ReMuNet
Pioneering resilient and adaptive multimodal transport networks

D5.3
Use Case description and first results of the ecological corridor pilot

Contargo GmbH & Co. KG

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Executive Summary

This deliverable examines key methodological and operational factors influencing greenhouse gas emission assessment in multimodal transport networks within the ReMuNet context. This deliverable supplements the project deliverables D5.1 and D5.4, where the platform demo and platform scalability roadmaps are described.

The analysis focuses on two central aspects: (i) the impact of emission factor selection and data inputs on corridor-level emission results, and (ii) the integration of terminal operations into full-chain emission assessment. Both of these aspects should be considered when supply chain emissison are calculated.

The first part compares default-based emission factors derived from established frameworks, such as the GLEC Framework and ISO 14083, with relation-specific and operator-specific data. The results indicate that while default factors provide a consistent baseline, they do not fully capture corridor-specific operational conditions. Differences in emission factors, transport distances and propulsion assumptions lead to variations in calculated results, while transport configuration remains the primary driver of emission outcomes.

The second part focuses on terminal operations as an often underrepresented component of emission assessment. The results show that terminal emissions represent a measurable share of total chain emissions and become increasingly relevant in low-emission transport scenarios. Their relative contribution increases significantly as transport-related emissions decrease. In addition, terminal-specific emission factors vary considerably across locations, highlighting the importance of primary data and consistent system boundaries.

Overall, the findings demonstrate that emission assessment is highly sensitive to both methodological assumptions and data inputs. Default and relation-specific emission factors should be understood as complementary approaches. A robust assessment requires transparent assumptions, consistent system boundaries and, where available, the integration of primary data.

From a ReMuNet perspective, the results underline the importance of flexible emission modelling, scenario-based analysis and the explicit integration of terminals as emission-relevant nodes. In addition, this deliverable shows the complexity of emission calculations, which needs to be considered when scaling up the platform. At the same time, special attention needs to be paid on EU COM activities, since the current ambition is to harmonize emission calculations and hence make it more transparent and easier to calculate and compare.

Following a formally approved budget and task reallocation within the consortium (Amendment AMD-101104072-13) — necessitated by data quality limitations and a reduced role of Contargo in Task 5.3 — the analysis presented in this deliverable draws on the Contargo operational data available and of sufficient quality, complemented by established emission-accounting frameworks and additional coordination support from Beneficiary 1-FIR; this does not affect the validity of the findings or their relevance for the further development of ReMuNet. For the same data-related reasons, the second alternative drive examined alongside battery-electric vehicles is HVO (Hydrotreated Vegetable Oil) rather than hydrogen-driven carriers (see Figure 5), while preserving the planned comparative two-drive analysis structure.

1. Introduction

The decarbonisation of transport systems is a central objective of European climate policy and requires a comprehensive understanding of greenhouse gas (GHG) emissions across entire transport chains. In the context of increasing regulatory requirements and a growing demand for transparent emission reporting, the need for robust and comparable emission assessment methods has become increasingly important.

Multimodal transport networks play a key role in this transition, offering significant potential for emission reduction through the combination of transport modes and the integration of low-emission technologies. At the same time, the complexity of such systems introduces methodological challenges for emission assessment, particularly with regard to the consistent representation of transport activities, operational conditions and system boundaries.

The ReMuNet project addresses these challenges by developing a data-driven and collaborative platform for modelling, analysing and optimising multimodal transport networks. By integrating real-time data, routing algorithms and network modelling capabilities, the platform aims to improve both the resilience and the environmental performance of freight transport systems. In this context, emission calculation is not only an analytical task but constitutes a value-adding service within the ReMuNet platform, enabling the systematic evaluation and comparison of alternative transport configurations with respect to their environmental impact.

Within this framework, Deliverable 5.3 focuses on enhancing the analytical foundation of corridor-level emission assessment by examining key methodological and operational factors that influence emission calculation results. The deliverable contributes to the ecological use case of ReMuNet by supporting the assessment of emission reduction potentials associated with alternative transport technologies and multimodal routing strategies. The deliverable suplements D5.1 and D5.4 where platform demo and scalability plans are documented. This includes the evaluation of low-emission transport options, such as electric and hydrogen-based propulsion systems, as well as their integration into multimodal transport chains.

The first key aspect concerns the use of emission factors. In practice, emission calculations are typically based on default emission factors derived from established frameworks and tools. While these values provide a consistent and comparable basis, they rely on aggregated assumptions and may not adequately reflect corridor-specific operational conditions. The increasing availability of relation-specific and operator-specific data therefore raises the question of how such differentiated emission factors influence corridor-level emission results compared to default-based approaches.

A second key aspect relates to the treatment of terminal operations. While emissions from transport segments such as pre-haulage, main leg and post-haulage are generally well represented in existing methodologies, terminal activities are often excluded or simplified. However, as transport emissions decrease with the adoption of low-emission technologies, the relative contribution of terminal operations increases, highlighting the need for their consistent integration into full-chain emission assessment.

Against this background, Deliverable 5.3 adopts a structured, hypothesis-driven approach to analyse these two aspects of emission modelling. The analysis is based on corridor-level examples within multimodal transport networks and applies established methodological frameworks, including the GLEC Framework, ISO 14083 and relevant European initiatives. In doing so, the deliverable supports the positioning of ReMuNet as a reliable tool for sustainable transport planning, enabling informed decision-making based on consistent and transparent emission data.

The document is structured as follows. Chapter 2 analyses the influence of emission factor selection on corridor-level emission results, comparing default-based and relation-specific approaches. Chapter 3 addresses the integration of terminal emissions into full-chain assessment and evaluates their contribution under different transport configurations. Chapter 4 summarises the key findings and derives methodological and practical implications for emission assessment within the ReMuNet context.

Taken together, the analyses presented in this deliverable follow a common analytical logic: to systematically assess how methodological assumptions, data inputs and system boundary definitions influence corridor-level emission results and their interpretation. By comparing default-based approaches with relation-specific data and extending the system boundary to include terminal operations, the deliverable provides an integrated perspective on key emission drivers in multimodal transport systems. This overarching perspective connects the individual analyses presented in Chapters 2 and 3 and forms the basis for the final synthesis and implications.

By addressing both the level of emission factor differentiation and the completeness of system boundary definitions, this deliverable contributes to a more robust and transparent understanding of emission drivers in multimodal transport systems and supports the further development of ReMuNet as a tool for emission assessment and optimisation.

1.1 Implementation Note

The work presented in this deliverable reflects an adaptation in the implementation of Task 5.3 relative to the original work plan described in the Grant Agreement. During implementation of WP5 (and the closely related WP3/WP4 validation activities), it became apparent that the operational datasets Contargo (Beneficiary 10, Task lead for T5.3) was expected to provide for the validation of ReMuNet's algorithms and for the ecological use case were not available at the quality, format and scale originally anticipated. This occurred in parallel with personnel changes and an internal business reorganisation at Contargo, which together led the partner to assume a more limited role in the project than foreseen at proposal stage.

As a result, the assessment presented in this deliverable draws on the Contargo operational data that is available and suitable for analysis, combined with established emission-accounting frameworks (GLEC, ISO 14083) and market/infrastructure information on alternative-drive technologies, rather than on a substantially larger, dedicated field-trial dataset as originally envisaged. This adjustment is consistent with the consortium's own assessment, confirmed in the amendment request, that the change does not constitute a significant change in the description of action. The core objective of Task 5.3 — to provide ReMuNet with a sound, evidence-based assessment of the emission-reduction potential and integration requirements of alternative-drive vehicles — remains fully achievable, and the resulting insights continue to feed directly into the roadmap and scalability strategy under Task 5.4 (D5.4). The change has no bearing on the project's overall milestones (MS9, MS10) or on the critical path towards the project's final objectives, and has been documented and monitored through the project's standard amendment and risk-management procedures.

A related, data-driven adjustment concerns the choice of the second alternative drive examined alongside battery-electric vehicles. The Grant Agreement foresees a feasibility analysis of two alternative drive types: electrically powered vehicles and hydrogen-driven carriers. As the underlying operational data for a hydrogen-specific feasibility assessment was subject to the same quality and granularity limitations described above, the consortium was not able to base a robust hydrogen feasibility analysis on the available Contargo/Schachinger data. Electric vehicles continue to be assessed as planned; as the second alternative drive, this deliverable instead presents an analysis of HVO (Hydrotreated Vegetable Oil), for which adequate data was available, as shown in Figure 5. HVO is a market-ready, drop-in alternative fuel applicable to existing combustion-engine vehicles and is fully in line with the Grant Agreement's underlying objective of identifying and assessing viable low-emission propulsion alternatives for the corridors studied in Task 5.3. The comparative structure of the analysis — two alternative drives benchmarked against the conventional baseline — is therefore preserved, and the substitution does not diminish the analytical depth or relevance of the use case for the project's overall emission-reduction objectives.

2. Adding Specific Emission Factors and Example Assessment

This chapter examines the role of emission factor choice in corridor-level greenhouse gas emission assessment within the ReMuNet context. Building on established emission calculation frameworks, it compares default-based calculations with calculations that incorporate relation-specific emission factors where data are available. The chapter first outlines the analytical rationale and hypothesis, then describes the methodological framework and system boundaries applied. It subsequently presents corridor-level example results and concludes with an evaluation of the findings and their implications for corridor-level emission analysis.

2.1 Rationale and hypothesis

Greenhouse gas emission calculations are a central component of sustainability assessments in multimodal transport networks. In practice, such calculations are commonly based on average emission factors derived from internationally recognised frameworks. These default factors provide a harmonised and comparable basis for estimating emissions across transport modes and corridors and are currently used within the ReMuNet platform for network-level assessments.

However, default emission factors are by definition based on aggregated assumptions regarding vehicle fleets, energy mixes and operational conditions (SFC 2025). As a result, they may not reflect corridor-specific characteristics where transport operations deviate from these averages. This issue becomes particularly relevant in contexts where low-emission transport solutions are applied, such as electric road transport, rail services powered by renewable electricity, or vessels using alternative propulsion systems. In such cases, it is not evident whether default factors adequately capture the emission performance of specific corridors or whether more granular data would lead to materially different results.

Within ReMuNet, emission calculations are intended to support corridor-level analysis and comparison, including the assessment of alternative routing options under disruptive conditions. From an analytical perspective, this raises the question of whether the use of relation-specific and operator-specific emission factors would alter the interpretation of emission results compared to default-based calculations.

Against this background, Task 5.3 addresses the following hypothesis:

Pre and post haulage as well as main leg transport segments contribute a significant share of total chain emissions. In transport corridors characterised by low emission technologies, the relative contribution of these segments may change. The use of relation specific and operator specific emission factors may lead to different corridor level emission assessments compared to calculations based solely on default factors.

This hypothesis provides analytical framing for the subsequent assessment. Its validity is examined through a structured comparison of default-based and relation-specific emission calculations, without presupposing the direction or magnitude of potential differences.

2.2 Frameworks and emission factor logic

The assessment presented in Deliverable 5.3 is grounded in internationally recognised emission calculation frameworks to ensure methodological consistency, transparency and comparability. Emission calculations in multimodal transport networks typically rely on default emission factors derived from established frameworks such as the GLEC Framework and ISO 14083. These factors provide a harmonised and comparable basis for estimating emissions across transport modes and corridors, but are based on aggregated assumptions regarding vehicle fleets, energy mixes and operational conditions. While this ensures methodological consistency, default emission factors do not reflect corridor-specific characteristics and may therefore deviate from real operational conditions.

The primary methodological references for this analysis are the GLEC Framework and ISO 14083. Both frameworks define activity-based emission calculation principles, harmonised functional units and clear system boundaries. E.g. emissions are typically expressed as kg CO_2e per tonne-kilometer or per TEU-kilometer, enabling consistent comparison across transport segments. While both frameworks give guidance on how to calculate emissions, they can also be a source for default emission factors. Default emission factors derived from these frameworks are based on aggregated assumptions regarding vehicle fleets, energy mixes and utilisation rates and are designed to serve as benchmark values for comparative assessments (SFC 2025; ISO 2023).

Those factors are particularly valuable in situations where operator-specific data are unavailable or incomplete. Their strength lies in providing a transparent and standardised reference that supports cross-corridor and cross-modal comparison. By relying on averaged assumptions, they ensure functional unit comparability and methodological consistency across the network, while abstracting from corridor-specific operational detail (SFC 2025; ISO 2023).

Additional sources of default emission factors commonly used in transport emission assessment include the Handbook Emission Factors for Road Transport (HBEFA) and the EcoTransIT World tool. Both provide empirically grounded emission values that are widely applied in practice and complement the methodological guidance provided by overarching frameworks such as GLEC and ISO 14083 (INFRAS; EcoTransIT World).

HBEFA offers highly differentiated emission factors for road transport based on detailed classifications of vehicle types, fuel technologies, emission standards and operating conditions. EcoTransIT World applies a harmonised, multimodal calculation approach to derive emission factors across transport modes, including road, rail, inland waterways and maritime transport. The emission values provided by these sources are likewise based on aggregated assumptions regarding fleet composition, energy use and operational conditions and can therefore be interpreted as default-type emission factors within a standardised calculation context (INFRAS; EcoTransIT World).

In addition to these established methodologies and data sources, Deliverable 5.3 refers to the emerging CountEmissionsEU initiative as a forward-looking methodological reference. CountEmissionsEU, currently under development by the European Commission, aims to establish a mandatory unified European approach for calculating and reporting GHG emissions from transport services. Its proposed methodology builds on ISO 14083 and follows the same activity-based logic as the GLEC Framework, while also providing a structured framework for the consistent application of emission factors across different transport modes and calculation approaches (European Parliament 2026).

Against this background, emission factors used in transport emission assessment originate from a combination of methodological frameworks, model-based approaches and reference datasets. While these sources are broadly aligned in their underlying calculation logic, differences in assumptions and levels of aggregation lead to variations in emission factors for comparable transport activities. The implications of these differences and their difference to corridor specific characteristics particularly in the context of low-emission transport technologies, are examined in the following sections of this chapter.

2.3 Definition of system boundaries and construction of relation-specific emission factors

The analytical comparison presented in this deliverable is based on a clearly defined set of system boundaries and calculation assumptions, as defined by GLEC and ISO 14083. These boundaries are required to ensure that default-based and relation-specific emission factors can be compared in a consistent and transparent manner.

The emission assessment follows a well-to-wheel perspective, covering all relevant greenhouse gas emissions associated with energy production and use. The transport chain is structured into three main components: pre-haulage, main-leg transport and post-haulage. Each component is treated as a distinct emission-relevant segment, allowing contributions to total chain emissions to be analyzed separately while remaining part of a coherent overall calculation (SFC 2025; ISO 2023).

Emission factors are expressed using a uniform functional unit of kg CO_2e per TEU·km. This unit is applied consistently across all transport modes and corridor examples, ensuring comparability between default-based and relation-specific calculations. The allocation logic follows activity-based principles as defined in the GLEC Framework and ISO 14083, with emissions attributed proportionally to transport activity (SFC 2025; ISO 2023).

Default emission factors represent aggregated average values derived from established frameworks. They reflect typical assumptions regarding vehicle technologies, energy mixes and utilisation rates and serve as reference values for network-level assessment. These factors are applied uniformly across corridors to provide a consistent baseline against which alternative assumptions can be examined.

Relation-specific emission factors are constructed where primary operational data are available. These factors are derived at corridor level and reflect the average operating conditions of the respective transport relation. Depending on data availability, this may include information on vehicle type, propulsion technology or electricity sourcing. Importantly, relation-specific factors are expressed using the same functional units and system boundaries as default factors. This ensures that any observed differences in emission results can be attributed to the underlying assumptions rather than to methodological inconsistencies.

The construction of relation-specific emission factors does not aim to represent real-time routing decisions or operational variability at shipment level. Instead, it provides a corridor-level characterisation that captures systematic deviations from average assumptions. Detailed routing logic, network optimisation and time-dependent operational dynamics remain outside the scope of this analysis and are addressed by other components of the ReMuNet platform.

This structured approach establishes the analytical basis for the example assessments presented in the following section. In particular, default emission factors are compared with relation-specific emission factors derived from Contargo operational data to assess deviations between standardized and real-world transport assumptions. By applying consistent system boundaries and functional units, the analysis enables a transparent comparison across corridors without presupposing the direction or magnitude of potential differences.

2.4 Corridor examples and emission calculation results

The following section presents the results of the corridor-level emission assessment conducted within Deliverable 5.3. The analysis compares emission results across selected transport corridors of ReMuNet under varying emission factors, transport distances and modelling assumptions.

The objective is to illustrate how these factors influence calculated emission levels and the relative contribution of transport chain components in multimodal transport systems. The results are presented stepwise, starting with an overview of the overall emission structure of the analyzed corridors, followed by a detailed examination of key sources of variation in emission results.

Overall emission structure of multimodal corridors

To provide a baseline for the subsequent analysis, Figure 1 compares total GHG emissions for selected transport corridors across different transport configurations. Emissions are reported in kg CO_2e per TEU and include the complete transport chain, covering main transport, pre- and post-haulage, as well as terminal activities within the defined system boundaries. For consistency in this chapter, terminal emissions are included using aggregated default assumptions. A more detailed methodology and analysis of terminal operations is provided in Chapter 3.

For the purpose of this comparison, a consistent set of assumptions is applied across all transport configurations and corridors.

Emission factors for inland waterway transport are calculated as the mean of values derived from EcoTransIT, ISO 14083, GLEC 3.2, GLEC 3.0 and relation-specific data from Contargo. For rail transport, average values are based on EcoTransIT, ISO 14083 and Contargo data. Road transport emission factors are represented as the mean of HBEFA 3.1, ISO 14083 and Contargo-specific values. For this comparison, transport distances are based on the routing assumptions used within ReMuNet.

For combined transport configurations, pre- and post-haulage distances of 40 km are assumed for both inland waterway and rail transport and calculated using emission factors from GLEC 3.2. Terminal emissions are included using aggregated emission factors per handled TEU based on GLEC 3.2.

The selection of corridors is limited to transport relations in which Contargo is operationally active and for which comparable routing options exist across all considered transport modes. This ensures a consistent basis for comparing unimodal and combined transport configurations.

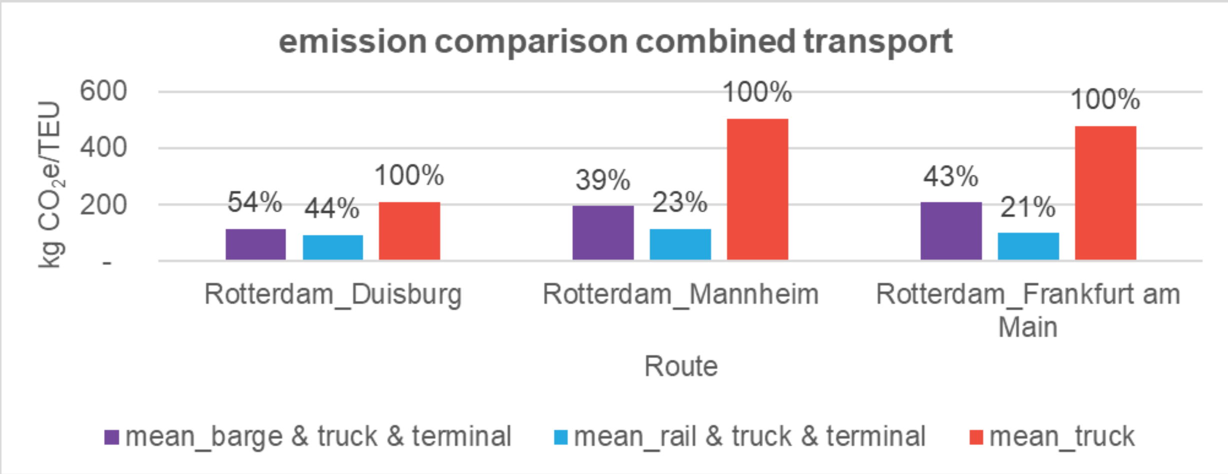

Figure 1: Emission comparison of combined transport and truck transport

The comparison indicates clear differences in total emission levels between unimodal road transport and combined transport configurations. Across all analyzed corridors, the road-only option exhibits the highest emission levels and is used as a reference for comparison.

In contrast, combined transport solutions integrating inland waterway or rail transport show consistently lower emission values. For the Rotterdam–Duisburg corridor, emissions are reduced to approximately 54 % for inland waterway transport and 44 % for rail transport relative to the road-only option. Similar patterns are observed for the other corridors, with reduction levels ranging between approximately 39 % and 21 % for combined transport configurations.

The comparison further indicates that rail-based transport solutions exhibit the lowest emission levels across all analyzed corridors, while inland waterway transport results in intermediate emission values. At the same time, the magnitude of emission reductions varies between corridors, reflecting differences in route characteristics and modal composition.

This comparison illustrates how the choice of transport configuration influences total corridor-level emission results and provides the basis for the subsequent analysis of methodological and operational factors affecting these outcomes.

Variability of emission factors across methodological sources

Figure 2 presents a comparison of emission factors for inland waterway transport across selected corridors, based on different methodological sources. The emission factors are expressed in kg CO_2e per TEU and include values derived from EcoTransIT, ISO 14083, GLEC (versions 3.0 and 3.2), as well as Contargo-specific values representing corridor-level operational conditions.

For this comparison, transport distances are based on the routing assumptions used within ReMuNet. The figure focuses on inland waterway transport as a representative example, while corresponding comparisons for rail and road transport are provided in the Appendix. It should be noted that the presented values reflect emission factors per transport relation and do not represent total corridor emissions, which are analyzed in the preceding section.

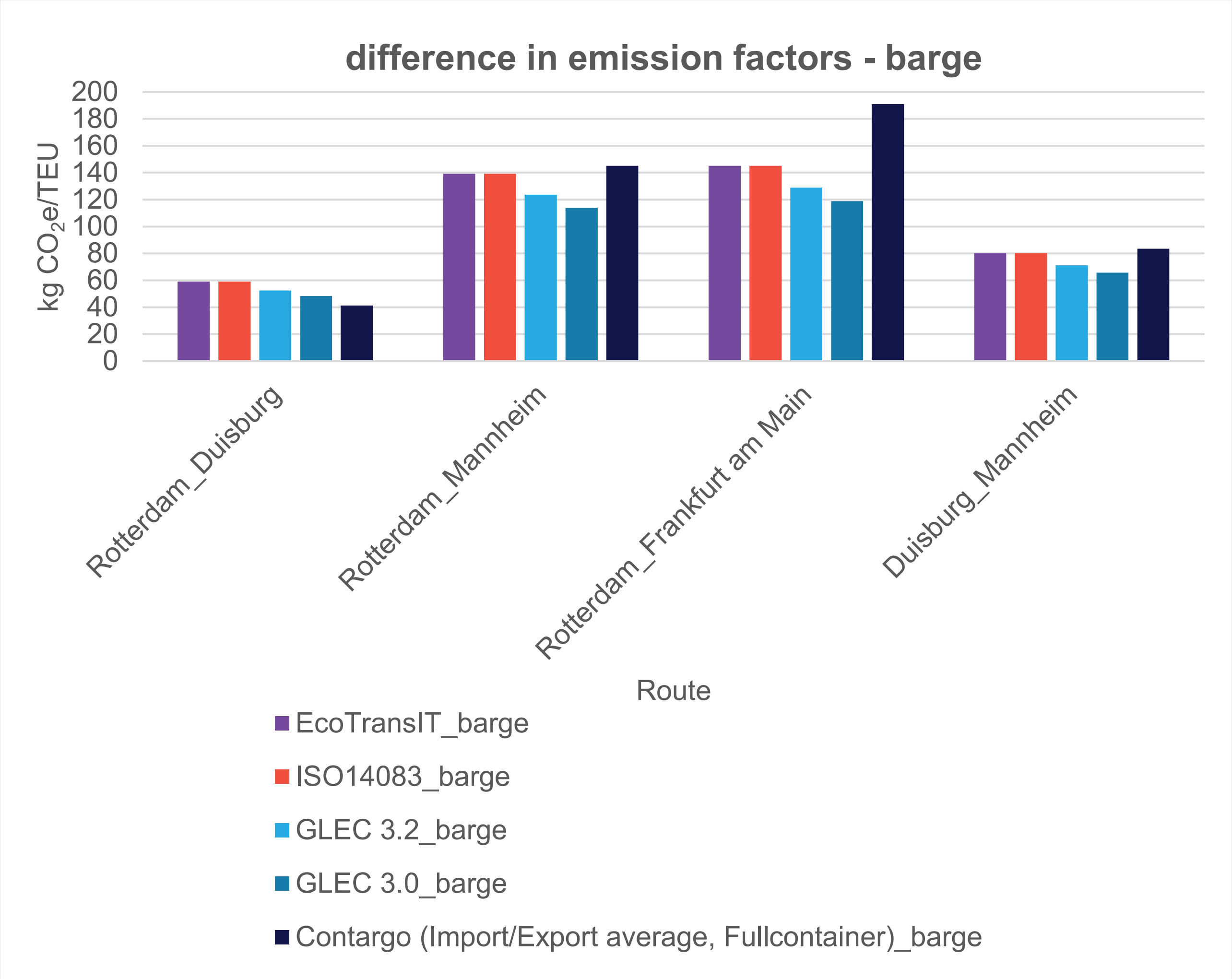

Figure 2: Comparison of different emission factors for barging

The comparison highlights that emission factors differ across all analyzed methodological sources for each corridor. For the Rotterdam–Duisburg corridor, values range from approximately 40 kg CO_2e/TEU for the Contargo-specific factor to around 60 kg CO_2e/TEU for EcoTransIT and ISO-based values. Similar patterns are observed for the other corridors, with absolute emission levels increasing for longer transport distances and more complex route configurations.

Across all corridors, EcoTransIT and ISO 14083 yield comparable emission factors, while GLEC 3.2 produces moderately lower values, followed by GLEC 3.0. The Contargo-specific emission factors show the largest variation across corridors, with values that are either lower or higher than the reference values depending on the specific transport relation. This reflects the use of region- and relation-specific emission factors, which account for corridor-level operational conditions, in contrast to the aggregated default values applied in the other methodologies. Notably, for the Rotterdam–Frankfurt corridor, the Contargo value exceeds all other calculated factors, reaching approximately 190 kg CO_2e/TEU, while being significantly lower for the Rotterdam–Duisburg corridor.

The comparison further indicates that variations also occur within the GLEC framework itself. Differences between GLEC 3.0 and GLEC 3.2 are observable across all corridors, with emission factors typically ranging between approximately 48 kg CO_2e/TEU and 59 kg CO_2e/TEU for shorter relations and increasing proportionally with distance.

Overall, the results illustrate that emission factors for identical transport modes are not uniform across methodological sources and may vary depending on the applied framework, version and underlying assumptions. These differences are observable across all analyzed corridors and represent a consistent characteristic of emission factor-based calculations.

Influence of underlying transport distance

Figure 3 present a comparison of transport distances used for emission calculations across different transport modes, contrasting the kilometer assumptions applied in ReMuNet with those derived from Contargo operational data. The comparison covers inland waterway as a representative example. Comparable patterns are observed for rail and road transport, which are documented in the Appendix. Distances are based on corridor-level assumptions and reflect the routing logic applied in both data sources rather than optimized or real-time routing conditions.

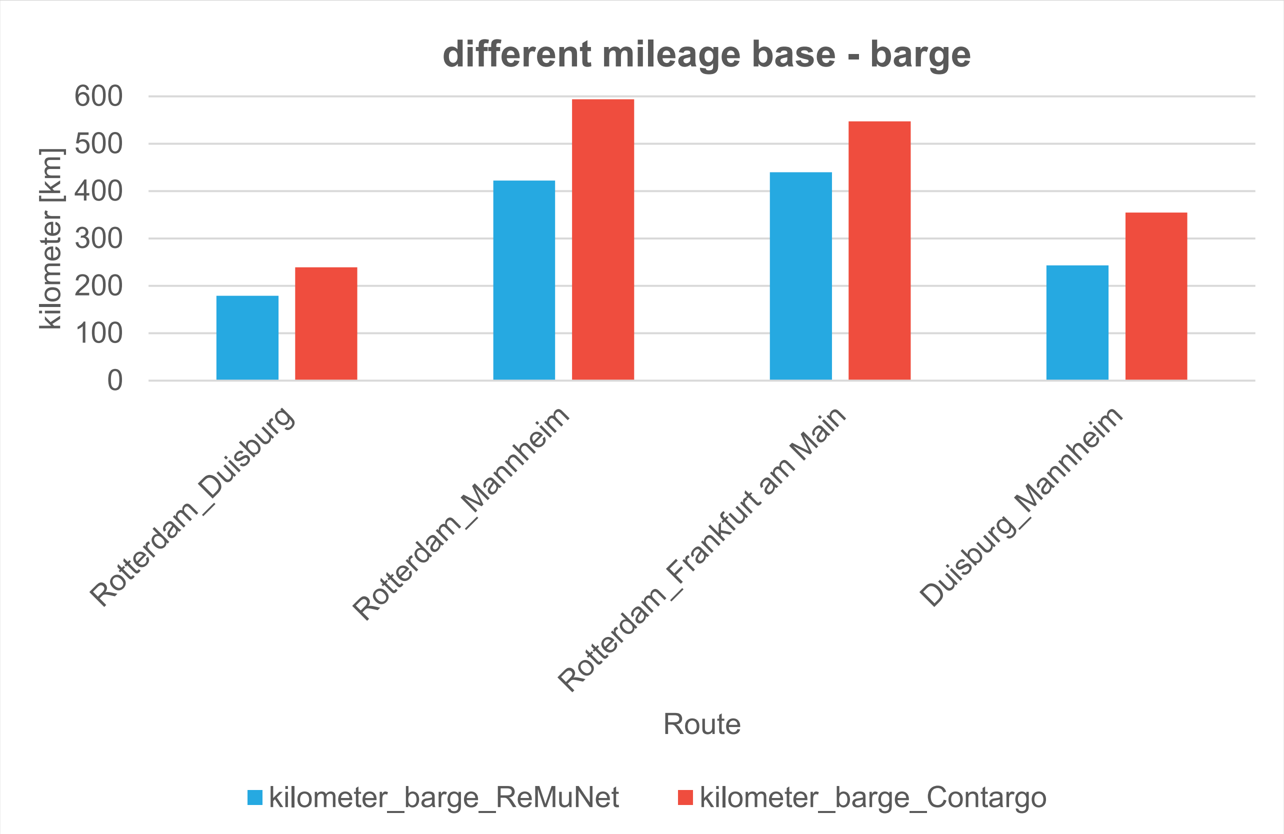

Figure 3: Comparison of different mileage bases for barging

For inland waterway transport, the results show consistent differences between the two data sources across all analyzed corridors. In all cases, the transport distances derived from Contargo are higher than those used within ReMuNet. The magnitude of these differences varies depending on the corridor, ranging from relatively small deviations for shorter routes, such as Rotterdam–Duisburg, to more pronounced differences for longer corridors, such as Rotterdam–Mannheim and Rotterdam–Frankfurt.

Comparable patterns can be observed for rail transport. As documented in the Appendix, Contargo-based distances generally exceed the ReMuNet values across analysed relations, with differences becoming more pronounced for longer-distance corridors such as Rotterdam–Linz, Rotterdam–Vienna and Rotterdam–Budapest. While relative differences remain moderate in most cases, absolute deviations increase with corridor length.

In contrast, road transport shows a lower level of variation between the two data sources. As shown in the Appendix, distances used in ReMuNet and those derived from Contargo are closely aligned across most corridors, with only minor deviations observed. These differences are generally small in both relative and absolute terms and remain consistent across short- and medium-distance routes.

Across all transport modes, the comparison indicates that deviations in underlying transport distances are not uniform, but depend on both the transport mode and the specific corridor. Larger discrepancies are observable for inland waterway and rail transport, while road transport distances show a higher level of consistency between the two datasets.

This comparison highlights that emission calculation inputs, such as assumed transport distances, vary between data sources and contribute to differences in calculated emission results across corridors.

Impact of traction assumptions in rail transport

Figure 4 presents a comparison of emission results for rail transport under different traction assumptions, contrasting emission values based on diesel-only operation with results incorporating electrified rail transport. The comparison includes emission values derived from default-based approaches as well as relation-specific assumptions reflecting a mix of diesel and electric traction.

As information on the share of diesel and electric traction is not available within ReMuNet, relation-specific calculations are based on transport distances and operational data provided by Contargo, which include the respective traction mix.

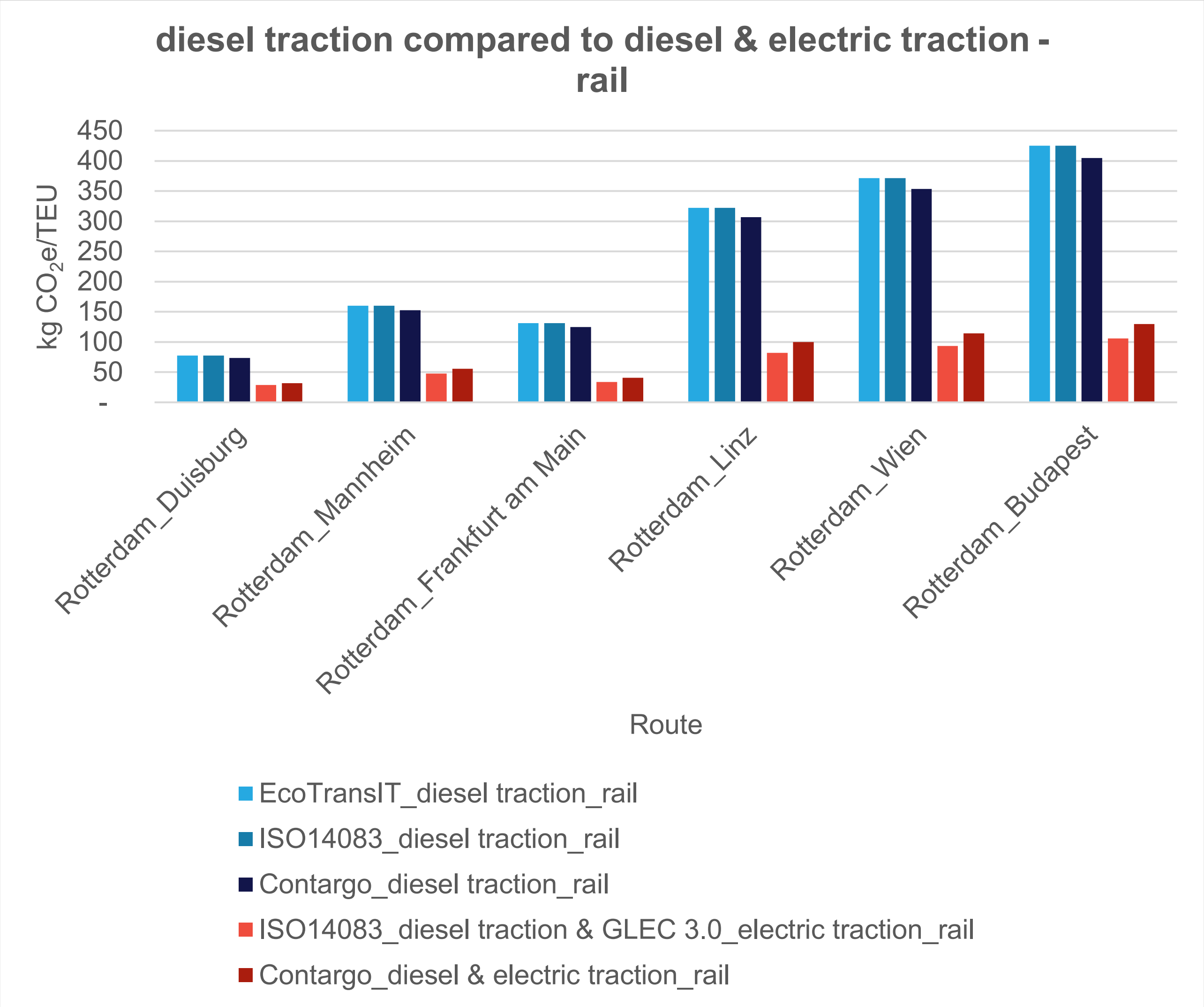

Figure 4: Comparison of emissions for diesel-traction and diesel- & electric traction for rail

The results show substantial differences in emission levels depending on the underlying traction assumptions. Across all analyzed corridors, emission values based on diesel-only operation are consistently higher than those calculated using a combination of diesel and electric traction. The magnitude of this difference varies between corridors but remains pronounced in all cases.

When electrified rail transport is considered, emission values decrease significantly compared to diesel-only assumptions. The reduction ranges between approximately 61 % and 72 % across the analyzed corridors, indicating a strong sensitivity of rail emission results to traction-related input parameters.

The comparison further illustrates that default-based approaches assuming uniform diesel traction lead to higher emission values compared to calculations that account for the actual share of electrified rail transport. This difference is consistently observable across all analyzed corridors, independent of distance or route characteristics.

Overall, the results demonstrate that rail emission outcomes are highly dependent on the modelling of traction types and associated energy sources. Differences in the representation of diesel and electric traction constitute a significant source of variation in corridor-level emission calculations.

Impact of alternative drive systems on emission levels

Figure 5 compares emission results for selected transport corridors under default propulsion assumptions and alternative drive or fuel options across inland waterway, rail and road transport. Emissions are reported in kg CO_2e per TEU and include results for conventional propulsion systems as well as alternative configurations based on hydrotreated vegetable oil (HVO) for inland waterway transport, green electricity for rail transport and battery-electric trucks for road transport.

Emission results are calculated using the same corridor-level distance assumptions derived from ReMuNet to ensure consistency across all transport configurations. Default emission values represent averaged results across the methodological sources introduced in the first example.

Alternative drive configurations are based on Contargo operational data. For inland waterway transport, HVO reflects the use of fuel in Contargo vessels as well as the associated emissions of purchased HVO. Rail transport emissions consider electrified traction based on actual operating conditions and electricity use, applying the Contargo-specific electricity mix. Battery-electric road transport is represented using Contargo data from electric truck operations, including corresponding electricity consumption and the Contargo-specific electricity mix.

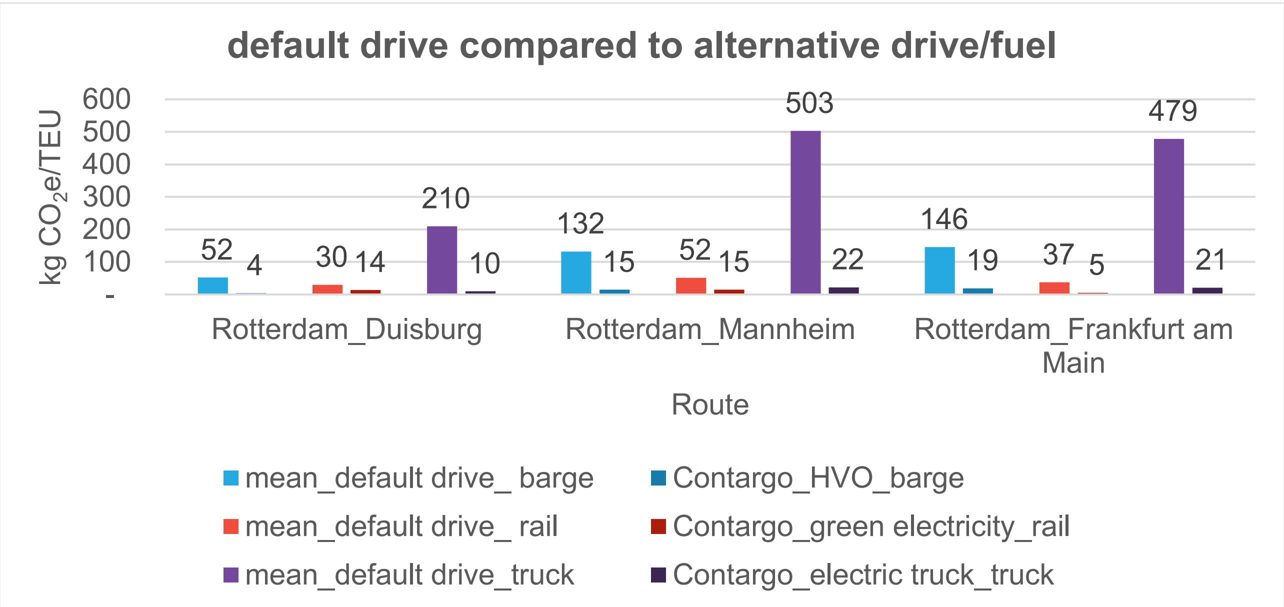

Figure 5: Comparison of default drive and alternative drive/fuel transports

Across all analyzed corridors, the results show substantially lower emission values for alternative drive or fuel configurations compared to default assumptions. For inland waterway transport, emissions decrease from approximately 52 kg CO_2e/TEU to around 4 kg CO_2e/TEU for the Rotterdam–Duisburg corridor when HVO is applied. Similar reductions are observed for the other corridors, with values decreasing from approximately 132 kg to 15 kg for Rotterdam–Mannheim and from approximately 146 kg to 19 kg for Rotterdam–Frankfurt.

A comparable pattern is visible for rail transport. Emission values based on default assumptions range from approximately 30 kg CO_2e/TEU for the Rotterdam–Duisburg corridor to around 52 kg and 37 kg for Rotterdam–Mannheim and Rotterdam–Frankfurt respectively. When green electricity is considered, emissions decrease to approximately 14–15 kg for the first two corridors and to around 5 kg for the Rotterdam–Frankfurt corridor.

For road transport, the largest absolute differences are observable. Default emission values range from approximately 210 kg CO_2e/TEU for the Rotterdam–Duisburg corridor to over 500 kg CO_2e/TEU for Rotterdam–Mannheim and approximately 479 kg CO_2e/TEU for Rotterdam–Frankfurt. In contrast, emissions for battery-electric trucks are significantly lower, ranging from approximately 10 kg CO_2e/TEU to 22 kg CO_2e/TEU across the analyzed corridors.

The comparison shows that the relative reduction in emission values is consistent across all transport modes and corridors, while absolute differences vary depending on the initial emission levels of the respective default configurations.

2.5 Hypothesis Evaluation & Implications

Synthesis of results

The analyses presented in the previous sections demonstrate that corridor-level emission results are influenced by multiple interacting factors, including emission factor selection, transport distances, propulsion assumptions and overall transport configuration.

Across the analysed examples, the choice of transport configuration represents a major driver of total emission outcomes. Differences between transport modes and modal combinations lead to larger variations in emission results than those observed between individual emission factor sources.

At the same time, the results show that emission outcomes are sensitive to the selection of emission factors. Values derived from different methodological sources vary significantly, even when applied to identical transport activities. This variation is particularly visible for inland waterway transport, where differences between GLEC versions indicate a notable sensitivity of emission factors to underlying assumptions.

The analysis of transport distances further demonstrates that emission results are affected by differences in the underlying activity data. Deviations between ReMuNet- and Contargo-based distances contribute directly to differences in calculated emissions. These deviations can be linked to variations in routing assumptions and the definition of origin and destination points, which are not always consistently specified across data sources.

In addition, the results highlight the significant impact of propulsion assumptions. The comparison between diesel-based and electrified rail transport shows substantial reductions in emission levels when electrification is considered. Similarly, alternative propulsion technologies such as HVO, green electricity for rail and battery-electric road transport lead to consistently lower emission values across all analysed corridors, while their remaining emissions highly depend on the operator and context-specific conditions.

Hypothesis evaluation

Taken together, these findings confirm the hypothesis formulated in Section 2.1. The use of relation-specific and operator-specific emission factors leads to differences in corridor-level emission results compared to calculations based solely on default values.

At the same time, the analysis refines the hypothesis. While emission factor selection has a measurable impact on results, the analysis shows that corridor-specific characteristics, particularly transport configuration and distances, constitute the primary drivers of emission performance. The relative contribution of transport segments and emission sources is therefore not fixed, but depends on both methodological assumptions and operational conditions. Default and relation-specific emission factors therefore are complementary. Default factors provide a consistent and comparable baseline for network-level assessment, particularly in contexts where primary data are unavailable. Relation-specific factors, where available, enable a more differentiated representation of corridor-specific conditions and refine the interpretation of emission performance. Together, both approaches support a balanced and robust emission assessment across different levels of data availability.

Furthermore, the results demonstrate that default emission factors cannot be interpreted as a neutral reference. Differences between methodological sources, as well as variations within individual frameworks, indicate that emission results are inherently dependent on the selected calculation approach and its underlying assumptions.

Implications for ReMuNet

From the perspective of the ReMuNet platform, these findings highlight several important implications for the application and interpretation of emission calculations.

First, emission assessment within ReMuNet should not rely on a single set of default emission factors. Instead, the platform should support the transparent use of multiple reference values and, where available, the integration of relation-specific and operator-specific emission data. This enables a more differentiated representation of corridor-level emission characteristics.

Second, the results indicate that emission outcomes are strongly influenced by transport configuration. This suggests that the optimisation of multimodal transport chains constitutes a key lever for emission reduction within the ReMuNet context, in addition to the refinement of emission factors.

Third, the analysis highlights the importance of accurate transport distance data. As emission results are directly influenced by assumed distances, the use of consistent and validated routing data is essential for ensuring reliable emission assessments. This is particularly relevant as inaccurate distance assumptions may distort the evaluation of routing options and emission reduction potentials.

Fourth, the results underline the need for transparency regarding methodological assumptions. Differences in emission factors, distance data and energy assumptions can significantly influence results and should therefore be clearly communicated within the platform.

Fifth, the findings support a flexible analytical use of emission factors within ReMuNet, adapted to both data availability and the specific requirements of corridor analysis. While default emission factors provide a robust and comparable baseline for network-wide assessment, relation-specific factors, where available, allow a more nuanced interpretation of corridor-level emission characteristics. When considering scalability and productization of the ReMuNet platfrom, these aspects must be considered.

Finally, the findings suggest that emission calculations within ReMuNet should be interpreted as part of a broader decision-support framework. While low-emission technologies can significantly reduce emissions, they may also differ in terms of operational flexibility and resilience. ReMuNet should therefore support a multi-criteria evaluation approach, enabling users to assess trade-offs between emission performance and other operational objectives.

3. Integration of emissions from terminal operations

This chapter examines the role of terminal operations in full-chain greenhouse gas emission assessment within the ReMuNet context. While transport emissions are commonly captured at pre-haulage, main-leg and post-haulage level, terminal activities constitute an additional source of emissions that is often treated separately or omitted altogether. The chapter introduces a dedicated hypothesis on the contribution of terminal operations, outlines the methodological framework for deriving terminal-specific emission factors, and evaluates their impact using illustrative corridor examples.

3.1 Rationale and hypothesis

Terminal operations are an integral part of combined and multimodal transport chains. Activities such as container handling, transshipment, storage and on-site movements require energy and therefore generate GHG emissions. Despite their relevance, terminal emissions are often excluded from corridor-level emission assessments or treated using highly aggregated assumptions, with the analytical focus placed primarily on transport segments.

In transport corridors characterised by conventional propulsion technologies, the omission of terminal emissions may have a limited effect on total chain results. However, as transport segments increasingly shift towards low-emission technologies, the relative importance of non-transport activities becomes more pronounced. In such contexts, excluding terminal operations risks systematically underestimating total chain emissions and obscuring emission hotspots outside the main transport legs.

ReMuNet aims to support full-chain emission assessment across multimodal networks. Its node-based structure provides a conceptual basis for assigning emissions not only to transport links but also to terminals as discrete network elements. From an analytical perspective, this raises the question of whether terminal emissions constitute a measurable and relevant share of total chain emissions, particularly in corridors where transport emissions are reduced.

Based on this consideration, Task 5.3 addresses the following second hypothesis:

Terminal operations contribute a measurable and non-negligible share to total transport chain emissions. This contribution becomes particularly relevant in corridors characterised by low-emission transport technologies, highlighting the importance of including terminal activities in full-chain emission assessments.

This hypothesis is examined through the derivation of terminal-specific emission factors and their application in illustrative corridor examples. The analysis focuses on the magnitude and relative contribution of terminal emissions without presupposing specific outcomes.

3.2 Available frameworks and benchmarking for terminal emissions

Building on the emission calculation frameworks introduced in Chapter 2, this section focuses on their application to terminal operations, which differ fundamentally from transport activities in terms of emission sources, system boundaries and allocation logic. While the same overarching methodological principles apply, terminal emissions require a more specific interpretation of existing frameworks.

Unlike transport segments, where emissions are primarily driven by distance-based vehicle operation, terminal emissions originate from stationary and mobile handling activities. These include electricity consumption for cranes and terminal infrastructure, fuel use of mobile equipment such as reach stackers and terminal tractors, and auxiliary consumables associated with handling operations. As a result, terminal emissions are typically allocated based on throughput rather than distance, using functional units such as kg CO_2e per TEU handled (SFC 2025).

Within the GLEC Framework, terminal emissions are defined as direct operational energy consumption associated with handling, transshipment and on-site movements. The framework explicitly excludes indirect activities such as office energy use or employee commuting, thereby ensuring consistency with transport emission system boundaries. GLEC further provides indicative benchmark ranges for terminal emissions, which support comparison across terminals and intermodal corridors (SFC 2025).

ISO 14083 follows a comparable approach for terminal operations, emphasising transparent and reproducible allocation of direct operational emissions to harmonised functional units. By clearly defining system boundaries and allocation rules, ISO 14083 supports the integration of terminal emissions into full-chain emission assessments alongside pre-haulage, main-leg and post-haulage transport segments (ISO 2023).

The emerging CountEmissionsEU initiative reinforces the relevance of terminal operations as an integral component of full-chain greenhouse gas emission assessment. Terminals are conceptualised as discrete emission-relevant nodes within the transport network (European Parliament 2026).

In contrast to transport segments, terminal emissions are commonly benchmarked using aggregated values (e.g. per TEU) derived from annual operational data. Tools such as the REFF Tool operationalise this approach by allocating total terminal energy consumption to throughput volumes. By doing so, they translate the methodological principles of GLEC and ISO 14083 into a reproducible calculation logic that supports comparability across terminals while remaining aligned with recognised standards (IML).

Across the referenced frameworks and tools, a consistent set of terminal-specific principles emerges: only direct operational emissions are included, emissions are allocated on an activity-based basis, and benchmarking is performed using harmonised functional units. These principles provide the methodological foundation for deriving terminal-specific emission factors and for analysing the contribution of terminal operations to total transport chain emissions in the subsequent sections.

3.3 Methodology for deriving terminal-specific emission factors

The derivation of terminal-specific GHG emission factors follows an activity-based methodology consistent with the system boundaries and principles defined in the last section. The objective is to quantify direct operational emissions at terminal level and allocate them to a harmonised functional unit to enable integration into full-chain emission assessment.
The GLEC Framework (SFC 2025) and ISO 14083 (ISO 2023) methodology focuses on direct operational energy consumption associated with terminal activities. This includes electricity use for handling equipment and terminal infrastructure, as well as fuel consumption of mobile handling equipment such as reach stackers, terminal tractors and cranes. Where applicable, on-site renewable electricity generation is taken into account to reflect the actual energy mix. In line with

the defined system boundaries, indirect emission sources such as administrative activities or employee commuting are excluded.
Operational energy consumption data are collected on an annual basis for each terminal. All energy flows are converted into kg CO_2e emissions using appropriate emission factors reflecting the respective electricity mix and fuel characteristics. The result represents the total annual direct operational emissions of the terminal.
To derive a terminal-specific emission factor, total annual emissions are allocated to the annual throughput measured in handled TEU. Emissions are expressed in kg CO_2e per TEU, ensuring consistency with established benchmarking approaches and comparability across terminals and corridors. The allocation follows the expression:

$$Terminal\ Emission\ Factor\ [\frac{kg\ CO2e}{TEU}] = \frac{Total\ annuall\ emissions\ \ [kg\ CO2e]}{Annual\ TEU\ [TEU]}$$

This aggregated allocation approach reflects current practice for deriving terminal emission factors based on primary operational data. While more granular allocation levels could provide additional detail, consistent data at this level is not yet available across all terminals. The applied approach therefore ensures a reproducible and transparent calculation of terminal-specific emission factors based on available primary data.

Quality assurance is performed through plausibility checks, cross-terminal comparison and consistency verification of input data and calculated results. Observed deviations are analyzed to identify potential data inconsistencies or structural differences in terminal operations.

The resulting emission factors represent terminal-specific values derived from primary operational data and enable the explicit representation of terminals as emission-relevant nodes within transport corridors. These primary data-based factors form the basis for the comparative analysis with framework-based default values, which is presented in the following section.

3.4 Corridor examples and emission calculation results

To assess the contribution of terminal operations to total transport chain emissions and to evaluate the hypothesis formulated in Section 3.1, a set of illustrative corridor-level examples was analyzed. The examples are designed to highlight three analytical aspects:

(i) the magnitude of terminal emissions relative to transport emissions,

(ii) the increasing relevance of terminal operations in low-emission transport corridors, and

(iii) the sensitivity of terminal emission results to system boundary definitions and energy-related assumptions.

Contribution of terminal emissions to total chain emissions

To assess the relevance of terminal operations within full-chain emission accounting, Figure X presents the contribution of terminal emissions to total greenhouse gas (GHG) emissions for selected corridors. The comparison distinguishes between conventional transport configurations and transport chains incorporating alternative drive or fuel options. Emissions are reported in kg CO_2e per TEU and include all transport segments as well as terminal activities within the defined system boundaries.

For the purpose of this comparison, a consistent set of assumptions is applied across all transport configurations and corridors. Transport distances are based on the routing assumptions used within ReMuNet to ensure comparability across all cases. Emission results represent average corridor conditions. Emission factors are applied in accordance with the averaging approach defined for the corridor examples in Chapter 2, combining values from different methodological sources and relation-specific data. The comparison focuses on inland waterway transport as a representative example, while corresponding analyses for rail transport are provided in the Appendix.

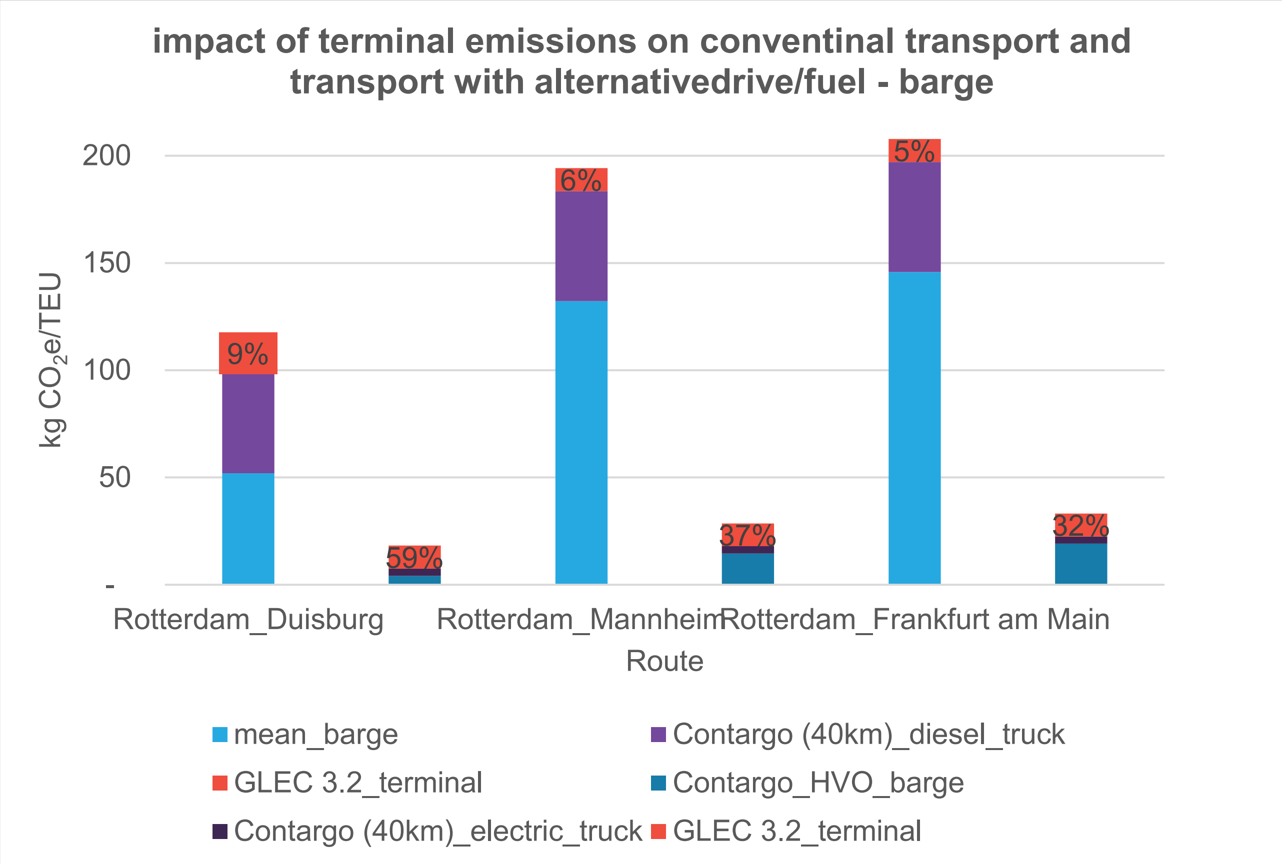

Figure 6: Impact of terminal emissions on conventional transport and alternative drives for barging

The results show that, under conventional transport assumptions, terminal emissions account for a smaller share of total chain emissions compared to transport segments. Across the analyzed inland waterway corridors, the contribution of terminal operations ranges between approximately 5 % and 9 % of total emissions. While this share is lower relative to transport-related emissions, it nonetheless represents a consistent and measurable component of the overall emission profile.
In contrast, a substantially different pattern is observed when alternative drive or fuel options are applied. In these scenarios, overall transport emissions decrease significantly, while terminal emissions remain unchanged in absolute terms. As a result, the relative contribution of terminal operations increases markedly, reaching values between approximately 32 % and 59 % across the analyzed corridors.
This comparison illustrates that the relative importance of terminal emissions is strongly dependent on the emission intensity of the transport chain. While terminal operations represent a minor share under conventional transport conditions, their contribution becomes considerably more pronounced in low-emission transport scenarios.

Variability of terminal emission levels across locations

Figure 7 provides an overview of terminal-specific emission factors derived from default data (GLEC 3.0) and Contargo primary data across a range of locations, expressed in kg CO_2e per handled TEU.

The comparison includes multiple inland terminals and illustrates the variability of emission levels between different sites.

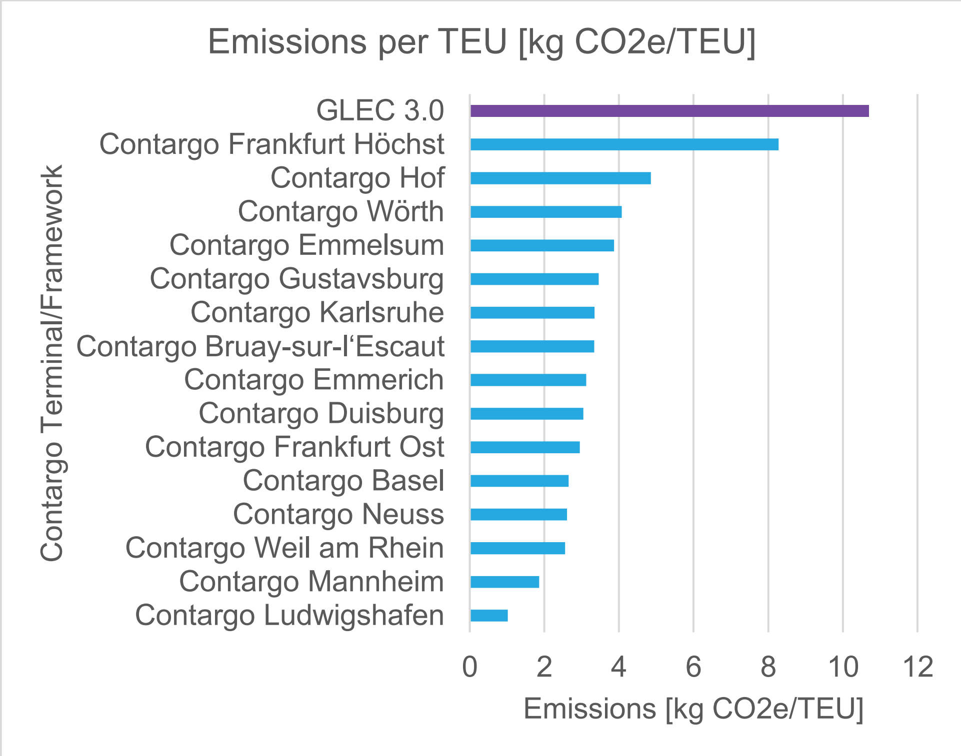

Figure 7: Emissions per TEU for Default-data and Contargo-data

The results indicate a wide range of terminal emission factors. Observed values extend from approximately 1.0 kg CO_2e/TEU at the lower end to around 10.7 kg CO_2e/TEU at the upper end of the range. This represents a variation by a factor of more than eight across the analyzed terminals.

In addition to this variability, the comparison also highlights differences between individual terminals and aggregated benchmark values derived from frameworks such as GLEC. In several cases, terminal-specific values deviate notably from the respective benchmark, either exceeding or falling below the reference level.

The observed range demonstrates that terminal emission levels are not uniform, but vary significantly depending on site-specific conditions. This variability reflects differences in operational characteristics, energy sourcing and infrastructure across terminals.

Influence of energy sources on terminal emissions

To further examine the drivers of variability in terminal emission levels, Figure 8 analyses the composition of terminal emissions in terms of energy sources, distinguishing between diesel-based and electricity-based emission contributions. The comparison relates the share of each energy source to total terminal emissions across multiple locations.

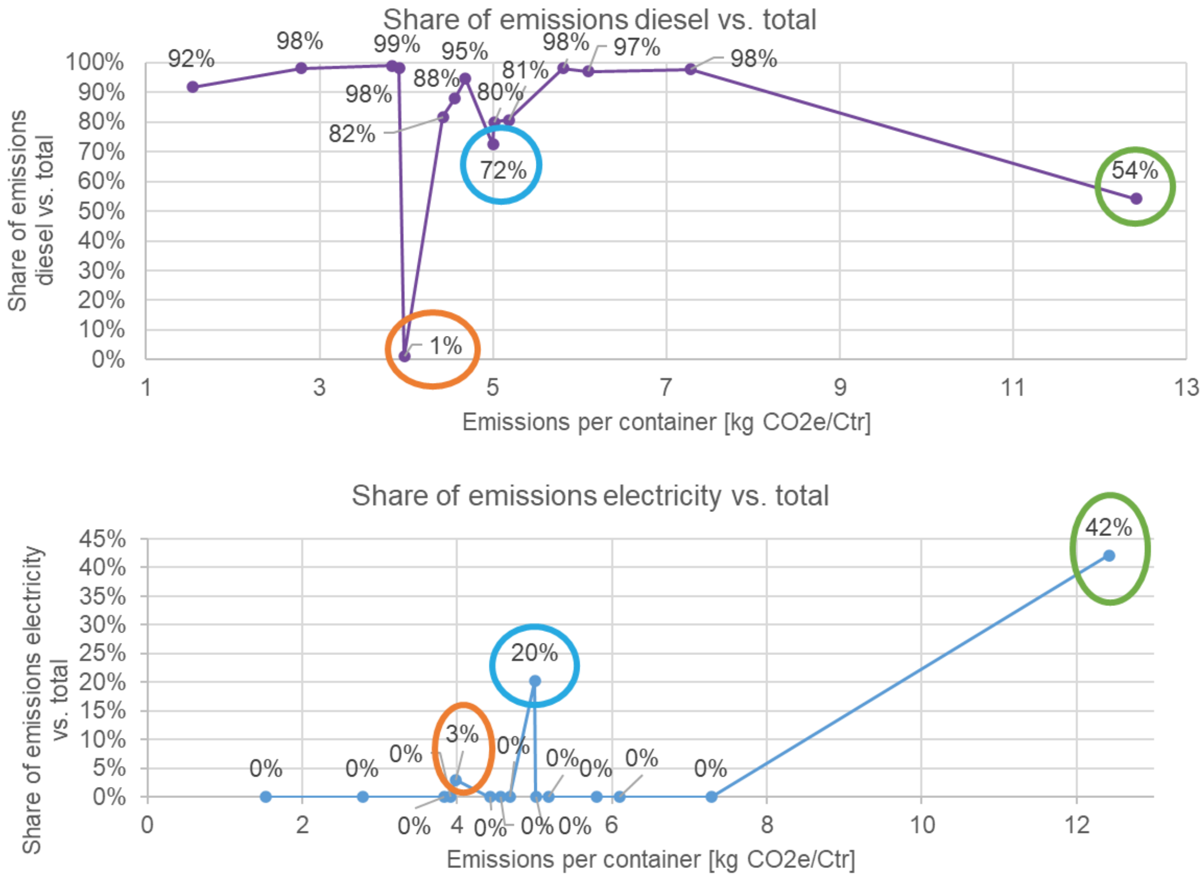

Figure 8: Share of terminal emissions for diesel (top) and electricity (bottom)

The results show that for Contargo, on average, diesel-based energy use accounts for approximately 92 % of total terminal emissions, while electricity-related emissions are close to zero for many locations.

This pattern does not necessarily reflect the relative share of energy use, but is primarily driven by differences in emission factors. In many cases, electricity is procured through green power purchase agreements or accounted for using low-emission factors, resulting in a negligible contribution of electricity to total emissions despite its operational use.

At the same time, deviations from this pattern can be observed where electricity is associated with higher emission factors. For example, terminals using locally generated electricity based on natural gas (marked green) show a measurable contribution of electricity-related emissions. In this case, differences in electricity sourcing alone can lead to substantial variations in reported emissions, with reductions of up to approximately 50 % depending on the applied electricity contract.

Further variation is observed for locations operating under different national electricity mixes. Terminals located in regions with electricity systems characterised by a high share of nuclear energy (marked in blue) show relatively low electricity-related emissions, illustrating the influence of classification approaches in emission accounting.

In addition to energy sourcing, differences in system boundaries affect the comparability of results. For demonstration purposes for one terminal coolant emissions where added to the overall terminal emission within explained boundaries (marked in orange). The inclusion of additional services, such as coolant filling, increases total emissions and alters the relative contributions of individual sources. These examples demonstrate that consistent system boundaries are required to ensure comparability across terminals.

3.5 Hypothesis evaluation and implications

The results presented in Section 3.4 provide the basis for evaluating the hypothesis that terminal operations contribute a measurable and non-negligible share to total transport chain emissions, with increasing relevance in low-emission transport corridors.

Across all analyzed examples, terminal emissions are consistently identifiable as a component of total chain emissions. Under conventional transport configurations, their relative contribution ranges between approximately 5 % and 9 % of total emissions. While transport segments dominate overall emission performance in these cases, terminal operations nonetheless represent a stable and measurable share within the system boundaries applied. This is particularly relevant for ReMuNet, where the inclusion of terminal operations allows for a more complete representation of multimodal transport chains at corridor level.

A substantially different pattern emerges in corridors characterised by low-emission transport technologies. As transport-related emissions decrease significantly, terminal emissions remain largely unchanged in absolute terms. This leads to a marked increase in their relative contribution, reaching values between approximately 32 % and 59 % across the analyzed examples. These results confirm that the relevance of terminal operations is strongly dependent on the emission intensity of the transport segments that constitute the overall chain.

In addition to this shift in relative importance, the analysis highlights a high degree of variability in terminal emission levels across locations. Terminal-specific emission factors vary by more than a factor of eight, reflecting differences in operational characteristics, energy sourcing and infrastructure. This variability is further reinforced by differences in emission composition, particularly with regard to the relative contribution of diesel- and electricity-based energy use.

The analysis of emission composition shows that the dominant share of diesel-related emissions and the often negligible share of electricity-related emissions are not primarily driven by differences in energy use, but by differences in emission factors applied in the accounting of electricity. The use of low-emission electricity contracts, differences in national electricity mixes and variations in accounting conventions significantly influence reported emission shares. In addition, inconsistencies in system boundaries—such as the inclusion of additional services—further affect comparability across terminals.

In addition, the comparison between terminal-specific emission factors and default-based emission factors indicates that default approaches capture the general order of magnitude of terminal emissions, but systematically smooth out terminal- and corridor-specific differences. Default and terminal-specific emission approaches should be understood as complementary, combining comparability with the ability to reflect location-specific conditions.

In particular, default factors do not adequately reflect variations arising from electricity sourcing, the degree of equipment electrification or the inclusion of auxiliary terminal services. As a result, default-based full-chain assessments tend to understate both the variability of terminal emissions and their relative importance in low-emission transport corridors.

Taken together, these findings confirm the hypothesis. Terminal operations constitute a measurable and non-negligible share of total transport chain emissions and become particularly relevant in low-emission transport contexts. At the same time, the analysis refines the hypothesis by demonstrating that both the magnitude and composition of terminal emissions are highly sensitive to methodological assumptions, energy sourcing and system boundary definitions.

From an analytical perspective, this underlines that the integration of terminal emissions into full-chain emission assessment is required to achieve a complete representation of corridor emissions. However, it also highlights the importance of transparent methodological assumptions and consistent system boundaries to ensure comparability and interpretability of results.

4. Summary, implications, limitations and outlook

This chapter summarises the key findings of Deliverable 5.3 and derives implications GHG emission assessment in multimodal transport networks within the ReMuNet context. Building on the analyses presented in Chapters 2 and 3, the chapter consolidates the main insights regarding the influence of methodological assumptions, data inputs and system boundaries on emission calculation results.

Summary of key findings

The analyses conducted in this deliverable show that greenhouse gas (GHG) emission results for multimodal transport chains are shaped by multiple interacting factors and cannot be attributed to a single parameter, hence sustainability and emission monitoring needs to be analyzed with specific knowledge and level of trust. For the ReMuNet platform, it is essential to use proper methods and trusted emissions factors, since sustainability is one of the core building blocks of the ReMuNet.

Across all examined corridor examples, transport configuration emerges as a major driver of emission outcomes. Differences in modal composition lead to substantially larger variations in total emissions than differences between individual emission factor sources.

At the same time, emission results are sensitive to methodological assumptions. Variations in emission factors across different frameworks, differences in transport distance data and assumptions regarding propulsion technologies all contribute to deviations in calculated emission values. These effects are particularly visible in inland waterway and rail transport and in the representation of electricity-based energy use.

The results further demonstrate that emission factors derived from different methodological sources are not interchangeable. Default values reflect specific assumptions regarding fleet composition, energy sourcing and operational conditions and therefore cannot be interpreted as neutral reference values.

In addition, the analysis highlights the importance of terminal operations within full-chain emission assessment. While terminal emissions represent a relatively small share under conventional transport conditions, their contribution increases significantly in low-emission transport scenarios. At the same time, terminal emission levels show a high degree of variability across locations and are strongly influenced by energy sourcing assumptions and system boundary definitions.

Overall, the findings confirm that emission assessment at corridor level is both data-dependent and assumption-sensitive, thus harmonized and transparent calculation models are preferred. Reliable interpretation therefore requires a clear understanding of the underlying methodological choices and their interaction with corridor-specific conditions. This reinforces the relevance of the presented results for ReMuNet, as emission outcomes are closely linked to routing decisions, data assumptions and corridor-specific configurations within the platform.

Implications for emission assessment

The findings imply that emission assessment in multimodal transport systems must be understood as a transparent and context-sensitive analytical process rather than a purely technical calculation. When scaling up the ReMuNet platform from proof of concept to product these findings must be consideder.

First, the variability of emission factors across different methodological sources requires that emission assessments explicitly document and communicate the selected data sources and assumptions. Without such transparency, results cannot be meaningfully interpreted or compared across corridors.

Second, the analysis shows that activity data, particularly transport distances, represent a critical input parameter rather than a fixed background variable. Variations in routing assumptions can significantly influence emission outcomes and may distort the evaluation of transport alternatives if not consistently applied.

Third, the results highlight the importance of clearly defined system boundaries. Differences in the inclusion of transport segments, terminal activities or auxiliary services can lead to non-comparable results if not consistently specified across assessments.

Fourth, the findings demonstrate that default and relation-specific emission factors should be understood as complementary. Default factors provide a consistent and comparable baseline for network-level assessment, while relation-specific data enable a more differentiated representation of operational conditions. A robust emission assessment therefore requires the combination of both approaches within a consistent methodological framework.

Finally, the results underline the need to account for variability and uncertainty in emission calculations. Scenario-based approaches, which reflect alternative assumptions regarding emission factors, routing and energy sourcing, provide a more suitable basis for analysis than single point estimates.

Implications for ReMuNet

From the perspective of the ReMuNet platform, these findings highlight several key implications for the design and application of emission assessment functionalities.

First, ReMuNet should support a flexible, but trusted and transparent handling of emission factors. Rather than relying on a single default dataset, the platform should enable the integration of relation-specific and operator-specific data where available, while maintaining comparability through clearly defined system boundaries.

Second, the results indicate that emission outcomes are strongly influenced by transport configuration. This implies that the primary analytical value of ReMuNet lies in the comparison and optimisation of multimodal transport chains. Emission calculation should therefore be closely linked to routing functionalities, allowing users to evaluate alternative corridor configurations.

Third, the sensitivity of emission results to transport distances highlights the importance of reliable routing data within the platform. Consistent and validated distance calculations are essential to ensure that emission results reflect actual transport conditions rather than modelling artefacts. In the ReMuNet platform routing methods and models can be harmonized.

Fourth, the increasing relevance of terminal emissions in low-emission transport scenarios requires their explicit integration into the ReMuNet network model. Representing terminals as emission-relevant nodes supports a more complete and realistic assessment of corridor emissions.

Fifth, the findings suggest that ReMuNet should support scenario-based analysis. Given the strong influence of methodological assumptions, the ability to compare alternative scenarios, such as different emission factors, transport technologies or energy sourcing options, is essential for robust decision-making.

Finally, the results underline that emission assessment should be integrated into a broader decision-support framework. While low-emission technologies can significantly reduce emissions, they must be evaluated in relation to other system objectives such as flexibility, resilience and operational feasibility. ReMuNet should therefore support multi-criteria analysis to capture these trade-offs.

Limitations

The results of this deliverable should be interpreted in light of several limitations related to methodological assumptions, data availability and the scope of the analysis. In this context, the findings should primarily be understood as indicative insights into key emission drivers within multimodal transport chains rather than as universally generalisable results.

One limitation concerns the use of default emission factors derived from tools such as EcoTransIT and the GLEC Framework. In these approaches, key input parameters, such as load factors or operational conditions, are not fully specified in all cases and therefore reflect predefined assumptions rather than corridor-specific configurations. As a result, the comparison between default-based and relation-specific emission factors does not fully exploit the potential for methodological alignment.

A second limitation relates to the use of relation-specific data from a single operator. While the integration of Contargo operational data enables a detailed and practice-oriented assessment, the results are not fully representative of other operators, transport systems or geographic contexts. A broader empirical basis would be required to validate the findings across different logistics structures and operational conditions.

In addition, the scope of the analysis is limited to container transport and focuses on TEU-based transport chains and terminal operations. Other cargo types, logistics processes and nodes, such as warehouses or distribution centres, are not included. This restricts the transferability of the results to other segments of the transport and logistics system.

Furthermore, the assessment of alternative drive systems is based on specific operational implementations within the Contargo context. While these cases provide valuable real-world insights, they do not represent a comprehensive or generic assessment of alternative propulsion technologies across the transport sector.

Finally, the emission calculation approaches analysed in this deliverable are not yet fully integrated into the ReMuNet platform. The results therefore reflect a static comparison of assumptions rather than a dynamic application within real-time routing and optimisation processes.

Outlook

Looking ahead, the findings highlight several opportunities for further development within the ReMuNet context.

A key area of improvement is the more detailed parameterisation of default emission factors. Better alignment of default assumptions with corridor-specific conditions would enhance comparability and reduce methodological uncertainty.

In addition, expanding the analysis to include multiple operators and a broader range of transport relations would improve the robustness and generalisability of the results.

Extending the scope beyond container transport to include additional cargo types, logistics nodes and operational processes would allow for a more comprehensive representation of multimodal transport systems.

A further step is the technical integration of emission calculation approaches into the ReMuNet platform. Linking emission assessment directly with routing and scenario-based analysis would enable dynamic evaluation of transport alternatives and support real-time decision-making.

Finally, future developments should aim to generalise the assessment of alternative propulsion technologies by incorporating a wider range of operational contexts, energy sources and technology configurations. This would support a more comprehensive evaluation of emission reduction potentials across multimodal transport systems.

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5. Appendix

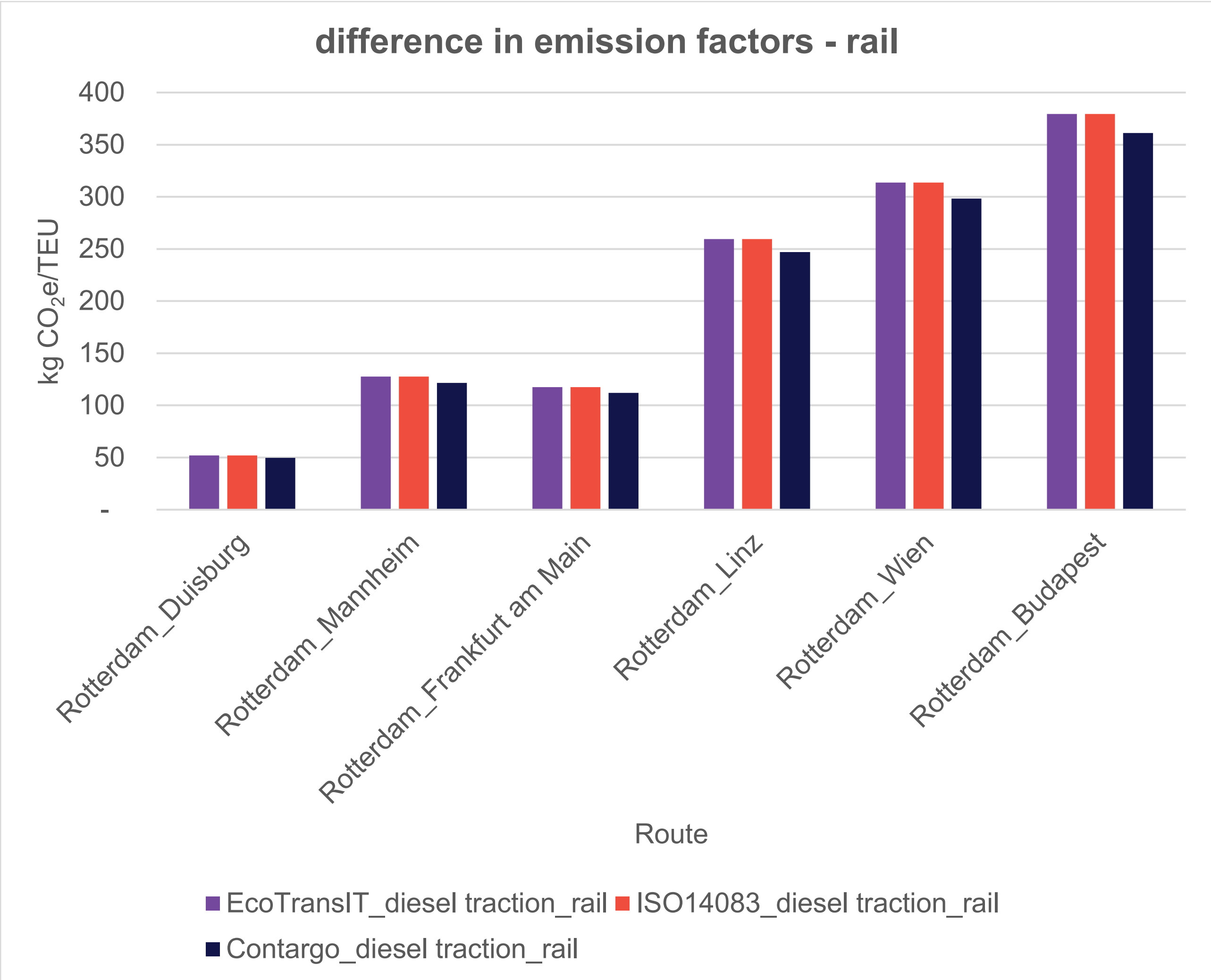

Figure 9: Comparison of different emission factors for rail

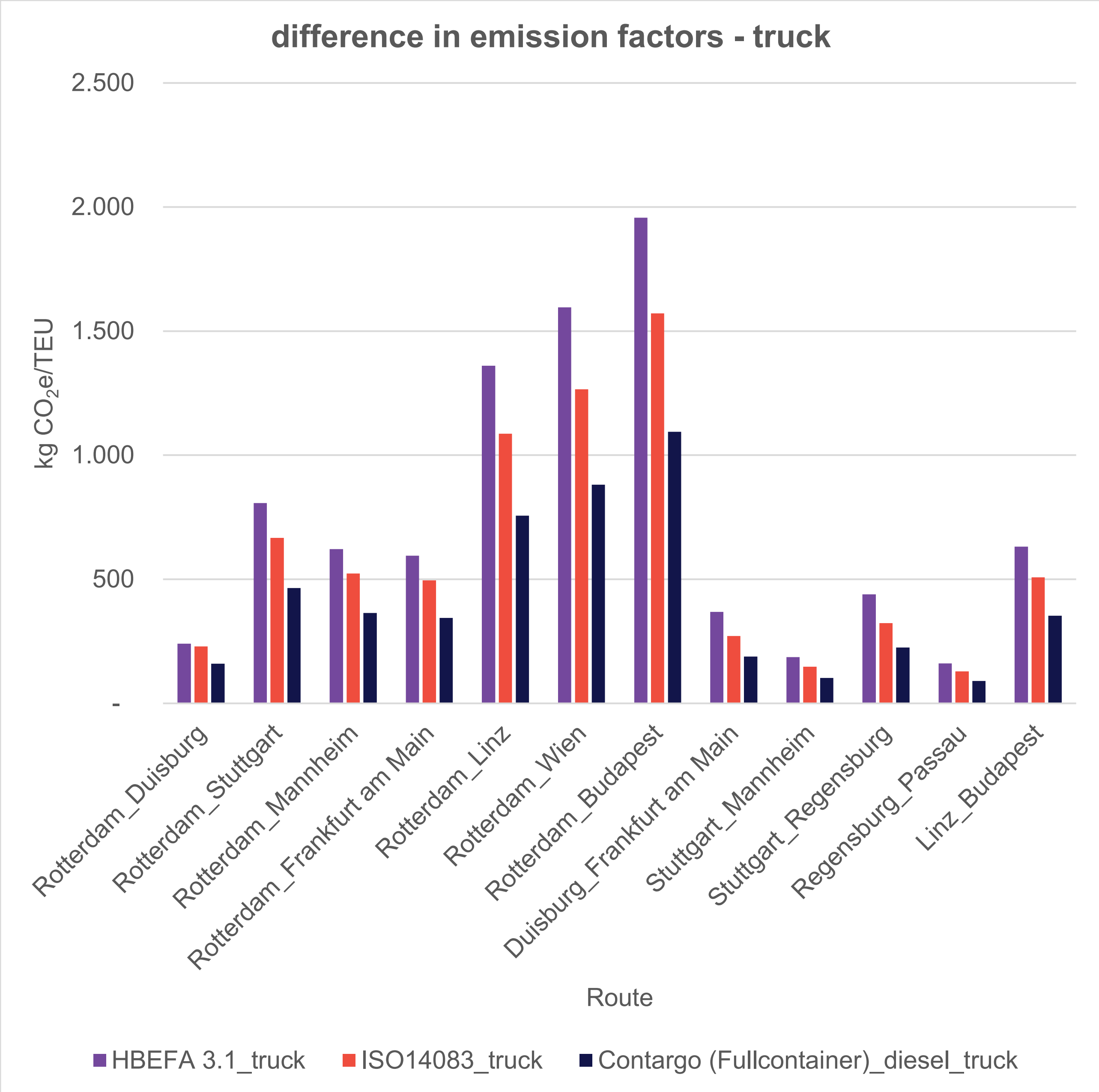

Figure 10: Comparison of different emission factors for truck

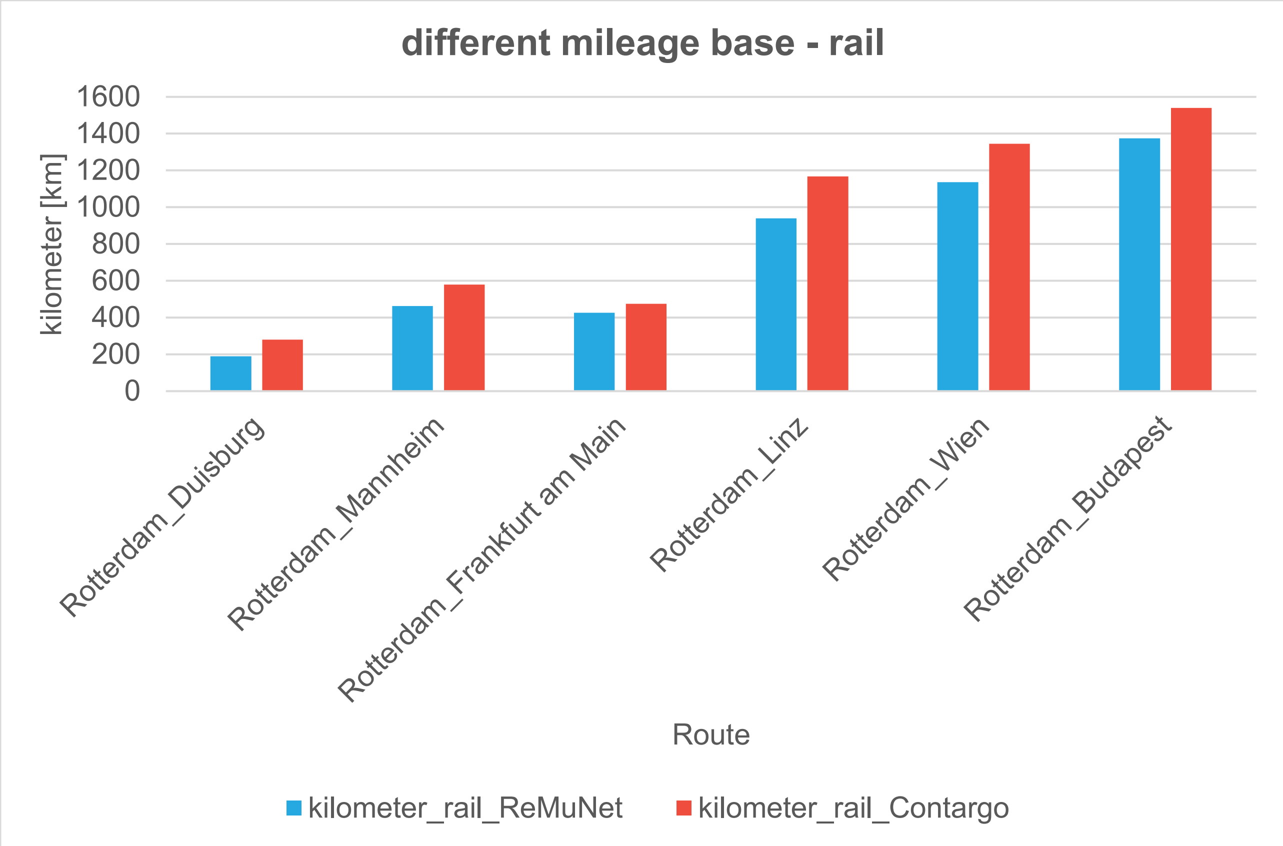

Figure 11: Comparison of different mileage bases for rail

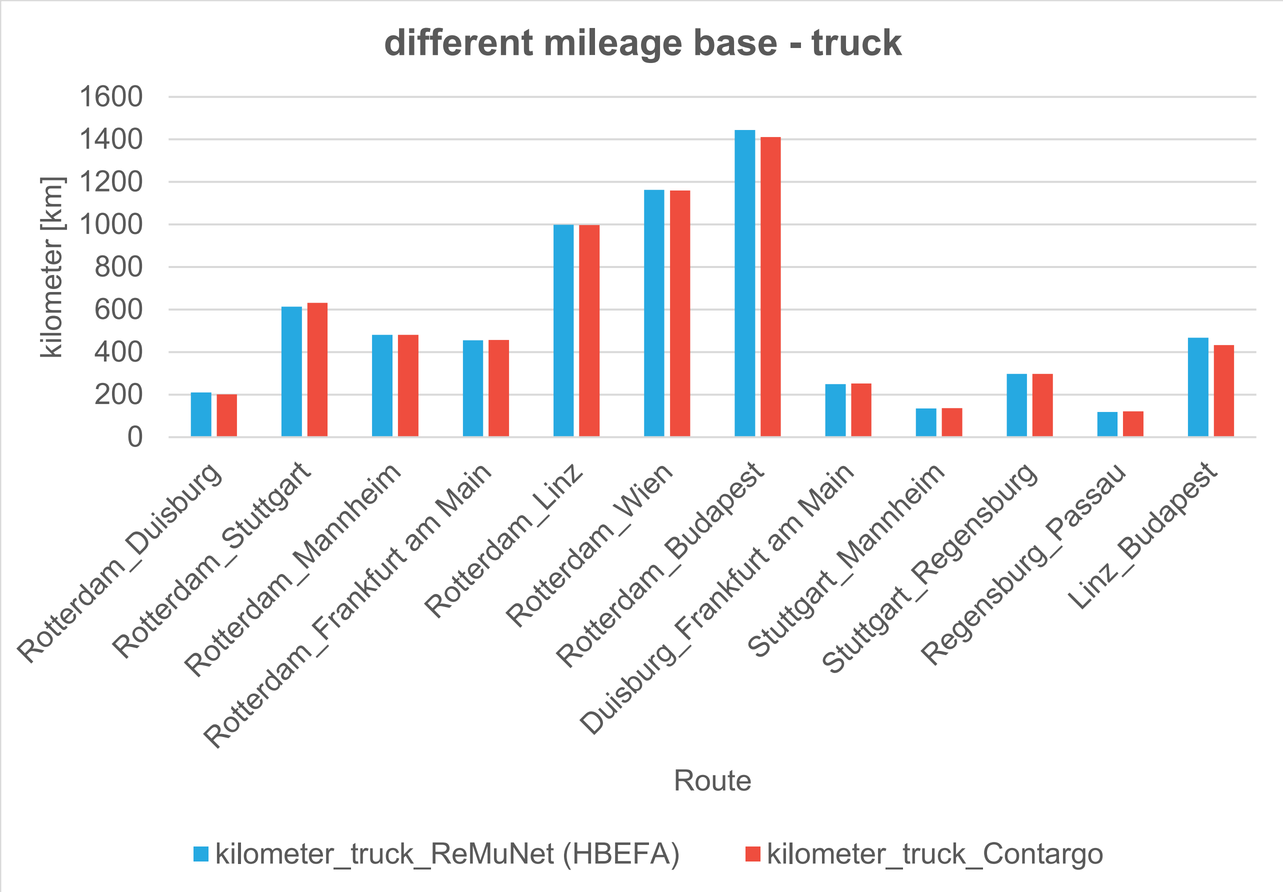

Figure 12: Comparison of different mileage bases for truck

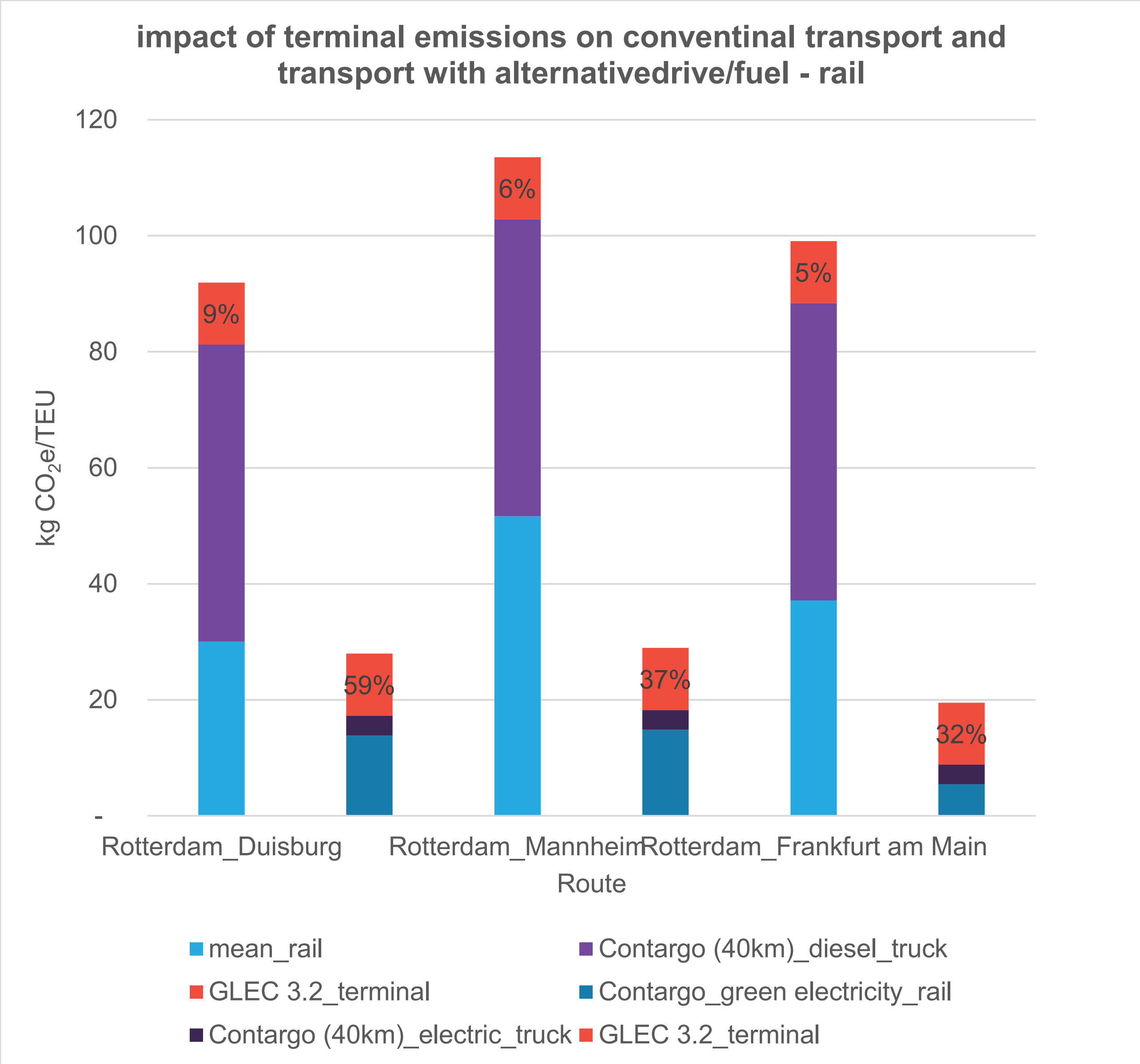

Figure 13: Impact of terminal emissions on conventional transport and alternative drives for rail

The project

ReMuNet identifies and signals disruptive events and assesses their impact on multimodal transport corridors. It reacts quickly and seamlessly upon disruptive events in real-time. It supports TMS providers to improve route planning resilience. ReMuNet communicates alternative, pre-defined, multimodal transport routes to logistics operators and subsequently to truck drivers, locomotive drivers and barge captains. Through this, it enables a faster and adaptive multimodal network response. ReMuNet orchestrates route utilization, suggests transshipment points and optimizes capacity allocation, minimizing damage and shortening the recovery time. What is ReMuNet's core objective? As trailblazer for the Physical Internet, ReMuNet pursues the vision to enable and incentivize synchro-modal relay transport on European rail, road, and inland waterways to increase the holistic network resilience. It significantly reduces emissions and boosts freight transport corridor efficiency in case of disruptive events. stakeholders to ensure Europe-wide practicability and acceptance.

Coordinator: FORSCHUNGSINSTITUT FUER RATIONALISIERUNG (FIR)

PARTNER		SHORT NAME
fir at RWTH Aachen University	FORSCHUNGSINSTITUT FUER RATIONALISIERUNG	FIR
HANKEN	SVENSKA HANDELSHOGSKOLAN	HANKEN
PTV GROUP	PTV PLANUNG TRANSPORT VERKEHR GmbH	PTV
4PL Intermodal	4PL INTERMODAL GMBH	INT
MANSIO truck meets truck	MANSIO GMBH	MAN
Fraunhofer AUSTRIA	FRAUNHOFER AUSTRIA RESEARCH GMBH	FHA
HAFEN WIEN ein unternehmen der wienholding	HAFEN WIEN GMBH	HWI
WHITE	WHITE RESEARCH SRL	WRE
UIRR UNION INTERNATIONALE POUR LE TRANSPORT COMBINE RAIL-ROUTE	UNION INTERNATIONALE DES SOCIETES DE TRANSPORT COMBINE RAIL-ROUTE SCRL	UIR
CONTARGO® trimodal network	CONTARGO GMBH & CO KG	CON
vedia	VEDIAFI OY	VED

RØDE KORS	DANSK RODE KORS (DANISH RED CROSS)	DRC
FMI	ILMATIETEEN LAITOS	FMI
alice	ALLIANCE FOR LOGISTICS INNOVATION THROUGH COLLABORATION IN EUROPE	ETP-ALICE
SCHACHINGER LOGISTIK	SCHACHINGER IMMOBILIEN UND DIENSTLEISTUNGS GMBH & CO OG	SCH