**RQ2: Chain cost**

In this section, the impact of vessel size on the cost structure of the logistics chain is evaluated. First, we run simulations for all routes from Chongqing, China, to Düsseldorf, Germany, using the base vessel of 23,964 TEU to select the route with the lowest cost for further analysis. This step aligns with the core objective of logistics service providers in real-world business, which consistently focus on enhancing shipping quality in terms of cost and performance. Based on the summary in Table 1, the route from Xiamen to Zeebrugge is considered the optimal choice for the base vessel of 23,964 TEU, as it offers the lowest total generalized chain cost of 2,595.44 EUR/TEU. This route is thus selected for subsequent analyses of the impact of vessel size on cost structure.

*Table 1. Total generalised chain cost for all route options with vessel size 23,964 TEU*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No.** | **From port** | **To port** | **Total generalised chain cost** | **Notes** |
| 1 | Ningbo | Hamburg | 2780.32 |  |
| 2 | Ningbo | Bremerhafen | 2737.97 |  |
| 3 | Ningbo | Zeebrugge | 2700.63 |  |
| 4 | Ningbo | Rotterdam | 2812.98 |  |
| 5 | Ningbo | Le Havre | 3247.98 |  |
| 6 | Shanghai | Hamburg | 2709.95 |  |
| 7 | Shanghai | Bremerhafen | 2667.6 |  |
| 8 | Shanghai | Zeebrugge | 2630.26 |  |
| 9 | Shanghai | Rotterdam | 2742.61 |  |
| 10 | Shanghai | Le Havre | 3177.62 |  |
| 11 | Xiamen | Hamburg | 2675.13 |  |
| 12 | Xiamen | Bremerhafen | 2632.78 |  |
| 13 | Xiamen | Zeebrugge | 2595.44 | Chain with lowest cost |
| 14 | Xiamen | Rotterdam | 2707.79 |  |
| 15 | Xiamen | Le Havre | 3142.79 |  |

Next, we examine the impact of vessel size on the logistics chain cost structure for the Xiamen–Zeebrugge route. Calculations are performed for six different vessel sizes, ranging from 4,600 TEU to 23,964 TEU, including one LNG-powered vessel of 14,800 TEU. The costs analyzed include hinterland costs (both from and to the port), port costs, maritime costs, and the total generalized chain cost. The results are summarized in Table 2 below.

*Table 2. Chain cost structure for all vessel options for Xiamen – Zeebrugge route*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **No.** | **Vessel size (TEU)** | **From Hinterland cost** | **From Port cost** | **Maritime cost** | **To Port cost** | **To Hinterland cost** | **Total generalised chain cost** |
| 1 | 4600 | 1085.75 | 102.53 | 896.65 | 388.59 | 390.62 | 2864.13 |
| 2 | 9115 | 1085.75 | 99.92 | 753.67 | 384.51 | 390.62 | 2714.46 |
| 3 | 14800 (LNG) | 1085.75 | 96.55 | 1069.38 | 202.08 | 390.62 | 2844.37 |
| 4 | 14990 | 1085.75 | 97.31 | 697.52 | 380.22 | 390.62 | 2651.41 |
| 5 | 20568 | 1085.75 | 97.35 | 646.77 | 379.28 | 390.62 | 2599.76 |
| 6 | 23964 | 1085.75 | 99.65 | 637.59 | 381.83 | 390.62 | 2595.44 |

The cost breakdown clearly shows that both "From" and "To" hinterland costs remain constant across all vessel sizes, indicating that hinterland logistics are not affected by vessel size variation. This is because hinterland transport primarily relies on land-based modes, such as trucks or trains, rather than vessels. In contrast, vessel size significantly impacts shipping activities that take place at ports and at sea. The trends of fluctuating costs and the proportion of each cost component are respectively illustrated in Figures 1 and 2.

*Figure 1. Chain cost component trend for all vessel options for Xiamen - Zeebrugge route*

*Figure 2. Proportion of chain cost component for all vessel options for Xiamen - Zeebrugge route*

The results indicate that the generalized chain cost generally decreases with increasing vessel size, demonstrating the economies of scale achieved by deploying larger vessels. The smallest vessel of 4,600 TEU incurs the highest total cost of 2,864.13 EUR/TEU, while the largest vessel size of 23,964 TEU achieves the lowest cost of 2,595.44 EUR/TEU, representing a cost reduction of approximately 9.4%. The second-largest vessel of 20,568 TEU also exhibits a comparable total cost of 2,599.76 EUR/TEU, suggesting that the marginal cost reduction from 20,568 TEU to 23,964 TEU is relatively small. An interesting exception to this trend is the LNG-powered vessel of 14,800 TEU, which shows a higher total cost (2,844.37 EUR/TEU) than both smaller and larger vessels. This is mainly due to its significantly higher maritime cost of 1,069.38 EUR/TEU, reflecting the increased operating expenses associated with LNG technology despite its potential environmental benefits, which will be discussed further in the next section.

The overall downward trend in total chain cost is driven by the concurrent reduction of both maritime and port costs. Among cost components, maritime cost consistently decreases as vessel size increases, driven by economies of scale. Larger vessels are equipped with more efficient engines and greater capacity, resulting in lower fuel and operational costs per TEU when distributed over more containers in one trip. Port costs, although relatively minor in the overall cost structure, also show a slight decline with increasing vessel size, with only a marginal rise for the 23,964 TEU vessel. This trend likely results from more efficient port handling procedures for larger vessels.

In conclusion, vessel size plays a pivotal role in determining the cost structure of logistics chains, with larger vessels generally offering lower costs due to economies of scale. Furthermore, the decrease in maritime costs with increasing vessel size is the most influential factor in achieving overall cost reductions. It is also noteworthy that, while hinterland costs remain constant in absolute terms, their relative importance within the total logistics chain cost increases as other cost components decline.