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Economic and environmental impacts of alternative routing scenarios in the context of China's belt and road initiative

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ABSTRACT

This paper provides an empirical study of combined land - ocean transport within the Belt and Road Initiative (BRI). The analysis is based on primary data in each transport activity taking place between Yiwu and Madrid. Five scenarios are modelled using alternative transport routes. Optimal choices for multi-modal transport combinations with regards to both economic and environmental perspectives are identified. By investigating freight transport from Yiwu to Madrid using the Yixinou line, the results suggest that the BRI has significant potential to reduce the cost of freight transport from China to Europe.

1. Introduction

China's Belt and Road Initiative (BRI), originally known as One Belt One Road (OBOR), was first announced in 2013 by President Xi Jinping and seeks to further integrate Asia, Europe, and Africa through two interlinked components. The first is the Silk Road Economic Belt - a land-based transport network connecting China to Europe and the Middle East through Central Asia and Russia, and the second is the twenty-first-century Maritime Silk Road - a maritime route connecting ports in Asia, Africa and Europe. Development under this US$1.2 trillion project includes roads, railways, airports, seaports, energy pipelines, and other core projects in the region (Len, 2015). Within the BRI, investments into a vast network of harbours and land infrastructure across the globe have created new sea lanes and trade corridors, which provide new choice of transport mode and combination of modes in the region.

With the development of the BRI, international trade and business volumes between Europe and Asia keep increasing. As the main initiator of this strategy, China is making major investments in the domestic transport and border-crossing infrastructure. This paper thus investigates the transport channels for the Silk Road and optimizes the transport paths. Therefore, it provides a theoretical consideration of development of combined land - ocean transport within the BRI, illustrating the characteristics of combining transport methods within Multi-modal transport. Since this paper considers the real network within the BRI, it provides a meaningful reference to the application of combined land-ocean arrangement. Moreover, in the model, we consider all the nodes/terminals where cargoes are handled or transferred, taking account of time, cost and derived emissions.

Meanwhile, the shipping industry is in a state of transition as it regularly adjusts to increasingly strict emissions standards set by regulators. There is an increasing awareness of shipping's contribution to global emissions of greenhouse gases; a low-carbon economy is identified as one of the Sustainable Development Goals from the UN. China's BRI has profound implications in supporting this transition and acting upon long-term environmental change (United Nations (UN), 2016). A multi-dimensional study was carried out by Nieuwenhuis et al (2012) who adapted an established transport cost model (Beresford, 1999) to track CO_2 emissions in

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automotive supply chains. Here, we further adapt and develop the original cost model to consider carbon emissions generated by using the new sea lanes and trade corridors encompassed in BRI. The BRI has far-reaching implications for the future volume and balance of shipping trade around the world. With its claim to boost support for green and low-carbon development, we are interested in its impact on carbon emissions and its viability and challenges contributing towards a low-carbon economy. Here, we consider cost –distance modelling, carbon emissions modelling, and economic/trade evaluation corridor under BRI.

This paper provides a theoretical consideration of economic and environmental perspectives for combined land - ocean transport within the Chinese Belt and Road Initiative. An empirical study is undertaken, with alternative transport channels investigated and optimised and the characteristics of a multi-modal transport approach presented. The design of the research focuses on the practical implementation of combined inland-ocean transport methods and paths. The analysis is based on primary data in respect each transport activity taking place between Yiwu and Madrid. An activity-based CO2 emission model is used to estimate the cost and CO2 emission impacts of five scenarios using alternative transport routes (current situation and four proposed scenarios). Optimal choices for multi-modal transport combinations with regards to both economic and environmental perspectives are identified. Results suggest the BRI can reduce the cost of freight transport, however CO2 emissions are not a large determinant for reducing environmental impact as only small differences between the carbon intensity of the rail and sea freight transport options exist. This paper provides an economic and environmental assessment of transport options in order to determine optimal choices for multi-modal transport combinations on BRI routes not previously analysed. By investigating freight transport from Yiwu to Madrid through China using the Yixinou line, the results suggest that the BRI has significant potential to reduce the cost of freight transport from China to Europe using these routes.

Our paper contributes to the current literature on maritime and hinterland transport chains and multimodal choices (For example, Talley and Ng, 2013; Talley and Ng, 2017 and Talley and Ng, 2018), through utilising realistic modelling and primary data, and focusing on the practical implementation of combined inland-ocean transport methods and paths. This paper also considers optimal choices of multi-modal transport combinations with regards to both economic and environmental perspectives.

2. BRI Research

While China's economic growth since the early 2000s has been rapid, as exemplified by its foreign exchange reserves growing from in $US 212 billion in 2001 to $US 4 trillion by June 2014 (Chinability, 2017) China's foreign policy had not been as dynamic (Ferdinand, 2016). However, during the latter stages of the Hu Jintao era a 'China dream' had begun to emerge, that of a successful, modern China taking precedence over individual success (Ferdinand, 2016). Economic reformers had begun to suggest, among other things, the better use of resources, and a more balanced approach to economic development and environmental impact. The idea was developed further when Xi Jinping became leader as he promoted the China Dream as one of the ideological objectives of his regime (Callahan, 2013). Thus, an important factor underpinning the China dream campaign was economic growth, and one foreign policy outworking of this was the BRI. (Summers, 2015).

In terms of policy dialogue, the BRI seeks to develop a multi-tier inter-governmental mechanism for macro-policy dialogue and provide policy support for cooperation. Infrastructure connectivity will underpin the overall scheme by developing infrastructure to link the sub-regions in Asia, Europe and Africa while promoting low-carbon and green economic approaches while also accounting for climate change. While effective infrastructure is key to the whole scheme, investment in trade facilitation and the elimination of trade and investment barriers are also seen as important in facilitating international value chains. Financial support is a key aspect of BRI with a range of financial mechanisms used to support and promote development. 'People-to-people exchange' is supposedly important in creating more effective inter-country links. However, while BRI provides important opportunities it also contains significant geopolitical risks and financial sustainability issues in cross-country projects which leave the host countries exposed to greater Chinese influence (Wang, 2016; Yu, 2016).

A multi-modal transport network opens up the widest possible range of transport options (UNESCAP, 2003; 2006), thus optimising the modal mix and maximising overall transport efficiency. Intrinsically, BRI is closely connected to both European economic area and Asia-Pacific economic area. Generally, it mainly has two types of transport modes: land transport and marine transport. Land transport within BRI is mainly based on Asian Highway Routes and Trans-Asian Railway (Tumonggor et al, 2013). Both of the two routes take China as the centre, and connect Europe and Asia, which are the strong support for the development of land silk road. According to the Intergovernmental Agreement on the Asia Highway Network, which was officially issued on 2004, the Asia Highway Routes are the transport network that connect the capitals, industrial centres, important harbours, and touring cities in all Asian countries (Hanaoka and Regmi, 2011). As the agreement stated, there are fifty-five road corridors in this network (Faber, 2014). The Trans-Asian Railway is a freight railway network passing through Asia and Europe. This network is comprised of the three channels shown in Table 1.

Maritime transport is also called "The 21st Century Maritime Silk Road". Through the integration and rearrangement of present shipping source, a comprehensive shipping network with a large shipping volume is established. According to BRI, there are two channels in the Maritime Silk Road (Len, 2015). The first channel begins from several coastal ports in China, passes through the South China Sea and the India Ocean, then fanning out into Europe. The second channel begins from several coastal ports in China, passes through the South China Sea, and finally arrive the South Pacific Ocean. There are more than five thousand shipping lines connect China and the other countries. An overall view of the BRI is presented in Figure 1.

There have been many recent papers considering China's Belt and Road Initiative reflecting on the rail transport mode and its comparison to the shipping transport mode. Sheu and Kundu (2018) looked into international logistics networks within the BRI region

Table 1
The distribution of Channels on the Belt and Road China-Europe block trains.

Channels	Departure ports	Function	Number of lines
West Channel	Alashankou	trade between Europe and middle west of China	15
Mid Channel	Erlianhaote	trade between Europe and north and central of China	3
East Channel	Manzhouli	trade between Europe and east and south of china	8

Source: Lin (2016)

Fig. 1. Belt and road initiative mapping (Source: The Mercator Institute for China Studies (MERICS).

and developed a model that forecasts time-varying freight flows on a BRI-relevant international logistics network. Liu et al. (2018) applied a game-theoretic approach to study e-commerce supply chain coordination issues arising from the BRI, particularly how the cost of the required investments should be shared. Shao et al. (2018) and Zhao et al. (2018) both investigated the issue of evaluating infrastructure investments. Investment decisions on shipping and railways/high-speed railway developments were looked into. Yang et al. (2018) studied how to improve the interconnectivity of international shipping services and international land-based railway infrastructure, in particular, Chinese liner shipping companies and the New Eurasian Land Bridge rail services. Zeng et al. (2018) and Tu et al. (2018) both looked at shipping network within China's BRI. The former developed a prediction model to forecast changes in transhipment traffic, in particular the Carat Canal from the Malacca Strait, whereas the latter analysed the optimum design for Indonesia's shipping network within BRI. Randrianariosa et al (2020) studied the relationship between the new rail and the existing port. Wang et al (2020) examined the impact of the railway and road infrastructure on economic growth.

While most of the literature on BRI consider the economic bearings, only a few papers i.e. Saud et al (2020) considered ecological footprint indicators for selected one-belt-one-road initiative countries. The environmental impact of BRI is not to be underestimated. BRI claims to boost support for green and low-carbon development, we are interested in its impact on carbon emissions and its viability and challenges contributing towards a low-carbon economy. We look into carbon emissions modelling alongside cost and distance modelling within BRI and compare economic and environmental impacts of different transport modal combination within BRI.

3. Carbon Emissions and the BRI

The complex and far-reaching BRI project offers an opportunity to test CO_2 footprinting in an extremely diverse operational environment which embraces a network of international transport corridors including road, rail and sea alternatives. (China Daily, 2018a, China Daily, 2018b). While the BRI is founded on the ancient silk trade routes, its modern form is derived from the landbridge routes developed through the 1980s and 1990s with a spine running from Vladivostok / Vostochny to Moscow. Route (and mode) alternatives fan out from Moscow southwards, westwards and northwards such that the major production centres (for eastbound) and markets (for westbound) are directly or indirectly accessible to or from it (UNESCAP, 2003). The spine distance, measured from, for example, Tokyo to Moscow is 10,375 kilometres. This compares with 23,576 kilometres using shipping via St Petersburg (Jung and Beresford, 1993).

For twenty years or so, China has recognised the importance of linking into this spine via infrastructural improvements in key locations. These include the new rail terminal and customs facility at the Kazakhstan – China border crossing at Khorgos, where major new terminal facilities were completed in 2017. Elsewhere network capacity has increased by means of, for example, a newly constructed rail-bridge over the Amur River linking China and Russia, which opened in 2018. These provide improved routing options mainly for westbound exports and a framework to promote fresh industrial locations. They should also increase overall transport cohesion, although problems have occurred such as inconsistency in customs procedures and the considerable variation in length of time for goods to be processed across the border (Financial Times, 2018). In the longer term however, new infrastructure, connectivity maximisation, and better interoperability will facilitate freight movements, improve the attractiveness of the landbridge option and raise the profile of the BRI network. It could be contended, therefore, that the continental-scale relaunch of the ancient silk routes between the Far East and Europe have inadvertently provided an ideal testing ground for carbon-footprinting of long-distance freight haulage embracing sea and rail as surface spine-haul options, trucking to provide feeder and / or first-mile / last-mile movement and air as the first-choice for most time-sensitive or highest-value shipments. (Ren, 2016)

In order to understand the environmental footprint created by the BRI project the extant literature on international freight transport offers some clues in relation to node, mode and route selection (Beresford and Pettit, 2018). This literature has expanded over the last decade (see, for example, Jonkeren at al., 2007; Beresford et al., 2009; Nieuwenhuis, 2012). In addition, there is extensive literature on carbon efficiency and carbon foot printing related to shipping, transport and distribution. Recent examples of research addressing this area include Sanchez Rodrigues et al (2014) and Harris et al (2018). In all cases it is clearly demonstrated that for long supply chains, transport solutions are invariably multimodal and complex and they operate against a background of physical, organisational and geo-political constraints. Further, economies of aggregation can be achieved by concentrating flows onto prescribed corridors such as the trans-Siberian rail route, with its offshoots in the form of the TMR and the TCR offering scope economies through widened access; the geopolitics of the region also enable governmental support to be used as an incentive to increase the attractiveness of the TMR, TCR and TSR vis-a-vis the established services linking the Far East with Europe (Du and Ma, 2015; Swaine, 2015; China Daily, 2018c).

4. Methodology

An activity-based CO_2 emission model is used to estimate the cost and CO_2 emission impacts of five scenarios (current situation and four proposed scenarios). A more disaggregated analysis than that implemented by Liao et al (2010) was undertaken, in a similar manner to that followed by Harris et al, 2018. In this study, standard vessel load and speed are considered.

4.1. The cost–distance model and emissions– distance model

Beresford (1999) outlined the four developmental stages of the cost –distance model from its basic form through two intermediate stages to its final mature form. In stage 1, road transport is cheaper than rail transport in short distances before the break-even point. As the distance increases, road transport has a higher per kilometre cost than rail transport. At stage 2, an intermodal transfer can be arranged at the closet rail terminal or inland clearance depot (ICD). A vertical step in the model represents the cost involved when goods are transhipped from road to rail at the rail terminal or ICD. The result of the combination can reduce the cost over long distances. At stage 3, especially for international trade, the most common destination for freight in transit may be a seaport, where the cargoes can be transferred to ships. Compared with stage 2, stage 3 adds a second vertical step which is the port handling charge. From the combination of the three different forms of transport, lower costs for long distance transport can thus be achieved. The final stage indicates that many modes of transport can be involved to transport goods and provide door-to-door services. It can be seen that a cost is incurred at each intermodal transfer, represented by a vertical step in the model. Depending on the route chosen, the combination of modes and cost will be different (Banomyong and Beresford 2001). The purpose is to find the most cost-saving and competitive route.

We further adapt the cost – distance model to an emission-distance model including both transport (five main transport modes under BRI: road, rail, inland waterway, sea and energy pipeline) and intermodal transfer (port terminal, rail terminal and river terminal) as emission components. The basic premise is that emissions vary between modes, for volume movements, road transport produces the highest emission per tonne-km followed by rail, inland waterway, sea and energy pipeline being the lowest. Table 2 summarises three routing alternatives under BRI. All-land and all-water alternatives are compared in Figure 2. The all-land route from China to Europe could potentially lead to much lower emission than the traditional maritime route, which is due to the significantly reduced distance. This is in line with Nieuwenhuis et al (2012) that the local option using road-based distribution leads to lower

Table 2
Routing alternatives under BRI.

All-road	Road – rail - road	China – Europe via Eurasian Landbridge*
All-water	Inland waterway – sea – inland waterway	China – Europe via Maritime Silkroad*
Energy pipeline	Sea - pipeline	Middle East – China via China Pakistan Corridor*

*Refer to Figure 1 Belt and road initiative mapping

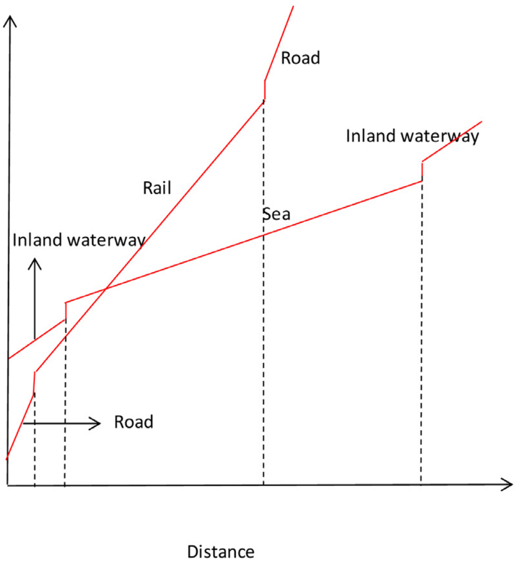

Fig. 2. The emission-distance model – all-water and all-road.

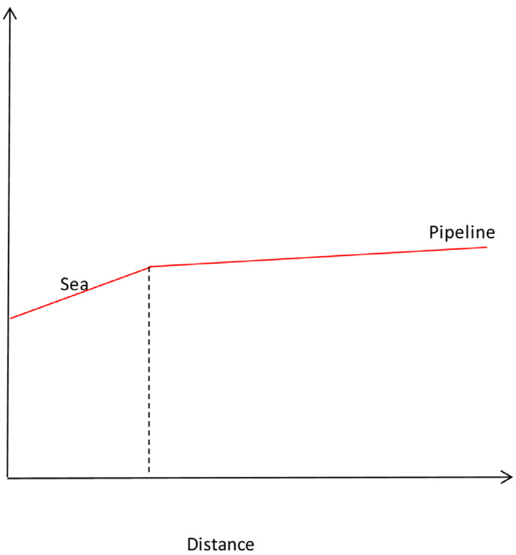

Fig. 3. The emission-distance model – energy pipeline.

emissions than shipping directly from South Korea. Figure 3 illustrates the potential to transport oil through energy pipelines from Middle Eastern countries to China, which also leads to substantially lower emissions compared to the traditional maritime route through the Strait of Malacca. These Figures do not show actual distances, rather they are generalised graphs to show how different modal combinations generate different emissions outputs.

Table 3
Trans-Asian Railway train lines.

Name	Original city	Destination	Distance/km	Time/days
Yuxinou	Chongqing	Germany	11179	16
Yumanou	Chongqing	Russia	-	14
Hanxinou	Wuhan	Czech	10863	23
Hanmanou	Wuhan	Russia	9755	-
Ronxingou	Chengdu	Poland	9826	14
Rongmengou	Chengdu	Poland	-	-
Zhengxingou	Zhengzhou	Germany	10214	16
Zhengmengou	Zhengzhou	Germany	10399	18
Yixinou	Yiwu	Spain	13000	21
Suxinou	Suzhou	Poland	11800	14
Xixinou	Xi'an	Kazakhstan	5926	8
Xiangxinou	Changsha	Germany	11808	18
Xiangmanou	Changsha	Uzbekistan	6476	11
Jinmengou	Tianjin	Mongolia	-	-
Jinmanou	Tianjin	Russia	8488	-
Yuexinou	Guangzhou	Russia	11000	-
Yuemanou	Guangzhou	Russia	10090	18
Shenmanou	Yingkou	Germany	14000	23

Source: Mo et al (2015)

Table 4
Transnational rail trains between China and Europe through the border ports by 2014.

Departure Port	Number of lines	Name of lines
Alashankou	8	Yuxinou, Exinou, Rongxinou, Zhengxinou, Xixinou, Xiangxinou, Yixinou, Yuexinou
Manzhouli	7	Yumanou, Emanou, Sumanou, Shenmanou, Jinmanou, Yuemanou, Xiangmanou
Erlianhaote	4	Jinmengou, Xiangmengou, Rongmanou, Zhengmengou
Suifenhe	1	Yuesuiou
Huoerguosi	1	Xiangxinou
Summary	21	

Source: Mo et al (2015)

4.2. Development of Scenarios – Modelling

Currently, there are 21 routes connecting China and Europe (Table 3). In this paper we choose the Yixinou line which connects China and Spain. The operation of this route improves the bilateral trade between two countries. Spain is the seventh trading partner of China in Europe, and China is the biggest trading partner of Spain beyond European Union. The Yixinou line and other 7 railway lines share the same departure port (Alashankou) in China (Table 4) (Mo et al, 2015).

The Yixinou line (Yiwu - Madrid Railway line) is a railway route taken by container trains from the Chinese city of Yiwu to the Spanish city of Madrid, a distance of approximately 13,000 kilometres (8,100 mi), and the longest in the world. When compared to other transport lines, this line has limited competitiveness. Since the transport distance of Yixinou is the longest railway freight transport, the time required for the freight container to transport from the origin city, Yiwu, to the destination city, Madrid, is the longest (Table 3)(Mo et al, 2015). As shown in Table 3, the Yixinou line has a 21 day transit time, while the other lines, such as Yuxinou and Rongxinou, take less than 20 days for transport. Besides, the operational frequency of the Yixinou line is also quite limited, offering only one train once per week. Compared to the relatively valuable automotive parts, the red wine and olive oil cargoes on the back-haul train from Spain to China are not profitable enough. As a result, the single transport from China to Europe in Yixinou line results in a profit loss. In this study cargoes are considered to be standard manufactured and semi-manufactured goods.

The overall transport cost for a container from Yiwu to Spain is about $US 10,000 for the railway transport. However, the transport cost for the ocean transport is around $US 5,000. Therefore, ocean transport provides the main transport mode between China and Europe (Zhao, 2015). To occupy the market, the local government provides a significant subsidy. Actually, this phenomenon is quite popular within all X-Xinou lines. With the subsidy, the transport cost is as low as $US 7,500 dollars for each container. However, because of insufficient regulation, control and negotiation between different cities, the subsidy also leads to a deterioration in competition. As a result, the healthy continuous development of the Yixinou freight transport is seriously hindered (Yang, 2016).

As Table 5 shows, the scenarios modelled in this study are contrasting, scenarios 1 and 2 are sea maximising scenarios that have over 90% of the distances covered by sea transport, although the rest of the distance is covered by train. On the other hand, scenarios 3 and 4 are slightly different to scenarios 1 and 2 since the transport used from the origin is road transport instead of rail as in the case of scenarios 1 and 2. In contrast, Scenario 5 is completely different to the other four scenarios, because it has a rail maximising scenario that means rail transport accounts for 13,052 Km while only 13 Km is by road. The modelling and analysis of these five scenarios allow an assessment of the performance of different alternative modes available for the transport of cargo between China and Spain. Table 6 details distance data for the different BRI transport paths/routes for the analysis. Tables 7 and 8 report on the costs per container-Km for all the journeys covered by the study in the five scenarios presented in Table 5.

Table 5
Five Scenarios multi-modal transport from Yiwu to Madrid.

Origin	First Leg	Transhipment Point	Second Leg	Transhipment Point	Third Leg	Transhipment Point	Fourth Leg	Transhipment Point	Fifth Leg	Arrival	
Land-sea-land											
1	Factory	Road	Yiwu train Station	Rail	Ningbo port	Sea	Barcelona	Rail	Madrid	Road	Market
2	Factory	Road	Yiwu train Station	Rail	Shanghai port	Sea	Barcelona	Rail	Madrid	Road	Market
3	Factory	Road	Ningbo port	Sea	Barcelona	Rail	Madrid	Road	Market		
4	Factory	Road	Shanghai port	Sea	Barcelona	Rail	Madrid	Road	Market		
Land											
5	Factory	Road	Yiwu Train Station	Rail	Alashankou, Xinjiang	Rail	Madrid	Road			Market

Table 6
Five Scenarios multi-modal transport from Yiwu to Madrid – data description.

Scenario	Origin	Distance (km) ROAD	Time (hr)	Transfer Terminal	Distance (km) (RAIL)	Time (hr)	Transfer Terminal	Distance (km) SEA/ RAIL	Time (hr)	Transfer Terminal	Distance (km) RAIL	Time (hr)	Destination
1	Factory	13	1	Yiwu Train Station	311	7	Ningbo (sea)	16110	696	Barcelona	620	8	Madrid
2	Factory	13	1	Yiwu Train Station	324	8	Shanghai (sea)	16250	744	Barcelona	620	8	Madrid
3	Factory	240	4				Ningbo (sea)	16110	696	Barcelona	620	8	Madrid
4	Factory	300	5				Shanghai (sea)	16250	744	Barcelona	620	8	Madrid
5	Factory	13	1	Yiwu Train Station	4907	60	Alashankou Train Station (rail)	8145	445				Madrid

Table 7
Containers types and weights used for this study.

Container	Average weight (tonne)
TEU/20' container	11
FEU/40' container	22

Table 8
Costs per Container.

Routes	Road Cost ($US)
Yiwu - Yiwu train station	75/100 - TEU/FEU
Yiwu - Port of Ningbo	300/450- TEU/FEU
Yiwu train station -Port of Shanghai	390/520 - TEU/FEU
Yiwu train station - Port of Ningbo	235/330 - TEU/FEU
Madrid - Market	85/110 - TEU/FEU
Routes	Rail Cost ($US)
Yiwu train station - Port of Shanghai	275/370 - TEU/FEU
Yiwu train station - Port of Ningbo	235/330 - TEU/FEU
Port of Barcelona - Madrid	434/558 - TEU/FEU
Yiwu train station - Alashankou Train Station	1473/1962 - TEU/FEU
Alashankou Train Station - Madrid	3828/5701 - TEU/FEU
Routes	Sea Freight Rate ($US)
Ningbo Port - Port of Barcelona	580/1100 - TEU/FEU
Shanghai Port - Port of Barcelona	530/1050 - TEU/FEU
Transfer Terminal	Unloading/lift costs ($US)
Yiwu	18/36 - TEU/FEU
Yiwu Rail Terminal	30/45 - TEU/FEU
Alashankou Train Terminal	200/300 - TEU/FEU
Port of Barcelona	150/200 - TEU/FEU
Port of Ningbo	202/357 - TEU/FEU
Port of Shanghai	202/357 - TEU/FEU

Table 9
CO_2 conversion factors – transport mode.

Mode	CO_2g/tonne-km
Road	96.1
Rail	18.8
Sea	12.5

Table 10
CO_2 conversion factors - terminals.

Transfer Terminal	Unloading/lift CO_2 g per TEU	Unloading/lift CO_2 g per FEU
Yiwu	700	1400
Yiwu Rail Terminal	700	1400
Alashankou Train Terminal	700	1400
Port of Barcelona	1100	2200
Port of Ningbo	1100	2200
Port of Shanghai	1000	2200

Tables 9 and 10 show the CO_2 conversion factors used for this study, which are sourced from a report on guidelines for measuring and managing CO_2 emission from freight transport operations published by Cefic (2011). It is clear that road is the most carbon intensive mode used in the five scenarios presented in Table 1 and sea has about a sixth of the emissions generated by road. However, although rail generates about 50% more emissions than that produced by sea transport, it has better connectivity than the sea routes included in the study. Furthermore, the CO_2 emissions generated from handling a container in rail terminals are about 70% of the CO_2 emissions produced from handling a container in a sea port.

5. Findings

Table 11 shows the overall results obtained from the modelling of the five scenarios included in the study. This section presents the overall analysis of the results considering three metrics, namely cost, CO_2 and delivery time.

Table 11
Overall comparative results of the five scenarios.

Scenario	Modes	Route	Delivery time (days)	Cost per TEU/FEU (US$)	CO_2e (Tonnes)
1	Road > Rail > Sea > Rail	Factory – Yiwu – Ningbo – Barcelona - Madrid	31	1724 / 2726	2.4 / 4.8
2	Road > Rail > Sea > Rail	Factory – Yiwu - Shanghai – Barcelona - Madrid	33	1714 / 2716	2.5 / 4.9
3	Road > Sea > Rail	Factory – Ningbo – Barcelona – Madrid	30	1684 / 2701	2.6 / 5.2
4	Road > Sea > Rail	Factory –Shanghai – Barcelona – Madrid	32	1724 / 2721	2.7 / 5.4
5	Road > Rail	Factory – Yiwu – Alshankou – Madrid	22	7523 / 8986	2.7 / 5.4

5.1. Overall comparison of the five scenarios

In terms of cost, Scenario 5, the rail maximising scenario, is about 4.4 times less cost effective than the sea maximising scenarios (scenarios 1 to 4). The considerable difference in cost between Scenario 5 and scenarios 1 to 4 is mainly caused by one single factor, namely the fact that the Yiwu - Alashankou and Alshankou - Madrid rail journeys have significantly higher costs per container than the alternative Ningbo - Barcelona and Shanghai - Barcelona sea journeys. For example, in the case of TEU containers, the Yiwu - Alashankou rail journey is about 2.7 times less cost effective per container than the Shanghai - Barcelona sea journey, whereas the Alashankou - Madrid rail journey is about 7 times less cost effective per container than the Shanghai - Barcelona sea journey.

There are however other cost factors that compensate for the much less competitive rates rail freight transport has in comparison to sea freight transport. Firstly, rail terminals have more competitive container handling fees than sea terminals; and, secondly, the distance covered by the rail journeys is about two thirds of the distance covered by the sea journeys; however, these factors are not as important a determinant as the difference in cost per container that rail freight transport has compared to sea freight transport. Furthermore, the cost of road transport is not a dominant factor, even in the case of Scenario 4 that has the highest proportion of the distance covered by road, since the distance covered by road in that specific scenario is less than 1.81% of the total distance covered.

With regards to CO_2 emissions, the results of the five scenarios are similar. The scenario that generates the lowest amount of CO_2 emissions is Scenario 1, which produces 2.4 Tonnes of CO_2 for TEU containers and 4.8 Tonnes of CO_2 for FEU containers; and, scenarios 4 and 5 are the scenarios with highest emissions, which generates 2.7 Tonnes of CO_2 for TEU containers and 5.4 Tonnes of CO_2 for FEU containers. Indeed, the better connectivity and directness of the rail routes modelled in Scenario 5 is not as large a determinant for reducing environmental impact as overall there are only relatively small differences between the carbon intensity of the rail and sea freight transport options..

Regarding delivery time, clearly Scenario 5 is the most responsive scenario, since it reduces the delivery time, compared to Scenario 3, from 30 to 22 days. The delivery time suggested in Scenario 5 could be compressed if the rail terminals included in this scenario were more responsive, containers spent three days in total in two rail terminals, which makes them less productive than the sea ports included in scenarios 1 to 4 that has a container handling time of 10 hours. However, the lack of productivity at rail terminals is not as important a determinant factor as the directness of rail routes and possibly the speed of trains used in Scenario 5. The need for transport using the routing detailed in Scenario 5 would depend on the urgency of the order, since its cost per day is US$ 341 for TEU containers, much higher than the cost per day of the slowest scenario, Scenario 2, which has a cost per day of US$ 52.

Figure 4 shows the comparative results among the five scenarios for cost and CO_2 emissions in the TEU and FEU container cases. The scenarios are presented as cumulative costs / CO_2 emissions against the number of legs of the journey, being either a transport leg or a 'lift' at a terminal. Thus Scenarios 1 and 2 have 8 'legs' while 3, 4 and 5 have 6 legs. Across all the scenarios it is clear that Scenario 5 has the highest cost due to the high cost of its fourth leg, the rail container movement between Yiwu and Alashankou; hence, for this particular scenario to be competitive commercially speaking, the cost of that leg of the route would need to decrease dramatically. The results obtained for TEU and FEU containers are very similar, in both cases, Scenario 5 is the least commercially competitive, however takes the shortest time. Scenarios 1 to 4 have very similar total costs.

In the case of the results obtained on CO_2 emissions, although all the scenarios have similar results around 2,500 Kg of CO_2, in the case of TEU containers and 5,000 Kg of CO_2 in the case of FEU containers, scenarios 1 and 2 have the lowest levels of CO_2, just under 2,500 and 5,000 Kg of CO_2 respectively. Therefore, it can be concluded that modal shift from road to rail in the inland movements can contribute to reducing the amount of CO_2 emissions across the whole journey.

5.2. Separate results for the five scenarios

Table 12 details the results obtained from Scenario 1. Firstly, the sea leg of the route is extremely cost competitive, since it represents 33% of the cost of the scenario, whereas it represents 94% of the total distance and delivery time. Secondly, the sea leg of Scenario 1 contributes to 91% of the total CO_2 emissions generated in the route, whereas the contribution of terminals to CO_2 is extremely small, 0.1% of the total CO_2 emitted in the whole journey.

In this scenario, there are three significant contributors to cost. The top contributor to cost is rail transport, which contributes to 39 and 32% of the total cost of the journey in terms of TEUs and FEUs respectively, whereas the sea leg of the journey contributes to 33% and 40% of the cost of the journey in the TEU and FEU container cases respectively. These two main cost contributors are expected since a considerable proportion of the journey is undertaken by either sea or rail, though port terminal charges are the

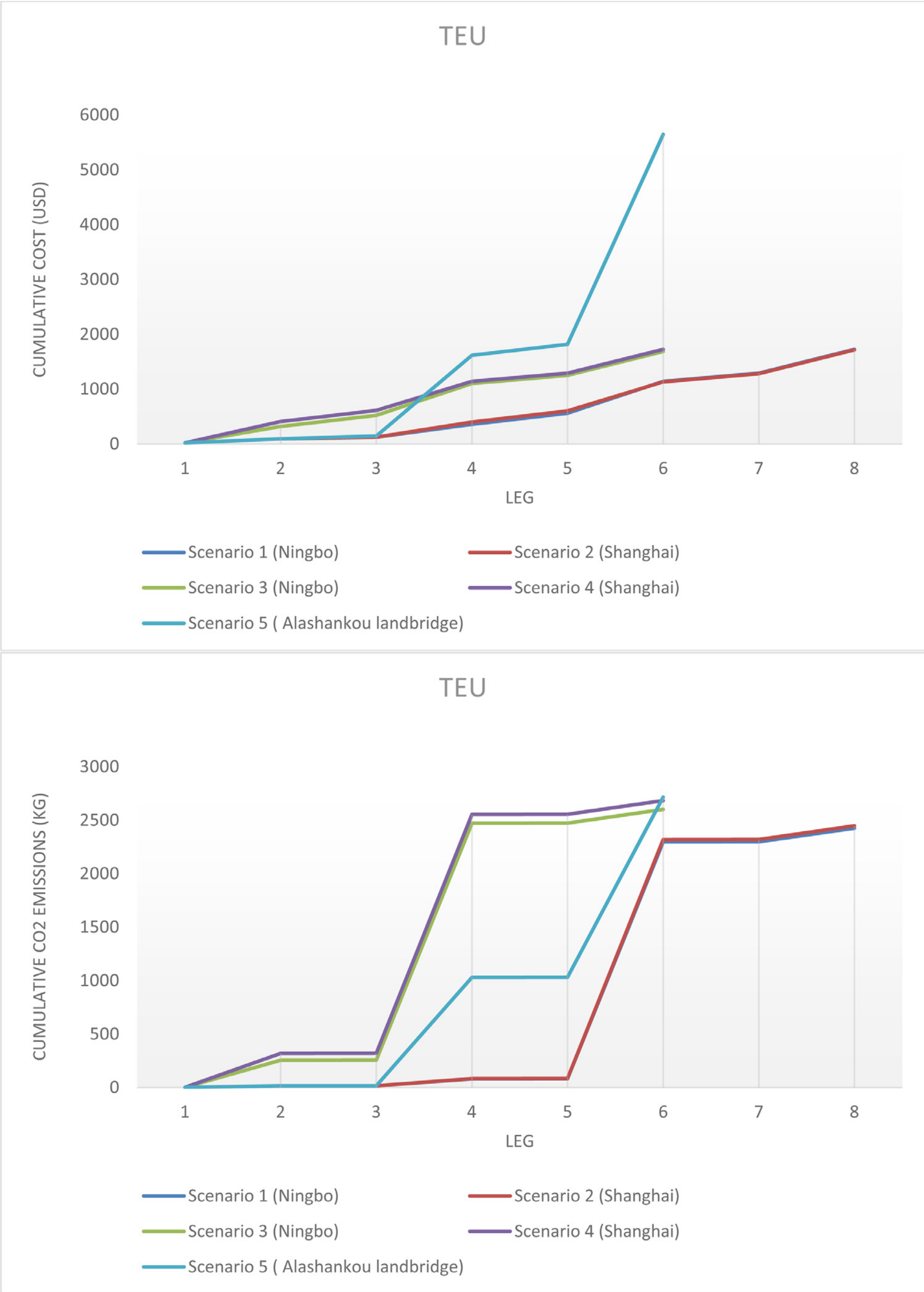

Fig. 4. Comparative results among the five scenarios for cost and CO2 emission for TEU and FEU containers.

other dominant cost factor, contributing to 20% of the total cost of the journey in both types of containers included in the scenarios modelled in this study.

Table 13 presents the results obtained from Scenario 2. Firstly, the sea leg of the route contributes only to 31% of the cost of the scenario, slightly lower proportion than the ones than Scenario 1 has; nevertheless, the sea leg has 94% of the total distance and 91% of the total delivery time. The CO_2 emissions generated from the sea leg of the scenario is 91% of the total CO_2 emissions generated in the scenario, which is exactly the same as in the case of Scenario 1. On the other hand, as in the case of Scenario 1, the contribution of terminals to CO_2 emissions of the whole journey is extremely small, 0.1% of the total CO_2 emitted.

In this scenario, there are three considerable cost contributors. The top contributor to cost is rail transport, which contributes to 41 and 34% of the total cost of the journey in terms of TEUs and FEUs respectively, whereas the sea leg of the journey contributes

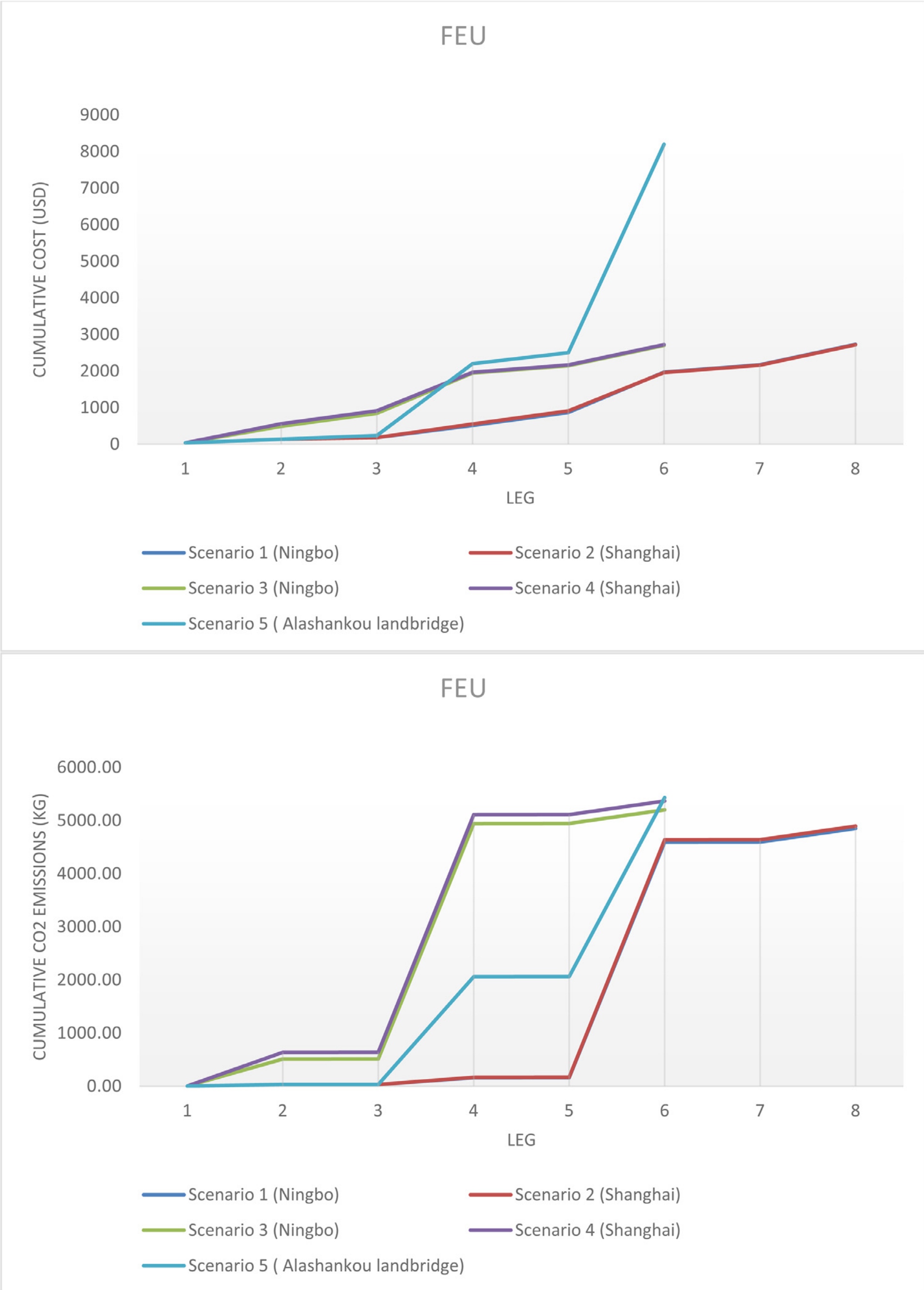

Fig. 4. Continued

31% and 38% of the cost of the journey for the same types of containers. Unsurprisingly, the two main cost contributors to cost are rail and sea transport because a considerable proportion of the journey undertaken by either sea or rail, though port terminal charges are the other dominant cost factor, contributing to 12% of the total cost of the journey in both types of containers included in the scenarios modelled in this study.

Table 14 shows the values obtained from Scenario 3. Firstly, similar to Scenario 1, the sea leg of the route contributes only to 34% of the cost, and 95% of the total distance and delivery time. The CO_2 emissions generated from the sea leg of this scenario is 85% of the total CO_2, which is slightly lower than the percentage of CO_2 emission generated by the sea leg of Scenario 1, which is 91%. However, terminals contribute to only 0.09% of the total CO_2 emitted in the whole journey.

Table 12
Scenario 1 Modal Combinations, Transit Times, Costs and Emissions.

	Leg	Mode	Transit time (Hours)	Distance (KM)	Cost (USD)	CO2 (g)
1	Yiwu		1	0	18/36 - TEU/FEU	700/1400 - TEU/FEU
2	Yiwu - Yiwu Train Station	Road	1	13	75/100 - TEU/FEU	13742.3 /27484.6 - TEU/FEU
3	Terminal Charge		10	0	30/45 - TEU/FEU	700/1400– TEU/FEU
4	Yiwu Train Station - Port of Ningbo	Rail	7	311	235/330 - TEU/FEU	64314.8/ 128629.6 - TEU/FEU
5	Port Charge		10	0	202/357 - TEU/FEU	1100/2200 - TEU/FEU
6	Port of Ningbo - Port of Barcelona	Sea	696	16110	580/1100 - TEU/FEU	2215125/ 4430250 - TEU/FEU
7	Port Charge		10	0	150/200 - TEU/FEU	1100/2200- TEU/FEU
8	Port of Barcelona - Madrid	Rail	8	620	434/558- TEU/FEU	128216/256432- TEU/FEU
			743	17054	1724/2726 - TEU/FEU	2424998.1/ 4849996.2- TEU/FEU

Table 13
Scenario 2 Modal Combinations, Transit Times, Costs and Emissions.

	Leg	Mode	Transit time (Hours)	Distance (KM)	Cost (USD)	CO2 (g)
1	Yiwu		1	0	18/36 - TEU/FEU	700/1400 - TEU/FEU
2	Yiwu - Yiwu Train Station	Road	1	13	75/100 - TEU/FEU	13742.3/ 27484.6 - TEU/FEU
3	Terminal Charge		10	0	30/45 - TEU/FEU	700/1400 - TEU/FEU
4	Yiwu Train Station - Port of Shanghai	Rail	8	324	275/370 - TEU/FEU	67003.2/ 134006.4 - TEU/FEU
5	Port Charge		10	0	202/357 - TEU/FEU	1000/2200 - TEU/FEU
6	Port of ShangHai - Port of Barcelona	Sea	744	16250	530/1050 - TEU/FEU	2234375/ 4468750 - TEU/FEU
7	Port Charge		10	0	150/200 - TEU/FEU	1100/2200 - TEU/FEU
8	Port of Barcelona - Madrid	Rail	8	620	434/558- TEU/FEU	128216/256432 - TEU/FEU
			792	17207	1714/2716 - TEU/FEU	2446836.5/ 4893873 - TEU/FEU

Table 14
Scenario 3 Modal Combinations, Transit Times, Costs and Emissions.

	Leg	Mode	Transit time (Hours)	Distance (KM)	Cost (USD)	CO2 (g)
1	Yiwu		1	0	18/36 - TEU/FEU	700/1400 - TEU/FEU
2	Yiwu - Port of Ningbo	Road	4	240	300/450 - TEU/FEU	253704/507408 - TEU/FEU
3	Port Charge		10	0	202/357 - TEU/FEU	1100/2200 - TEU/FEU
4	Port of Ningbo - Port of Barcelona	Sea	696	16110	580/1100 - TEU/FEU	2215125/4430250 - TEU/FEU
5	Port Charge		10	0	150/200 - TEU/FEU	1100/2200 - TEU/FEU
6	Port of Barcelona - Madrid	Rail	8	620	434/558- TEU/FEU	128216/256432 - TEU/FEU
			729	16970	1684/2701 - TEU/FEU	2599945/ 5199890 - TEU/FEU

In this scenario, there are three significant contributors to the total journey cost. The top contributor is sea transport, which adds 34 and 41% of the total cost of the journey in terms of TEUs and FEUs respectively, whereas the rail leg of the journey contributes 26% and 21% of the cost of the journey. These two main cost contributors are expected because of the fact that a considerable proportion of the journey is undertaken by either sea or rail, though port terminal charges are the other dominant cost factor, contributing to 21% of the total cost of the journey in both types of containers included in this study.

Table 15 shows the results obtained from Scenario 4. The sea leg of the route contributes only to 31% of the cost of the scenario, 94% of the total delivery time and 83% of the total CO_2 emissions. However, terminals contribute to only 0.08% of the total CO_2 emitted in the whole journey.

In this scenario, there are three significant contributors to cost. The top contributor to cost is sea transport, which contribute to 31% and 39% of the total cost of the journey in terms of TEUs and FEUs respectively, whereas the rail leg of the journey contributes 25% and 21% of the cost of the journey. These two main cost contributors are expected since a significant proportion of the journey is undertaken by either sea or rail, though port terminal charges are the other fairly important cost factor, adding 9% and 7% of the total cost of the journey in the TEU and FEU container cases.

Table 16 presents the results obtained from scenario 5. The rail leg of the route contributes to 70% of the cost of the scenario, 99.9% of the total delivery time and 99.4% of the total CO2 emissions; and, terminals only contribute to 0.05% of the total CO2 emitted in the whole journey.

Table 15
Scenario 4 Modal Combinations, Transit Times, Costs and Emissions.

	Leg	Mode	Transit time (Hours)	Distance (KM)	Cost (USD)	CO2 (g)
1	Yiwu		1	0	18/36 - TEU/FEU	700/1400 - TEU/FEU
2	Yiwu - Port of Shanghai	Road	5	300	390/520 - TEU/FEU	317130/634260 - TEU/FEU
3	Port Charge		10	0	202/357 - TEU/FEU	1000/2200 - TEU/FEU
4	Port of Shanghai - Port of Barcelona	Sea	744	16250	530/1050 - TEU/FEU	2234375/ 4468750 - TEU/FEU
5	Port Charge		10	0	150/200 - TEU/FEU	1100/2200 - TEU/FEU
6	Port of Barcelona - Madrid	Rail	8	620	434/558 - TEU/FEU	128216/256432 - TEU/FEU
			778	17170	1724/2721 - TEU/FEU	2682521/5365242 - TEU/FEU

Table 16
Scenario 5 Modal Combinations, Transit Times, Costs and Emissions.

	Leg	Mode	Transit time (Hours)	Distance (KM)	Cost (USD)	CO2 (g)
1	Yiwu		1	0	18/36 - TEU/FEU	700/1400 - TEU/FEU
2	Yiwu - Yiwu Train Station	Road	1	13	75/100 - TEU/FEU	13742.3/ 27484.6 - TEU/FEU
3	Terminal Charge		10	0	30/45 - TEU/FEU	700/1400 - TEU/FEU
4	Yiwu Train Station - Alashankou Train Station	Rail	60	4907	1473/1962 - TEU/FEU	1014767.6/2029535.2 - TEU/FEU
5	Terminal Charge		10	0	200/300 - TEU/FEU	700/1400 - TEU/FEU
6	Alashankou Train Station - Madrid Train Station	Rail	445	8145	3828/5701 - TEU/FEU	1684386/3368772 - TEU/FEU
			527	13065	7523/8986 - TEU/FEU	2714995.9/5429991.8- TEU/FEU

In this scenario, there are two main contributors to cost. The main contributor to cost is rail transport, which represents 70% and 85% of the total cost of the journey in terms of TEUs and FEUs respectively. This is as expected since in this scenario most of the travel distance is covered by rail. Port terminal charges are a fairly modest contributor to cost in this scenario, representing just 4% of the total cost of the journey in two types of containers included in this study.

6. Conclusions and Managerial Implications

The BRI has far-reaching implications for the future volume and balance of shipping trade around the world. With its claim to boost support for green and low-carbon development, we are interested in its impact on carbon emissions and its viability and challenges contributing towards a low-carbon economy. Transport between different continents and countries occur at a high frequency within the BRI. To find the optimal transport method, the original cost model (Beresford, 1999) and adapted version to account for emissions are used in this paper to establish the optimal transport path for the export of goods from China to Europe. Here, we consider cost –distance modelling, carbon emissions modelling, and economic/trade evaluation of the corridors under BRI.

In this paper, we considered optimal choices for multi-modal transport combinations with regards to both economic and environmental perspectives. By investigating freight transport from Yiwu to Madrid through China using the Yixinou line, the results suggest that the BRI has significant potential to reduce the cost of freight transport from China to Europe. We also considered carbon emissions alongside cost and distance modelling within BRI, and compared the economic and environmental impacts of different transport modal combinations. Through this analysis, it can be concluded that different combinations of transport modes have different economic and environmental outcomes; however, Scenarios 1 and 2 perform best in terms of both cost and lowest emissions. To determine the optimal transport method, various factors need to be considered. In our study, the cost, time, distance differences are more prominent than CO_2 emissions consideration, although emissions are slightly lowest in the lowest cost scenarios. The BRI has far-reaching implications for the future volume and balance of shipping trade around the world. With its claim to boost support for green and low-carbon development.

The modelling developed in this study can be taken further by introducing an opportunity cost component to the cost equation to include delivery time in the optimisation logic, working capital of cargo on route can be acknowledged as an important input metric. The results of this study are also related to the choice of the sample line, especially the differences in CO2 emissions between land-based transport and sea-based transport. Rail is more carbon-intensive than sea shipping, but the former has a much shorter distance than the latter, which could reverse their discrepancy in CO2 emissions. The results might change if a train line with a much shorter distance was chosen. Future research in this area could choose different train lines with different distances as samples. Moreover, government subsidies on rail services have an impact on costs significantly. Future research could incorporate the subsidies into the calculus of transport costs. For the subsidy issue of Chinese Rail Express, Randrianariosa et al (2020) explores the link between the maritime market conditions and the government subsidies received by the new rail operators to find the minimum subsidy, which could provide a reference for this analysis.

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