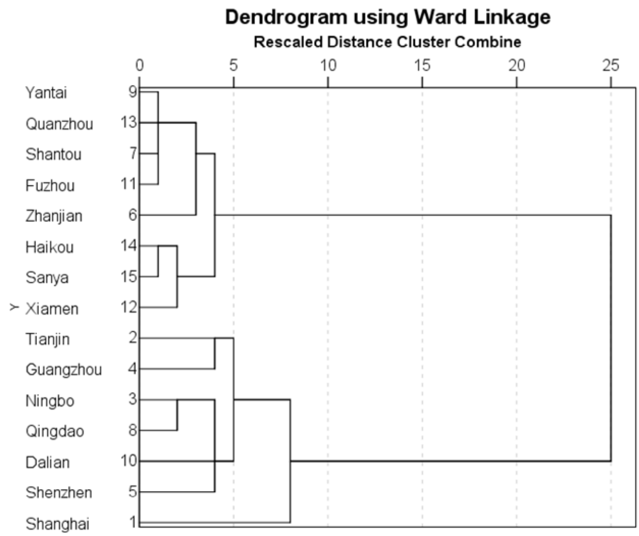
Based on the sustainability of ports and their rankings, resulted from the last section above, we use the same 32 indicators in AHP and PCA and continue with cluster analysis to further study the ports' *respective roles*. *Clustering* classifies objects according to their similarity. The most common classification method is *K*-mean clustering, but this method needs to set a *category K* classification in advance, and classification results are very sensitive to the *K* value. Of the many ways to carry out clustering analysis, the *Ward systematic clustering method* is the most mature one, suitable for multi-index classifications (Ke and Wang, 2017; Schipper et al., 2017). The method does not need to set the classification type in advance, and it has good convergence and fast computing speed.

The clustering results calculated by this method are shown in Figure 1. Data on abscissa represents the relative distance between different categories, calculated from the 32 indicators. *Rescaled distance cluster combine* refers to the clustering calculation of the standardised data, directly comparing the distance between different categories. According to Figure 1, firstly, Shanghai, Shenzhen, Dalian, Qingdao, Ningbo, Guangzhou and Tianjin can be classified in the same category, and Yantai, Quanzhou, Shantou, Fuzhou, Zhanjiang, Haikou, Sanya and Xiamen would be grouped in another one, because these two categories show the largest relative distance. Further clustering, now *within* the two categories, is carried out next. In view of the large relative distance between Shanghai and the rest of the ports in the first category, we divide the latter into two sub-categories: namely, Shanghai on the one hand, and Shenzhen, Dalian, Qingdao, Ningbo, Guangzhou and Tianjin on the other. Similarly, the ports in the second category are divided into two sub-categories: in the first, there are the ports of Yantai, Quanzhou, Shantou, Fuzhou and Zhanjiang, while the second sub-category comprises the ports of Haikou, Sanya and Xiamen. As a result, the 15 ports have now been allocated in our four categories: Shanghai is the only port in the first category (international hub port). The second category (regional hub ports) enlists the ports of Tianjin, Guangzhou, Shenzhen, Dalian, Ningbo, and Qingdao. The third category (node ports) includes the ports of Zhanjiang, Yantai, Quanzhou, Shantou and Fuzhou. Finally, the fourth category (regional gate ports) consists of the ports of Xiamen, Haikou and Sanya.

Table 5 Score and ranking of the sustainable development level of the 15 Chinese ports

Seaports	*Expert group 1*		*Expert group 2*		*Expert group 3*		*Expert group 4*		*Average*	
	Scores	*Rank*	*Scores*	*Rank*	*Scores*	*Rank*	*Scores*	*Rank*	*Scores*	*Rank*
Shanghai	1.53	1	1.70	1	1.62	1	1.53	1	1.70	1
Tianjin	0.59	4	0.68	4	0.67	4	0.59	4	0.68	4
Ningbo	0.31	5	0.45	5	0.48	5	0.31	5	0.45	5
Guangzhou	0.87	2	0.74	3	0.69	3	0.87	2	0.74	3
Shenzhen	0.81	3	0.83	2	0.77	2	0.81	3	0.83	2
Zhanjiang	–0.84	14	–0.78	14	–0.78	14	–0.84	14	–0.78	14
Shantou	–0.89	15	–0.92	15	–0.89	15	–0.89	15	–0.92	15
Qingdao	0.13	6	0.18	6	0.20	6	0.13	6	0.18	6
Yantai	–0.32	9	–0.32	9	–0.30	9	–0.32	9	–0.32	9
Dalian	0.07	7	0.17	7	0.19	7	0.07	7	0.17	7
Fuzhou	–0.37	10	–0.46	10	–0.44	10	–0.37	10	–0.46	10
Xiamen	–0.22	8	–0.29	8	–0.27	8	–0.22	8	–0.29	8
Quanzhou	–0.50	11	–0.56	11	–0.54	11	–0.50	11	–0.56	11
Haikou	–0.54	12	–0.65	12	–0.64	12	–0.54	12	–0.65	12
Sanya	–0.65	13	–0.78	13	–0.76	13	–0.65	13	–0.78	13

Figure 1 Ward cluster analysis



3.2 Sensitivity analysis

We subject the above results to further sensitivity analysis, aiming to test the stability of the model and the credibility of our results. By varying the original average weight of one dimension while keeping the weights of the other three dimensions unchanged, so as to ensure that the sum of the four weights is 1, we normalise the weights to get the adjusted ones; these are used to calculate *port sustainability*. The stability of the model can be judged by observing the fluctuation in the rankings of *port sustainability*. The results of this exercise are shown in Table 6. As it can be seen, sustainability rankings do change, albeit by a small amount. For instance, when the weight of *capacity of port operations* increases by 50%, the ranking of Tianjin Port goes up two places, which is the largest change in all sensitivity analysis. This is sufficient evidence of model stability. The subjective judgments of a few experts do not appear to have a significant impact on the overall ranking, and they do not cause large errors in our results.

Table 6a Sensitivity analysis of the weight of *capacity of port operations*

Change in weight	*Ascending ports in ranking*		*Declining ports in ranking*	
	Port	*Change in ranking*	*Port*	*Change in ranking*
–20%	---	0	---	0
–50%	---	0	---	0
+20%	Tianjin	+1	Shenzhen	–1
	Zhanjiang	+1	Sanya	–1
+50%	Tianjin	+2	Guangzhou	–1
	Zhanjiang	+1	Shenzhen	–1
	Yantai	+1	Xiamen	–1
			Sanya	–1

Table 6b Sensitivity analysis of the weight of *economic conditions*

Change in weight	*Ascending ports in ranking*		*Declining ports in ranking*	
	Ports	*Change in ranking*	*Ports*	*Change in ranking*
–20%	---	0	---	0
–50%	Tianjin	+1	Shenzhen	–1
+20%	---	0	---	0
+50%	---	0	---	0

Table 6c Sensitivity analysis of the weight of *environment factors*

Change in weight	*Ascending ports in ranking*		*Declining ports in ranking*	
	Ports	*Change in ranking*	*Ports*	*Change in ranking*
–20%	Tianjin	+1	Shenzhen	–1
	Zhanjiang	+1	Sanya	–1
–50%	Tianjin	+1	Shenzhen	–1
	Zhanjiang	+1	Xiamen	–1
	Yantai	+1	Sanya	–1
+20%	---	0	---	0
+50%	Shenzhen	+1	Guangzhou	–1

Table 6d Sensitivity analysis of the weight of HIT

Change in weight	*Ascending ports in ranking*		*Declining ports in ranking*	
	Ports	*Change in ranking*	*Ports*	*Change in ranking*
–20%	---	0	---	0
–50%	Shenzhen	+1	Guangzhou	–1
+20%	---	0	---	0
+50%	Tianjin	+1	Shenzhen	–1

4 Results

4.1 Overall results

Through a comprehensive analysis of our four dimensions, the *sustainability rankings* of the 15 ports are Shanghai, Guangzhou, Shenzhen, Tianjin, Ningbo, Qingdao, Dalian, Xiamen, Yantai, Fuzhou, Quanzhou, Haikou, Sanya, Zhanjiang and Shantou (Table 5). Shanghai ranks first due to its advantages in economic conditions, capacity of port operations, and HIT. As regards Guangzhou, although its score in 'capacity of port operations' is not as high as that of Tianjin and Ningbo, its sustainable development level ranks second after Shanghai, due to its advantage in economic conditions and HIT. In the case of the port of Shenzhen, located in an emerging city with a short history, its HIT dimension lags far behind that of Guangzhou – a developed coastal city 1,000 years old, as a result, Shenzhen ranks third, after Guangzhou.

4.2 Results by sub-indicator dimensions

4.2.1 Capacity of port operations

The *capacity of port operations* is a direct indicator of the level of port development and an important measure of a port's sustainability. It can be seen from Table 2 that the top three ports in 'capacity of port operations' are Shanghai, Tianjin and Ningbo, all with a throughput above 500 million tons. Their container throughputs with the countries along the BRI are all in excess of 4.5 million TEUs, far above the average of the 15 ports. Although most of the indicators of the port of Dalian are also high, some are low because the port's major import and export countries are non-belt-and-road ones (its largest partners are Japan, the USA, South Korea, and Hong Kong) (National Statistical Bureau of the People's Republic of China, 2017). Dalian thus ranks fourth in terms of 'capacity of port operations'.

4.2.2 Economic conditions

A port's fate is closely related to the economic development of its city and, often, the opposite is also true. Our analysis of the indicators of GDP; industrial structure; and foreign trade volumes of the (port-) city ranks the ports of Shanghai, Shenzhen and Guangzhou as the highest among the 15 ports (Table 2) in terms of *economic conditions*. As Shanghai is the largest economic and trade centre in China, and Shenzhen and Guangzhou are first-tier cities in China's economic development, the economic advantages of these port cities are far superior to those of others.

4.2.3 Environmental factors

Environmental factors have always been among the main factors affecting sustainable port development. A long-term adverse environment would have an indirect impact on the development of all industries in the port-city, thus reducing its sustainable development level. Through the comprehensive evaluation of the city's air, afforestation, and water quality, the values of the environmental factors of the ports of Shenzhen, Sanya, Xiamen and Haikou score the highest, while Shanghai and Tianjin score lower (Table 2). In recent years, the illegal discharge of industrial waste by the enterprises in the upstream part of the Yangtze River has caused serious pollution and has affected the river's water quality. Shanghai is located in the Yangtze River Estuary. The water quality compliance rate of the coastal areas of Shanghai is the lowest among our 15 port cities. Tianjin is located in the Beijing-Tianjin-Hebei region, with a concentration of large-scale chemical enterprises, arid climate, frequent haze, and serious land desertification. The annual air quality rate of Tianjin is only around 60%, the lowest among the 15 port cities examined here.

4.2.4 Human intellect and technology

HIT is an important factor in port development, playing an important supporting role in the sustainable growth of a port. According to the results of Table 2, the ports of Guangzhou, Shanghai and Tianjin score the highest in this dimension. There are many colleges and universities in these three cities, with more than a million college students in Guangzhou, ranking first in the country in the HIT dimension. The number of college students in Shanghai and Tianjin is over 500,000, also putting these two cities at the top of the list. It is worth noting that although Shenzhen is an emerging city with relatively few higher education institutions, its high-tech enterprises are nevertheless numerous. The city's annual patent authorisation number is approximately 70,000, putting it at the top position in the ranking of the 15 port cities. Thus, its score for HIT is higher and it ranks fifth.

4.2.5 Cluster analysis

Through cluster analysis, we divided the 15 BRI ports into four categories (Figure 1). Shanghai is the only port in the first category, scoring first in 'capacity of port operations' and 'economic conditions', as well as in 'port sustainability'. Shanghai is thus the most sustainable BRI port. In 2016, the port of Shanghai handled a throughput of 702 million tons and 37.13 million TEUs. The latter figure makes Shanghai the number one container port in the world and this position has remained unchallenged for eight years in a row (since 2010). As China's largest city and international maritime centre *par excellence*, Shanghai has close economic and trade ties with the foreign countries along BRI. In 2016, the total import and export volume of goods between Shanghai and the BRI countries reached 82.6 billion US dollars, ranking Shanghai first in China, with an increase of 2.6% over the same period of the previous year, and accounting for nearly one-fifth of the city's total trade. In the same year, 2016, the container traffic of Shanghai with the BRI countries amounted to 9.64 million TEUs, accounting for 35% of Shanghai's total container throughput (National Statistical Bureau of the People's Republic of China, 2017). Therefore, Shanghai can rightfully act as the international hub port along OBOR, assuming the important task of transshipping goods between China's Yangtze River valley and even parts of the coastal areas of China and the BRI countries.

Ports in the second category are Tianjin, Guangzhou, Shenzhen, Dalian, Ningbo and Qingdao. The average score of these ports on 'capacity of port operations' is lower than Shanghai, but far above the total average. At the same time, the sustainable development level of these ports is also higher. These cities play a pivotal role in China, as regional development centres. The ports' container throughput with foreign ports along BRI has been increasing recently.

Table 7 Port data in the second category (2016)

Ports	*Cargo throughput (million tons)*	*Container throughput (million TEUs)*	*Container throughput with foreign ports along BRI (million TEUs)*	*Total imports and exports with foreign countries along BRI (billion USD)*
Tianjin Port	550.51	14.50	4.99	200.5
Guangzhou Port	544.53	18.86	1.30	318.3
Shenzhen Port	214.06	23.98	8.57	673.3
Dalian Port	355.00	94.49	1.01	152.1
Ningbo Port	910.96	21.56	9.07	705.5
Qingdao Port	500.36	17.51	2.02	312.4

Source: National Statistical Bureau of the People's Republic of China (2017)

For example, the port of Tianjin, as the eastern starting point of the *China-Mongolia-Russia Economic Corridor* and the strategic starting point of the 21st century MSR, achieved a throughput of 550 million tons in 2016, ranking fourth in the country, with an annual increase of 1.9%. In terms of container throughput, in the same year, the port handled 14.5 million TEUs, with an annual increase of 2.8%. Of these, over 5 million TEUs were exchanged with countries along BRI, ranking the port fourth in China, and accounting for over 30% of the port's total container throughput.

Ningbo-Zhoushan Port, an important hub connecting the vast hinterland of China's central and western regions with the countries and regions along BRI, achieved 910 million tons of cargo throughput in 2016, up 3.3% over the same period of the previous year. In addition, in the same year, the port handled 21.56 million TEUs, ranking third in the country, with an annual increase of 4.5%. Finally, the container throughput of Ningbo-Zhoushan with the countries along BRI increased from 8.38 million TEUs to 9.08 million TEUs, accounting for 41.2% of the total container throughput of the port.

Both total cargo throughput and container throughput of the ports in this category are of the highest in the world, and the ports have close trade relationships with the countries along BRI. They are therefore classified as regional hub ports along BRI, with the role of transporting goods between their port-regions and the countries along BRI.

Table 8 Port data in the third category (2016)

Ports	*Cargo throughput (million tons)*	*Container throughput (million TEUs)*	*Container throughput with countries along BRI (million TEUs)*	*Total imports and exports with countries along BRI (billion USD)*
Yantai Port	265.7	2.58	0.26	107.1
Quanzhou Port	107.4	1.93	0.84	134.6
Fuzhou Port	149.6	2.05	0.75	169.8
Zhanjiang Port	248.3	0.71	0.07	21.6
Shantou Port	95.81	1.15	0.53	41.9

The third category includes the ports of Yantai, Quanzhou, Fuzhou, Zhanjiang and Shantou. Of these, the port with the largest cargo throughput is Yantai, with an annual throughput of about 260 million tons, slightly lower than the average throughput of the 15 ports. In terms of their level of sustainable development, the ranking of these ports is below average. Most of the cities where these ports are located are sub-central cities in their provinces, such as Yantai, Zhanjiang and Shantou, while most of the ports perform a role as regional nodes.

Yantai, the second-largest port in the Shandong Province, handled 265 million tons of cargo in 2016 (ranking 11th in the country), up 5.8% from the previous year. In the same year, the port also handled 2.6 million TEUs. Yantai City has trade relationships with the 64 countries of 'BRI interest' (see Table B1 in Appendix B), with a total volume of import and export trade with these countries reaching 10.7 billion US dollars in 2016, accounting for 20% of the total import and export volume of the city.

The two ports in the third category can be important *nodes*, transporting goods between their cities and foreign countries along BRI.

The fourth category comprises the relatively small ports of Xiamen, Haikou and Sanya (Table 9). Of these, Xiamen is the port with the highest sustainability level, albeit with an annual throughput of only 200 million tons (well below the average of the 15).

The population of the city of Xiamen is higher only to that of Haikou and Sanya (among the 15 port cities of BRI), with an annual GDP of about 400 billion yuan (well below Fuzhou and Quanzhou in the same province). Although the three ports and their cities are of relatively small economic significance, they nevertheless play an important role in promoting trade between the cities and the foreign countries along BRI, especially Xiamen (container throughput of Xiamen reached 9.6 million TEUs in 2016, ranking eighth in the country).

Haikou and Sanya are the major ports in the Hainan Province. The throughput of Haikou in 2016 was 57.63 million tons, a year-on-year increase of 8.05%. The throughput of Sanya was 3.28 million tons (in 2015), a year-on-year increase of 113%. The throughput *growth* of the two ports was the highest among the 15 ports. In 2015, the import and export volume between the Hainan Province and the countries along BRI reached 8.92 billion Yuan, accounting for 69.8% of the province's total imports and exports; of them, the foreign trade of the cities of Haikou and Sanya (with the countries along BRI) was 2.87 billion US dollars (Haikou City: 2.73 billion, Sanya City: 139 million), accounting for 32.1% of the total trade volume of the province with the countries along BRI. The ports in this category can serve as *gates* along BRI.

Table 9 Port data in the fourth category (2016)

Ports	*Cargo throughput (million tons)*	*Container throughput (million TEUs)*	*Container throughput with countries along BRI (million TEUs)*	*Total imports and exports with countries along BRI (billion USD)*
Xiamen Port	210.22	9.58	1.18	52.34
Haikou Port	57.63	1.27	0.55	27.2
Sanya Port	3.28	0.10	0.03	1.19

5 Conclusions and recommendations

Based on the concept of *capability for sustainable development* and the daily realities of the Chinese ports, we have used *PCA* and *analytic hierarchy process* to assess the sustainability of the Chinese ports on the BRI. This was done on the basis of four dimensions: capacity of port operations; economic conditions; environmental factors; and HIT. Through cluster analysis, we divided the 15 Chinese BRI ports into four categories. Shanghai was categorised as the only international hub port along BRI, while the ports of Tianjin, Guangzhou, Shenzhen, Dalian, Ningbo and Qingdao were assessed as important regional hubs along BRI. The remaining ports were seen as important *nodes* or *regional gate ports* on BRI.

In addition, the following recommendations are made, based on our results. Firstly, the environmental governance of the ports of Shanghai and Tianjin should improve. Although the sustainability of the two ports ranks them no. 1 and no. 4, respectively, mainly due to their advantages in economic conditions, HIT, and capacity of port operations, their comprehensive environmental indicators rank them 14 and 15, respectively, as a result of water pollution in the Yangtze River and air pollution in the Beijing-Tianjin-Hebei region. If the environmental problems in the two cities are left unaddressed, their negative impact on economic conditions and living standards will gradually increase, seriously affecting the overall sustainability of the two ports.

Therefore, policymakers should strengthen water pollution control in the Yangtze River Basin, as well as atmospheric and environmental management in the Beijing-Tianjin-Hebei region. An important first step would be stricter ship emissions management and the promotion of terminal shore-power technology (cold-ironing), to ensure the sustainable development of Shanghai and Tianjin ports.

Secondly, the *capacity of port operations* in the coastal area of the Fujian Province should increase. The province is an important node on China's 21st century MSR, and Quanzhou City in particular has been identified as the starting point of the *south route* of BRI (NDRC of China, 2015). However, there is a big gap between the status quo of Fujian's port development and its role in BRI, as seen by the Chinese Government (Fujian Provincial People's Government of China, 2017).

The sustainability level of the Quanzhou, Xiamen and Fuzhou ports is below the 15-port average, and so is their throughput and other indicators. The Fujian Province was the starting point of China's ancient Silk Road, and Quanzhou was the largest port of China, from the late Song Dynasty to the Yuan Dynasty. However, port development in this area has been slow in recent years. In 2016, the cargo throughput of Xiamen decreased by 0.53%. The throughput of Quanzhou and Fuzhou increased from 103 and 143 million tons in 2015, to 107 and 150 million tons respectively in 2016. However, the two ports are still not up to the development requirements of BRI. Upgrading the 'capacity of port operations' in Quanzhou and the other ports of the Fujian Province is important, in terms of enhancing their sustainable development, thus effectively meeting the BRI requirements.

Thirdly, the economic development of the port-cities of Zhanjiang and Shantou should accelerate. The Guangdong Province has a large trade volume with the countries along the BRI, but it is also the province in China with the most imbalanced development. One of the main reasons for the relatively low sustainability level of the ports of Zhanjiang and Shantou is to be found in the economic development of their respective cities. The per capita GDP of Zhanjiang and Shantou is less than half of the average of the 15 port-cities. In December 2017, the Guangdong Provincial People's Government officially promulgated the Comprehensive Development Plan for the Coastal Economic Zone of Guangdong Province (2017–2030), which clearly indicated Zhuhai, Zhanjiang and Shantou as the sub-central cities of the province. However, the various economic indicators of Zhanjiang and Shantou remain lower than the provincial average. Policy-makers of the Guangdong province should stimulate the economic development of the port-cities of Shantou and Zhanjiang, using the great economic strength of the Guangdong Province. The aim should be to transform the above two port-cities into the new poles of economic growth along the southern coast of China, in this way promoting the further development of BRI.

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Notes

1 Through a cooperation between Haralambides & Associates and the School of Maritime Economics and Management of Dalian Maritime University, we have established the ports which would make meaningful economic sense for inclusion in the BRI network in West Africa; Along the Yangtze River; and along the 'road' from Valencia-Genova-Trieste-Piraeus to East China. In the same research, we have also looked into Chinese industry relocation due to port development along the BRI. Much of this research has already been published.

2 The *institutional* dimension ought to be understood as consisting of those forms of governance which through transparency, independence and objectiveness – formulate policies that ensure the right development (and equilibrium) of the other dimensions.

Appendix A

Results of PCA

Capacity of port operations

It can be seen from Table A1 that the total contribution rate of the three principal components reaches 83%. '% of variance' is the individual weights of the three principal components. We normalise the three weights, and the final score calculation formula is the following:

$$y = \frac{59.935}{83.370} x_1 + \frac{12.196}{83.370} x_2 + \frac{11.238}{83.370} x_3 = 0.723 x_1 + 0.144 x_2 + 0.132 x_3$$

Table A1 Total variance explained: capacity of port operations

Component	*Initial eigenvalues*			*Extraction sums of squared loadings*		
	Total	*% of variance*	*Cumulative %*	*Total*	*% of variance*	*Cumulative %*
1	5.394	59.935	59.935	5.394	59.935	59.935
2	1.098	12.196	72.131	1.098	12.196	72.131
3	1.011	11.238	83.370	1.011	11.238	83.370
4	0.656	7.294	90.663			
5	0.389	4.327	94.990			
6	0.267	2.967	97.957			
7	0.106	1.173	99.130			
8	0.053	0.591	99.721			
9	0.025	0.279	100.000			

Notes: Extraction method: principal component analysis.
1 – cargo throughput (tons), 2 – growth rate of port throughput (%), 3 – cargo throughput (foreign trade) (tons), 4 – container throughput (TEUs), 5 – growth rate of container throughput (%), 6 – container throughput with countries along BRI (TEUs), 7 – number of berths, 8 – number of berths with capacity greater than 10,000 tons, 9 – investment in transportation, storage and supporting facilities (yuan).

Loading factor matrix

It is shown from the loading factor matrix Table A2 that: the first principal component is mainly related to cargo throughput (foreign trade) and container throughput (TEUs); the second principal component is mainly related to the growth rate of port throughput, investment in transportation, and storage and supporting facilities; the third principal component is mainly related to the growth rate of container throughput and to the number of berths.

Table A2 Component matrix[a]: capacity of port operations

	Component		
	1	*2*	*3*
Zscore (VAR00001)	0.882	0.202	0.068
Zscore (VAR00002)	–0.607	0.616	0.273
Zscore (VAR00003)	0.908	0.203	0.112
Zscore (VAR00004)	0.939	–0.137	0.005
Zscore (VAR00005)	–0.149	–0.230	0.952
Zscore (VAR00006)	0.881	–0.135	0.004
Zscore (VAR00007)	0.796	–0.276	0.090
Zscore (VAR00008)	0.843	0.014	0.035
Zscore (VAR00009)	0.631	0.685	0.058

Notes: Extraction method: principal component analysis.
[a]three components extracted.

Economic conditions

It can be seen from Table A3 that the final score calculation formula is as follows:

$$y = \frac{55.826}{78.126} x_1 + \frac{13.860}{78.126} x_2 + \frac{8.440}{78.126} x_3 = 0.714 x_1 + 0.177 x_2 + 0.108 x_3$$

Table A3 Total variance explained: economic conditions

Component	*Initial eigenvalues*			*Extraction sums of squared loadings*		
	Total	*% of variance*	*Cumulative %*	*Total*	*% of variance*	*Cumulative %*
1	6.699	55.826	55.826	6.699	55.826	55.826
2	1.663	13.860	69.686	1.663	13.860	69.686
3	1.013	8.440	78.126	1.013	8.440	78.126
4	0.891	7.429	85.555			
5	0.773	6.445	92.000			
6	0.570	4.753	96.753			
7	0.241	2.006	98.758			
8	0.105	0.873	99.631			
9	0.023	0.190	99.821			
10	0.016	0.131	99.952			
11	0.005	0.044	99.996			
12	0.000	0.004	100.000			

Notes: Extraction method: principal component analysis.
1 – gross domestic product of port-city (yuan), 2 – annual growth rate of GDP (%), 3 – GDP per capita (yuan), 4 – added value of industry (yuan), 5 – added value of tertiary industry (yuan), 6 – tertiary sector output to GDP (%), 7 – local government expenditure (yuan), 8 – investment in fixed assets (yuan), 9 – investment in transportation, storage and post services as per cent of investment in fixed assets (%), 10 – use of foreign capital (USD), 11 – total amount of imports and exports (USD), 12 – total imports and exports with countries along BRI (USD).

Loading factor matrix

It is shown from the loading factor matrix Table A4 that: the first principal component is mainly related to gross domestic product of the port-city and the added value of industry; the second principal component is mainly related to the added value of the tertiary sector, investment in transportation, storage and post services as percent of investment in fixed assets; the third principal component is mainly related to the annual growth rate of GDP, investment in transportation, storage and post services as per cent of investment in fixed assets.

Table A4 Component matrix[a]; economic conditions

	Component		
	1	*2*	*3*
Zscore (VAR00001)	0.983	0.090	0.026
Zscore (VAR00002)	0.024	–0.416	0.731
Zscore (VAR00003)	0.792	0.125	–0.243
Zscore (VAR00004)	0.970	–0.126	–0.008
Zscore (VAR00005)	0.281	0.681	–0.006
Zscore (VAR00006)	0.911	0.126	0.042
Zscore (VAR00007)	0.746	–0.566	–0.008
Zscore (VAR00008)	0.892	–0.174	0.167
Zscore (VAR00009)	–0.167	0.556	0.602
Zscore (VAR00010)	0.875	–0.229	0.062
Zscore (VAR00011)	0.718	0.444	0.126
Zscore (VAR00012)	0.772	0.247	–0.087

Notes: Extraction method: principal component analysis.
[a]three components extracted.

Environmental factors

It can be seen from Table A5 that the final score calculation formula is as follows:

$$y = \frac{43.554}{76.884}x_1 + \frac{33.340}{76.884}x_2 = 0.566x_1 + 0.434x_2$$

Table A5 Total variance explained: environmental factors

Component	*Initial eigenvalues*			*Extraction sums of squared loadings*		
	Total	*% of variance*	*Cumulative %*	*Total*	*% of variance*	*Cumulative %*
1	2.177	43.544	43.544	2.177	43.544	43.544
2	1.167	33.340	76.884	1.167	33.340	76.884
3	0.974	9.473	86.357			
4	.501	8.021	94.379			
5	.181	5.621	100.000			

Notes: Extraction method: principal component analysis.
1 – days of air quality equal to or above grade II (days), 2 – rate of treatment of city waste water (%), 3 – standard-reaching rate of nearshore water (%), 4 – green coverage rate in developed areas (%), 5 – expenditure on energy saving per capita (yuan).

Loading factor matrix

It is shown from the loading factor matrix Table A6 that: the first principal component is mainly related to days of air quality equal to or above grade II and standard-reaching rate of nearshore water; the second principal component is mainly related to rate of treatment of city waste water and expenditure on energy saving per capita.

Table A6 Component matrix[a]: environmental factors

	Component	
	1	*2*
Zscore (VAR00001)	0.882	–0.049
Zscore (VAR00002)	–0.504	0.463
Zscore (VAR00003)	0.832	–0.135
Zscore (VAR00004)	0.666	0.455
Zscore (VAR00005)	0.100	0.851

Notes: Extraction method: principal component analysis.
[a]two components extracted.

Human intellect and tech

It can be obtained from Table A7 that the final score is as follows:

$$y = \frac{61.442}{78.573} x_1 + \frac{17.131}{78.573} x_2 = 0.782 x_1 + 0.218 x_2$$

Table A7 Total variance explained: human intellect and tech

Component	*Initial eigenvalues*			*Extraction sums of squared loadings*		
	Total	*% of variance*	*Cumulative %*	*Total*	*% of variance*	*Cumulative %*
1	3.687	61.442	61.442	3.687	61.442	61.442
2	1.028	17.131	78.573	1.028	17.131	78.573
3	0.683	11.390	89.963			
4	0.361	6.010	95.973			
5	0.231	3.844	99.817			
6	0.011	0.183	100.000			

Notes: Extraction method: principal component analysis.
1 – year-end permanent population (persons), 2 – number of patents certified (number), 3 – student enrolment to higher education institutions, 4 – expenditure on education (yuan), 5 – expenditure on education per capita (yuan), 6 – proportion of expenditure on education to local financial expenditure (%).

Loading factor matrix

It is shown from the loading factor matrix Table A8 that: the first principal component is mainly related to year-end permanent population and expenditure on education; the second principal component is mainly related to student enrolment to higher education institutions and proportion of expenditure on education to local financial expenditure.

Table A8 Component matrix[a]: human intellect and tech

	Component	
	1	*2*
Zscore (VAR00001)	0.921	0.237
Zscore (VAR00002)	0.854	–0.278
Zscore (VAR00003)	0.653	0.318
Zscore (VAR00004)	0.950	0.108
Zscore (VAR00005)	0.813	0.017
Zscore (VAR00006)	–0.345	0.884

Notes: Extraction method: principal component analysis.
[a]two components extracted.

Appendix B

Table B1 Countries along BRI (64 countries)

Region	*Countries*
Northeast Asia (2 countries)	Mongolia; Russia
Southeast Asia (11 countries)	Singapore; Malaysia; Indonesia; Myanmar; Thailand; Laos; Cambodia; Vietnam; Brunei; the Philippines; Timor-Leste
South Asia (7 countries)	India; Pakistan; The People's Republic of Bangladesh; Sri Lanka; Maldives; Nepal; Bhutan
West Asia and North Africa (20 countries)	UAE; Kuwait; Turkey; Qatar; Oman; Lebanon; Saudi Arabia; Bahrain; Israel; Yemen; Egypt; Iran; Jordan; Syria; Iraq; Afghanistan; Palestine; Azerbaijan; Georgia; Armenia
Central and Eastern Europe (19 countries)	Poland; Albania; Estonia; Lithuania; Slovenia; Bulgaria; Czech Republic; Hungary; North Macedonia; Serbia; Romania; Slovakia; Croatia; Latvia; Bosnia and Herzegovina; Montenegro; Ukraine; Belarus; Moldova
Central Asia (5 countries)	Kazakhstan; Kyrgyzstan; Turkmenistan; Tajikistan; Uzbekistan

Notes: Countries along BRI refer to countries with which the Chinese Government has signed an MoU before December 2017.

Source: https://www.yidaiyilu.gov.cn/info/iList.jsp?tm_id=513

Table B2 Evaluation of indicators of port sustainability

Main objective	*Dimensions*	*Indicators*
Sustainability of the port	Capacity of port operations	Cargo throughput (tons)
		Growth rate of port throughput (%)
		Cargo throughput (foreign trade) (tons)
		Container throughput (TEUs)
		Growth rate of container throughput (%)
		Container throughput with countries along BRI (TEUs)
		Number of berths
		Number of berths with capacity greater than 10,000 tons
		Investment in transportation, storage and supporting facilities (yuan)
	Economic conditions	Gross domestic product of port-city (yuan)
		Annual growth rate of GDP (%)
		GDP per capita (yuan)
		Added value of industry (yuan)
		Added value of tertiary industry (yuan)
		Tertiary sector output to GDP (%)
		Local government expenditure (yuan)
		Investment in fixed assets (yuan)
		Investment in transportation, storage and post services as per cent of investment in fixed assets
		Use of foreign capital (USD)
		Total amount of imports and exports (USD)
		Total imports and exports with countries along BRI (USD)
	Environmental factors	Days of air quality equal to or above grade II (days)
		Rate of treatment of city waste water (%)
		Standard-reaching rate of nearshore water (%)
		Green coverage rate in developed areas (%)
		Expenditure on energy saving per capita (yuan)
	Human intellect and tech	Year-end permanent population (persons)
		Number of patents certified (number)
		Student enrolment to higher education institutions
		Expenditure on education (yuan)
		Expenditure on education per capita (yuan)
		Proportion of expenditure on education to local financial expenditure (%)

Appendix C

Table C1 Description of the 'capacity of port operations' dimension

Indicators	*Description*
Port throughput (tons)	It refers to the total amount of cargo loaded and unloaded during a period of time, and reflects the port's logistics service capacity towards the countries along BRI.
Growth rate of port throughput (%)	It refers to the annual growth rate of port throughput, and reflects the potential of servicing the countries along BRI.
Port throughput with foreign countries (tons)	This concerns the amount of cargo handled by the port, regarding only foreign trade and it indirectly indicates the connectivity of the port with international markets.
Container throughput (TEU)	It refers to the total number of containers loaded and unloaded at the port during a period of time, and it reflects the port's container logistics service capacity to the countries and regions along BRI.
Growth rate of container throughput (%)	It refers to the annual growth rate of container throughput, and reflects the potential of container logistics services to the countries along BRI.
Container throughput with countries along BRI (TEU)	It refers to the total number of containers loaded and unloaded at the port during a period of time, and transported to/from the countries along BRI.
Number of berths	This indicates the service capacity of Chinese container ports.
Number of berths over 10,000 tons	It reflects the ability of the port to berth large ships that transport to/from BRI ports.
Investment in transportation, storage and services (yuan)	It represents the development potential and future scale of port infrastructure and thus its ability to connect with BRI.

Table C2 The description of the economic conditions dimension

Indicators	*Description*
Gross domestic product (yuan)	It is often considered as an indicator of the economic rigor of a port-city and it is usually positively correlated with port development.
Annual growth rate of GDP (%)	It reflects the growth potential of the hinterland economy and the future trends in port demand.
GDP per capita (yuan)	An important indicator of the economic situation of a port-city, positively correlated with port development.
Value added of industry (yuan)	Port throughput is closely related to industrial production, so this is an important indicator, affecting the sustainable development of the port.
Value added of the tertiary sector (yuan)	Logistics services constitute an important part of the tertiary sector, whose output is closely related to port development.
Proportion of tertiary sector to GDP (%)	To a certain extent, this reflects the economic development of the port-city and in this way it can be used as an index in evaluating the sustainable development of ports.
Local financial expenditure (yuan)	Generally speaking, financial expenditures, such as utilities, education and R&D are conducive to city development, thus promoting the development of ports.

Table C2 The description of the economic conditions dimension (continued)

Indicators	*Description*
Investment in fixed assets (yuan)	This stimulates economic growth, which is conducive to improving demand for port services.
The proportion of investment in transportation, storage and supporting facilities to investments in fixed assets (%)	Public investment in transport infrastructure improves port infrastructure, port hinterland links and distribution conditions. At the same time, such investments facilitate economic development, thereby increasing port demand.
Use of foreign capital (USD)	It reflects a city's ability to attract international capital. The higher the foreign investment entering city finances, the better the economic development of the port-city and the higher the demand for port services.
Total imports and exports (USD)	As the imports and exports of the port city are closely related to port throughput, this indicator directly reflects the scale of port demand.
Total imports and exports with the countries along the BRI (USD)	This index reflects the degree of connection between the port and ports along BRI, reflecting also the position of the port in BRI.

Table C3 The description of the *environmental factors* dimension

Indices	*Description*
Days of air quality equal to or above grade II (days)	This reflects the air quality of the port-city. Good air quality contributes to the sustainability of the port.
Rate of treatment of city waste water (%)	It reflects the strength of water quality protection in the port-city. Water quality is an important part of the natural environment of the city. High-quality water contributes to the sustainable development of the port.
Standard-reaching rate of nearshore water (%)	Similarly, this reflects the water quality environment of the port-city and it is an important indicator, affecting the sustainable development of the port.
Green coverage rate in developed areas (%)	This reflects the *greening* degree of the port-city. A 'green' environment improves the image of the port and helps in attracting new customers.
Expenditure on *energy saving* per capita (yuan)	Energy-saving expenditure is closely related to polluting emissions of the port-city. The higher the index value, the more ready is the city to reduce its emissions and to promote the sustainable development of the port.

Table C4 The description of the *HIT* dimension

Indices	*Description*
Permanent population (persons)	This describes the number of permanent residents in the port-city. The sustainable development of ports is related to the economic engagement of human resources.
Patents deposited (number)	It shows the scientific and technological level of the port-city. A high level of science and technology promotes the development of the port and provides technical support for its sustainable development.

Table C4 The description of the *HIT* dimension (continued)

Indices	*Description*
Student enrolment to higher education institutions (per 10,000 persons)	It shows the number of persons who receive higher education in the port-city, and is one of the important indicators reflecting the development level of science and technology.
Expenditure on education (yuan)	It reflects the investment on education of port-cities and indirectly the city's level of science and technology.
Expenditure on education per capita (yuan)	It is one of the indicators reflecting the future scientific and technological prospects of the city. The greater the per capita investment in education, the better the development prospects of science and technology.
Proportion of expenditure on education to local financial expenditure (%)	It reflects the local government's attention to education. The higher this proportion, i.e., the more attention the local government attaches to it, the better the development prospects of science and technology would be.

Appendix D

Table D1 Basic information of experts (judgment matrices of AHP)

Institution	*Field*	*Number*
Shipping companies	Shipping management	4
Port group	Port management	4
Trading company	Economy and trade	4
Shanghai international shipping institute	Shipping and environment	4

Appendix E

Table E1 A container throughput among the 15 Chinese BRI ports and the foreign BRI ports (2016)

Ports	*Container throughput with BRI countries (million TEUs)*	*Ports*	*Container throughput with BRI countries (million TEUs)*
Shanghai	9.41	Tianjin	4.99
Ningbo	9.07	Guangzhou	1.30
Shenzhen	8.57	Zhanjiang	0.07
Shantou	0.53	Qingdao	2.02
Yantai	0.26	Dalian	1.01
Fuzhou	0.75	Xiamen	1.18
Quanzhou	0.84	Haikou	0.55
Sanya	0.03		