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Research

Trade, economic growth, and transportation sustainability perspectives of the Gulf-Europe corridor in the GCC countries

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Abstract

The Gulf-Europe transportation project, also known as Iraq's Development Road Project (DRP), is a transformative supply chain initiative aimed at constructing a corridor from Al Faw Port in Iraq to Turkey, linking Gulf Cooperation Council (GCC) countries with Europe. The project's goal is to establish a robust transport corridor through the extensive construction of roads and railways, facilitating the fast and seamless movement of goods between the East and the West. By creating land-based direct transportation routes to complement traditional maritime pathways, the project seeks to reduce transit times, lower shipping costs, increase trade flows, and improve regional integration. This study qualitatively examines how the corridor will impact trade, the economy, and transportation sustainability in the Gulf nations. We explore potential increases in trade volumes, foreign investments, logistics sustainability, and economic diversification within the region. Additionally, we recommend the adoption of hydrogen fuel cell vehicles (HFCVs) and hydrogen-powered trains in the corridor to align with the United Nations Sustainable Development Goals (SDGs). Furthermore, we suggest that the corridor's development will create opportunities for economic diversification and reduce the GCC countries' reliance on oil revenues. Finally, the study provides strategic recommendations for policymakers and stakeholders to maximize the project's benefits and address potential challenges, emphasizing its potential to drive long-term economic growth and strengthen the GCC countries' global trade positioning.

Keywords Gulf-Europe transportation project · Development road project · Trade expansion · Economic benefits · Transportation sustainability

1 Introduction

The Gulf-Europe transportation project aims to revolutionize trade, economic growth, and transportation sustainability by developing a corridor of road and rail connections between the GCC and European countries. Current maritime routes involve multiple transshipments at key locations such as Salalah (Oman), Jeddah (the Kingdom of Saudi Arabia-KSA), the Red Sea Passage, the Suez Canal, and the Mediterranean Sea. These transshipments cause delays due to port congestion and extended travel distances. To address these challenges, Qatar, Turkey, Iraq, and the United Arab Emirates (UAE) signed a $17 billion agreement for this project. Upon completion in 2050, the corridor will connect the Gulf to Europe via Turkey, supported by the development of Al Faw Port and a 1200-km infrastructure. This project is expected to transform Iraq into a regional trade hub, providing a much-needed economic boost [1]. Currently, Baghdad's oil sector accounts for 90%

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of its revenue, with exports making up over 55% of its gross domestic product (GDP) [2]. By 2050, this direct land-based alternative will enhance logistics operations, trade opportunities, and economic-environmental sustainability between the Gulf and Europe, effectively overcoming current logistical barriers. The adoption of HFCVs will add a new dimension to trade for potential hydrogen-exporting countries such as Qatar, Saudi Arabia, and the UAE. It will also strengthen trade for other Gulf nations, including Bahrain, Kuwait, and Oman, by increasing their participation in continental trade. Furthermore, the project will boost the economies of connecting countries such as Iraq and Turkey [2–4].

This study aims to assess the impact of this corridor on trade, economic growth, and transportation sustainability in the GCC countries. It builds on insights from various studies related to the Belt and Road Initiative (BRI). For instance, Foo et al. [5] analyzed the effects of the BRI on China's trade with other economies, while Ullah et al. [6] examined the role of China-BRI trade in participating countries. Deng and Du [7] estimated the environmental efficiency of BRI nations, whereas Fang et al. [8] and Senadjki et al. [9] evaluated progress toward achieving the SDGs within the BRI framework. Therefore, our study provides a detailed analysis of how the corridor can reduce transshipment times, lower transportation costs, and create trade opportunities by connecting the GCC and European countries. Additionally, we examine the broader economic benefits for Gulf nations, including opportunities for economic diversification, job creation, trade expansion, and sustainable development. Furthermore, this study offers a comprehensive understanding of the economic landscape influenced by this project, providing guidelines for policymakers, investors, and other stakeholders to maximize its benefits.

According to a report on the Middle East economy [10], GCC countries import more than 85% of their food needs from European countries, relying on air and sea shipments for various perishable items, including cereals, meat, and vegetables. The food and beverage market in the Gulf region is significant, with KSA and the UAE being key importers. The UAE's food manufacturing sector alone is expected to reach $23.2 billion by 2025. Transportation and transshipment costs constitute a large portion of the total import expenses and result in extended import times. Therefore, to lower transportation costs over time as well as improve transportation sustainability, this study proposes the adoption of hydrogen vehicles and trains in this corridor. This adoption will also contribute to fulfilling the United Nations SDGs [8, 9] through green transformation [11]. Implementing HFCVs will also boost KSA's, and the UAE's hydrogen exports, with production anticipated to begin in 2026 and 2031, respectively. Furthermore, we consider various risks and challenges in implementing such a large-scale infrastructure project, including political, geopolitical, environmental, economic, and other factors.

Finally, this study provides valuable insights for investors and entrepreneurs, highlighting how they can benefit from this transportation route. By analyzing the project's risks and challenges, we offer strategic recommendations for policymakers and stakeholders to maximize profits and expand both new and existing trade opportunities. Furthermore, we illustrate how GCC-European countries, along with the connecting nations, can achieve regional integration and strengthen economic cooperation. By examining the effects of comparable initiatives such as the BRI, the Trans-European Transport Network (TEN-T), the International North–South Transport Corridor (INSTC), and the Panama Canal Expansion, we propose strategic recommendations and emphasize the project's potential to foster sustainable economic growth and enhance the Gulf region's global trade position. To explore the project's potential and identify its infrastructural risks and challenges, we set the following two research questions (RQs):

RQ1 How will the Gulf-Europe corridor improve the current trade and economic conditions of the GCC countries?

RQ2 How can transportation sustainability be achieved through the adoption of hydrogen vehicles, and what positive environmental effects will this corridor bring in the future?

RQ3 What are the potential political, environmental, and economic challenges and risks associated with the infrastructural development of this corridor?

The remainder of the paper is structured as follows: Sect. 2 provides a literature review and identifies the research gap; Sect. 3 presents an overview of the Gulf-Europe transportation project; Sect. 4 outlines the study framework; Sect. 5 offers strategy proposals and aligns our findings with recent policies; and Sect. 6 concludes with future research directions.

2 Literature review and research gap

The Gulf-Europe corridor serves as a vital trade and logistics network, linking the GCC countries with the European markets. Given the rapid economic transformation in both regions, analyzing trade relations and sustainability challenges is essential to developing long-term policies that support growth and environmental responsibility.

Studies by Yaseen [12] and Öztürk [13] suggest that trade between GCC countries and Europe will expand due to increasing energy exports, infrastructure investments, and policy liberalization. The GCC countries are among the leading exporters of oil and liquefied natural gas to Europe, playing a significant role in their economic growth [14]. Additionally, diversification efforts under frameworks such as Saudi Vision 2030 and UAE Vision 2050 aim to enhance non-oil trade and strengthen economic resilience [14, 15]. These strategies emphasize industrialization, the development of logistics hubs, and the expansion of digital trade networks to foster economic integration between the regions. Rahman et al. [16] highlighted that a heavy reliance on fossil fuel exports and a limited manufacturing sector reduce the Gulf's trade competitiveness beyond hydrocarbons. Moreover, customs regulations, border controls, and bureaucratic inefficiencies continue to hinder seamless trade flows between the two regions [12, 17–19]. Additionally, the European Union (EU)'s evolving regulatory framework, particularly its Green Deal initiative [20], presents both challenges and opportunities for GCC countries as they transition toward low-carbon economies [16].

The transportation network of the Gulf-Europe corridor will shift from maritime and air routes to a direct road and rail route, which will play a dominant role in trade logistics [1, 2]. However, Kazim [21], Mendez [22], and Rahman et al. [16] stated that concerns about environmental sustainability have led to a growing emphasis on green logistics and alternative energy sources, such as hydrogen-powered freight transport. Sustainable transport systems are increasingly being prioritized to align with international climate commitments and carbon neutrality goals [22–24]. Studies indicate that the transportation sector in the Gulf remains heavily reliant on diesel-fueled trucks, leading to high carbon emissions and air pollution. Greene et al. [25] noted that maritime transport, which accounts for a significant share of Gulf-Europe trade, also contributes to environmental degradation due to heavy fuel oil consumption. While efforts to introduce HFCVs are gaining momentum, they face infrastructure and policy challenges. Research by Habibur et al. [16] suggests that adopting sustainable freight corridors, investing in renewable hydrogen, and integrating digital tracking systems could significantly reduce carbon footprints and enhance economic efficiency. Furthermore, Rutter et al. [26] and Alkaabi [27] found that transportation bottlenecks, including congestion at major seaports such as Jebel Ali (UAE) and King Abdulaziz Port (Saudi Arabia), hinder efficiency. Infrastructure expansion projects, such as the Gulf-Europe corridor, are expected to improve logistics efficiency and strengthen connectivity between the Gulf and European markets [3, 4, 16].

Furthermore, Al-Haji et al. [28] and Haas and Sander [20] stated that the EU's Green Deal and the GCC countries' SDGs have spurred collaborative efforts to enhance transportation sustainability. Strategic initiatives, such as the EU-GCC Clean Energy Partnership, emphasize investment in hydrogen infrastructure and green shipping corridors, which could redefine trade logistics in the coming decades. However, this transition requires coordinated efforts among private sector stakeholders, governmental institutions, and international regulatory bodies to ensure successful implementation.

While previous studies have examined the EU's Green Deal and the GCC's SDGs in promoting transportation sustainability, a gap remains in understanding how the adoption of HFCVs in the Gulf-Europe corridor can contribute to this goal. This study aims to address that gap. Additionally, existing research has explored the various challenges and barriers the GCC faces in trading with European countries, indicating another gap in the literature regarding how the development of this corridor can help overcome these obstacles. Furthermore, there is limited research on how the corridor could expand trade opportunities and drive economic growth in GCC countries, an aspect also explored in this study.

3 Overview of the Gulf-Europe transportation project

On April 22, 2024, Qatar, Iraq, Turkey, and the UAE signed a Memorandum of Understanding (MoU) to initiate the Gulf-Europe transportation project, also known as Iraq's DRP. The purpose of this project is to strengthen the transportation systems among the GCC-European countries as well as the connecting countries, Iraq and Turkey, as depicted in Fig. 1a. This encompasses the extensive construction of 1200 km (745 miles) of rail and road corridors for the efficient transportation of goods and passengers among GCC and European countries [4, 29]. This shows the main routes linking the GCC countries to Europe, indicated by a red line that starts from Kuwait, the KSA, Qatar, Bahrain, the UAE, and Oman, continuing to Turkey [3, 29]. The MoU also includes the development of Al Faw Port in Basra, Iraq's key port [2, 4], which

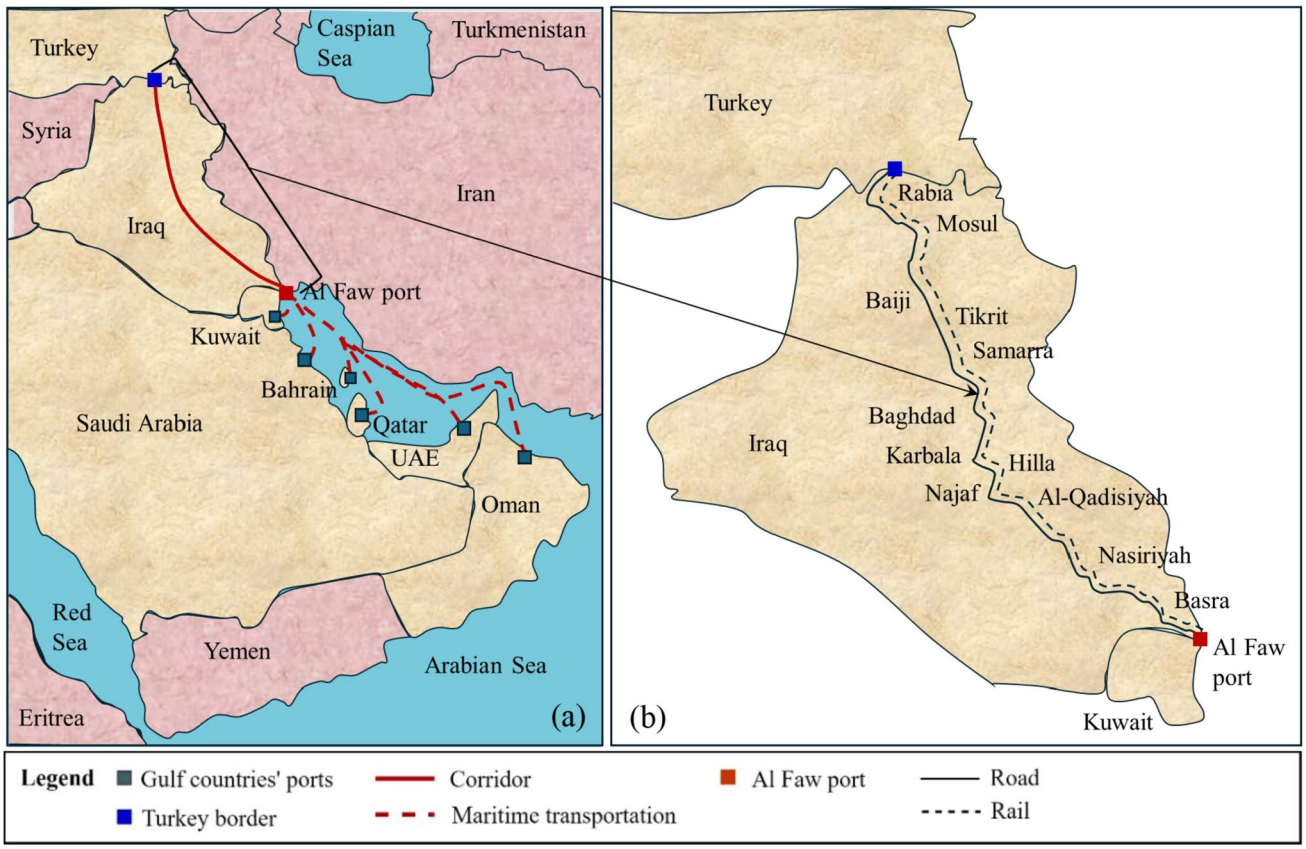

Fig. 1 The corridor links (**a**) GCC countries with European countries, and (**b**) larger cities of Iraq from Al Faw port to the Turkey border

will be linked to Turkey. Key components of the project include a rail line starting at Basra and extending to the Turkish border, and a parallel road line providing an additional overland route for vehicles, as shown in Fig. 1b. This route connects Iraq's main cities [1], such as Nasiriyah, Al-Qadisiyah, Hilla, Baghdad, Karbala, Najaf, Samarra, Tikrit, Baiji, Mosul, and Rabia, eventually reaching the Turkish border. Roads are marked with solid black lines, while rail lines are depicted with dashed lines, as shown in Fig. 1b.

According to the MoU, the project will be constructed in three phases [2], beginning in 2024 and concluding in 2050. The first phase, focused on building the core segments of both networks, is scheduled for completion by 2028. It will establish road maps, travel operations, and foundational functionalities. The second phase, expected to conclude by 2033, will expand infrastructure by increasing the number of stations and improving road capacity and efficiency. The final phase aims for full operational capability, integrating the transportation networks of the GCC countries and Iraq while optimizing logistics operations with European networks to reduce transportation costs. This phased approach ensures gradual development, allowing for adjustments based on initial performance and emerging needs [1, 2].

4 Study methodology

Figure 2 presents a six-step framework outlining the complete methodological process conducted in this study. Each step contributes to understanding the corridor's trade, economic, and transportation sustainability potential.

4.1 Current trade and economic landscape of the GCC countries

Bahrain focuses on financial services and aluminum production [30], while Kuwait relies on oil production and imports, supported by a strong sovereign wealth fund [31]. Oman is expanding fisheries and tourism [30], and Qatar capitalizes on its natural gas reserves [32]. Saudi Arabia is investing in multi-sector diversification under Vision 2030. The UAE advances

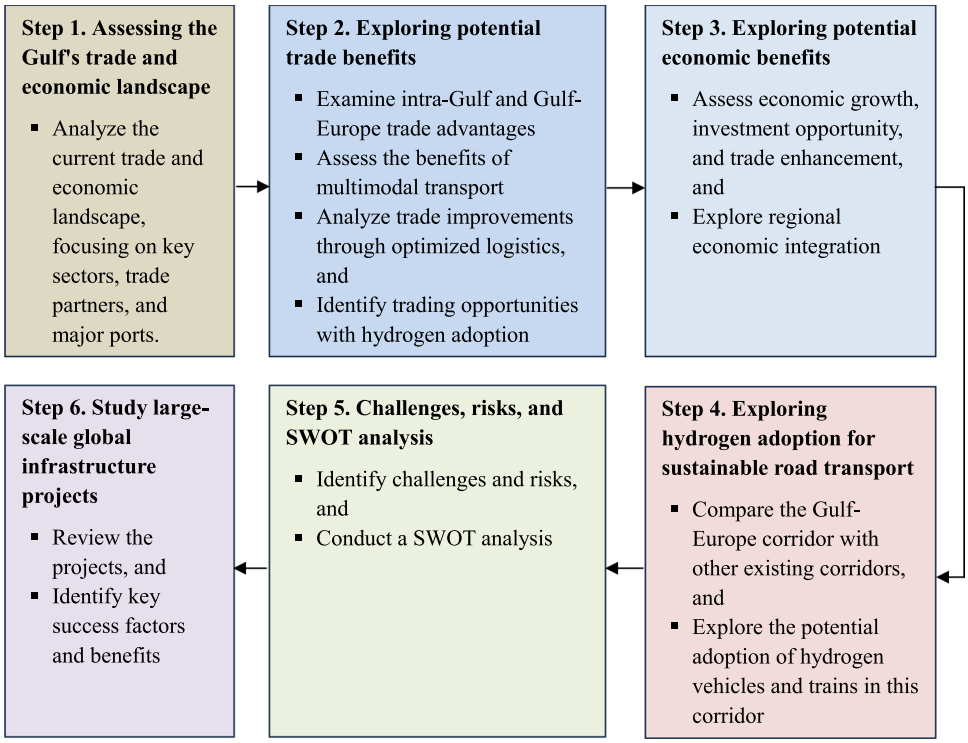

Fig. 2 A six-step study framework

in tourism, aviation, and financial services [30]. However, traditional transportation systems entail high costs and long delivery times [33]. Table 1 summarizes the current trade landscape, partners, and logistics hubs of the GCC.

4.2 Expected trade benefits

The Gulf-Europe corridor offers several benefits in trade, enhancing transportation infrastructure, and optimizing logistics systems. The anticipated benefits in trade are detailed in the following.

4.2.1 Intra-Gulf trade benefits

Current transportation systems face several challenges, including slow transit times, high costs, and long delivery periods due to reliance on maritime transport and underdeveloped routes [14]. Maritime transport is often hindered by limited lanes, leading to frequent congestion [34]. Additionally, some routes within the existing transportation network remain underdeveloped, further obstructing efficient transport [33]. However, the project has the potential to enhance economic integration and drive growth across the Gulf region, as summarized in Table 2.

Table 1 A summary of the trade and economic landscape of the GCC countries

Country	Trades of	Trade partners	Logistics ports	References
Bahrain	Finance, oil, and aluminum	KSA, UAE, USA	Khalifa Bin Salman Port	[30]
Kuwait	Oil	China, Japan, India, USA	Shuwaikh Port, Shuaiba Port, Mubarak Al Kabeer Port (under development)	[31]
Oman	Oil, gas, fisheries, and tourism	China, UAE, India	Port Sultan Qaboos, Port of Salalah	[30]
Qatar	Natural gas	Japan, South Korea, China	Hamad Port, Hamad International Airport	[32]
KSA	Oil	China, Japan, USA	Jeddah Islamic Port, King Abdullah Port	[30]
UAE	Tourism, aviation, and finance	China, India, USA	Jebel Ali Port, Khalifa Port (Aviation hubs: DXB, AUH)	[30]

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Table 2 Comparison of intra-Gulf trade benefits between current scenarios and post-project scenarios

Aspect	Traditional trade	Post project trade	Expected post-project benefits
Transportation efficiency			
Speed	Comparatively much slower	Significantly increased	Integrated rail and road networks
Transit times	Longer with more delays	Reduced delays	Faster and more predictable deliveries
Congestion	High congestion due to limited lanes	Minimized congestion	Diversified transport routes and modernized infrastructure
Costs			
Transportation costs	Higher costs due to inefficiencies and longer transits	Lower costs with hydrogen fuel	Enhanced efficiency and reduced transit times
Logistics costs	Higher due to multiple handling points	Decreased costs	Streamlined processes and fewer handling points
Infrastructure			
Development level	Underdeveloped	Developed	Modern infrastructure
Connectivity	Limited integration	Improved integration	Cohesive and efficient transport system
Trade volumes			
Trade volumes	Limited volumes due to higher costs and inefficient logistics	Increased volumes	Reduced costs and optimized logistics
Economic impact			
Market access	Restricted due to transportation inefficiencies and higher costs	Expanded market	More reliable and cost-effective transportation options
Economic integration	Weaker integration among GCC countries due to logistical and infrastructural challenges	Strengthened integration	Economic growth and diversification

4.2.2 Gulf-Europe trade benefits

The development of this corridor will increase trade volumes, support economic growth, and enhance market access and flexibility through joint ventures between the GCC and European countries [2]. Moreover, the corridor offers environmental benefits with the usage of hydrogen energy for transportation, greater stability, and more [1, 4], as summarized in Table 3.

4.2.3 Trade benefits of multi-modal transport: road and rail

Integrating rail and road networks enhances reliability, reduces congestion, and leads to faster transit times and lower transportation costs [29]. These routes are less affected by weather and maritime hazards, ensuring more consistent delivery schedules. The adoption of hydrogen vehicles in transportation will further benefit the environment and potentially lower costs [35]. By diversifying trade routes, it provides benefits such as increased reliability, reduced congestion, and lower transportation costs [7, 11, 16], as summarized in Table 4.

4.2.3.1 Trade benefits for perishable goods The Gulf-Europe corridor introduces diversified routes that significantly accelerate the delivery of perishable goods, including fruits, vegetables, dairy products, and meats. These new routes enhance the reliability and efficiency of transportation networks [36]. Given the limited shelf life of perishable foods, fast and dependable transport is crucial for maintaining quality and preventing spoilage [37, 38]. The quality and trade volume of perishable foods have improved due to faster product delivery across multiple countries, the integration of a cold supply chain within One Belt One Road (OBOR)'s supply chain management, and an estimated time savings of 25 days [37]. Traditional systems in GCC countries, which primarily rely on maritime transport, experience long transit times that can compromise freshness and reduce trade volumes [14, 30]. The Gulf-Europe corridor offers significant advantages in the following areas:

Faster transit times: As this corridor reduces transit times and alleviates congestion, it will be highly effective for transporting perishable goods between the GCC and European countries. The direct rail links will transport goods from the Gulf to Europe or from Europe to the Gulf in a fraction of the time it would take by sea, thereby minimizing the risk of spoilage and reducing waste [36]. Similar benefits for the OBOR project highlight the effectiveness of such infrastructure improvements in enhancing the quality and volume of the perishable food trade [37].

Improved temperature control: Temperature control is crucial for maintaining high postharvest quality and extending the shelf life of perishable goods, protecting them from high environmental temperatures. Without temperature control, long-distance transportation from producers to consumers typically results in significant food losses [37]. Refrigerated trucks and rail cars within this network will provide a controlled environment, preventing temperature fluctuations that could degrade the quality of the products [36].

Increased reliability: Land-based routes are less susceptible to disruptions such as port strikes, piracy, and severe weather conditions, as evidenced by studies on the OBOR project by Abbas et al. [37] and China's BRI by Sørensen [39]. The development of this road project enhances supply chain reliability, which is crucial for businesses that depend on the timely delivery of fresh produce.

4.2.3.2 Trade benefits for non-perishable goods For non-perishable goods, such as electronics, machinery, textiles, and manufactured products, diversifying routes offers several advantages, including cost efficiency, improved security, and flexibility [40]. These advantages are described in detail below:

Cost efficiency: Parfitt et al. [40] note that while non-perishable goods are not as time sensitive as perishable items, reducing transit times can still result in substantial cost savings. Additionally, Soysal et al. [41] argue that faster transportation reduces the need for large inventory holdings and the associated storage costs. Moreover, the rail transport system in the DRP may be more cost-effective than shipping, particularly for landlocked destinations [42, 43].

Enhanced security: Expanding overland routes helps mitigate risks associated with maritime transport. High-value, non-perishable goods benefit from the increased security of rail and road networks, reducing the risk of damage. Abbas et al. [37] have demonstrated this in the context of the OBOR project.

Flexibility and market access: Overland transport offers greater flexibility and access to inland markets that are not directly reachable by sea, as examined by Wang [44] for China's BRI. This expanded market reach enables businesses to distribute their goods more widely and efficiently, tapping into new customer bases.

Table 3 Comparison of Gulf-Europe trade benefits between current scenarios and post-project scenarios

Aspect	Traditional trade	Post project trade	Expected post-project benefits
Transportation modes	Limited land-based transport	Enhanced intermodal transport	Integrated road and rail networks
Efficiency and speed	Slower transit, longer travel distances	Faster transit, reduced dependency on maritime routes	Direct road and rail links
Cost	Higher shipping costs and variable costs	Reduced logistics costs	Direct routes
Trade volumes	Limited volumes	Increased volumes	Higher capacity infrastructure
Economic impact	Limited economic growth due to slower and costlier logistics	Greater economic growth and integration with Europe	Economic diversification and competitiveness
Environmental impact	Higher emissions due to reliance on shipping	Potentially lower emissions with hydrogen technology	Sustainable trade practices
Market access and flexibility	Limited flexibility and market access	Enhanced market access and flexibility	Direct land-based routes
Reliability and stability	Vulnerable to maritime disruptions (e.g., port strikes, piracy)	Increased reliability and stability with secure land-based routes	Reduced risk from geopolitical tensions affecting sea routes

Table 4 A summary of the benefits of post-project trade diversification

Benefit	Description	References
Increased reliability	Land-based transportation, such as road and rail, is more reliable than sea transport because it is less susceptible to weather conditions and maritime hazards like storms and piracy	[1, 48, 87]
Reduced congestion	As ports frequently experience heavy congestion and prolonged loading and unloading times, alternative routes can alleviate these issues and significantly enhance overall transportation speed	[88]
Lower transportation costs	Overland routes can be more cost-effective by reducing the need for transshipment and port fees. Additionally, rail transport can offer lower fuel costs compared to shipping	[2, 42]
Faster transit times	Direct rail and road connections can significantly cut down transit times compared to longer maritime routes, particularly for time-sensitive goods	[2, 42]
Environmental benefits	Hydrogen-powered vehicles and trains can significantly reduce greenhouse gas emissions than shipping, thereby enhancing environmental sustainability	[89, 90]
Flexibility and accessibility	Overland routes offer greater flexibility and accessibility than sea transportation, thereby expanding market reach and accessibility	[87, 91]
Enhanced security	Land-based routes reduce the risk of piracy and other maritime security threats while providing better safety for perishable goods and sensitive items	[17, 87]
Economic resilience	Diversifying transport options reduces risks and disruptions, making trade routes more resilient to issues such as port strikes, shipping delays, and other challenges, thereby ensuring economic resilience	[87]
Increased trade volumes	The development of this project will create new opportunities for investors and is likely to increase trade volumes that can be accommodated	[1, 2]
Support for regional development	Developing inland infrastructure such as roads and railways can enhance regional economic development, create jobs, and promote local industries	[2, 3]

4.2.4 Trade benefits of optimized logistics

Kostecka-Tomaszewska and Czerewacz-Filipowicz [45] optimized the route from Romania to Poland, analyzing China's BRI, while Li et al. [46] focused on optimizing intermodal hub locations for China's BRI, finding significant transportation and cost efficiencies. Similarly, the Gulf-Europe corridor aims to enhance the current logistics system by integrating advanced road and rail networks, significantly improving connectivity, and reducing transit times [47]. By shifting a substantial portion of goods transport from maritime to land-based routes, the corridor addresses issues such as port congestion, shipping delays, and high maritime costs [4]. This will enable seamless intermodal transport, combining road, rail, and maritime logistics to create a more efficient and flexible supply chain. Additionally, Abbas et al. [38] note that the corridor will support faster and more reliable delivery schedules, crucial for both perishable and non-perishable goods. Enhanced security along land routes will further reduce the risks associated with maritime transport [17, 48]. Overall, the corridor fosters greater economic integration, increases trade volumes, and supports regional development by making logistics more efficient and cost-effective.

4.2.5 Trading opportunities with hydrogen adoption

The adoption of hydrogen vehicles and trains in the Gulf-Europe corridor will create significant trade opportunities by developing a more sustainable and efficient transport network to meet the rising global demand for eco-friendly logistics. GCC countries like Qatar and Saudi Arabia, already investing in green hydrogen production [49], can leverage this transition to position themselves as leaders in exporting hydrogen-based technologies, diversifying their economies beyond fossil fuels. Meanwhile, European nations such as Germany and the Netherlands, advancing in hydrogen infrastructure [50], can foster new markets for hydrogen-powered goods and services, strengthening trade in advanced technologies and renewable energy systems. This shift may also drive bilateral trade agreements focused on sustainable transport, opening new avenues for the exchange of hydrogen-related innovations, automotive components, and industrial machinery.

4.3 Economic benefits

4.3.1 Economic growth

According to Wang et al. [51] and Jiang et al. [52], China's BRI has demonstrated significant potential for stimulating regional economic growth in Asia, Europe, and Africa. Similarly, the project is expected to enhance the economic growth of the GCC and European countries by facilitating export and import activities. The developed Gulf-Europe corridor is expected to streamline the transport of goods, reducing costs and time, and thereby boosting trade volumes [43]. Economic forecasts suggest that increased efficiency in logistics and transport could raise the economies of participating GCC countries [51]. KSA, the largest economy in the region, could see substantial gains due to its pivotal role in the project, potentially adding billions of dollars to its economy. Similarly, the UAE, with its advanced logistics infrastructure, stands to benefit greatly, enhancing its position as a global trade hub [32].

Economic growth with hydrogen adoption: The adoption of hydrogen vehicles in the Gulf-Europe corridor will drive economic growth by fostering innovation, reducing operational costs, and creating new industries. GCC countries like Saudi Arabia and the UAE, investing heavily in hydrogen production, can stimulate economic diversification by becoming major exporters of hydrogen fuel and technologies [49]. For example, Qatar's hydrogen production initiatives could attract global investments and create new jobs in clean energy sectors. In Europe, countries like Germany, already pioneers in hydrogen vehicle manufacturing and infrastructure [50, 53], can expand their automotive and green technology industries, boosting exports and industrial productivity. The widespread use of hydrogen vehicles will also reduce fuel costs and maintenance for logistics companies across the corridor, leading to more competitive pricing and increased trade, further fueling economic growth in both regions.

4.3.2 Investment opportunities

According to Liu et al. [54], China's outbound investment now surpasses its inbound investment, and they found that China's expansive industrial sector and high savings level could lead to a global reallocation of economic activity, influencing the future of globalization. Similarly, the Gulf-Europe corridor offers numerous opportunities for both

local and foreign investments. This creates opportunities for private investors, international financial institutions, and sovereign wealth funds to invest in infrastructure projects such as railways, roads, ports, and logistics hubs. Beyond infrastructure, there are other investment opportunities in additional services such as technology for logistics management, supply chain solutions, and security services [55].

Sengupta [56] analyzed how China leverages the Asian Infrastructure Investment Bank (AIIB) and its markets in Central Asia to expand its influence, highlighting its complex role in shaping relationships through infrastructure financing and trade. Enhanced transport links will also make the Gulf region more attractive for foreign direct investment (FDI) across various sectors, including manufacturing, tourism, and services, as noted by Sengupta [55]. These investments will not only inject capital into the region but also facilitate knowledge and technology transfer, further accelerating economic development and diversification efforts [55].

4.3.3 Trade enhancement

This corridor aims to enhance existing trade routes and logistics infrastructure, boosting trade between the GCC and European countries. Additionally, it will provide extra benefits, such as minimizing transportation costs, reducing delivery times, and increasing trade volume, as detailed below.

4.3.3.1 Seamless connectivity Konings [57] found that the BRI enhances transport connections between Asia and Europe, significantly impacting international trade. With the involved countries accounting for over a quarter of global trade, better connections and lower trade costs could boost world trade by 12% if trade costs are halved. Similarly, this corridor aims to establish a continuous road and rail network from the Gulf to Europe, creating seamless connectivity among these countries [2].

4.3.3.2 Cost reduction According to Konings [57], Eastern Europe and Central Asia will benefit the most from the BRI, depending on reductions in trade costs. Halving trade costs between BRI countries could boost world trade by 12%. Enhanced infrastructure from this project will streamline transportation and significantly lower logistics costs, making the Gulf region more globally competitive by enabling exporters to offer more attractive pricing [4].

4.3.3.3 Increased trade volumes Foo et al. [5] demonstrated that OBOR significantly boosts trade flows between ASEAN countries and China. Similarly, this project's improved infrastructure will increase trade routes' capacity, supporting higher volumes of goods and driving economic growth. As trade volumes rise, participating countries will experience increased economic output. Additionally, the enhanced trade routes will expand market access, benefiting Gulf exporters [2, 29].

4.3.4 Regional economic integration

Ma [58] examined the impact of economic integration on local economies through the BRI, proposing an innovative model by China. Between 2013 and 2019, over 120 countries joined the BRI, intensifying regional integration and interdependence. Ma [58] found that the BRI significantly improved the economic performance of local economies, particularly benefiting lower-income countries. This growth was largely driven by increased foreign trade and inward FDI, supported by Ullah et al. [6].

Similarly, the Gulf-Europe transportation initiative seeks to enhance regional economic integration by facilitating the efficient movement of goods from GCC countries to European nations, as illustrated in Fig. 3. Goods from the Gulf will be consolidated in Turkey, utilizing the developed road and rail networks, with Turkey serving as a hub, as depicted in Fig. 3. Ullah et al. [6] suggest that by creating a unified transportation network, the corridor will enhance economic collaboration, leading to bilateral and multilateral agreements that streamline customs, trade regulations, and logistics processes. King and Du [59] found that China's Asian economic strategy needs to integrate the BRI into the existing framework of international economic cooperation. Vinokurov et al. [60] also found that harmonized policies, like those in the INSTC, will reduce trade barriers and facilitate efficient cross-border movement of goods, promoting greater economic cooperation.

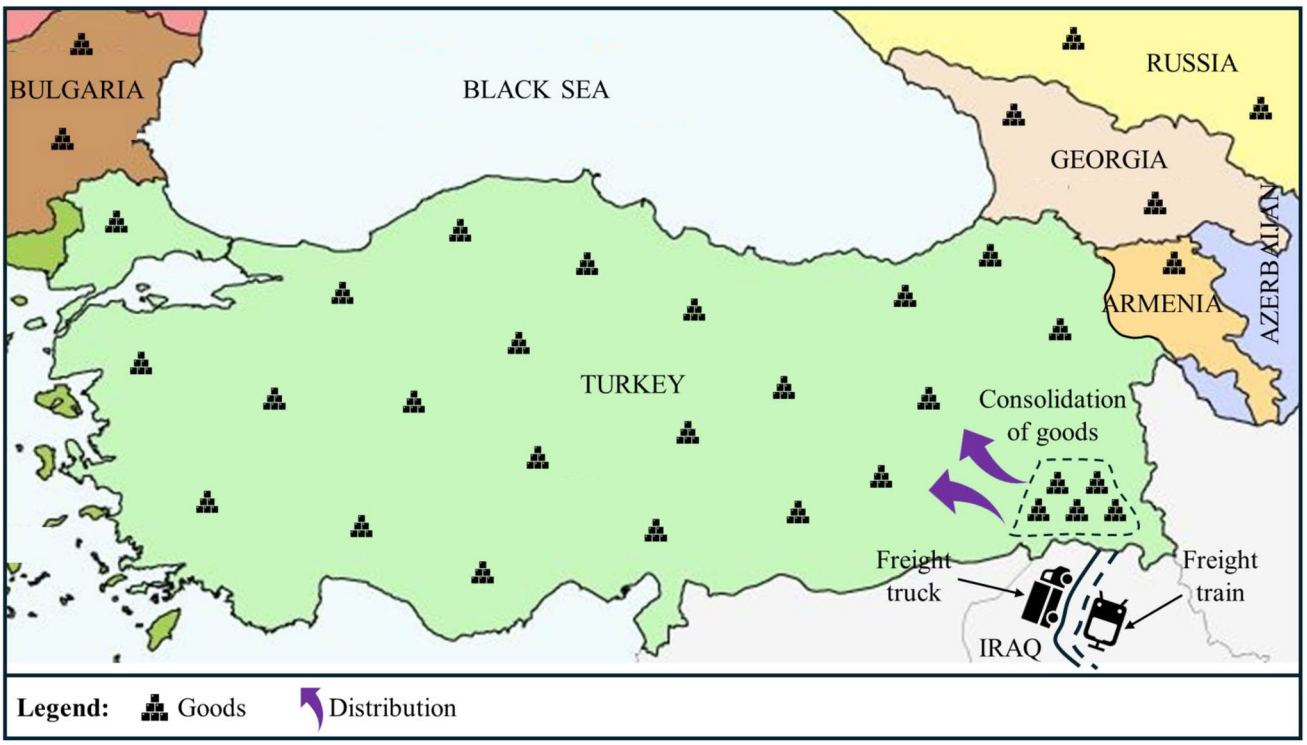

Fig. 3 Consolidation and distribution of goods from Turkey to Europe

4.4 Hydrogen adoption in transportation and sustainable road transport enhancement

This corridor opens an opportunity to adopt hydrogen vehicles and trains that will offer various aspects of road transportation sustainability and economic growth that are detailed below.

4.4.1 A comparative study of existing freight corridors with the Gulf-Europe corridor for HFCV adoption

A notable example of HFCV adoption is the deployment of hydrogen-powered trucks along the Los Angeles–San Francisco freight corridor in the United States. This 612-km route serves as a key connection between the Greater Los Angeles area and the San Francisco Bay Area. This initiative aligns with California's broader strategy to lower emissions and transition to zero-emission freight transport, backed by significant investments in hydrogen infrastructure [61, 62]. Likewise, the Houston-Los Angeles (H2LA) Corridor along Interstate 10 (I-10) is designed for hydrogen-powered heavy-duty trucks, spanning approximately 2300 km and linking major freight hubs, as shown in Fig. 4. This project is supported by multiple hydrogen refueling stations (HRSs) to facilitate long-haul operations. Additionally, the Texas Triangle Hydrogen Network, covering Houston, Dallas, and San Antonio, supports both medium- and heavy-duty hydrogen vehicles within a regional framework [61, 62].

These initiatives demonstrate the role of hydrogen in promoting sustainable transportation by reducing greenhouse gas emissions. By 2025, they are expected to advance hydrogen integration into freight systems [61, 62], offering a model that could be applied to the Gulf-Europe corridor for enhanced economic cooperation and transportation sustainability.

4.4.2 Potential adoption of hydrogen vehicles

Hydrogen vehicles will offer significant benefits for GCC countries such as Qatar, the UAE, and the KSA because these nations are going to produce hydrogen soon [21, 22]. Moreover, the global sales of hydrogen fuel cell buses and trucks are increasing due to their environmental friendliness and cost-effectiveness over time [23]. A global rise in the adoption of HFCVs has been illustrated in Fig. 5. South Korea leads this trend, with HFCV adoption reaching

Fig. 4 H2LA: I-10 Hydrogen corridor (Source [62])

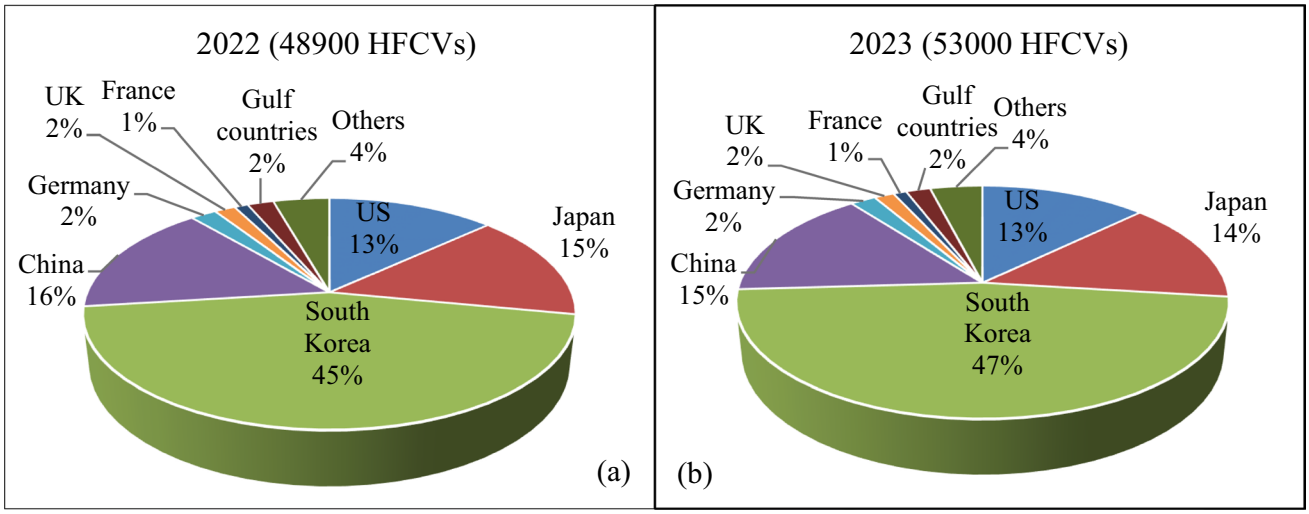

Fig. 5 Adoption of HFCVs by country worldwide in (**a**) 2022 and (**b**) 2023 (Source: Samsun et al. [23]; Statista [85])

47% in 2023, totaling 25,000 vehicles. In comparison, the total number of HFCVs worldwide increased from 48,900 in 2022 to 53,000 in 2023, as shown in Figs. 5a and b. This upward trend is evident across various countries, not just in European nations like France, Germany, and the UK, but also in GCC countries including Qatar, the UAE, and the KSA. According to Kazim [21], this move will align with global sustainability goals and meet environmental regulations. Additionally, it will attract national and international investors to green logistics and foster economic growth [4].

The strategic placement of HRSs along the route will bolster the GCC countries, especially Qatar's role as a potential logistics hub in the region by producing hydrogen from natural gas. However, the successful deployment of hydrogen infrastructure depends on technical readiness, including advancements in hydrogen storage, fuel cell efficiency, and refueling technologies. According to insights from Foo et al. [5] and Konings [57], this infrastructure will not only support domestic transportation needs but also facilitate international freight transportation through seamless connectivity among logistics companies. Despite its potential, the cost structure remains a critical factor, as establishing a single HRS costs between $1 million and $2 million, while hydrogen fuel cell trucks currently range from $200,000 to $600,000 per unit, nearly double the price of conventional diesel trucks [63]. Deployment challenges such as regulatory hurdles, supply chain constraints, and the need for standardized refueling protocols must also be addressed. The hydrogen production cost in the GCC region varies between $1.50 and $2.50 per kilogram for blue hydrogen, making it competitive with conventional fuels but still requiring infrastructure scaling [64]. Policy frameworks supporting hydrogen adoption, including tax incentives, carbon pricing, and cross-border agreements, will be essential to attract investment and accelerate the transition.

4.4.3 Potential adoption of hydrogen trains

In recent years, hydrogen-powered trains have primarily been developed for passenger transport, with most advancements focusing on reducing emissions in regional rail services [24, 53]. However, the shift toward using hydrogen fuel for freight transport is also gaining traction. A notable example is the HydroFLEX Freight, a hydrogen train concept developed by Porterbrook and the University of Birmingham in the UK, initially launched as a passenger service in 2019 but with potential applications for freight transport [65]. Another significant development is the Siemens Vectron Dual Mode, as shown in Fig. 6a, introduced by Siemens Mobility in 2020. Although primarily a dual-mode locomotive using both electric and diesel power, Siemens is exploring hydrogen as a future power option for this model, aiming to transition to hydrogen fuel for freight operations. Additionally, the Alpha Trains Hydrogen Locomotive, developed by Alpha Trains in collaboration with Siemens in 2023, represents another key advancement in hydrogen freight technology [66, 67]. This locomotive, as depicted in Fig. 6b, is designed to convert existing freight locomotives to hydrogen power, further reducing emissions in rail freight transport. These developments indicate a growing interest in applying hydrogen technology to freight transport, with companies like Siemens and Porterbrook leading the way in exploring sustainable alternatives for goods movement on rail networks [68].

The potential for using hydrogen trains in the Gulf-Europe corridor is considerable. This corridor, extending from the Gulf region to Europe, encompasses a substantial distance of 1200 km, traversing a variety of terrains. Hydrogen trains can offer a sustainable and efficient solution for these routes, reducing dependency on diesel and lowering carbon emissions significantly.

4.5 Challenges, risks, and SWOT analysis

4.5.1 Challenges and risks

Githaiga et al. [69] assessed the potential challenges of the BRI for Africa, focusing on various national projects. Similarly, Khor et al. [70] found that the BRI faces criticism for China's geopolitical motives and warns partner countries about the risks of heavy debt and dependence on Chinese business platforms. The Gulf-Europe project may encounter significant challenges and risks across political, economic, and environmental dimensions, as noted by Leandro [18]. Table 5 outlines the risks and challenges, while Fig. 7 highlights some key benefits.

4.5.2 SWOT analysis

Figure 8 presents a SWOT analysis examining the project's strengths, weaknesses, opportunities, and threats. The project offers several strengths, including enhanced connectivity [2, 57], economic diversification [3, 5], regional integration [2, 60], and investment attraction [71], all of which can improve trade efficiency and foster economic growth. However, significant weaknesses must be considered. The high initial cost (US$17 billion) and lengthy construction timeframe (25 years) are major challenges. Additionally, political and security risks [17, 18], regulatory obstacles [19], and environmental concerns [72, 73] present further implementation difficulties.

Fig. 6 Latest freight trains (**a**) Vectron Dual-Mode Locomotive (Source: SIEMENS [86]), (**b**) Alpha Trains Hydrogen Locomotive (Source: Alpha Trains [66])

Table 5 Key infrastructure challenges and risks associated with the project

Challenges and risks	Description
Political risks	
Regional conflicts	Political violence and conflicts in Iraq may arise as a major issue, leading to increased construction disruptions, costs, and extended project durations, as found in Leandro [18]
Diplomatic relations	As demonstrated by Singh's [92] standoff between Chinese and Indian troops, deteriorating diplomatic ties between participating countries could hinder cooperation and project continuity
Regulatory challenges	Yu [19] demonstrated that differences in regulatory frameworks and bureaucratic delays, particularly in inter-organizational and central-local coordination, can impede project progress
Government changes	Political changes in the participating countries might result in policy shifts that could affect the project's execution [18]
Environmental concerns	
Pollution	Higher greenhouse gas emissions could hinder project progress due to strict environmental standards, green market access requirements, and anti-eco dumping measures [72]
Resource consumption	Ensuring an adequate supply of natural resources like water, minerals, and energy can occasionally pose challenges for infrastructural development [93]
Waste management	Managing the waste and scrap generated during infrastructural development can be challenging; otherwise, it leads to environmental degradation [73]
Economic risks	
High initial costs	As noted by Cai [71] regarding the OBOR initiative, the project necessitates a substantial initial investment for the construction of roads, railways, ports, and other infrastructure
Funding sources	Relying on international loans and investments can expose a project to risks associated with interest rate and exchange rate fluctuations. For funding the OBOR initiative, China adopted a geoeconomic and geopolitical strategy by securing a loan from the AIIB [71]
Uncertain economic benefits	Public and private financial organizations investing in this project may face uncertainty regarding financial returns. This is due to the variability in how long loan-receiving countries can sustain their policies, as described by Sun et al. [94] for the BRI
Operational costs	Ongoing operational and maintenance costs can sometimes exceed incomes due to improper planning and management, negatively impacting the economic benefits for participating countries [94]
Inflation and cost overruns	Construction projects are susceptible to significant budget increases due to unforeseen inflationary pressures and cost overruns, as evidenced by research conducted by Andrić et al. [74] and Khor et al. [70]

Moreover, this analysis presents some opportunities. Seamless connectivity will create opportunities for trade expansion [5, 57], economic enhancement [2, 52, 59], global trade positioning [3], technological advancements, sustainable development with hydrogen adoption [6, 44], and market expansion [55, 56]. These factors suggest the potential for long-term economic benefits and innovation [51]. Besides, economic fluctuations, geopolitical tensions, competing projects, and stringent environmental regulations all pose significant threats to its stability [71, 74].

4.5.2.1 Potential solutions to weaknesses and threats To address the weaknesses and threats outlined in the SWOT analysis, potential solutions can be drawn from successful large-scale transportation initiatives such as the BRI, TEN-T, INSTC, and the Panama Canal Expansion. These are explained in detail below:

Potential solutions to weaknesses: One major weakness, the high initial cost, can be mitigated through public–private partnerships (PPPs), a strategy successfully employed in the development of infrastructure along the BRI. PPP models distribute financial risks and reduce the burden on governments, as seen in China's collaborations with partner nations in Southeast Asia [75]. Additionally, international green financing mechanisms, such as those used in the Panama Canal Expansion through multilateral lenders like the Inter-American Development Bank, can provide funding for sustainable and economically significant projects [76]. Breaking the project into smaller, phased implementations, similar to the TEN-T corridors'development, can also help manage financial pressures while allowing for incremental assessments of the project's outcomes [77].

Political and security risks can be addressed through bilateral agreements and collaborative mechanisms, as demonstrated by the INSTC, which strengthens trade ties between India, Iran, and Russia while fostering geopolitical stability through mutual agreements [78]. Risk mitigation can also involve contingency plans and insurance mechanisms to address potential disruptions—key components of the risk management strategy employed during the Panama Canal Expansion [79]. Regulatory challenges can be tackled by harmonizing cross-border standards, similar to how the

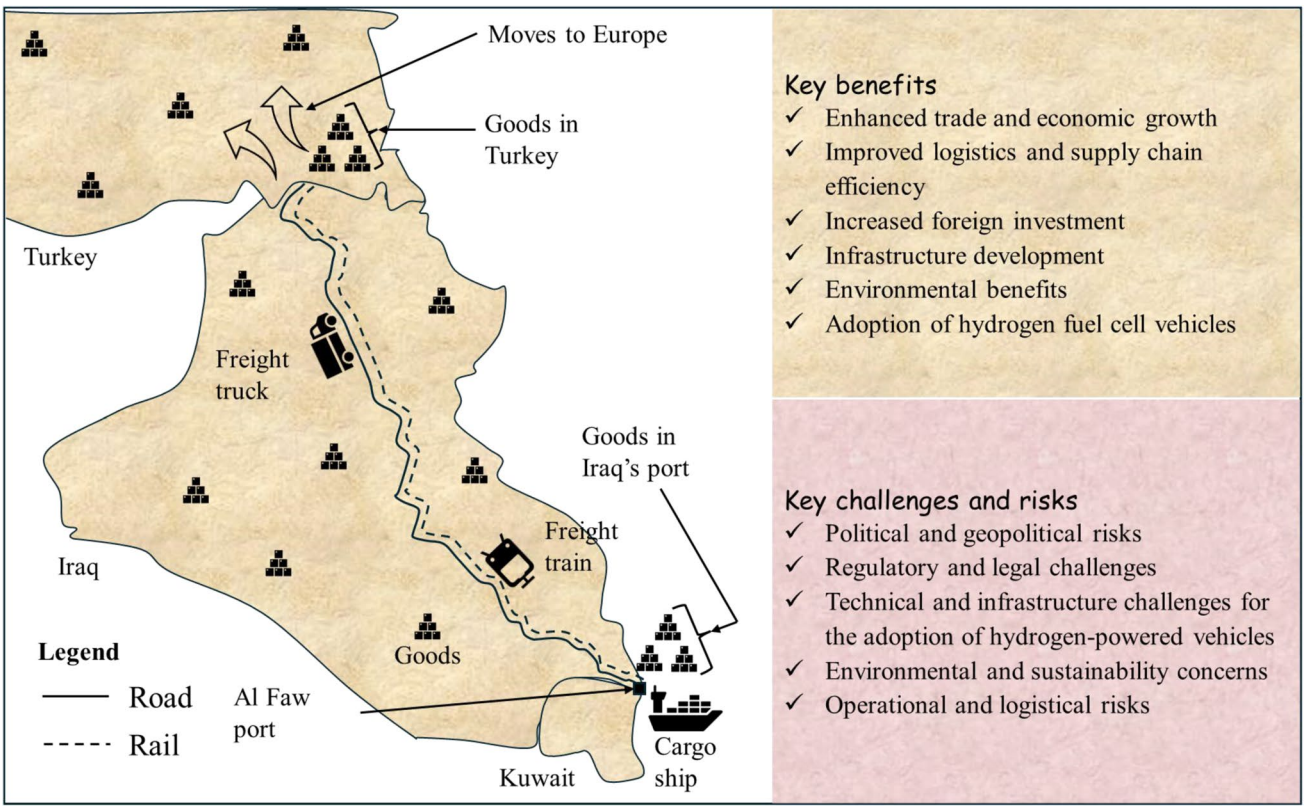

Fig. 7 Key benefits, challenges, and risks of the project

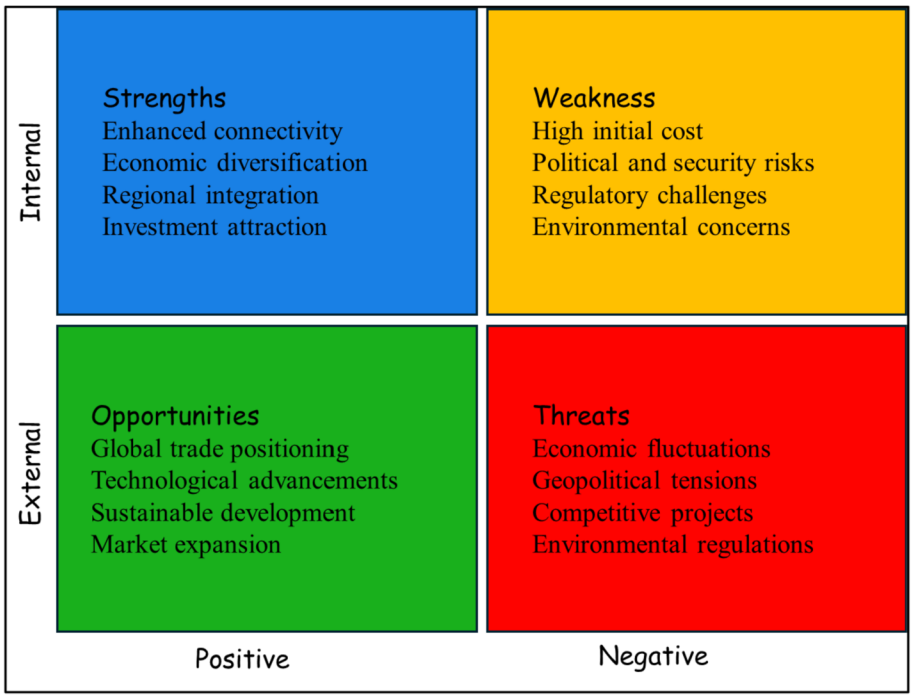

Fig. 8 SWOT analysis of Iraq's DRP or the Gulf-Europe Corridor Project

TEN-T promotes seamless transport infrastructure integration across EU member states. Encouraging stakeholder dialogues among policymakers, industry leaders, and transportation authorities, as observed in the BRI's multi-stakeholder approach, can further ensure that regulations align with project goals [80]. Environmental concerns can be mitigated by

integrating sustainability-focused technologies, as demonstrated by the BRI's Green Silk Road initiative, which emphasizes the use of renewable energy in transportation projects [81]. Comprehensive environmental impact assessments, a critical component of the Panama Canal Expansion, can also help minimize ecological damage while supporting the project's sustainability.

Potential solutions to threats: To mitigate external threats like economic fluctuations, the Gulf-Europe transportation project can diversify revenue streams by incorporating auxiliary services such as logistics hubs and trade facilitation platforms, similar to the INSTC's approach of combining maritime, rail, and road networks to foster economic resilience [78]. Adaptive pricing models, like those implemented for the expanded Panama Canal toll system, can further stabilize revenue streams during periods of market volatility [79]. Geopolitical tensions can be addressed by employing neutral mediators and fostering regional cooperation, as exemplified by the BRI's emphasis on multilateral collaboration to resolve conflicts [80]. Developing integrated trade zones along the corridor, akin to the economic zones established along TEN-T routes, can also incentivize cooperation.

Competition from alternative projects can be countered by emphasizing the unique value propositions of the Gulf-Europe corridor, such as faster transit times, reduced environmental impact, and advanced technology integration. Strategic alliances with other regions to embed the corridor into global trade networks, as demonstrated by the INSTC's integration into Eurasian trade, can further enhance its competitiveness. Finally, environmental regulations can be proactively managed by designing the project to exceed compliance requirements, similar to the Panama Canal Expansion's focus on water conservation and sustainability [76]. Investments in renewable energy and circular economy practices, as promoted by the Green Silk Road initiative under the BRI, can also align the project with global sustainability goals [81].

By adopting these strategies, the Gulf-Europe transportation project can effectively overcome its weaknesses and mitigate external threats, aligning with global standards and sustainability objectives. Insights drawn from initiatives like the BRI, TEN-T, INSTC, and the Panama Canal Expansion provide robust and practical solutions for addressing similar challenges.

4.6 Studies of large-scale global infrastructure projects

4.6.1 Projects overview

Table 6 presents a comprehensive overview of four large-scale infrastructure projects: the BRI, TEN-T, INSTC, and Panama Canal Expansion, along with the Gulf-Europe transportation project. The estimated completion year for the BRI, TEN-T, and the Gulf-Europe project is 2050. By then, these projects aim to establish robust transportation networks with European countries.

4.6.2 Key success factors and project benefits

The key success factors and project benefits of the Panama Canal Expansion project, as well as ongoing projects like the BRI, TEN-T, and INSTC, have been summarized in Table 7. These factors can be considered for the Gulf-Europe project, as some may prove effective.

5 Proposed strategies and alignment of our findings with recent policies

Based on a rigorous analysis of BRI, TEN-T, and INSTC, along with a transportation sustainability assessment and a SWOT analysis of the Gulf-Europe corridor in the previous sections, this study proposes strategies and policy pathways for policymakers to maximize benefits for both GCC and European countries. These include:

5.1 Proposed strategies for the policymakers

5.1.1 Short-term strategies

- **Invest in infrastructural development:** Policymakers should prioritize investments in key infrastructure projects, such as HRSs, port expansions, and modern transport corridors, to enhance trade efficiency and regional connectivity. These developments will support the transition to hydrogen-powered transportation and attract

Table 6 Overview of the large-scale global infrastructure projects

Project	Budget (USD)	Duration	Length (km)	Financial partners	References
BRI	Up to 8 trillion	2013–2050	Land: 12,000, Sea: 21,000	China, Asia, Europe, Africa	[95]
TEN-T	500 billion by 2030	1990–2050	Road: around 1,20,000 Rail: around 1,38,072	EU, European investment bank	[96]
INSTC	620 million	2000–ongoing	7,200 (road, rail, and maritime routes)	India, Iran, Russia, Asian development bank	[97, 98]
Panama Canal Expansion	5.25 billion	2007–2016	77.1 (Waterway)	Panama Canal authority, International lenders	[99, 100]
The Gulf-Europe corridor	17 billion	2024–2050	Around 1200 (road and rail)	Gulf, EU	[1, 2]

Table 7 Key success factors and project facilities

Project	Description	Success factors	Project benefits	References
BRI	Multi-modal networks of road, rail, and maritime connects Asia, Africa, Europe, and beyond	Substantial investment, political support, international partnerships	Reduced shipping times, increased trade, and economic development	[5, 72]
TEN-T	Integrates transport across Europe	Regulatory framework, EU funding and cooperation	Improved mobility, economic cohesion, and increased trade volumes	[101]
INSTC	Multi-modal route links India, Iran, and Russia	Usage of existing infrastructure, efficient customs, political support	Reduced transportation time, increased trade, and economic collaboration	[60, 102]
Panama Canal expansion	Allows for larger ships and increases capacity	Advanced engineering, financial investment, project management	Increased shipping capacity, reduced transit times, enhanced global shipping role	[103, 104]

private sector participation by showcasing long-term benefits. As noted by Cai [71], strategic infrastructure investments are essential for reducing costs and ensuring sustainable transport growth.

- **Strengthen regional cooperation:** Policymakers should initiate high-level dialogues between GCC countries, Iraq, and Turkey to harmonize regulations, simplify customs procedures, and develop unified trade policies. These efforts will reduce bureaucratic hurdles and facilitate smoother trade. Establishing pilot joint ventures in key sectors like logistics and energy will promote cross-border investments and technology transfer. As highlighted by Ciborowski et al. [82] and Khor et al. [70], regional cooperation can streamline trade processes, lower barriers, and enhance the corridor's economic resilience and competitiveness.
- **Promote awareness of sustainable practices:** Launch awareness campaigns to educate stakeholders on the benefits of hydrogen as a clean fuel and its potential to reduce carbon emissions in transportation. These campaigns can foster public support and encourage the early adoption of hydrogen technologies, as supported by Abbas et al. [38] and Mendez et al. [22].

5.1.2 Medium-term strategies

- **Expand infrastructure networks:** Expand infrastructure networks by increasing investments in hydrogen supply chains, focusing on large-scale production facilities, dedicated pipelines, and additional refueling stations along the corridor. This development should align with projected demand growth to ensure long-term sustainability and efficiency. Strengthening hydrogen infrastructure will enhance energy security, support decarbonization efforts, and improve regional connectivity, fostering economic growth and a more resilient transportation network.
- **Institutionalize regional cooperation:** Formalize agreements and frameworks to establish a unified regulatory environment that will facilitate cross-border trade and investment. These agreements should establish clear standards for hydrogen production, transportation, and usage, ensuring compatibility and efficiency across jurisdictions. Strengthening regional collaboration will promote market stability, encourage private-sector participation, and accelerate the transition to a sustainable hydrogen economy within the transportation corridor.
- **Adopt incentives for sustainable practices:** Provide subsidies, tax incentives, or grants to promote the adoption of hydrogen vehicles and trains. These measures can lower upfront costs for consumers and businesses, encourage widespread adoption, and accelerate the transition to sustainable transport systems, as supported by Abbas et al. [38].

5.1.3 Long-term strategies

- **Establish integrated hydrogen ecosystems:** Establish integrated hydrogen ecosystems by developing fully integrated systems for hydrogen production, storage, distribution, and consumption. These ecosystems should support diverse applications, including industrial processes, power generation, and transportation, ensuring a seamless and efficient hydrogen supply chain. By fostering synergies between different sectors, integrated hydrogen ecosystems will enhance energy security, drive technological innovation, and accelerate the transition toward a low-carbon economy within the transportation corridor.
- **Deepen regional integration:** Establish long-term partnerships and joint ventures between Gulf and Turkish entities to drive innovation and investment in hydrogen technologies. This collaboration will facilitate technology transfer, enhance competitiveness, and create synergies across the hydrogen value chain. Strengthening regional ties will drive economic growth, support sustainable energy transitions, and position the corridor as a key player in the global hydrogen market.
- **Achieve SDGs:** Leverage hydrogen infrastructure and technologies to advance broader SDGs, including affordable and clean energy (SDG 7), industry, innovation, and infrastructure (SDG 9), sustainable cities and communities (SDG 11), and climate action (SDG 13). Policymakers should prioritize monitoring progress and ensuring that these efforts align with global sustainability targets, as supported by Mendez et al. [22].
- **Encourage private sector leadership:** Establish regulatory stability and long-term policies to empower private sector leaders to innovate and invest in the hydrogen economy. PPPs should be utilized to address challenges and scale solutions effectively, as supported by Sengupta [55, 56].

5.2 Trade, economic growth, and sustainable transportation in alignment with recent policies

5.2.1 Trade and economic growth

Recent policy developments, such as GCC food security initiatives, emphasize the need for resilient and efficient food supply chains. By reducing trade barriers and improving cold chain logistics, both regions can boost agricultural exports, minimize food wastage, and enhance trade efficiency [30, 36–38]. Further policy integration, including mutual recognition agreements for food standards, specialized economic zones for agribusiness investments, and harmonized tariff structures, can significantly contribute to GDP growth and regional trade expansion. These measures will not only strengthen trade flow but also improve market access and economic diversification in both the GCC and Europe [3, 4].

5.2.2 Sustainable transportation

The adoption of HFCVs aligns with the EU Green Deal and SDGs by promoting zero-emission logistics and reducing reliance on diesel-powered trucks [22, 23]. Large-scale adoption requires investment in hydrogen refueling networks, financial incentives such as subsidies and carbon pricing mechanisms, and cross-border agreements for hydrogen supply stability. Additionally, PPPs should be encouraged to accelerate hydrogen infrastructure development. By incorporating these policies, the Gulf-Europe corridor can transition toward a low-carbon transport system, reducing its environmental footprint while aligning with global sustainability commitments [22, 24].

6 Conclusion

Through extensive analysis, we identify several key findings that highlight the corridor's potential impact on trade dynamics, economic diversification, and transportation sustainability.

The corridor has the potential to significantly reduce transportation times and costs by providing a direct and efficient land-based transportation route, compared to the traditional reliance on slower and more expensive maritime routes. While sea transport is cost-effective, it typically takes 20–30 days for shipments to reach European markets, depending on port congestion and weather conditions. In contrast, air transport delivers within 1–3 days but incurs costs up to 5–10 times higher than sea or land transport, making it impractical for bulk commodities and lower-value goods. The proposed corridor offers a balanced alternative, with estimated delivery times ranging from 7–10 days and potential cost reductions of 30–40% compared to air freight. According to projections by regional logistics authorities and feasibility studies, the corridor could boost trade volume between the Gulf and Europe by 20–30% within the first five years of operation, potentially increasing annual revenue by US$4 billion [13]. This is especially vital for industries handling perishable goods like fresh produce, pharmaceuticals, and chemicals. Faster, cost-effective transport will enhance supply chain reliability and export competitiveness, directly addressing RQ1.

The establishment of the Gulf-Europe corridor is poised to become a key driver of economic diversification in both regions. By improving connectivity, it will support the growth of non-oil sectors such as manufacturing, technology, agriculture, and services. Notably, Saudi Arabia's non-oil sector is projected to grow at a steady rate of 4.5% in 2025–2026, highlighting the momentum of diversification efforts [83]. Moreover, the corridor is expected to attract substantial FDI. According to the International Monetary Fund, closing the FDI gap could raise real non-oil per capita GDP growth by up to one percentage point [83]. This investment will accelerate infrastructure development—roads, railways, logistics hubs, and digital platforms—leading to job creation, knowledge transfer, and innovation. In turn, these improvements will align with national strategies for sustainable development. Enhanced infrastructure and regulatory reforms will also improve the region's appeal to global investors, boosting economic activity across both urban and rural areas and supporting broader regional growth goals.

A particularly innovative aspect of the corridor is its potential for hydrogen-powered transportation. Traditional freight transport, particularly diesel-powered trucks, contributes approximately 25% of CO_2 emissions from transport in the EU and around 8% of total greenhouse gas emissions globally [84]. Transitioning to HFCVs and hydrogen-powered trains presents a cleaner, more sustainable alternative. When produced from renewable sources, hydrogen fuel can achieve up to 90–100% reduction in CO_2 emissions compared to diesel, significantly improving air quality and reducing the

environmental footprint [22, 50]. According to the International Energy Agency, replacing a diesel truck with an HFCV can cut up to 73 tons of CO_2 annually per vehicle. This aligns with global climate objectives and the United Nations SDGs, particularly SDG 7, SDG 9, SDG 11, and SDG 13. By investing in hydrogen infrastructure along the corridor, both Gulf and European nations can fast-track their clean energy transition, supporting RQ2 and positioning the corridor as a global model for green freight transport.

The infrastructural development of the corridor presents several political, environmental, and economic challenges. Politically, regional instability, diplomatic tensions, and regulatory differences between participating countries could delay progress and complicate trade agreements. Environmental concerns include the impact of large-scale construction on ecosystems, carbon emissions from infrastructure development, and the sustainability of hydrogen production. Additionally, ensuring an adequate supply of renewable energy for hydrogen generation remains a challenge. Economically, high initial investment costs, fluctuating fuel prices, and uncertain demand for hydrogen-powered transportation pose financial risks. The long-term success of the corridor relies on effective policy coordination, cross-border cooperation, and sustained investment, all of which address RQ3. Mitigating these risks requires a strategic approach that includes regulatory alignment, commitments to green energy, and robust infrastructure financing mechanisms to ensure a resilient and sustainable transport network.

In conclusion, the Gulf-Europe corridor presents a game-changing opportunity for trade, economic development, sustainability, and regional cooperation. By offering a faster and more cost-effective transportation route, it will enhance trade efficiency and competitiveness. The corridor's integration of hydrogen-powered transportation will further reinforce its role as a sustainable trade route, aligning with international climate goals and promoting clean energy adoption. By capitalizing on these opportunities, the corridor can serve as a model for similar projects worldwide, contributing to a more efficient, sustainable, and interconnected global economy.

6.1 Future research directions

While the project is in its early stages, future studies can explore various dimensions to maximize its effectiveness. Key areas of research include trade optimization, economic diversification, sustainable transportation, environmental impact, and geopolitical considerations.

One important area for future studies is trade and supply chain optimization. Researchers can analyze how the corridor influences trade volumes between GCC countries and Europe, comparing it with existing trade routes such as the BRI and TEN-T. The efficiency of supply chains, multimodal transport integration, and the role of advanced logistics in reducing costs and transit times are important aspects to examine. Additionally, studies on customs facilitation and digital trade platforms can help streamline cross-border trade. From an economic perspective, investment potential and sectoral diversification are key areas for future research. The corridor is expected to attract FDI and promote the growth of various industries beyond the traditional oil sector. Researchers can explore how this project contributes to job creation, workforce development, and industrial expansion. Additionally, studying different PPP models can provide insights into effective funding mechanisms for large-scale infrastructure development. Transportation sustainability is another critical research domain. The adoption of HFCVs and hydrogen-powered trains is expected to play a major role in making freight transport more eco-friendly. Future studies can compare the efficiency of rail versus road transport and analyze the corridor's integration with other regional and international transportation networks. The environmental impact of the corridor also requires extensive research. Shifting freight transport from road to rail could significantly reduce carbon emissions, but further studies are needed to quantify these benefits.

Additionally, researchers can explore the role of renewable energy sources, such as solar and wind power, in powering transportation hubs and HRSs. The geopolitical and strategic implications of the Gulf-Europe corridor warrant further analysis. Researchers can examine how the project influences trade alliances, security dynamics, and regulatory harmonization among participating nations. The corridor's potential to enhance Gulf-Europe relations and its role in global trade realignments should also be explored. Furthermore, conducting risk assessments on geopolitical conflicts and regulatory challenges can help policymakers implement effective mitigation strategies.

Finally, policy recommendations and governance frameworks need further investigation. Future studies can propose strategies for establishing special economic zones along the corridor to attract businesses and investors. Research on cross-border cooperation, trade regulations, and infrastructure governance will be crucial for ensuring seamless operations. Studies should also assess the socio-economic impact of the corridor, including its effects on local communities, employment rates, and regional development.

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Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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