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Locating dry ports in the function of maritime logistics

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ABSTRACT

Maritime logistics remains the backbone of international trade; however, rising container volumes, terminal congestion and environmental pressures increasingly necessitate stronger hinterland integration. Dry ports; as strategically located inland intermodal terminals that relocate customs, storage and consolidation functions from seaports; offer a proven solution to extend seaport hinterlands, facilitate modal shifts to rail and inland waterways, and alleviate coastal bottlenecks. This study aims to evaluate and identify the most suitable dry port locations in Europe by integrating sustainability, connectivity, infrastructure readiness, institutional support and cargo attraction potential. To address this objective, a novel hybrid multi-criteria decision-making (MCDM) approach is proposed, combining fuzzy Step-Wise Weight Assessment Ratio Analysis for stakeholder-based criteria weighting, a fuzzy Delphi method to consolidate expert judgments, and a fuzzy Axial Distance-based Aggregated Measurement model to rank alternatives. The model is applied to twelve candidate cities, with results identifying Duisburg as the top-ranked location, followed by Vienna and Belgrade. These findings suggest that both established multimodal hubs and strategically positioned emerging nodes justify investment. Overall, the findings demonstrate the effectiveness of the proposed hybrid fuzzy MCDM approach for complex infrastructure location problems, contribute a comprehensive stakeholder-informed criteria framework, and provide a practical decision-support tool for policymakers, port authorities and investors seeking to align dry port development with Trans-European Transport Network priorities and decarbonization goals.

1. Introduction

Maritime logistics form the foundation of global trade, with seaports serving as primary gateways for international cargo flows. However, growing container volumes, terminal congestion, and environmental concerns increasingly challenge the efficiency of maritime logistics chains [1,2]. To address these issues, dry ports have emerged as vital elements in contemporary seaport systems, contributing to sustainable supply chains. Functioning as inland extensions of seaports, dry ports move customs, storage, consolidation, and value-added services closer to the hinterland [3]. By integrating inland waterways, rail, and road transport, dry ports strengthen maritime–inland connectivity, expand seaport hinterlands, and support more sustainable modal shifts. Their strategic positioning is particularly important in Europe [4], where dense freight corridors and diverse regional markets require logistics solutions that balance efficiency and sustainability.

Selecting appropriate dry port locations is therefore crucial. Poorly sited facilities may create inefficiencies, reduce utilization, and

duplicate infrastructure, whereas optimally located dry port can enhance seaport–hinterland integration, alleviate bottlenecks, and stimulate regional development [5]. Accordingly, this study aims to evaluate and identify the most suitable dry port locations serving maritime and inland waterway ports in Europe. The specific problem addressed is the prioritization of candidate locations based on connectivity, sustainability, infrastructure readiness, institutional support, and economic potential. To this end, a hybrid multi-criteria decision-making (MCDM) model is proposed, integrating the Step-Wise Weight Assessment Ratio Analysis (SWARA), Delphi, and Axial Distance-based Aggregated Measurement (ADAM) methods within a fuzzy environment. This approach combines expert judgment with structured evaluation framework. The results indicate that Duisburg ranks as the most suitable location, followed by Vienna and Belgrade, reflecting both the strength of established Central European hubs and the growing importance of the Western Balkans in regional logistics.

This research contributes by applying a comprehensive criteria-based MCDM framework that incorporates sustainability, institutional,

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and policy dimensions into dry port location planning while extending the analysis across a wide European context. Theoretically, the study reinforces the applicability of MCDM in maritime and transport research. Practically, it provides a decision-support tool for policy-makers, port authorities, logistics operators, and investors, offering an evidence-based ranking that can guide infrastructure development and policy alignment with European transport strategies.

The remainder of the paper is structured as follows: [Section 2](#) reviews relevant literature; [Section 3](#) outlines the problem and stakeholders; [Section 4](#) presents the methodology; [Section 5](#) reports the analysis; [Section 6](#) discusses the results; and [Section 7](#) concludes the study.

2. Background and related literature

The selection of dry port locations constitutes a strategic planning problem at the intersection of maritime logistics systems, inland transport corridors, and regional economic development. While prior research has extensively examined the role of dry ports in improving hinterland accessibility and reducing pressure on seaports, most studies focus on individual dimensions of the problem, such as infrastructure availability, corridor positioning, or environmental performance, rather than integrating them within a unified decision-support framework that explicitly reflects maritime–inland system interactions and stakeholder perspectives. This study addresses this gap by positioning dry port location selection within the broader context of European maritime logistics networks and by applying a hybrid multi-criteria framework that simultaneously incorporates connectivity, sustainability, institutional readiness, and expansion potential.

To clarify this positioning, the literature review is organized around three interconnected research streams: (i) maritime logistics and hinterland integration, (ii) dry port development and location planning, and (iii) the application of hybrid MCDM methods in infrastructure decision-making.

2.1. Maritime logistics and hinterland integration

Maritime logistics research has progressively evolved from port-centric analyses toward integrated network perspectives that explicitly link maritime and inland transport systems. Early studies focused primarily on shipping markets, port competition, and logistics outsourcing structures [6–8]. Subsequent research shifted attention to ports as nodes embedded within extended supply chains and logistics clusters [9–11]. More recent contributions emphasize regionalization processes and the increasing importance of inland integration for improving supply-chain efficiency and resilience [12]. At the operational level, research has focused on terminal automation, energy efficiency, and digitalization as drivers of performance improvement [1,13,14]. In parallel, sustainability-oriented studies examine decarbonization strategies, biodiversity impacts, and responses to supply-chain disruptions [15,16].

Within this evolving research landscape, hinterland connectivity has emerged as a central determinant of port competitiveness. Logistics corridors, inland terminals, and logistics clusters increasingly function as extensions of maritime gateways, supporting cargo consolidation, modal shift, and regional accessibility [17–19]. Accordingly, conceptual models describe maritime logistics as a multi-layered system comprising liner shipping networks, port interfaces, and inland transport structures, whose performance depends on coordinated development across all layers [20–22]. Within this system, dry ports play a particularly important role as inland extensions of seaports, relocating logistics functions closer to hinterland markets and improve the efficiency of maritime–inland transport integration [11,23–25]. However, despite their strategic importance, limited attention has been given to systematic approaches for selecting dry port locations in a way that explicitly reflect their function within maritime logistics networks. Addressing this gap constitutes a central motivations of the present study.

2.2. Dry port development and location planning

Research on dry ports has developed along several complementary directions reflecting their multifunctional role within transport and logistics systems. One stream focuses on conceptualization and classification of dry ports as inland extensions of seaports and components of global supply chains [26–28]. A second stream examines their contribution to hinterland accessibility, congestion reduction, and overall logistics chain efficiency [29–31].

Other studies emphasize the economic and regional development impacts of dry ports, including their role in strengthening national competitiveness and supporting corridor-based freight redistribution [32]. Operational and managerial perspectives, in turn, focus on productivity, governance structures, and value-added logistics services such as customs clearance and cargo consolidation activities [33–35].

Environmental and sustainability considerations represent another important research direction, particularly in relation to modal shift towards rail and inland waterways, emission reductions, and alignment with climate-policy objectives [36–38]. Institutional and regulatory aspects have also received attention, especially concerning investment models and the role of public-sector coordination in dry port development [39].

Within this broad research landscape, location planning has emerged as a central topic. Existing studies typically evaluate infrastructure availability, corridor positioning, and accessibility conditions using GIS-based models, optimization approaches, or cost–benefit analyses [4,40]. Given that dry port development involves multiple stakeholders and often conflicting objectives, hybrid multi-criteria decision-making approaches are increasingly employed to balance economic, environmental, and institutional considerations [5,41–44].

Nevertheless, most existing location-selection frameworks treat dry ports primarily as inland logistics nodes, rather than as functional components of integrated maritime logistics systems. Furthermore, relatively few studies explicitly integrate stakeholder perspectives and sustainability-oriented criteria within a unified Europe-wide evaluation framework. This study addresses both limitations.

2.3. Hybrid MCDM approaches in infrastructure and logistics decision-making

Multi-criteria decision-making methods are widely applied in infrastructure planning, as they enable the structured evaluation of alternatives under conflicting technical, environmental, institutional, and economic criteria. These methods differ in how they derive criteria weights and aggregate preferences, ranging from additive approaches (e.g., WSM, ARAS, COPRAS) to compromise-based techniques (e.g., TOPSIS, VIKOR, EDAS, CODAS), pairwise comparison models (e.g., AHP, ANP, BWM, FUCOM), and outranking approaches (e.g., ELECTRE, PROMETHEE).

However, individual MCDM methods often exhibit methodological limitations, particularly with respect to sensitivity in weighting procedures or aggregation structure. As a result, recent studies increasingly adopt hybrid frameworks combining complementary techniques [45]. Such hybrid approaches are particularly common in logistics and infrastructure planning context characterized by uncertainty and heterogeneous stakeholder inputs, where fuzzy environments enable more realistic representation of linguistic judgments [46].

Within this context, fuzzy SWARA has been widely applied to derive expert-based criteria weights [47–51], while fuzzy Delphi supports consensus formation and screening of evaluation structures under uncertainty [52–55]. The recently developed ADAM method introduces a geometric ranking logic designed to reduce rank-reversal effects while maintaining interpretability and computational simplicity [56,57].

Although these approaches have each been applied independently or in partial combinations, their integration within a unified fuzzy hybrid framework tailored to dry port location selection in the context of

maritime–hinterland logistics systems remains largely unexplored. The present study addresses this gap by combining fuzzy SWARA, fuzzy Delphi, and fuzzy ADAM into a structured group decision-support model for evaluating potential dry port locations across Europe.

3. Problem statement

The selection of dry port locations is a complex decision, as European cities vary significantly in terms of connectivity, infrastructure, land availability, and institutional conditions, all of which influence logistics performance and sustainability outcomes. This study addresses this complexity by systematically comparing potential locations across Europe using a structured multi-criteria approach aligned with stakeholder requirements and EU objectives for sustainable, resilient transport networks.

3.1. Potential locations

The selection of Belgrade, Budapest, Zagreb, Ljubljana, Vienna, Duisburg, Bratislava, Linz, Straubing, Basel, Kaunas, and Vilnius as potential dry port locations (Fig. 1) reflects a deliberate focus on cities that are well connected with the major European maritime ports, located at the intersection of key Pan-European and TEN-T corridors, as well as along major inland waterways such as the Danube and Rhine. Each candidate inland location was evaluated in terms of its functional role as a potential inland extension of major European maritime gateways, particularly the North Sea ports (Rotterdam, Antwerp, Hamburg), Adriatic ports (Koper, Rijeka, Trieste), and the Black Sea port of Constanța. These maritime linkages were explicitly considered when assessing connectivity, cargo attraction potential, and corridor

integration of the candidate dry port locations. Previous studies indicate that the integration of inland ports and dry ports within these corridors enhances the competitiveness of maritime gateways by extending their hinterlands and enabling more efficient inland distribution [3,58]. The chosen set covers both established logistics hubs like Duisburg, Vienna, and Basel, which serve as benchmarks for intermodal integration; and emerging nodes such as Belgrade, Zagreb, and Kaunas, which are gaining importance due to increasing container flows and expanding industrial bases. The selected locations provide a balanced representation of Western and Eastern Europe, bridging North–South and East–West transport flows, and ensuring broad geographic coverage of the European hinterland. Empirical evidence further shows that positioning dry ports along these corridors can reduce seaport congestion, lower environmental impacts through modal shift to rail and inland waterways, and support regional economic development [59,60]. Overall, this set offers a robust foundation for MCDM analysis, by capturing diverse spatial, economic, and environmental conditions across Europe. The following section provides a more detailed description of the selected locations.

Budapest (Hungary) (PL1) is an established logistics hub in Central Europe and one of the most strategically significant inland locations for dry port development. Situated on the Danube River, it benefits from strong multimodal connectivity, including access to river waterways, an extensive rail network, and a dense highway network. As the capital and largest economic center of Hungary, Budapest supports a diversified industrial base, generating substantial volumes of containerized cargo from the automotive, chemical, and electronics sectors. The city is located on the Rhine–Danube TEN-T Core Corridor, making it a key node for both east–west and north–south freight flows. Its position ensures efficient access to major maritime gateway ports on the Adriatic, North



Fig. 1. Dry port potential locations (PLs).
Source: authors' own work.

Sea, and Black Sea. In particular, Budapest can function as an inland extension for the ports of Rotterdam and Antwerp via the Rhine–Danube corridor, as well as for Koper, Rijeka, and Constanța through rail and inland waterway connections. This strategic positioning enables the consolidation of cargo flows from both Northern and Southern maritime gateways. From a sustainability perspective, Budapest's existing intermodal terminals and its national transport policy emphasize the modal shift to rail and inland waterways, in line with EU decarbonization objectives. The city already hosts major logistics parks and distribution centers that could be effectively integrated into a dry port system. Furthermore, ongoing railway modernization projects in Hungary's enhance its long-term potential as an inland extension of seaports. Budapest's combination of strategic location, multimodal connectivity, industrial capacity, and institutional support makes it a highly competitive candidate for dry port development.

Belgrade (Serbia) (PL2) represents a highly strategic potential location for a dry port development due to its position at the intersection of two Pan-European transport corridors: Corridor X, linking Central Europe with the Aegean Sea, and Corridor VII, following the Danube River. The city's port infrastructure, including the Port of Belgrade, provides direct access to road, rail, and inland waterway networks, ensuring trimodal connectivity. As the economic and administrative center of Serbia, Belgrade has a strong industrial and commercial base, generating significant freight flows in sectors such as construction materials, automotive components, and agricultural products. Its integration within the Western Balkans' regional trade network further reinforces its role as a transit and logistics hub, connecting Southeastern Europe to maritime gateways such as Bar, Thessaloniki, Rijeka, and Constanța, while also maintaining indirect connectivity to major North Sea ports such as Rotterdam and Antwerp via the Danube corridor. This multidirectional maritime connectivity strengthens its role in extending seaport hinterlands into the Balkans. From a sustainability perspective, EU and national policies promoting multimodal integration and rail modernization strengthen the potential of a Belgrade dry port, particularly by enabling a modal shift away from road transport. The city also benefits from available land and institutional support for logistics development, creating favorable conditions for future expansion. Overall, Budapest's combination of strategic location, multimodal connectivity, industrial capacity, and institutional support makes it a highly competitive candidate for dry port development.

Zagreb (Croatia) (PL3) is strategically positioned to serve as the inland counterpart to the Port of Rijeka, Croatia's main maritime gateway. The capital lies on Pan-European Corridor Vb and forms part of the Mediterranean TEN-T Corridor, linking the Adriatic region with Central and Eastern Europe. Its strong multimodal connectivity is supported by direct rail and road links to Rijeka, while the ongoing modernization of the port's container terminal reinforces the need for an inland extension to accommodate growing cargo volumes. Zagreb hosts a well-developed industrial base, with distribution centers, manufacturing facilities, and customs zones generating substantial freight flows. As Croatia's economic and political center, the city also functions as a key logistics platform for domestic markets and neighboring countries, including Slovenia, Hungary, and Bosnia and Herzegovina. From a sustainability perspective, the development of a dry port in Zagreb could help alleviate congestion at the Port of Rijeka while promoting modal shifts toward rail transport. Although primarily linked to the Port of Rijeka, Zagreb also maintains functional connections to the ports of Koper and Trieste. Moreover, its inland connections toward Central Europe enable indirect integration with North Sea ports such as Rotterdam and Antwerp, allowing it to act as a consolidation point for both Adriatic- and North Sea-oriented cargo flows.

The city benefits from the availability of land for logistics development, while national transport strategies emphasize intermodal expansion and EU-funded infrastructure integration. These factors position Zagreb as a promising inland logistics hub capable of consolidating Adriatic-Balkan flows and strengthening trade connections between

maritime gateways and inland markets in Central Europe.

Ljubljana (Slovenia) (PL4) benefits from a central location in Slovenia and direct connection to the Port of Koper, one of the fastest-growing container ports on the Adriatic. The city lies along the Baltic–Adriatic TEN-T Corridor, providing strong rail and road connections to Austria, Italy, and Hungary, and enhancing its role as a cross-border logistics hub. Its multimodal connectivity is further supported by an extensive railway system, which is currently undergoing modernization to increase capacity and efficiency for freight transport. Although Ljubljana's economic base is smaller than that of larger European capitals, it is strengthened by logistics parks, freight villages, and a growing services sector that supports intermodal operations. As the Port of Koper continues to expand, Ljubljana emerges as a natural inland extension, capable of accommodating customs, storage, and consolidation functions that help relieve pressure on the seaport. While closely linked to the Port of Koper, Ljubljana also connects to the ports of Trieste and Venice. In addition, its position along the Baltic–Adriatic corridor facilitates broader connectivity toward Northern European ports such as Rotterdam and Hamburg. Sustainability is a key priority in Slovenia's transport policy, which emphasizes rail as the backbone of freight transport, in line with EU Green Deal objectives. National strategies support the development of intermodal terminals and promote partnerships between public authorities, ports, and private logistics operators. Ljubljana's combination of strategic location, multimodal connectivity, institutional support, and proximity to a major seaport makes it a highly suitable candidate for dry port development in Central Europe.

Vienna (Austria) (PL5) is one of Europe's most advanced inland logistics hubs, combining geographic centrality with high-quality multimodal infrastructure. Located on the Rhine–Danube TEN-T Corridor, the city benefits from direct access to inland waterways, supported by well-developed rail and road networks. Vienna's port facilities on the Danube handle millions of tons of freight annually, including containers, bulk cargo, and project shipments, demonstrating strong capacity for intermodal operations and future expansion. As Austria's capital and a major economic center, Vienna hosts well-developed logistics, industrial, and service sectors that generate substantial import and export flows. Its role in European freight distribution extends beyond national borders, serving as a logistics hub for neighboring countries such as Slovakia, Hungary, and the Czech Republic. Sustainability is a central component of Austria's transport policy, and Vienna is at a forefront of promoting green logistics, digitalization, and modal shift toward rail and inland waterways. The city also benefits from a stable institutional environment that supports large-scale infrastructure investment, including EU-funded intermodal projects. With strong connectivity to both North Sea and Black Sea ports, Vienna functions as an inland extension of Rotterdam and Antwerp via the Rhine–Danube corridor, as well as Constanța through inland waterways. This dual maritime orientation enhances its strategic relevance in European logistics networks. Vienna's combination of advanced infrastructure, industrial strength, and alignment with European transport strategies makes it an exemplary candidate for dry port development.

Duisburg (Germany) (PL6) is widely recognized as Europe's largest and most advanced inland port, making it both a benchmark and a strong candidate for further dry port development. Strategically located at the confluence of the Rhine River and one of the continent's densest rail and road networks, Duisburg offers exceptional multimodal connectivity. The port complex, known as Duisport, operates numerous trimodal terminals handling over three million TEUs annually. It provides direct inland waterway access to major maritime gateways such as Rotterdam and Antwerp, as well as strong rail connections to Hamburg. This positions Duisburg as a key inland extension of North Sea ports, directly integrating maritime and inland logistics systems. Its logistics base is highly developed, hosting global shipping lines, freight forwarders, and major distribution centers that serve both European and intercontinental trade. Integration within the Rhine–Alpine TEN-T

Corridor further reinforces its role as a key axis for north–south and east–west freight flows. In addition, Duisburg serves as a European gateway for the Belt and Road Initiative, with frequent rail services to China and Central Asia, thereby enhancing its long-distance connectivity. Sustainability is a central element of Duisburg’s development strategy, supported by investments in green logistics, digitalization, and energy-efficient operations. Institutional support is also strong, with close collaboration between government, port authorities, and private stakeholders ensuring long-term competitiveness. Although Duisburg is already highly developed, its capacity to expand value-added logistics services and its role as a model inland port make it a leading reference point for dry port development in Europe.

Bratislava (Slovakia) (PL7), located on the Danube River at the tri-border area of Slovakia, Austria, and Hungary, represents a strong candidate for dry port development in Central Europe. The city benefits from multimodal connectivity through inland waterways, an extensive rail network, and highway links to Vienna, Budapest, and Brno, creating a highly interconnected logistics environment. Its industrial and logistics base is well developed, with significant activity in automotive, machinery, and chemical sectors that generate substantial containerized and bulk freight flows. Bratislava is integrated into the Rhine–Danube TEN-T Corridor, reinforcing its role as a strategic inland node with direct access to maritime gateways such as Rotterdam and Antwerp via inland waterways, and Constanța via the Danube. This positioning enables Bratislava to act as a key connector between North Sea and Black Sea logistics systems. From a sustainability perspective, the city strong potential for shifting freight from road to rail and inland waterways, thereby reducing congestion and emissions in this densely cross-border region. The Slovak government has prioritized the modernization of port facilities and rail infrastructure, further strengthening institutional support for future dry port development. In addition, the availability of land near existing industrial and logistics zones makes feasible expansion. Bratislava’s combination of geographic centrality, multimodal connectivity, and growing regional demand positions it as an effective logistics hub capable of consolidating and redistributing freight flows across Central and Southeastern Europe, while complementing both maritime and inland waterways systems.

Linz (Austria) (PL8), located on the upper Danube, is one of Austria’s key industrial and logistics centers, offering strong potential for dry port development. The city benefits from trimodal connectivity through its inland port, direct integration into Austria’s extensive railway network, and proximity to major highways linking it to Vienna, Munich, and Bratislava. Linz’s has particularly strong industrial base, hosting leading companies in the steel, chemicals, and heavy machinery sector, generating high volumes of inbound raw materials and outbound finished products. These flows already rely on intermodal transport and could be further optimized through the development of a dedicated dry port. Linz is part of the Rhine–Danube TEN-T Corridor, ensuring integration with European transport strategies and providing connectivity to major maritime gateways including Rotterdam, Antwerp, and Constanța. These connections allow Linz to support both westbound and eastbound maritime cargo flows. From a sustainability perspective, Linz benefits from Austria’s strong national emphasis on modal shift and green logistics, closely aligned with EU policy objectives. The city already hosts a trimodal terminal with logistics parks and available land for expansion, providing a strong foundation for growth. Institutional support for intermodal investment is also strong, with both government and private operators committed to strengthening Austria’s role in multimodal freight transport. Linz’s strategic location, strong industrial base, and integration into European corridors make it a highly viable candidate for dry port development.

Straubing (Germany) (PL9), located in Bavaria on the Danube River, represents an emerging inland logistics hub with strong potential for dry port development. Its strategic position along the Rhine–Danube TEN-T Corridor provides inland waterway access to Rotterdam and Antwerp via the Rhine–Danube axis, as well as Constanța toward the

Black Sea. This positioning allows Straubing to function as a secondary yet complementary inland node within the broader maritime logistics network. Straubing’s port infrastructure is already trimodal, integrating inland waterway, rail, and road transport. It is further supported by regional highway and rail networks connecting Straubing to Munich, Nuremberg, and Vienna. Although its logistics and industrial base is smaller compared to major hubs, it is steadily growing, with activity in agricultural products, renewable energy, and manufacturing sectors. Sustainability is a distinctive feature of Straubing’s development strategy with strong emphasis on environmentally friendly freight solutions and integration of renewable energy into logistics operations. The institutional framework is also supportive as regional policies in Bavaria prioritize investments in green transport and inland waterway development. Straubing benefits from the availability of land for expansion and experiences lower congestion compared to larger logistics hubs, offering flexibility for future infrastructure development. Its role as a regional logistics node complements larger inland ports like Linz and Vienna, strengthening multimodal capacity along the upper Danube corridor. Overall, Straubing combines geographic centrality, a strong sustainability focus, and growth potential, making it a promising but still developing candidate for dry port infrastructure.

Basel (Switzerland) (PL10) is Switzerland’s largest inland port and a critical logistics hub located at the tri-border area with Germany and France. Positioned on the Upper Rhine, it provides direct inland waterway access to Rotterdam and Antwerp, as well as rail connections to Hamburg, thereby functioning as Switzerland’s primary inland extension of North Sea ports. Basel’s logistics base is highly developed, supporting the key export-oriented industries such as chemical, pharmaceutical, and machinery. Its multimodal infrastructure includes several container terminals, extensive rail connections to European freight corridors, and strong road connections to Central and Southern Europe. Basel is integrated into the Rhine–Alpine TEN-T Corridor, making it an essential node in one of Europe’s busiest freight axes. Sustainability is a core component of Swiss logistics policy, and Basel has made significant investments in reducing emissions through modal shift, energy-efficient operations, and strict environmental regulations. Institutional support is particularly strong, supported by stable governance and cross-border collaboration with France and Germany. In addition, Basel offers potential for further expansion in both capacity and digitalization, ensuring continued competitiveness as freight volumes increase. Basel’s combination of advanced infrastructure, strategic cross-border location, and alignment with sustainable transport goals makes it an exemplary inland logistics hub and a strong candidate for further dry port integration within the European network.

Kaunas (Lithuania) (PL11) is emerging as a strategically important logistics hub in the Baltic region, positioned at the intersection of the Rail Baltica project and Lithuania’s main highway network. Although not directly on a major navigable river, Kaunas offers strong multimodal connectivity through rail, road, and air links, supported by proximity to the seaport of Klaipėda. Integration with Rail Baltica further enables connections to major North Sea ports such as Rotterdam and Hamburg via Poland, positioning Kaunas as an emerging inland extension linking Baltic and North Sea maritime systems. Its logistics base is expanding rapidly, with intermodal terminals, distribution centers, and industrial zones generating increasing freight flows, particularly in automotive, agricultural, and electronics sectors. Kaunas plays a pivotal role in the Rail Baltica project, which connects the Baltic states with Poland and the rest of the European rail network, reinforcing its importance as a corridor-based logistics node. Sustainability is embedded in Lithuania’s transport strategy, with EU funding supporting modal shift to rail and the integration of green technologies in logistics operations. Kaunas also benefits from available land and infrastructure capacity, enabling its development into a dedicated dry port that could provide consolidation and customs services while reducing pressure on Baltic seaports. Institutional support is strong, with national and EU-level initiatives prioritizing Kaunas as a central hub in the North Sea–Baltic Corridor. Kaunas

growing logistics base, strategic position, and alignment with European corridor development make it a highly promising location for future dry port development.

Vilnius (Lithuania) (PL12), the capital of Lithuania, is gaining importance within the Baltic logistics landscape, particularly through its integration into the Rail Baltica corridor. Although not located on a navigable river, the city compensates with strong multimodal connectivity, including expanding rail infrastructure, highway access to Poland, Latvia, and Belarus, and an international airport. Vilnius has a diverse and growing logistics base, with increasing activity in retail distribution, automotive supply chains, and high-technology industries, generating substantial freight flows. Its inclusion in the North Sea–Baltic TEN-T Corridor highlights its role as an emerging logistics hub, facilitating cargo flows between the port of Klaipėda and inland European markets. Rail Baltica further strengthens its integration with ports such as Rotterdam and Hamburg, enhancing its role within extended maritime supply chains. Sustainability considerations further support its development, as Lithuania's transport policies encourage modal shift and investments in environmentally friendly transport under the EU Green Deal framework. Vilnius also has significant expansion potential, with logistics parks and intermodal terminals already under development that could be integrated into a dry port system. Institutional support is strong, driven by national strategies and EU investments in Rail Baltica, which is expected to transform Vilnius into a key inland gateway connecting Northern and Central Europe. By combining its capital city status, emerging logistics infrastructure, and strategic integration into pan-European corridors, Vilnius is a competitive and future-oriented candidate for dry port development.

3.2. Evaluation criteria

As stated previously, the potential locations differ in several aspects, therefore, a structured set of criteria has been established for their evaluation and ranking. The evaluation criteria used in this study were derived based on a structured review of the relevant literature on dry port location planning, intermodal terminal assessment, and maritime–hinterland connectivity, complemented by the authors' expert judgment in the fields of logistics, intermodal transport, and infrastructure planning. The selection process aimed to identify criteria that capture the most relevant infrastructural, connectivity-related, economic, environmental, and institutional dimensions of dry port development in the function of maritime logistics systems. In addition, each criterion included in the final set is explicitly supported by references from previous studies addressing similar location-selection problems, ensuring both theoretical grounding and practical relevance of the adopted criteria framework.

Intermodal Connectivity (C1) - This criterion evaluates how well the location is connected to rail, road, and inland waterway networks. Efficient intermodal connectivity reduces transshipment costs and time, enhances reliability, and enables modal shift toward more sustainable transport. A strong dry port candidate should offer high-capacity, synchronized links to maritime ports and regional logistics hubs. Similar intermodal-connectivity indicators have been widely applied to evaluate dry port efficiency and classify hinterland terminals according to rail–road–waterway linkages [3].

Proximity to Maritime and Inland Waterway Ports (C2) - This refers to the physical and operational distance from seaports and navigable inland waterways. Proximity was interpreted not only in terms of physical distance but also as functional accessibility to major European maritime gateways such as Rotterdam, Antwerp, Hamburg, Koper, Rijeka, Trieste, and Constanța, which represent the primary seaport interfaces considered in the evaluation of candidate dry port locations. Locations closer to seaports are better positioned to function as inland extensions of maritime gateways, enabling faster cargo transfers.

However, moderate distance can be advantageous for decongesting port areas and serving inland markets more directly. Distance to seaports or navigable waterways is a standard location factor in dry port typology and implementation analyses [60].

Availability of Land and Infrastructure (C3) - This criterion assesses whether the location has sufficient space for terminal expansion and existing infrastructure for dry port operations, including container yards, storage facilities, and customs areas. It also includes the potential for future upgrades. Sites with modern infrastructure require less investment and allow for faster deployment. Land availability and existing intermodal-yard infrastructure were explicit decision criteria in AHP-based dry port location studies such as that for the Port of Rijeka [4].

Environmental Sustainability (C4) - This criterion considers the environmental implications of establishing a dry port at given location. It includes factors such as potential reductions in road freight emissions, opportunities to use rail or inland waterways, impact on local ecosystems, and alignment with EU Green Deal goals. Sites with strong sustainability performance contribute to the decarbonization of logistics chains. Environmental and emission-reduction aspects are often used in sustainability-oriented dry port assessments (e.g. [5]).

Potential to Attract Cargo Flows (C5) - This criterion reflects the ability of a location to generate or attract freight volumes based on its industrial base, population density, consumption zones, or position within supply chains. Locations situated near manufacturing clusters, large distribution centers, or consumption markets are more likely to support high cargo throughput. Cargo-flow potential and hinterland demand have been used to evaluate dry port competitiveness and throughput capabilities [29].

Integration into TEN-T Corridors and EU Policy Frameworks (C6) - This criterion evaluates whether the location is along European Core or Comprehensive TEN-T Corridors and whether it is aligned with EU infrastructure investment strategies. Integration into these networks supports long-term funding, harmonization of technical standards, and better access to cross-border logistics flows. Alignment with the TEN-T core-network corridors is a recognized evaluative dimension in European dry port and freight-corridor planning [61].

Institutional and Regulatory Support (C7) - This criterion addresses the level of national, regional, or local government support, policy alignment, and the presence of public-private partnerships. Strong institutional support facilitates planning approvals, access to funding, and long-term sustainability of projects. It also includes customs efficiency and, where relevant, border procedures. Institutional support, customs efficiency, and public–private cooperation are repeatedly highlighted as decisive factors for the successful dry port implementation [39].

Economic Viability and Investment Attractiveness (C8) - This criterion assesses the economic feasibility of dry port development at the specific location, including land and labor costs, ease of doing business, and the likelihood of attracting private investment. Locations with favorable economic conditions and low development barriers are more likely to attract logistics operators and generate returns. Economic feasibility and investment attractiveness criteria are central in optimization-based dry port location models [62].

Existing Logistics Ecosystem (C9) - This criterion measures the presence of existing logistics services such as freight forwarders, 3PL/4PL providers, warehousing companies, and technology infrastructure. A developed logistics ecosystem reduces the startup time of a dry port and enhances synergies among supply chain actors, improving service quality and competitiveness. The presence of logistics clusters and value-added service providers is commonly considered a positive locational attribute [11].

Resilience and Risk Factors (C10) - This criterion includes the vulnerability of the location to geopolitical, economic, or climate-related disruptions. Locations in politically stable areas with low

exposure to natural hazards and solid infrastructure maintenance regimes are more likely to offer reliable long-term performance, which is essential for investors and supply chain continuity. Recent models include infrastructure reliability, geopolitical stability, and environmental risk among dry port selection criteria to enhance network resilience [62].

3.3. Stakeholders

When addressing the complex problem of dry port location selection, it is essential to consider the perspectives of all relevant stakeholders, as their diverse interests, resources, and objectives [2] directly influence feasibility and long-term sustainability. Integrating these perspectives helps ensure that selected locations support efficient logistics operations, align with policy goals, and gain broad acceptance across economic, environmental, and social dimensions. The main stakeholder groups and their goals are outlined below.

National and Regional Governments shape policy, land-use planning, and funding mechanisms that are critical for dry port development [63]. Their priorities include strengthening connectivity, supporting regional development, attracting investment, and reducing freight-related environmental impacts. Governments aim to balance economic benefits with public interest, ensuring alignment with broader transport, spatial planning, and sustainability strategies, including EU and TEN-T requirements.

Port Authorities (Seaports and Inland Waterway Ports) are responsible for coordinating capacity, hinterland connections, and community systems [64]. Their main goal is to extend hinterland reach, reduce port congestion, and improve cargo flow efficiency by developing inland extensions. Well-positioned dry ports enhance ports competitiveness, attract shipping lines, and support high-volume multimodal distribution.

Logistics Service Providers—including freight forwarders, rail operators, trucking firms, and 3PL/4PL companies—integrate dry ports into supply chains to improve efficiency [39]. Their priorities include reliable operations, shorter transit times, and cost reductions. They prioritize multimodal access, infrastructure quality, and digital integration that support coordinated, real-time logistics.

Logistics Service Users (Shippers and Receivers) represent the primary demand drivers [29]. Manufacturers, retailers, and importers/exporters seek predictable, cost-effective, low-risk supply chains. Proximity to dry ports can reduce lead times and facilitate sustainable modal shifts toward rail and inland waterways, supporting corporate ESG goals.

EU Institutions and Funding Bodies play a key role in shaping investment priorities for hinterland logistics infrastructure [65]. Through TEN-T, CEF/CINEA, and EIB programs, they promote cross-border connectivity, decarbonization, and resilient logistics net-

stakeholder integration, and the fuzzy ADAM method for ranking the alternatives. This structure enables the incorporation of multiple stakeholder perspectives, linguistic uncertainty, and complex trade-offs within a unified decision-support model. The implementation steps of the model are defined below.

Step 1: Define a problem structure. The first step implies the establishment of the sets of alternatives, criteria for their evaluation and relevant stakeholders interested in solving the problem.

Step 2: Adopt a fuzzy evaluation scale. Since the evaluations of criteria and alternatives is performed by the decision-makers representing one of the stakeholders, a linguistic scale that could be transformed into triangular fuzzy numbers is adopted (Table 1).

Step 3: Obtain the stakeholder-based criteria weights by applying the FSWARA method [66]. In this step FSWARA method is used to obtain criteria weights according to representatives of each stakeholder, separately. The result is a number of criteria weight sets that correspond to the number of considered stakeholders.

Step 3.1: Arrange the criteria in a descending order of the expected importance. As the evaluations are provided by representatives of multiple stakeholder groups, the Borda count method [67] is used to determine the aggregated ranking of criteria. Each stakeholder representative assigns a rank to all criteria, and points were allocated in reverse order (e.g., in a list of n criteria, the top-ranked criterion received n points, the second $n-1$, and so on). The points assigned by all experts are then aggregated, and the final ranking of criteria was established according to the total scores, with higher scores indicating higher overall priority.

Step 3.2: Evaluate the relative importance of the criterion j in relation to the criterion $(j-1)$ starting from the second criterion for each stakeholder d , $d = 1, \dots, o$, where o is the total number of stakeholders. Since there are multiple stakeholder representatives, the criterion scores were obtained by aggregating their individual assessments, whereby the value that appeared most frequently among the responses (i.e., the mode) was adopted for each criterion. This approach, known as mode-based aggregation [68], enables straightforward identification of the dominant opinion within each stakeholder groups, without the use of weighting or compromise. In this way, the relation called the comparative importance of the average value is obtained and it is denoted as \tilde{g}_{jd} , where $\tilde{g}_{jk} = \left(l_{jd}^{\tilde{g}}, m_{jd}^{\tilde{g}}, u_{jd}^{\tilde{g}} \right)$, $j=1, \dots, n$, is a triangular fuzzy number which corresponds to the most frequent linguistic response, transformed according to the terms given in Table 1. $l_{jd}^{\tilde{g}}$, $m_{jd}^{\tilde{g}}$ and $u_{jd}^{\tilde{g}}$ denote a lower, middle and upper value of the triangular fuzzy number \tilde{g}_{jd} , respectively.

Step 3.3: Calculate the coefficient \tilde{c}_{jk} in the following way:

$$\tilde{c}_{jd} = \begin{cases} (1, 1, 1), j = 1 \\ \left(l_{jd}^{\tilde{g}} / \max_j l_{jd}^{\tilde{g}}, m_{jd}^{\tilde{g}} / \max_j m_{jd}^{\tilde{g}}, u_{jd}^{\tilde{g}} / \max_j u_{jd}^{\tilde{g}} \right) \oplus (1, 1, 1), j = 2, \dots, n, \forall d = 1, \dots, o \end{cases} \quad (1)$$

works. Dry ports aligned with EU corridors and capable of enabling modal shift receive policy and financial support.

4. Methodology – a hybrid fuzzy SWARA- Delphi-ADAM model

To identify the most suitable dry port location in the function of maritime and inland waterway logistics, this study applies a hybrid fuzzy MCDM framework that combines the fuzzy SWARA method for criteria weighting, a fuzzy Delphi-based aggregation procedure for

Step 3.4: Calculate the preliminary weight values \tilde{q}_{jk} in the following way:

$$\tilde{q}_{jd} = \begin{cases} (1, 1, 1), j = 1 \\ \tilde{q}_{(j-1)d} \odot \tilde{c}_{jd}, j = 2, \dots, n, \forall d = 1, \dots, o \end{cases} \quad (2)$$

Table 1
Evaluation scale.

Linguistic evaluation	Abbreviation	Numerical value
“Extremely low”	“EL”	(1,1,2)
“Very Low”	“VL”	(1,2,3)
“Low”	“L”	(2,3,4)
“Fairly Low”	“FL”	(3,4,5)
“Medium”	“M”	(4,5,6)
“Fairly High”	“FH”	(5,6,7)
“High”	“H”	(6,7,8)
“Very High”	“VH”	(7,8,9)
“Extremely High”	“EH”	(8,9,10)

Step 3.5: Calculate the relative weights \tilde{w}_{jd} in the following way:

$$\tilde{w}_{jd} = \tilde{q}_{jd} \div \sum_j \tilde{q}_{jd}, \forall d = 1, \dots, o \tag{3}$$

where $\tilde{w}_{jd} = (l_{jd}^w, m_{jd}^w, u_{jd}^w)$

Step 3.6: Obtain the final criteria weights by integrating the assessments of different stakeholders by applying the following formula which represent part of the fuzzy Delphi method (adopted from Mikaeil et al. [69]):

$$\tilde{\delta}_j = (\alpha_j, \beta_j, \gamma_j), \alpha_j < \beta_j < \gamma_j, \tag{4}$$

$$\alpha_j = \min(l_{jd}^w), d = 1, \dots, o \tag{5}$$

$$\beta_j = \left(\prod_{d=1}^o m_{jd}^w \right), d = 1, \dots, o \tag{6}$$

$$\gamma_j = \max(u_{jd}^w), d = 1, \dots, o \tag{7}$$

where α_j, β_j and γ_j are the lower, medium and upper values of the integrated fuzzy evaluation $\tilde{\delta}_j$ respectively.

Step 4: Apply the fuzzy ADAM method [56] to rank the alternatives.

Step 4.1: Define the matrix.

$$\tilde{E} = [\tilde{e}_{ij}]_{m \times n} \tag{8}$$

where $\tilde{e}_{ij} = (l^e, m^e, u^e)$ are the evaluations of the alternatives i in relation to criteria j , m is the total number of alternatives.

Step 4.2: Define the matrix.

$$\tilde{S} = [\tilde{s}_{ij}]_{m \times n} \tag{9}$$

where $\tilde{s}_{ij} = (l^s, m^s, u^s)$ indicate the sorted evaluations \tilde{e}_{ij} in descending order.

Step 4.3: Find the fuzzy coordinates $(\tilde{x}_{ij}, \tilde{y}_{ij}, \tilde{z}_{ij})$ of the fuzzy reference \tilde{R}_{ij} and fuzzy weighted reference \tilde{P}_{ij} points:

$$\tilde{x}_{ij} = (l^{x_{ij}}, m^{x_{ij}}, u^{x_{ij}}) = (l^{s_{ij}} \times \sin \alpha_j, m^{s_{ij}} \times \sin \alpha_j, u^{s_{ij}} \times \sin \alpha_j), \forall j = 1, \dots, n; \forall i = 1, \dots, m \tag{10}$$

$$\tilde{y}_{ij} = (l^{y_{ij}}, m^{y_{ij}}, u^{y_{ij}}) = (l^{s_{ij}} \times \cos \alpha_j, m^{s_{ij}} \times \cos \alpha_j, u^{s_{ij}} \times \cos \alpha_j), \forall j = 1, \dots, n; \forall i = 1, \dots, m, \tag{11}$$

$$\tilde{z}_{ij} = (l^{z_{ij}}, m^{z_{ij}}, u^{z_{ij}}) = \begin{cases} (0, 0, 0), & \text{for } \tilde{R}_{ij} \\ (l^{p_{ij}}, m^{p_{ij}}, u^{p_{ij}}), & \text{for } \tilde{P}_{ij} \end{cases}, \forall j = 1, \dots, n; \forall i = 1, \dots, m \tag{12}$$

where α_j is obtained as:

$$\alpha_j = \left(\begin{matrix} j \\ -1 \end{matrix} \right) \frac{90^\circ}{n-1}, \forall j = 1, \dots, n \tag{13}$$

Step 4.4: Obtain the fuzzy values:

$$\tilde{V}_i^C = \oplus_{k=1}^{n-1} \tilde{V}_k, \forall i = 1, \dots, m \tag{14}$$

where \tilde{V}_k is obtained as:

$$\tilde{V}_k = \frac{1}{3} \tilde{B}_k \otimes \tilde{h}_k, \forall k = 1, \dots, n-1 \tag{15}$$

where \tilde{B}_k is obtained as:

$$\tilde{B}_k = \tilde{c}_k \otimes \tilde{a}_k \oplus \frac{\tilde{a}_k \otimes (\tilde{b}_k \ominus \tilde{c}_k)}{2} \tag{16}$$

where $\tilde{a}_k = (l^{a_k}, m^{a_k}, u^{a_k})$ in which:

$$l^{a_k} = \min \left(\sqrt{(u^{x_{j+1}} - l^{x_j})^2 + (u^{y_{j+1}} - l^{y_j})^2}, \sqrt{(l^{y_{j+1}} - u^{y_j})^2 + (l^{z_{j+1}} - u^{z_j})^2} \right)$$

$$m^{a_k} = \sqrt{(m^{x_{j+1}} - m^{x_j})^2 + (m^{y_{j+1}} - m^{y_j})^2}$$

$$u^{a_k} = \max \left(\sqrt{(u^{x_{j+1}} - l^{x_j})^2 + (u^{y_{j+1}} - l^{y_j})^2}, \sqrt{(l^{y_{j+1}} - u^{y_j})^2 + (l^{z_{j+1}} - u^{z_j})^2} \right) \tag{17}$$

$\tilde{b}_k = (l^{b_k}, m^{b_k}, u^{b_k})$ and $\tilde{c}_k = (l^{c_k}, m^{c_k}, u^{c_k})$ are equal to:

$$\tilde{b}_k = \tilde{z}_j \tag{18}$$

$$\tilde{c}_k = \tilde{z}_{j+1}, \tag{19}$$

Following the Eqs. (16)-(18), the Eq. (15) can be expressed as $\tilde{B}_k = (l^{B_k}, m^{B_k}, u^{B_k})$ in which:

$$l^{B_k} = l^{c_k} \times l^{a_k} + \frac{l^{a_k} \times (l^{b_k} - l^{c_k})}{2}$$

$$m^{B_k} = m^{c_k} \times m^{a_k} + \frac{m^{a_k} \times (m^{b_k} - m^{c_k})}{2}$$

$$u^{B_k} = u^{c_k} \times u^{a_k} + \frac{u^{a_k} \times (u^{b_k} - u^{c_k})}{2} \tag{20}$$

$$\tilde{h}_k = \frac{2\sqrt{\tilde{s}_k(\tilde{s}_k - \tilde{a}_k)(\tilde{s}_k - \tilde{d}_k)(\tilde{s}_k - \tilde{e}_k)}}{\tilde{a}_k} \tag{21}$$

where

$$\tilde{s}_k = \frac{\tilde{a}_k \oplus \tilde{d}_k \oplus \tilde{e}_k}{2} \tag{22}$$

where \tilde{d}_k can be expressed as $\tilde{d}_k = (l^{dk}, m^{dk}, u^{dk})$ in which:

$$\begin{aligned}
 l^{dk} &= \sqrt{(l^j)^2 + (l^j)^2} \\
 m^{dk} &= \sqrt{(m^x)^2 + (m^y)^2} \\
 u^{dk} &= \sqrt{(u^x)^2 + (u^y)^2}
 \end{aligned}
 \tag{23}$$

and \tilde{e}_k can be expressed as $\tilde{e}_k = (l^{ek}, m^{ek}, u^{ek})$ in which

$$\begin{aligned}
 l^{ek} &= \sqrt{(l^{j+1})^2 + (l^{j+1})^2} \\
 m^{ek} &= \sqrt{(m^{x+1})^2 + (m^{y+1})^2} \\
 u^{ek} &= \sqrt{(u^{x+1})^2 + (u^{y+1})^2}
 \end{aligned}
 \tag{24}$$

Following the Eqs. (22) and (23), the Eq. (21) can be expressed as $\tilde{s}_k = (l^{sk}, m^{sk}, u^{sk})$ in which:

$$\begin{aligned}
 l^{sk} &= \frac{l^{ak} + l^{dk} + l^{ek}}{2} \\
 m^{sk} &= \frac{m^{ak} + m^{dk} + m^{ek}}{2} \\
 u^{sk} &= \frac{u^{ak} + u^{dk} + u^{ek}}{2}
 \end{aligned}
 \tag{25}$$

and the Eq. (22) can be expressed as $\tilde{h}_k = (l^{hk}, m^{hk}, u^{hk})$ in which:

$$\begin{aligned}
 l^{hk} &= \frac{2\sqrt{|l^{sk} - l^{ak}| |l^{sk} - u^{dk}| |l^{sk} - u^{ek}|}}{u^{ak}} \\
 m^{hk} &= \frac{2\sqrt{|m^{sk} - m^{ak}| |m^{sk} - m^{dk}| |m^{sk} - m^{ek}|}}{m^{ak}} \\
 u^{hk} &= \frac{2\sqrt{|u^{sk} - l^{ak}| |u^{sk} - l^{dk}| |u^{sk} - l^{ek}|}}{l^{ak}}
 \end{aligned}
 \tag{26}$$

According to the transformed equations (19) and (25), the Eq. (14) can be expressed as $\tilde{V}_k = (l^{vk}, m^{vk}, u^{vk})$ in which:

$$\begin{aligned}
 l^{vk} &= \frac{l^{bk} \times l^{hk}}{3} \\
 m^{vk} &= \frac{m^{bk} \times m^{hk}}{3} \\
 u^{vk} &= \frac{u^{bk} \times u^{hk}}{3}
 \end{aligned}
 \tag{27}$$

and Eq. (13) as $\tilde{V}_i^C = (l^{vi^C}, m^{vi^C}, u^{vi^C})$ in which:

$$\begin{aligned}
 l^{vi^C} &= \sum_{k=1}^{n-1} l^{vk} \\
 m^{vi^C} &= \sum_{k=1}^{n-1} m^{vk} \\
 u^{vi^C} &= \sum_{k=1}^{n-1} u^{vk}
 \end{aligned}
 \tag{28}$$

$$\text{Crisp}(\tilde{V}_i^C) = (4 \times m^{vi^C} + u^{vi^C} - 2l^{vi^C}) / 3 (u^{vi^C} - 2l^{vi^C})
 \tag{29}$$

5. Results

To obtain the results and address the problem defined in Section 3, the MCDM model defined and described in Section 4 was applied. The stability of the obtained solution was assessed through sensitivity analysis, and the validity of the obtained results was verified by comparison with several selected MCDM methods.

5.1. Ranking of potential locations

Input data for the ranking of potential locations consisted of assessments by 34 experts, stakeholder representatives, regarding the importance of criteria and potential locations in relation to them. They used a linguistic scale that could be transformed into triangular fuzzy numbers (Table 1). The structure of those stakeholders representatives is shown in Table 2. The expert panel was formed using purposive sampling, including the key stakeholder group representatives involved in maritime logistics, intermodal transport planning, infrastructure development, and public-sector decision-making. Experts were selected based on demonstrated professional experience and familiarity with European transport corridors and logistics systems. To ensure the relevance of the assessments for a pan-European context, the panel included participants affiliated with institutions from different European regions (Western, Central, Southeastern, and Baltic Europe), providing a balanced geographical perspective on dry port location development.

During the evaluation process, experts assessed candidate locations with explicit consideration of their connectivity to specific maritime gateways, particularly the North Sea, Adriatic, Baltic, and Black Sea port systems. This ensured that the rankings reflect their role within maritime–inland logistics chains, rather than only inland accessibility.

After collecting the responses of the stakeholders representatives on the importance of the criteria, the Borda count method and mode-based aggregation approach were applied to obtain representative ratings of stakeholders, shown in Table 3. For illustration, the Borda count method was first applied to determine the ranking of criteria within each stakeholder group. For example, for the stakeholder group National and Regional Governments (6 experts), if the criteria C1, C4, C7, C10, C3, C5, C6, C8, C2, and C9 received the total Borda scores of 59, 54, 48, 42, 36, 30, 27, 17, 13, and 6, respectively, the resulting order was C1 > C4 > C7 > C10 > C3 > C5 > C6 > C8 > C2 > C9 (Table A1 in the Appendix 1), which corresponds to the order shown in Table 3. After establishing the

Table 2
Structure of representatives of stakeholders.

Stakeholder	Experience (Years)	Number of Experts	Regional affiliation
National and Regional Governments	<5 5–15 >15	2 3 1	Central Europe, Southeastern Europe
Port Authorities	<5 5–15 >15	1 2 2	North Sea region, Adriatic region, Baltic region
Logistics service providers	<5 5–15 >15	3 4 3	Western Europe, Central Europe
Logistics service users	<5 5–15 >15	3 3 3	Central Europe, Southeastern Europe
EU Institutions	<5 5–15 >15	1 2 1	Pan-European level

Source: authors' own work

Step 5: Rank the alternatives by the crisp values (adapted from [70])

Table 3
Representative evaluations of criteria in relation to stakeholders.

National and Regional Governments		Port Authorities		Logistics service providers		Logistics service users		EU Institutions	
C1	C1	C1	C5	C1	C5	C1	C1	C1	C1
C4	"EL"	C2	"EL"	C3	"EL"	C8	"EL"	C4	"EL"
C7	"EL"	C3	"L"	C5	"EL"	C1	"L"	C6	"EL"
C10	"EL"	C5	"EL"	C8	"EL"	C3	"EL"	C10	"EL"
C3	"M"	C7	"EL"	C9	"EL"	C9	"EL"	C2	"M"
C5	"EL"	C10	"EL"	C2	"FH"	C2	"FL"	C5	"EL"
C6	"EL"	C4	"M"	C10	"EL"	C4	"EL"	C7	"EL"
C8	"EL"	C6	"EL"	C7	"L"	C10	"EL"	C3	"FL"
C2	"M"	C8	"EL"	C4	"VL"	C6	"FL"	C8	"EL"
C9	"EL"	C9	"EL"	C6	"EL"	C7	"EL"	C9	"L"

Source: authors' own work

ranking order, mode-based aggregation was applied to obtain the representative comparative importance ratings within each stakeholder group. For example, when comparing C4 with the immediately preceding criterion C1, the six representatives of National and Regional Governments provided the following linguistic evaluations: EL, EL, VL, EL, EL, and L. Since "EL" (Extremely Low) was the most frequent response, it was adopted as the representative group assessment (Table A2 in the Appendix 2). The rest of the evaluations were obtained in the same manner.

The ratings shown in Table 3 represent the comparative importance of the average value, which were transformed into triangular fuzzy numbers based on the relations from Table 1. For the values obtained in this way, the coefficient \tilde{c}_{jk} was calculated by applying Eq. (1), and then by applying Eq. (2) and preliminary weight values \tilde{q}_{jk} . The relative weights \tilde{w}_{jd} were calculated using Eq. (3) and the final criteria weights were obtained by integrating the assessments of different stakeholders using Eqs. (4)-(7). These values are shown in Table 4.

Representatives of decision-makers also evaluated potential locations in relation to the criteria, and once again, by applying the mode-based aggregation approach, the scores shown in Table 5 were obtained.

The evaluations shown in Table 5 form the matrix \tilde{E} (8), which was transformed into the matrix \tilde{S} by applying Eq. (9). By applying Eqs. (10)-

Table 4
Final criteria weights.

Crit.	\tilde{w}_{jd} (National and Regional Governments)	\tilde{w}_{jd} (Port Authorities)	\tilde{w}_{jd} (Logistics service providers)
C1	(0.21,0.22,0.30)	(0.21,0.23,0.31)	(0.19,0.20,0.27)
C2	(0.01,0.03,0.04)	(0.16,0.20,0.26)	(0.04,0.06,0.09)
C3	(0.04,0.08,0.11)	(0.10,0.13,0.20)	(0.15,0.18,0.23)
C4	(0.16,0.19,0.25)	(0.02,0.05,0.07)	(0.01,0.03,0.05)
C5	(0.03,0.06,0.10)	(0.07,0.11,0.17)	(0.12,0.15,0.20)
C6	(0.03,0.06,0.08)	(0.02,0.04,0.06)	(0.01,0.03,0.05)
C7	(0.12,0.16,0.22)	(0.05,0.10,0.15)	(0.02,0.04,0.06)
C8	(0.02,0.05,0.07)	(0.01,0.03,0.06)	(0.09,0.13,0.18)
C9	(0.01,0.02,0.04)	(0.01,0.03,0.05)	(0.07,0.12,0.16)
C10	(0.09,0.14,0.19)	(0.04,0.08,0.12)	(0.03,0.06,0.08)
Crit.	\tilde{w}_{jd} (Logistics service users)	\tilde{w}_{jd} (EU Institutions)	\tilde{w}_{jd} (FINAL)
C1	(0.09,0.14,0.21)	(0.21,0.22,0.30)	(0.19,0.23,0.35)
C2	(0.02,0.05,0.09)	(0.05,0.08,0.11)	(0.01,0.07,0.26)
C3	(0.07,0.11,0.17)	(0.01,0.03,0.06)	(0.01,0.09,0.23)
C4	(0.02,0.04,0.08)	(0.16,0.19,0.25)	(0.01,0.04,0.25)
C5	(0.24,0.26,0.35)	(0.03,0.07,0.10)	(0.03,0.11,0.35)
C6	(0.01,0.02,0.04)	(0.12,0.16,0.22)	(0.01,0.05,0.22)
C7	(0.00,0.02,0.03)	(0.03,0.06,0.08)	(0.00,0.06,0.22)
C8	(0.17,0.22,0.29)	(0.01,0.03,0.05)	(0.01,0.07,0.29)
C9	(0.05,0.10,0.14)	(0.01,0.02,0.04)	(0.01,0.04,0.16)
C10	(0.01,0.04,0.06)	(0.09,0.14,0.19)	(0.01,0.08,0.19)

Source: authors' own work

(13) and based on the values from the previous matrix, the coordinates of the fuzzy reference \tilde{R}_{ij} and fuzzy weighted reference \tilde{P}_{ij} points were obtained. Using Eqs. (13)-(28), fuzzy values \tilde{V}_i^C were calculated for each potential location, and after their defuzzification using Eq. (29), they were used to obtain the final rank shown in Table 6.

The results indicate that the highest ranked potential location is PL6 (Duisburg), followed by locations PL5 (Vienna) and PL2 (Belgrade). The lowest ranked locations are PL8 (Linz) and PL9 (Straubing).

5.2. Sensitivity analysis

Solution stability was tested through a sensitivity analysis comprising eighteen additional scenarios (Sc.1-Sc.18) in which key input parameters, primarily criteria weights, were varied. The first twelve scenarios adjusted the weights of the three most influential criteria (C2, C6, C4) using lower, upper, defuzzified, and zero values, since these criteria dominate the model and are most likely to affect the ranking. Scenario 13 applied equal weights to all criteria, while Sc.14-Sc.18 used weight sets of individual stakeholder groups. All scenario results (Table 7) were compared with the baseline (Sc.0) to assess robustness.

In the first thirteen scenarios, there are no significant changes in the ranking of potential locations. Somewhat more significant deviations in ranking occur in the last five scenarios (Fig. 2). This was expected because the members of different stakeholders had significantly different views on the importance of certain criteria. Furthermore, this led to significantly different weights and, ultimately, to significant differences in rank. However, even in these scenarios, the first three ranked locations from the base scenario (Sc.0) were highly ranked. PL6 was between first and third position, PL5 between first and fourth, and PL2 between second and fifth. Overall, the sensitivity analysis showed a high degree of stability of the obtained solution, which is why it can be adopted as final.

5.3. Results validation

Validation was performed by comparing the obtained results with the results obtained using other, well-established and widely used MCDM methods, such as fuzzy VIKOR (*Vlsekriterijumska Optimizacija I Kompromisno Resenje*), fuzzy TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), fuzzy COBRA (Comprehensive distance-Based Ranking) and fuzzy CODAS (Combinative Distance-based Assessment). The results of the comparison are shown in Table 8 and Fig. 3. Spearman Correlation Coefficients (SCC) were calculated to determine the degree of agreement between the results obtained using different methods. The average SCC value of 0.945 indicates a very high degree of matching, on the basis of which it can be concluded that the proposed model is valid and that the obtained results can definitely be adopted as final.

It should be noted that the comparison with alternative fuzzy MCDM methods primarily confirms the internal consistency and methodological robustness of the proposed approach, rather than its external validity. However, the obtained ranking is broadly consistent with existing practitioner and policy-oriented assessments of major European inland logistics hubs. In particular, the leading positions of Duisburg and Vienna reflect their well-established roles as key inland extensions of North Sea and Danube maritime gateway systems, while the strong position of Belgrade corresponds with its increasing strategic importance within Southeastern European corridor development initiatives. This alignment with infrastructure planning priorities and logistics network development trends reported in policy and professional sources provides additional indirect support for the plausibility of the obtained results.

Table 5
Ratings of potential locations in relation to the criteria.

	PL1	PL2	PL3	PL4	PL5	PL6	PL7	PL8	PL9	PL10	PL11	PL12
C1	“VH”	“VH”	“VH”	“VH”	“EH”	“EH”	“VH”	“H”	“M”	“VH”	“FH”	“FH”
C2	“EH”	“VH”	“FH”	“H”	“VH”	“EH”	“H”	“H”	“M”	“H”	“FH”	“FH”
C3	“VH”	“VH”	“H”	“H”	“EH”	“EH”	“H”	“H”	“FH”	“H”	“H”	“H”
C4	“VH”	“VH”	“H”	“VH”	“EH”	“EH”	“H”	“H”	“FH”	“H”	“H”	“H”
C5	“H”	“H”	“H”	“VH”	“VH”	“EH”	“VH”	“H”	“H”	“EH”	“FH”	“FH”
C6	“FH”	“VH”	“H”	“VH”	“EH”	“EH”	“VH”	“VH”	“H”	“EH”	“H”	“H”
C7	“H”	“VH”	“H”	“VH”	“EH”	“EH”	“H”	“H”	“FH”	“EH”	“H”	“H”
C8	“FH”	“H”	“FH”	“H”	“VH”	“H”	“H”	“VH”	“VH”	“VH”	“H”	“H”
C9	“FH”	“VH”	“H”	“VH”	“EH”	“EH”	“VH”	“H”	“FH”	“VH”	“H”	“H”
C10	“H”	“VH”	“H”	“H”	“EH”	“EH”	“FH”	“FH”	“M”	“VH”	“FH”	“FH”

Source: authors’ own work

Table 6
Potential locations final ranking.

	\tilde{V}_i^c	Crisp(\tilde{V}_i^c)	Rank
PL1	(0.027;0.024;1.143)	0.354	6
PL2	(0.040;0.026;0.796)	0.361	3
PL3	(0.032;0.020;0.944)	0.351	8
PL4	(0.037;0.024;0.893)	0.357	4
PL5	(0.038;0.031;1.045)	0.362	2
PL6	(0.044;0.033;0.915)	0.367	1
PL7	(0.032;0.023;1.101)	0.352	7
PL8	(0.030;0.022;1.231)	0.349	11
PL9	(0.021;0.015;1.417)	0.343	12
PL10	(0.036;0.026;1.053)	0.356	5
PL11	(0.027;0.018;0.968)	0.349	9
PL12	(0.027;0.018;0.968)	0.349	9

Source: authors’ own work

6. Discussion

The results of the proposed hybrid fuzzy SWARA–Delphi–ADAM model indicate that Duisburg ranks as the most suitable location for dry port development in the function of maritime and inland waterway logistics systems in Europe. Unlike explanations based solely on its status as Europe’s largest inland port, the ranking can be interpreted through

the combined influence of several dominant criteria identified in the weighting process. Duisburg achieved particularly strong evaluations in intermodal connectivity (C1), integration into TEN-T corridors and EU logistics policy frameworks (C6), and cargo-flow attraction potential (C5). Its direct inland waterway connectivity with the major North Sea maritime gateways of Rotterdam and Antwerp, complemented by strong rail links to Hamburg, significantly strengthens its role as a primary inland extension of maritime logistics systems rather than merely a regional logistics hub. These characteristics explain its stable first position across most sensitivity scenarios.

Vienna ranked second due to its balanced performance across connectivity (C1), institutional support (C7), sustainability alignment (C4), and corridor integration (C6). Unlike Duisburg, whose strength derives from its proximity to the North Sea port system, Vienna’s strategic advantage lies in its position along the Rhine–Danube corridor, enabling simultaneous functional integration with Rotterdam, Antwerp, and Constanța. This dual maritime orientation increases its importance as a bridging node between Western and Southeastern European logistics systems.

Belgrade ranked third primarily because of its strong performance in geographic accessibility (C2), cargo-flow attraction potential (C5), and land availability and expansion capacity (C3), combined with its position at the intersection of Corridors X and VII. Its connectivity toward the ports of Thessaloniki, Rijeka, Bar, and Constanța enables it to serve

Table 7
Sensitivity analysis results.

	Sc.0	Sc.1	Sc.2	Sc.3	Sc.4	Sc.5	Sc.6	Sc.7	Sc.8	Sc.9
PL1	6	6	6	6	6	7	5	7	7	6
PL2	3	3	3	2	3	3	2	3	3	3
PL3	8	8	8	11	8	6	8	6	6	7
PL4	4	4	4	4	4	4	4	4	4	4
PL5	2	2	2	3	2	2	3	2	2	2
PL6	1	1	1	1	1	1	1	1	1	1
PL7	7	7	7	7	7	8	7	8	8	8
PL8	11	11	11	10	11	11	11	11	11	11
PL9	12	12	12	12	12	12	12	12	12	12
PL10	5	5	5	5	5	5	6	5	5	5
PL11	9	9	9	8	9	9	9	9	9	9
PL12	9	9	9	8	9	9	9	9	9	9
	Sc.10	Sc.11	Sc.12	Sc.13	Sc.14	Sc.15	Sc.16	Sc.17	Sc.18	
PL1	5	6	6	8	10	9	6	5	8	
PL2	2	3	3	2	5	3	2	2	4	
PL3	8	7	7	6	7	8	8	11	6	
PL4	4	4	4	4	3	2	5	7	2	
PL5	3	2	2	3	4	4	3	3	1	
PL6	1	1	1	1	2	1	1	1	3	
PL7	7	8	8	7	6	7	9	10	7	
PL8	11	11	11	11	11	6	7	6	11	
PL9	12	12	12	12	12	12	12	12	12	
PL10	6	5	5	5	1	5	4	4	5	
PL11	9	9	9	9	8	10	10	8	9	
PL12	9	9	9	9	8	10	10	8	9	

Source: authors’ own work

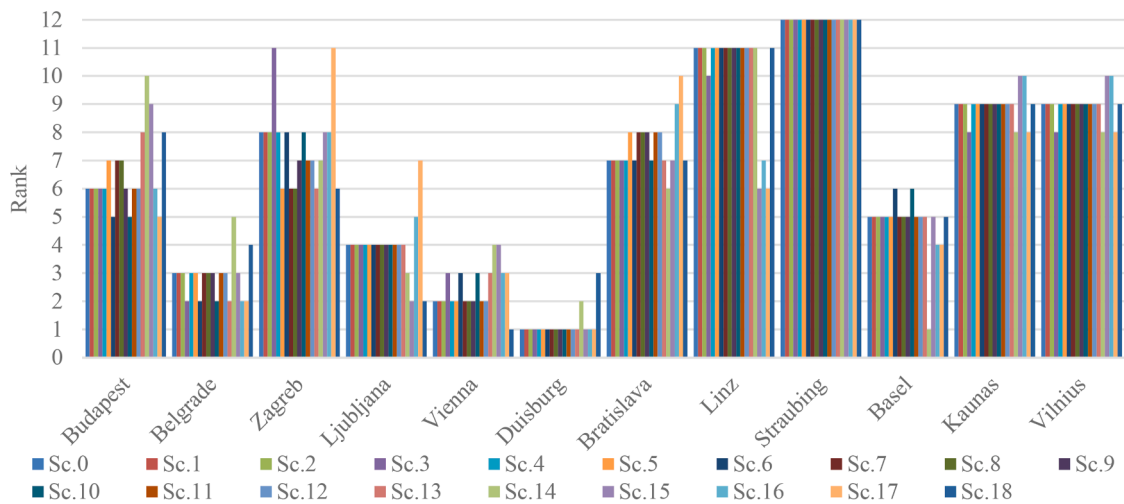


Fig. 2. Sensitivity analysis. Source: authors' own work.

Table 8 Results validation.

	FADAM	FVIKOR	FTOPSIS	FCOBRA	FCODAS
PL1	6	6	4	6	6
PL2	3	4	3	4	4
PL3	8	9	8	9	8
PL4	4	5	6	5	5
PL5	2	2	2	2	2
PL6	1	1	1	1	1
PL7	7	7	7	7	7
PL8	11	8	9	8	9
PL9	12	12	12	12	12
PL10	5	3	5	3	3
PL11	9	11	10	10	10
PL12	9	10	10	10	10
SCC	/	0.9352	0.95088	0.93684	0.9579

Source: authors' own work

as a key inland extension of maritime gateways for the Western Balkans. Compared with Budapest and Zagreb, Belgrade benefits from greater availability of expansion space and stronger strategic positioning within emerging Southeastern European freight corridors, which explains its advantage despite somewhat lower infrastructure maturity.

Budapest achieved slightly lower ranking than Belgrade mainly due to relatively higher infrastructure saturation and lower expansion flexibility (C3), although it performs strongly in corridor integration (C6)

and industrial cargo generation (C5). Zagreb ranked lower primarily because its maritime orientation is largely concentrated toward a single gateway (Rijeka), which limits diversification of maritime connectivity compared with locations positioned along multiple corridor systems.

Similarly, Linz and Straubing, despite their location along the Danube corridor and access to inland waterway transport, achieved lower rankings because of comparatively smaller logistics ecosystems (C9) and lower cargo-flow attraction potential (C5) relative to the leading

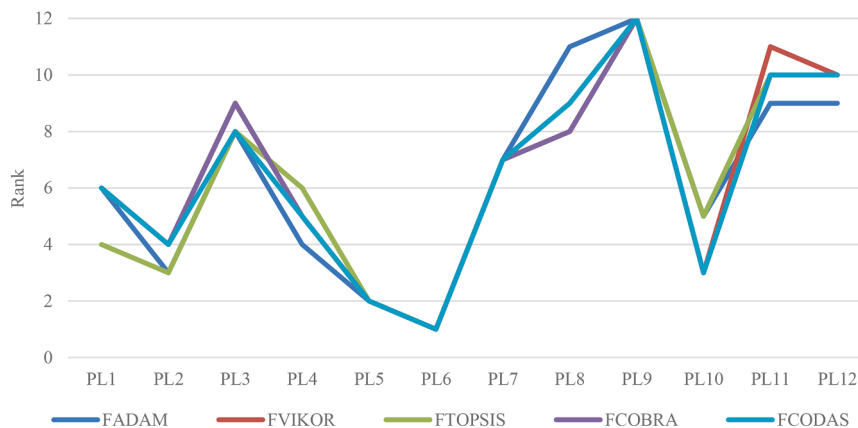


Fig. 3. Results validation. Source: authors' own work.

alternatives. Their maritime connectivity remains structurally indirect compared with Duisburg, Vienna, or Basel, which function as stronger inland extensions of major North Sea gateways.

The sensitivity analysis results further confirm the robustness of the obtained ranking. Variations in the weights of the most influential criteria (C2, C6, and C4) did not significantly affect the leading position of Duisburg, indicating that its dominance is structurally supported across multiple evaluation dimensions. However, scenarios based on individual stakeholder weight sets produced noticeable variations among middle-ranked alternatives, particularly between Belgrade, Budapest, Bratislava, and Linz. This reflects the different priorities of stakeholder groups, where policymakers emphasize corridor integration and sustainability, logistics operators prioritize connectivity and cargo-flow concentration, and investors focus on economic feasibility and expansion capacity. Such divergence confirms that dry port location selection is inherently a multi-stakeholder decision problem rather than a purely infrastructure-based optimization task.

Overall, the results demonstrate that the highest-ranked locations are those that simultaneously function as inland extensions of major maritime gateways, integrate multiple transport corridors, and offer sufficient infrastructure capacity and institutional support for long-term logistics development. This confirms the importance of combining maritime connectivity, corridor integration, and stakeholder perspectives within a unified evaluation framework when selecting dry port locations in Europe.

Compared with prior studies reviewed in Section 2, which typically evaluate dry port locations primarily from infrastructure availability, corridor positioning, or environmental perspectives individually, the proposed framework contributes by integrating these dimensions within a single stakeholder-oriented evaluation structure explicitly linked to maritime–hinterland logistics systems. Moreover, whereas earlier applications of MCDM methods in dry port location planning often focus on national or corridor-level analyses, this study extends the evaluation to a pan-European scale. It also combines structured expert consensus formation (Delphi), criteria weighting (SWARA), and geometric ranking logic (ADAM) within a unified fuzzy decision-making environment. These methodological and empirical extensions position the proposed framework beyond existing approaches and enable a more comprehensive assessment of dry port locations in relation to major European maritime gateway systems.

The study's main contributions lie in applying an integrated multi-criteria framework that evaluates dry port locations through sustainability, connectivity, industrial foundations, institutional readiness, and expansion capacity. A key methodological contribution is the introduction of a hybrid fuzzy MCDM model combining SWARA, Delphi, and ADAM, enabling a structured and transparent evaluation across a diverse European geography. Although the proposed model integrates already established MCDM techniques, its methodological contribution lies in the novel hybridization of the fuzzy SWARA, Delphi, and ADAM methods within a unified decision-making framework for dry port location selection. To the best of the authors' knowledge, this specific combination has not previously been applied in either conventional or uncertainty-based environments (e.g., fuzzy, grey, or rough sets). In the MCDM literature, the development of hybrid models that combine complementary weighting and ranking techniques is widely accepted methodological contribution, particularly in complex infrastructure and logistics planning problems characterized by multiple stakeholders and uncertainty. The proposed framework contributes by integrating structured expert consensus building (Delphi), criteria weighting (SWARA), and alternative ranking (ADAM) within a single fuzzy group decision-making environment tailored to maritime–hinterland logistics system planning.

Nonetheless, several limitations exist. The analysis is based on current infrastructure and policy conditions, which may evolve with technological change, new EU transport initiatives, or geopolitical developments. While the weighting approach is systematic, some level

of subjectivity inherent to expert-based MCDM frameworks remains. Future research could incorporate dynamic or scenario-based models to account for long-term changes in trade flows, digitalization, or climate resilience.

Theoretically, this study reinforces the value of MCDM in structuring complex logistics-location decisions, while practically, it provides useful guidance for policymakers, port authorities, logistics operators, and investors. The findings support investment prioritization, planning of multimodal corridors, and identification of locations with high strategic potential, thus offering a decision-support tool that contributes to more sustainable, efficient, and well-balanced maritime–inland logistics development across Europe.

7. Conclusion

This study addressed the problem of selecting suitable dry port locations in the function of maritime logistics by developing and applying a stakeholder-oriented hybrid fuzzy MCDM framework integrating fuzzy SWARA, Delphi-based aggregation, and the ADAM method. The proposed framework enabled a structured evaluation of twelve potential inland locations across Europe using connectivity, sustainability, institutional, economic, and logistics ecosystem criteria aligned with maritime–hinterland integration objectives.

The results confirmed the dominant strategic position of Duisburg as the leading inland logistics node, due to its exceptional multimodal connectivity, strong integration with major North Sea gateways such as Rotterdam and Antwerp, and its role within trans-European freight corridors. Vienna and Belgrade followed as highly competitive alternatives, reflecting the importance of corridor positioning, institutional support, and expansion potential in shaping future inland logistics structures in Central and Southeastern Europe. Importantly, the results demonstrate that dry port competitiveness depends not only on inland waterway accessibility but on balanced performance across connectivity, policy alignment, and logistics ecosystem readiness.

From a methodological perspective, the study contributes by integrating three complementary MCDM techniques within a unified fuzzy decision-support framework tailored to dry port location analysis in a maritime logistics context. Unlike many previous studies focusing primarily on infrastructure or cost-based indicators, the proposed framework explicitly incorporates stakeholder perspectives and links inland terminal selection with major European maritime gateways, thereby strengthening the maritime logistics positioning of dry ports within extended hinterland systems.

From a practical perspective, the results provide decision-support insights for policymakers, port authorities, logistics operators, and infrastructure investors. The proposed framework supports transparent prioritization of inland logistics investments and helps identify locations capable of strengthening seaport–hinterland integration, reducing congestion at maritime gateways, and supporting modal shift toward rail and inland waterways in line with EU transport and sustainability strategies.

The study has several limitations. The evaluation reflects current infrastructure conditions and expert-based assessments that may change with future corridor development, geopolitical shifts, and technological transformation of logistics systems. Future research could extend the framework through dynamic scenario modelling, integration of quantitative freight-flow simulations, or application to other corridor systems outside Europe.

CRedit authorship contribution statement

Violeta Roso: Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Conceptualization. **Snezana Tadić:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mladen Krstić:** Writing – review & editing, Writing – original

draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of competing interest

The authors declare that they have no known competing financial

Appendix 1. Illustrative example of applying the Borda count method

To determine the ranking order of criteria required for the application of the SWARA method, the Borda count procedure was applied to the individual rankings provided by representatives of each stakeholder group. As an illustration, Table A1 presents the example of the stakeholder group National and Regional Governments, consisting of six experts who ranked ten criteria according to their perceived importance.

Table A1

Order of criteria given by the experts belonging to National and Regional Governments stakeholder.

Expert	Criteria order									
	1	2	3	4	5	6	7	8	9	10
E1	C1	C4	C7	C10	C3	C5	C6	C8	C2	C9
E2	C1	C4	C10	C7	C3	C6	C5	C2	C8	C9
E3	C1	C7	C4	C10	C3	C5	C8	C6	C2	C9
E4	C1	C4	C7	C3	C10	C5	C6	C8	C2	C9
E5	C4	C1	C7	C10	C5	C3	C6	C8	C2	C9
E6	C1	C4	C7	C10	C3	C6	C5	C8	C2	C9

In the Borda count method, each ranking position is assigned a score inversely proportional to its ordinal position. Since ten criteria were evaluated, the criterion ranked first received 10 points, the second-ranked criterion received 9 points, and so on, while the last-ranked criterion received 1 point. By summing the scores assigned by all six experts, the total Borda scores for the criteria were obtained as follows:

$$C1 = 59, C4 = 54, C7 = 48, C10 = 42, C3 = 36, C5 = 30, C6 = 27, C8 = 17, C2 = 13, \text{ and } C9 = 6.$$

Based on these aggregated scores, the final ranking order of criteria for this stakeholder group was established as:

$$C1 > C4 > C7 > C10 > C3 > C5 > C6 > C8 > C2 > C9.$$

This ranking order was subsequently used as the input sequence required for the application of the SWARA method.

Appendix 2. Illustrative example of applying the mode-based aggregation approach

To obtain representative stakeholder-group evaluations of the comparative importance between criteria, the mode-based aggregation approach was applied to the linguistic assessments provided by individual experts within each stakeholder group. This approach selects the most frequently occurring linguistic evaluation as the representative group assessment.

As an illustration, Table A2 presents an example for the stakeholder group National and Regional Governments, consisting of six experts who evaluated the comparative importance of criterion C4 relative to criterion C1 using the linguistic scale defined in Table 1. The individual expert evaluations were: EL, EL, VL, EL, EL, and L.

Table A2

Evaluation of C1 against C4 according to the experts belonging to National and Regional Governments stakeholder.

Expert	Evaluation
E1	EL
E2	EL
E3	VL
E4	EL
E5	EL
E6	L

Since the linguistic evaluation EL (Extremely Low) appeared most frequently among the six responses, it was adopted as the representative stakeholder-group assessment. According to the predefined evaluation scale, this linguistic value corresponds to the triangular fuzzy number (1,1,2).

This representative fuzzy value was subsequently used as the group evaluation of the relative importance of criterion C4 with respect to criterion C1 in the further steps of the fuzzy SWARA procedure.

Data availability

Data will be made available on request.

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