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# SDG 13-Oriented Freight Decarbonization through Railway Modal Shift: A Scenario-Based Assessment of Carbon Reduction Potential in the Umm Qasr–Mosul Corridor, Iraq

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**Abstract:** Freight transport is a key facilitator for economic growth, international business, and supply chains connectivity; however, increased freight activities have been identified as major sources of greenhouse gas emissions and environmental problems. Road freight transport systems that involve mainly heavy-duty vehicles cause higher fuel consumption, carbon emissions, congestion, and road deterioration. Thus, the development of low-carbon solutions for freight transportations is vital for the achievement of Sustainable Development Goal 13 (SDG 13) – Climate Action via reducing greenhouse gas emissions and sustainable transport policy making. In Iraq, freight transportation is road network-based leading to increased environmental impact and difficulties in sustainable logistics development. Modernization of railway transport systems is considered as potential directions towards freight decarbonization, but quantified assessments of the carbon reduction potential still lack. The current research attempts to fill this gap by proposing a scenario-based assessment framework targeting SDG 13 to assess environmental and economic effects of railway modal shift of freight traffic on the Umm Qasr–Mosul freight transport corridor. Proposed framework includes comparative emissions assessment of the road and rail transportations in different modal shift scenarios with consideration of projected freight traffic volumes, activity analysis in tonne-kilometres and standard $CO_2$ emission factors. Four scenarios reflecting the proportion of freight shifting from road to rail transport in 25%, 50%, 75%, and 100% correspondingly are being analyzed for different transport distances to estimate potential carbon emissions reduction. As observed, the railway freight system emits considerably less greenhouse gases than heavy trucks. It shows that modal shift is quite beneficial for achieving emission reduction, which is crucial for carbon reduction in transportation systems. This paper also estimates the financial value of such avoidance by applying carbon pricing techniques. The results show that the railway modal shift can be used for contributing to SDG 13 in a clear manner. The research provides valuable information on sustainable transport planning. It helps in implementing low-carbon policies in Iraq.

**Keywords:** SDG 13 Climate Action; Freight Decarbonization; Railway Modal Shift; Sustainable Transportation; Carbon Emission Reduction; Green Logistics; Transport Sustainability; Iraq Railway Corridor.

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## I. Introduction

### *Background: Freight Transportation and Climate Change*

Freight transportation is an essential element of economic development since it allows manufacturing, international trade, and supply chain functioning worldwide. The constant rise in demand for freight transportation caused by population growth, industrialization, urbanization, and business activities has led to increased energy consumption and the environment's degradation. Road freight transportation is the main form of transportation for cargo in numerous regions due to its flexibility, availability, and possibility of door-to-door delivery (Piecyk & McKinnon, 2010). Nevertheless, the reliance on trucks that operate with fossil fuel consumption makes road freight one of the biggest sources of greenhouse gas (GHG) emissions in transportation sector (Churchman et al., 2026).

Currently, the transportation sector is the main contributor to global $CO_2$ emissions and requires an efficient strategy for mitigating their negative effect on the environment. Traditional road freight transportation systems require lots of fuel and lead to great amounts of carbon dioxide emissions, as well as to the additional negative effects such as traffic congestion, air pollution, noise pollution, and rapid deterioration of infrastructure. At the same time, the constant increase in the demand for freight transportation means the difficulty of achieving global climate goals and building sustainable mobility networks using traditional transportation systems.

Thus, the reduction of transport emissions became a critical issue for implementing climate actions. Low-carbon transportation systems contribute to achieving Sustainable Development Goal 13 (SDG 13) – Climate Action, according to which the climate change mitigation should be integrated into national planning and infrastructure development. Current climate-oriented transport policies prioritize higher energy efficiency, lower dependency on fossil fuel consumption, and sustainability solutions that allow ensuring the economic development with the lowest environmental effects. Freight modal shift from high emission road transport to more energy-efficient transportation modes including railways seems to be one of the key solutions to achieve it (Jonkeren et al., 2023).

### *Sustainable Freight Transportation for SDG 13 Achievement*

The application of sustainable freight transport is of great importance for SDG 13 as it helps reduce greenhouse gas emissions, increases energy efficiency, and promotes the construction of climate-resilient infrastructure (Jonkeren et al., 2019). The inclusion of climate-related factors in the planning of transport systems allows for the creation of sustainable logistics networks while ensuring economic performance and reliability of supply chains.

Among different approaches to freight decarbonization, there are mainly measures concerning operational efficiencies, alternative transport systems, optimization of logistics processes, and sustainable investments in infrastructure (Gökbunar & Tozak, 2026; Hudenko et al., 2025). In particular, the shift from road transport to railways is being increasingly recognized as a useful climate change mitigation strategy (Boehm et al., 2021). It is worth mentioning that railway freight transport systems allow carrying large volumes of goods at significant distances with lower emission intensity than road haulage. The high transport efficiency of rail transport combined with the ability to carry large freight volumes with minimal consumption of fuel per tonne-km allows this mode of transport to play a very important role in reducing emissions.

Railway freight transportation supports SDG 13 and helps reduce emissions and develop sustainable transport systems (Pinchasik et al., 2020). However, effective modal shift from road to rail is not possible only with the development of railway infrastructure. The effectiveness of such shift depends on reliable freight transport operations, logistics connectivity, efficiency of transport terminals, policy initiatives, and the encouragement of industries to shift freight demand from road systems.

### *Road Freight Emission Challenge*

The use of roads as a means of freight transportation in Iraq has been substantial in the past years owing to its efficiency and ease of access. The result has been a freight transport system that relies mainly on heavy-duty road vehicles, leading to environmental and economic problems. Road-based freight transportation causes higher fuel use, $CO_2$ emissions, congestion, and rapid degradation of the transportation infrastructure (Janic, 2007).

Road-based freight transport is environmentally unsustainable due to higher fuel use, higher emission intensity, and growing infrastructure burden. HGVs are less fuel-efficient for moving huge cargo amounts over long distances when compared with railways. For Iraq, increasing freight railway transport capacity will help reduce road transport reliance, minimize environmental damage, and enhance logistics sustainability.

### *Railway Modal Shift as a Decarbonization Strategy*

Railway modal shift is an important approach to the reduction of emissions during the transportation of goods due to shifting cargo transportation from emission-intensive road transportation to railway that is more energy efficient (Kurtuluş & Çetin, 2020). The possibility to transfer bigger loads with less energy consumption per ton-kilometer allows railway freight to have lower operational emission intensity than that of heavy road transport.

The sustainability advantages of railway freight transportation include lower emissions, greater freight carrying capacity, energy efficiency, smaller carbon footprint, and lower pressure on the road infrastructure. Railway transportation has the potential to be used by countries willing to improve their logistics and decrease freight emissions at the same time.

The Umm Qasr–Mosul railway corridor of Iraq is an important case of sustainable freight transformation in the country. This railway line is related to the project of Iraq Railways Extension and Modernization (IREM) and its key goals are connected to improvements in railway infrastructure and freight transportation capacity, as well as logistics connectivity (Firoz & Panicker, 2025). The modernization of this corridor can bring not only economic but also environmental advantages due to the possibility to increase the role of railway freight transportation and decrease the usage of road-based transportation (Wei & Wang, 2025).

Freight transportation through railway networks via the Umm Qasr–Mosul corridor can help in reaching SDG 13 because of the reduction of carbon emissions in the process of freight transportation. However, the impact of railway freight transformation on climate change will be defined by such factors as the share of shifted freight from road to railway, the efficiency of railway operation, freight demand, and logistics network infrastructure. Hence, it is important to conduct quantitative assessment of modal shift scenarios (Zgonc & Jakšič, 2025).

### Research Gap

Despite being acknowledged as one of the key strategies for enhancing transportation sustainability in Iraq, there is currently not much quantitative evidence about railway modernization's role in climate change mitigation. Studies conducted so far have concentrated mainly on infrastructure development, enhancement of connectivity, and economic impacts, whereas little consideration has been paid to the carbon reduction potential of rail transport.

- Specifically, the research gap exists in such areas as:
- Potential for $CO_2$ emission reductions due to modal shift from road to rail freight transportation.
- Scenario analysis for different levels of modal shift.
- Economic value of the reduced carbon emissions.
- Potential for railway modernization contribution to the achievement of SDG 13.

Thus, an estimation framework is needed in order to analyze the environmental impacts of railway freight development and its contribution to climate change mitigation.

### Research Objectives

In order to fill in this gap in the literature, this paper develops a SDG 13 based scenario evaluation framework to evaluate the carbon saving potential of rail mode shifting in Iraq.

The key purposes of this research are:

- To calculate carbon savings potential through the mode shifting of road freight to rail by assessing the emissions released from road and rail freight transportation operations.
- To compare different scenarios by analyzing the impact of 25%, 50%, 75%, and 100% freight mode shifting on different transportation distances.
- To calculate the monetary value of carbon savings through the application of carbon valuation techniques to the $CO_2$ savings potential.

- To calculate the contribution of rail infrastructure development to SDG 13 – Climate Action.

The organization of this paper is as follows: Section 1 outlines the significance of decarbonization of freight transport and links it to the SDG 13 Climate Action with regard to modal shift strategies for railways in Iraq. Section 2 discusses the literature review on decarbonization of transport, freight modal shift, and sustainable logistics. The SDG 13-based methodology framework suggested in Section 3 includes scenario development, emission calculation, and carbon benefit evaluation. Results are presented in Section 4 and include emission reduction, economic benefits, and sensitivity analysis. Section 5 discusses the findings and limitations. Sections 6 - 8 provide recommendations, research limitations, and conclusions.

## II. Literature Review

### *SDG 13 and Transportation Decarbonization*

Mitigation of climate change has become one of the biggest priorities nowadays and requires large cuts in emissions of GHGs in various spheres, such as transport. Sustainable Development Goal 13 (SDG 13) – Climate Action highlights the need for integration of climate mitigation measures in national policy-making, infrastructure development and sustainable development projects. As transportation processes cause a large share of global carbon emissions, transition from fossil fuel-based systems to low-carbon solutions is crucial for achievement of climate goals.

Strategies for green transport seek to minimize environmental footprint of transport, but not to compromise its economic and social functions. Such strategies involve improvement of energy efficiency, decrease of carbon intensity, optimization of logistic operations and introduction of new transport modes. Regarding freight transport, sustainable strategies become more oriented towards structural solutions, rather than technological innovations, and, in particular, involve shifting of cargo flow to low-intensity transport modes.

Railway freight systems present an important chance to promote climate action, as these transport systems allow carrying large volume of freight with much lower intensity of emissions per tonne-km, comparing to road transport systems. Thus, integration of sustainable freight planning with climate policy allows countries to develop low-carbon logistic systems and assess infrastructure investment options by their potential emission reduction.

### *Freight Modal Shift and Emission Reduction*

The concept of freight modal shift involves moving cargo transportation from one mode to another, mainly from emission-intensive road transport to more energy-efficient forms like railways. Several past studies have shown that railways can offer environmental benefits since have the capacity to move a bigger quantity of cargo using less energy than heavy vehicles.

Road transportation has higher $CO_2$ emissions owing to its high fuel dependence, operating characteristics of the vehicle, and low transport efficiencies (Tao et al., 2017). On the other hand, railway systems operate under economies of scales and hence can make transportation more efficient over medium and long distances. Freight modal shifts from roads to railways are hence a good source for reducing carbon emissions (Meers & Macharis, 2015).

Existing research has used the tonne-kilometre-based emissions assessment methods in making comparisons of transportation modes and estimating emissions avoidance. The scenario-based methods have also been widely employed to examine different levels of modal shifts by taking into consideration changes in freight quantity, distance, and operating conditions. Nonetheless, there are several factors affecting the effectiveness of freight modal shifts, and include the capacity of railway system, availability of infrastructure, logistic compatibility, and the actual percentage of modal shift (Langenus et al., 2022).

While past studies indicate the carbon reduction potential of the freight modal shift, most studies conducted are in developed regions where railway systems are available (Peng et al., 2025). Only a few studies have explored railway expansion as a strategy for climate change mitigation in regions where freight transportation relies heavily on road transport.

### *Railway Infrastructure Development and Sustainable Logistics*

Sustainable freight transport entails the development of railway infrastructure since the latter facilitates the movement of goods in an energy-efficient and environmentally friendly way. Well-developed railway infrastructure and its improved operation along with enhanced freight capability can provide for the establishment of sustainable logistics systems without the use of emission-heavy road transport.

Railway modernization ensures the improvement of freight transport in the form of better connections between ports, industrial zones and logistics centers. Nevertheless, the sustainability of railway transport depends not only on infrastructure conditions but also on operational aspects such as the level of freight flow, loading effectiveness, reliability, and multi-modal transport.

A combination of transport infrastructure development and logistics management can ensure the establishment of sustainable supply chains. The development of railway corridors between economic zones will allow creating green trade routes by means of sustainable transport alternatives. Iraq offers an excellent example of the Umm Qasr-Mosul railway corridor.

### *Research Gap Summary*

Freight modal shifts and railway improvements have already been identified as effective instruments for the decarbonization of transportations in previous studies. Nevertheless, a number of knowledge gaps still exist in this regard. Firstly, not many regional cases have been analyzed, which assesses the potential of decarbonization in developing transportations where road freight transportation prevails. Secondly, many studies do not include climate-based scenarios concerning different levels of the freight shift and transportation development. Thirdly, there is not much research that quantitatively associates railway improvement projects and SDG 13 benefits.

Thus, in this study, create an SDG 13 scenario-based approach to evaluate the carbon emission reduction potential, cost savings through emission avoidance, and sustainability contribution of road to rail freight shift in the Umm Qasr-Mosul corridor of Iraq.

## III. SDG 13-Based Methodology Framework

### *Framework Overview*

The purpose of this study is to create an evaluation framework based on SDG 13 for analyzing the climate impacts of transitioning freight transport from road to rail. Figure 1 illustrates the framework in which freight demand, transportation scenario, $CO_2$ emissions calculation, carbon reduction, and cost-benefit evaluation is included to examine the effect of railway modal shift on climate change.

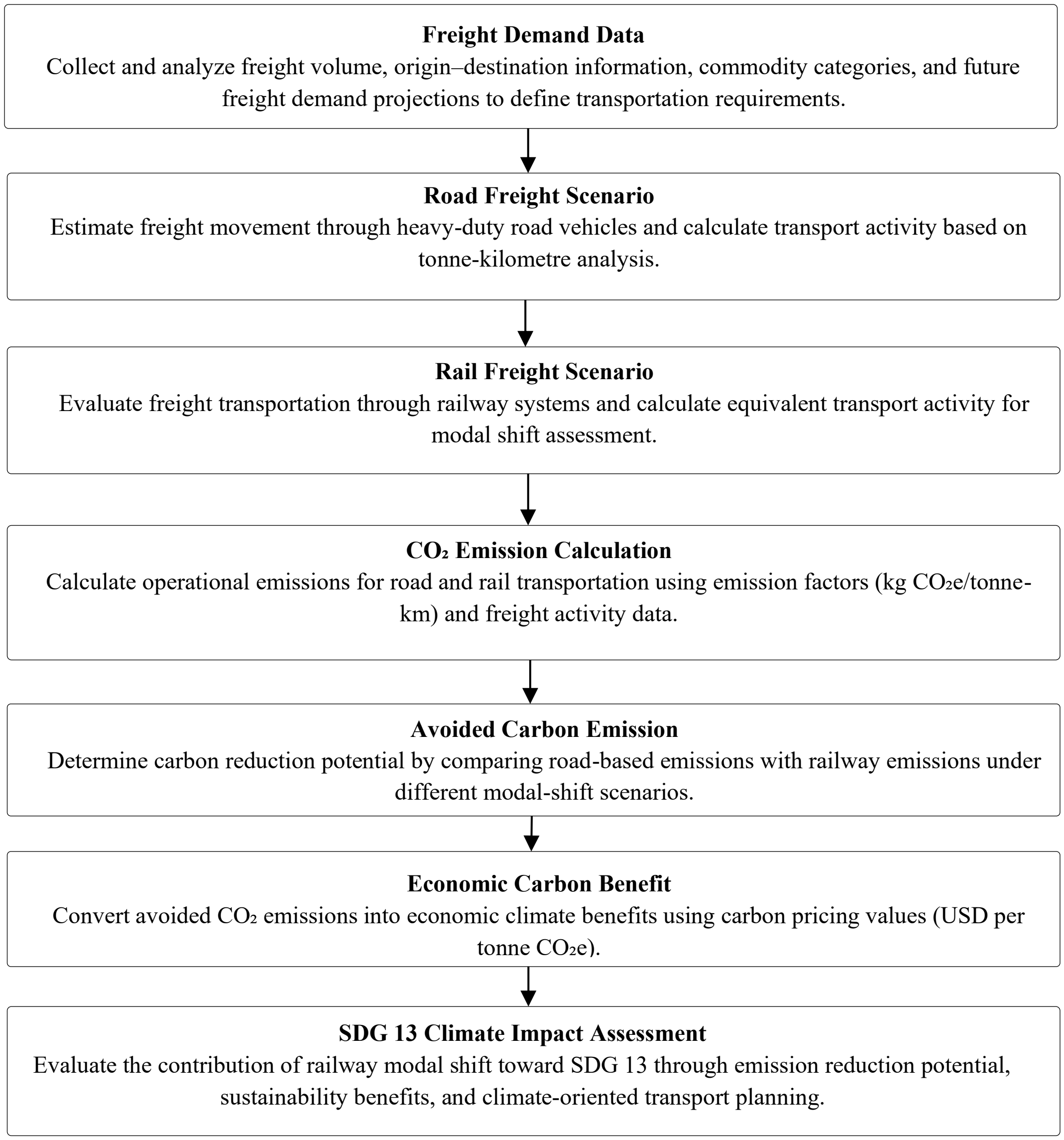


Figure 1: SDG 13-oriented Freight Decarbonization Assessment Framework

### *Study Corridor and Data Description*

Table 1: Study Corridor and Freight Data Parameters

| Parameter | Value | Source |
|---|---|---|
| Corridor | Umm Qasr–Baghdad–Mosul | IREM Project |
| Railway length | 1047 km | World Bank |
| Domestic freight projection | 6.3 million tonnes/year | World Bank |
| Import/export freight projection | 1.1 million tonnes/year | World Bank |
| Total projected freight | 7.4 million tonnes/year | Calculated |
| Current rail freight | 654 thousand tonnes/year | CSO Iraq |

The study is focused on the rail transit system of Umm Qasr-Mosul, which goes from Umm Qasr port to Baghdad and Mosul. The rail transit system has been associated with the extension and modernization project of Iraq Railways (IREM). The following table 1 describes the variables used in this study for the analysis of emission reductions in the railway transportation system.

### *Modal Shift Scenario Development*

Four scenarios have been selected to determine the varying degrees of freight transition and climate change impacts.

The 25% scenario (S1) has been chosen to represent a low level of freight transition, where only 25% of the total potential freight volumes are transferred from road to rail transportations. In the 50% scenario (S2), there is an intermediate level of transition whereas in the 75% scenario (S3) there is a relatively higher adoption of railway freight transport. In the 100% scenario (S4), the complete maximum level of freight transition is taken into account, wherein all the freight volume is shifted from road to rail transportations.

All these four scenarios have been adopted for evaluating the impact of increased utilization of railways on carbon emission reduction.

### *Carbon Emission Calculation Model*

Carbon emission assessment is conducted in terms of freight activities measured in tonne kilometers (tkm). The freight activity is determined through multiplying freight volume, mode shift ratio, and distance travelled.

Freight activity shifted from road to rail is shown in equation (1):

$$\mathrm{TKM} = \mathrm{V} \times \mathrm{S} \times \mathrm{D} \qquad (1)$$

Where:

- TKM = freight activity (tonne-kilometres)
- V = total freight volume (tonnes)
- S = modal-shift proportion
- D = transportation distance (km)

Operating emissions for different modes of transport are calculated using equation (2):

$$\mathrm{CO_2} = \mathrm{TKM} \times \mathrm{EF} \qquad (2)$$

Where:

- $CO_2$ = operational greenhouse gas emissions
- EF = emission factor (kg $CO_2e$/tkm)

The reduction of carbon emissions due to shifting from road to rail transport is calculated using:

$$\mathrm{AE} = \mathrm{CO_{2,road}} - \mathrm{CO_{2,rail}} \qquad (3)$$

Where:

- AE = avoided carbon emissions
- $CO_2$road = emissions from road freight transportation
- $CO_2$rail = emissions from railway freight transportation

Equation (3) allows direct comparison of carbon dioxide emissions for road transport and rail transport for the same freight transport.

Table 2: Emission Factors and Scenario Parameters

| Parameter | Value | Unit | Purpose |
|---|---|---|---|
| Freight rail emission factor | 0.02779 | kg $CO_2e$/tkm | Rail emission calculation |
| Road freight emission factor | 0.12226 | kg $CO_2e$/tkm | Road emission calculation |
| Articulated HGV factor | 0.09675 | kg $CO_2e$/tkm | Sensitivity analysis |
| Rigid HGV factor | 0.22580 | kg $CO_2e$/tkm | Sensitivity analysis |
| Transport distance | 250, 500, 1047 | km | Scenario variation |
| Carbon price | 40, 60, 80 | USD/t$CO_2e$ | Economic valuation |

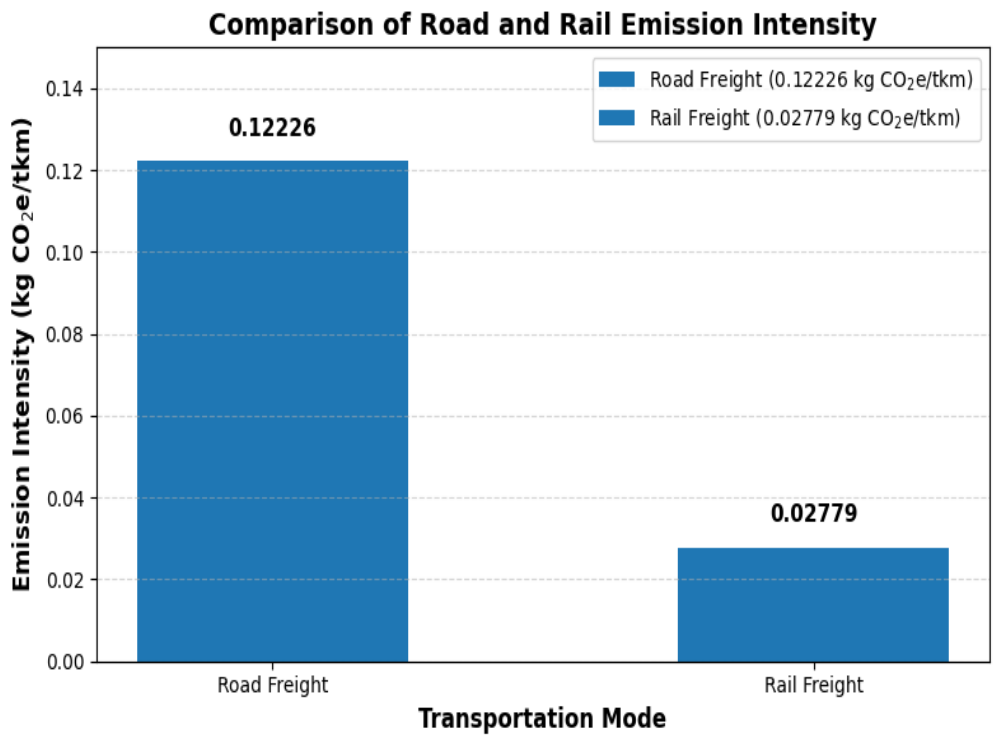


Figure 2: Comparison of Road and Rail Emission Intensity

Comparison between emission intensities of the operation of road transport and rail transport is presented in figure 2 and table 2. Emission intensity of road freight is higher (0.12226 kg $CO_2e$/tkm) compared to emission intensity of railway freight, which is significantly lower (0.02779 kg $CO_2e$/tkm).

### *Economic Carbon Benefit Assessment*

Value of emission reduction in monetary terms is estimated by the following equation (4):

$$CB = AE \times CP \tag{4}$$

Where, CB = carbon benefit, AE = avoided emission, and CP = carbon price.

This measure helps in estimating climate benefits of railway modal shift towards achievement of SDG 13.

## IV. Results

### *Comparative Emission Performance of Road and Rail Freight*

Performance in emission terms for freight transportation via road and rail was analyzed based on the emission factors from table 3. As seen from the results below, there is a big difference between the performance of both transportation means. Emission intensity of road freight transportation is 0.12226 kg $CO_2e$/tkm, while railway freight transportation emits 0.02779 kg $CO_2e$/tkm.

According to the above results, it could be stated that railway freight transportation produces about 77.3% less operational emissions than road freight transportation. It occurs because the energy efficiency of railways is higher as railways use less energy for bigger volumes of freight transportation.

Based on the above analysis, one may conclude that railway freight transportation is an efficient way to reduce greenhouse gas emissions. Thus, railway freight transportation will contribute to SDG 13 Climate Action goal.

### *SDG 13 Climate Impact Under Different Modal Shift Scenarios*

In assessing the climate impacts of rail transport transition, four different scenarios for modal shift were considered: 25%, 50%, 75%, and 100%. This assessment was conducted based on an average transport distance of 500 km.

As seen in table 4 below, the carbon dioxide reduction depends directly on the amount of freight transferred into railway transport. In case of a 25% modal shift, 87.4 thousand tonnes of $CO_2e$ per year may be saved. Transition rates of 50% and 75% lead to a decrease in $CO_2e$ of 174.8 and 262.2 thousand tonnes per year, correspondingly.

With a full transition of freight to rail, 349.5 thousand tonnes of $CO_2e$ per year may be saved, which is the maximal result obtained. These outcomes prove that rail transport has higher mitigation capacity with respect to emission reduction goals under SDG 13.

Table 3: Carbon Reduction Under Different Modal Shift Scenarios (500 km)

| Scenario | Freight Shift (%) | Avoided $CO_2$ Emission (thousand tonnes/year) |
|---|---|---|
| S1 | 25 | 87.4 |
| S2 | 50 | 174.8 |
| S3 | 75 | 262.2 |
| S4 | 100 | 349.5 |

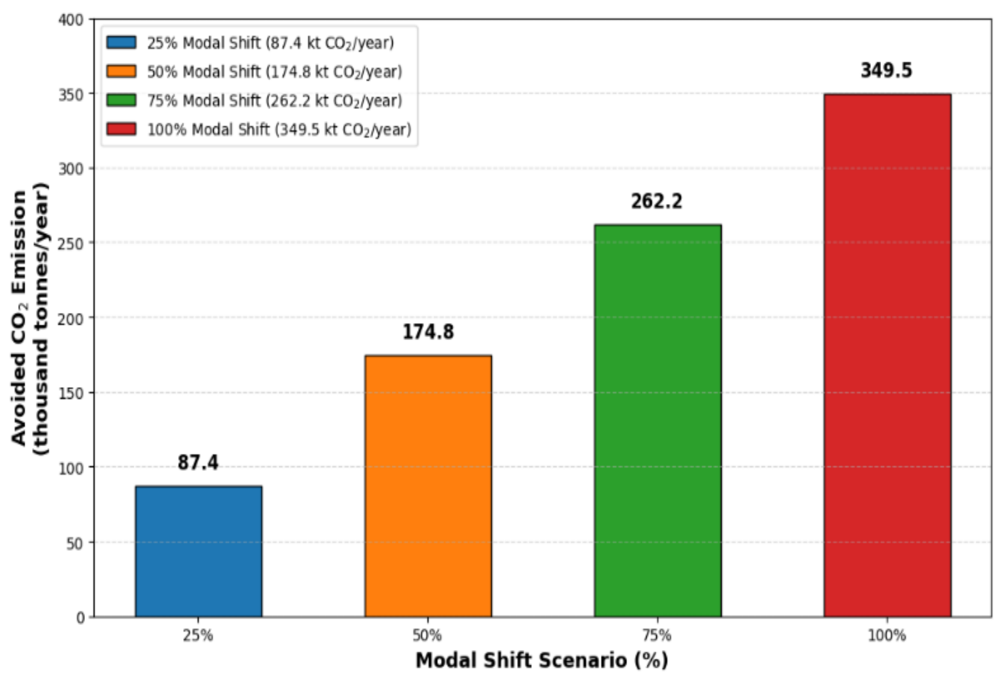


Figure 3: Carbon Reduction Potential Under Different Modal Shift Scenarios

Figure 3 depicts the linear relationship that exists between carbon reduction and the rise in usage of railway freight. Increased levels of modal shift bring more climate advantages through reducing emissions by switching from the road to rail freight.

### *Impact of Transport Distance on Carbon Reduction*

The influence of transportation distance on carbon reduction potential was analyzed by considering three distances: 250 km, 500 km, and 1047 km in case of total modal shift scenario.

Table 5 indicates that longer distances for freight transportation have more carbon reduction potential because carbon reduction increases as the tonne-kilometers of freight increases. In case of 250 km distance, the rail shift will help save about 174.8 thousand tonnes of $CO_2e$ each year. With increasing distance up to 500 km, carbon reduction potential is doubled to 349.5 thousand tonnes of $CO_2e$.

In case of 1047 km distance (complete distance of the corridor), the carbon reduction potential is estimated at 731.9 thousand tonnes of $CO_2e$ each year.

Table 4: Effect of Transport Distance on Carbon Reduction

| **Transport Distance (km)** | **Avoided $CO_2$ Emission (thousand tonnes/year)** |
|---|---|
| 250 | 174.8 |
| 500 | 349.5 |
| 1047 | 731.9 |

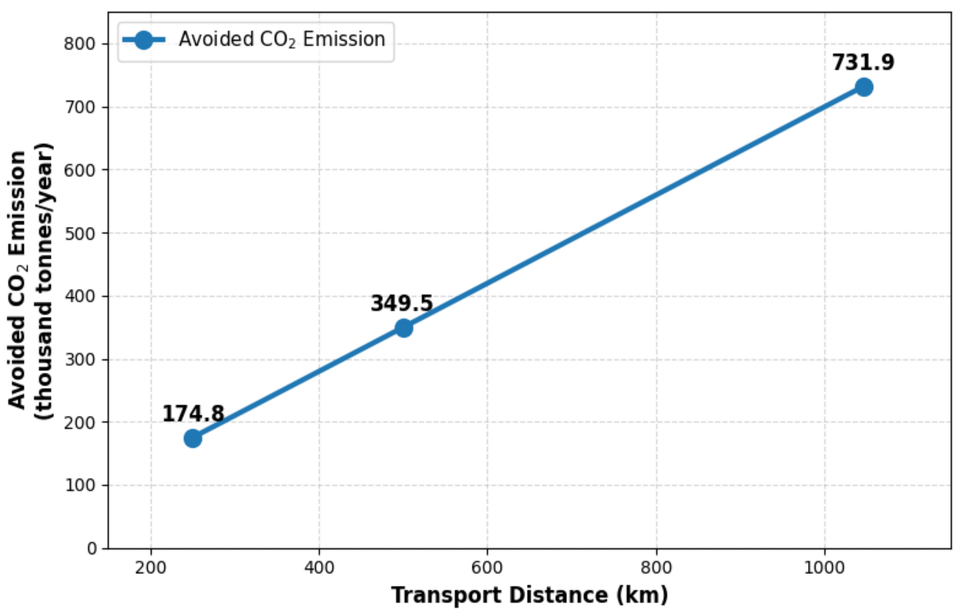


Figure 4: Influence of Transport Distance on Carbon Reduction

Figure 4 demonstrates how the distance of freight transportation can increase the chances of reducing carbon footprint by a great deal. This figure proves the viability of railways for transporting freight at longer distances.

### *Economic Value of Climate Benefits*

The economic value of carbon emission reduction was evaluated based on the carbon pricing options of US$40, US$60, and US$80 per tonne of $CO_2e$.

As it can be seen from table 6, the higher level of railway penetration leads to better climate effects. Under the full shift scenario in a distance of 500 km, 349.5 thousand tonnes $CO_2e$/year of carbon emissions avoidance are equivalent to the economic climate benefit from US$14.0 million up to US$28.0 million.

Under the middle carbon pricing of US$60/t$CO_2$e, the estimated economic climate benefit is about US$21.0 million per year. These estimates show that railways modernization brings not only environmental but also economic benefits through the avoided carbon emissions.

Table 5: Economic Value of Avoided Carbon Emissions

| Scenario | Avoided $CO_2$ (kt/year) | US$40/t$CO_2$ | US$60/t$CO_2$ | US$80/t$CO_2$ |
|---|---|---|---|---|
| 25% | 87.4 | 3.5M | 5.2M | 7.0M |
| 50% | 174.8 | 7.0M | 10.5M | 14.0M |
| 75% | 262.2 | 10.5M | 15.7M | 21.0M |
| 100% | 349.5 | 14.0M | 21.0M | 28.0M |

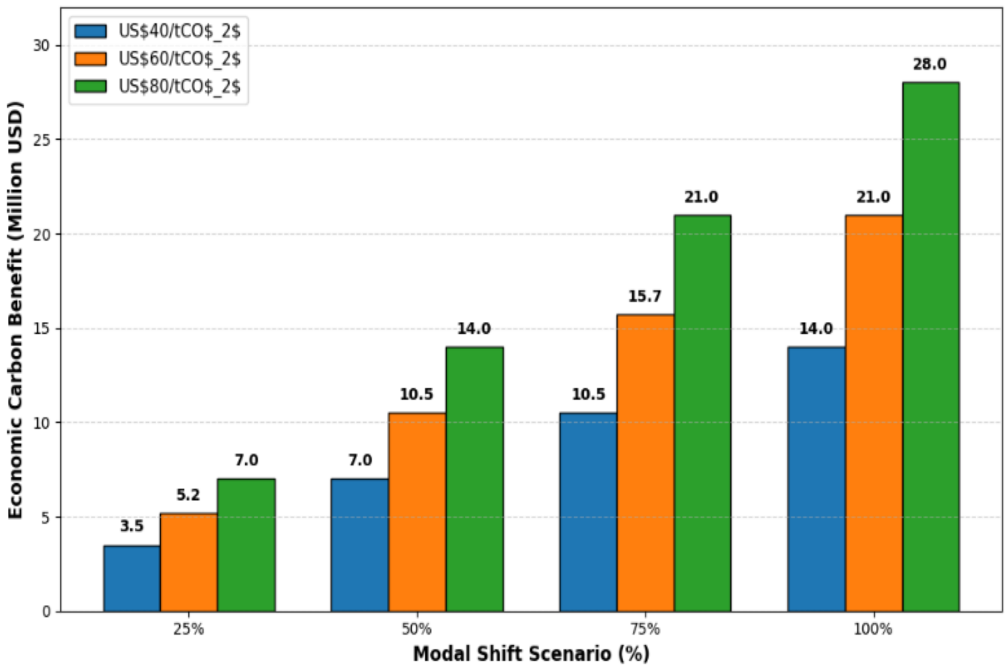


Figure 5: Economic Carbon Benefit Under Different Carbon Pricing Scenarios

Figure 5 depicts the economic value of avoided carbon dioxide emission under various modal shift scenarios and carbon price assumptions. This figure indicates that the more the modal shift from road to rail transport, the higher is the economic value associated with the reduction of carbon dioxide emission, particularly at high carbon price levels.

### *Sensitivity Analysis of Emission Uncertainty*

Sensitivity analysis was performed to assess the impact of varying road freight emission factors on carbon reduction calculations. The following types of trucks were taken into account:

- Articulated HGV
- Average HGV
- Rigid HGV

Table 7 demonstrates the regardless of conditions railway freight retains considerable emission benefits. Even in case of the low-emission articulated HGV, railway modal shift still implies 71.3% of emission reductions compared to road transport.

In case of the average HGV factor, there is a 77.3% reduction in emissions, whereas rigid HGV gives 87.7% reduction.

Thus, the total environmental benefits of the railway shift remain stable regardless of road freight peculiarities.

Table 6: Sensitivity Analysis of Road Freight Emission Factors

| Road Freight Type | Emission Factor (kg $CO_2e$/tkm) | Emission Reduction Compared with Rail |
|---|---|---|
| Articulated HGV | 0.09675 | 71.3% |
| Average HGV | 0.12226 | 77.3% |
| Rigid HGV | 0.22580 | 87.7% |

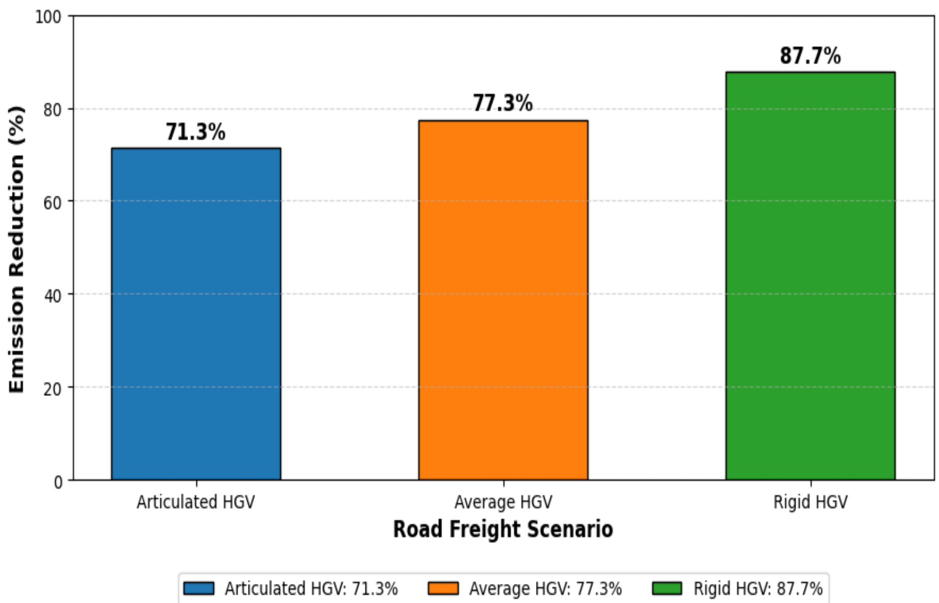


Figure 6: Sensitivity of Carbon Reduction to Road Freight Emission Factors

The sensitivity analysis for the railway modal shift with respect to the road freight emission factor is illustrated in figure 6. From the results, there is a carbon reduction advantage in all three types of HGVs.

## V. Discussion

### *Contribution Toward SDG 13 Climate Action*

The suggested framework on railway modal shift is the key contribution towards SDG 13 – Climate Action due to the provision of the quantitative tool for assessing the possibilities for decarbonization of freight transportation.

In terms of climate impacts, the results of the work suggest that the railway freight transportation is much less emitting compared with road freight transportation. In particular, the emission analysis demonstrated that the level of emissions associated with the former equals to 0.02779 kg $CO_2e$/tkm, while the latter equals to 0.12226 kg $CO_2e$/tkm, which makes the former 77.3% less emitting than the latter. The shift of freight activities from road towards railway transport may be seen as one of the possibilities of reducing greenhouse gas emissions.

Moreover, the scenario-based analysis of the problem proves that the higher share of railway transport in freight activity leads to higher benefits from carbon emissions reduction. Thus, the analysis proved that the increase of the share of rail to 25%, 50%, 75% and 100% of the total number of trips results in the higher avoided $CO_2$ emissions.

Apart from reducing emissions, rail transport also enhances energy efficiency through the ability to transport more cargo at a reduced energy cost per tonne-kilometer. Thus, the proposed solution facilitates sustainable freight planning by offering insights based on data that help to choose strategies that are compatible with the goals of SDG 13. The inclusion of carbon reduction analysis and economic value calculation adds another dimension to the decision-making process.

### *Implications for Sustainable Transport Policy*

The results suggest that the modernization of railways and modal shift towards railway transportation should be regarded as an indispensable component of climate change mitigation measures. In the case of Iraq, where road freight transportation plays a predominant role, the development of railway capacities might prove an effective way of lowering the environmental impact of freight transportation and optimizing logistics (Karam et al., 2023; Ghisolfi et al., 2024).

Investments into railway infrastructure are an essential element of freight transformation towards sustainability. Infrastructure upgrading, capacity enhancement, and reliability of railway services should be used as means of incentivizing industrial producers and logistics service providers to switch freight volumes from roads to railways. The construction of the railway corridor between Umm Qasr and Mosul provides an excellent example of how sustainable infrastructure development and climate change mitigation goals can be aligned.

Moreover, integration of logistics is another vital factor needed to benefit from railways. Effective coordination of ports, railway stations, distribution centers, and road networks can increase freight accessibility and support multimodal freight transportation. The creation of integrated logistics systems is expected to promote the use of railways.

The research also brings to light the significance of emission monitoring policies and green freight policies. The development of emission monitoring systems in the transport sector will enable the policy makers to track their progress towards achieving the climate change goals and devise efficient carbon reduction policies. Green freight policies such as incentive plans for railways can contribute to that end.

### *Practical Implementation Challenges*

Despite the substantial climate gains from the railway modal shift, a number of issues should be taken into account when it comes to implementation of this measure. Railway efficiency plays an important role in the success of the transition to railway transportation. The factors that influence the efficiency are the number of trains, loading capacities, travel times, and reliability. Hence, better management and services performance are necessary for efficient freight transition (Hasan et al., 2021).

In addition to that, the terminal infrastructure poses a challenge. Effective freight transfer presupposes the presence of developed loading and storage facilities along with intermodal connections between different types of transportations and railways. Terminal infrastructure may become a limitation for the implementation of modal shift even in case of its obvious environmental benefits.

The achieved level of the freight diversion is another issue. As can be seen from the scenario analysis, the increase of railway modal shift brings certain gains. However, in real life it depends on economic, logistic, and industrial factors. That is why sustainable policies and gradual strategies of implementation are needed.

Moreover, it is important to maintain the reliability of the operation to guarantee future success. Railway systems have to ensure predictable and efficient freight services. Addressing all these issues will contribute to the achievement of the expected results and to the support of SDG 13 Climate Action goals.

## VI. Policy Recommendations for SDG 13 Implementation

1. Create decarbonization strategies for national freight movements in order to reduce emissions and achieve climate objectives.
2. Expand the freight transport capacity via infrastructure development and better freight movements.
3. Develop road-to-rail switching policies in order to ensure sustainable freight transport.
4. Develop emission monitoring systems for freight transport in order to track carbon reduction progress.
5. Use carbon reduction indicators in transport planning in order to make climate-based infrastructure choices.
6. Enhance sustainable logistics collaboration between ports, railroads and freight transport system.

## VII. Limitations and Future Research

In terms of SDG 13 assessment, the present study evaluates railway modal shift for freight decarbonization; yet, there are a number of limitations that need to be discussed. First, the research is based on predetermined scenarios of modal shifts, and the outcomes in real-life situations may differ according to operational, economical, and logistic factors. Second, international emission factors were used because of a lack of Iraq-specific data concerning freight emissions, which might affect the estimation results.

It should be noted that the study analyzes only the operational impacts of transportation and does not consider the whole life cycle of emissions and such aspects as infrastructural development, maintenance procedures, and energy generation. Besides, the lack of a comprehensive database regarding freight emissions in Iraq complicates the analysis of local transportation specifics.

Further research can take into account these limitations using such tools as life-cycle assessments for analyzing the complete impact of transportation. The use of AI techniques to optimize freight routing and modal shifts can be suggested as one of the future directions. Real-time emission monitoring in railway transport may be helpful for continuous carbon assessment.

## VIII. Conclusions

This study aimed to explore the feasibility of the rail modal shift as a sustainable freight transportation measure for minimizing greenhouse gas emissions and contributing to the SDG 13 – Climate Action goals. The SDG 13-oriented assessment framework, including freight demand assessment, road and rail transportation scenarios, $CO_2$ emission estimation, avoided carbon calculation, and economic carbon benefit analysis, was developed to perform this study. The developed framework was applied to the Umm Qasr–Mosul railway corridor in Iraq in order to evaluate environmental and economic benefits associated with switching freight transportation from the road-based one towards rail transportation.

As shown by comparative emissions assessment, freight by rail transportation involves substantially lower operation emissions compared to road transportation. In particular, it was found that road transportation emits 0.12226 kg $CO_2$e/tkm, whereas rail transportation emits 0.02779 kg $CO_2$e/tkm, which is approximately 77.3% lower. Furthermore, modal shift scenario analysis proved that higher rail transportation adoption leads to the higher potential for carbon reduction. Under 500 km of transport distance, freight transition at 25%, 50%, 75%, and 100% scenarios can lead to approximately 87.4, 174.8, 262.2, and 349.5 thousand tonnes of annual $CO_2$ reduction.

Distance-based assessment proved that higher distances of freight transport result in higher climate benefits, and the maximum 1047 km freight route distance under the condition of 100% modal shift can lead to the annual $CO_2$ reduction of approximately 731.9 thousand tonnes. Economic benefit analysis showed that such avoided emissions imply significant climate benefits of approximately US$14.0–28.0 million annually based on carbon price of US$40–80 per tonne of $CO_2e$.

Furthermore, sensitivity analysis proved the reliability of the approach, with a reduction of 71.3%, 77.3%, and 87.7% in carbon emissions in the cases of articulated HGV, average HGV, and rigid HGV, respectively. Overall, results reveal that railway modernization and shift of transport modes present realistic solutions for emission reduction, energy efficiency, and sustainable logistics development. The corridor between Umm Qasr and Mosul is a valuable chance for Iraq to develop its infrastructure in a way that would allow carbon reductions and contribute to achieving the SDG 13 targets.

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