

**iNEST – Interconnected Nord-Est
Innovation Ecosystem:
General Frame of the Project and Activities
of Young Researchers at the University of Trieste**



PNRR project “iNEST – Interconnected Nord-Est Innovation Ecosystem”
developed at the University of Trieste, Italy from 01/09/2022 to 31/12/2025

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Spoke 8 Maritime, marine and inland water technologies:
towards the Digital Twin of the Upper Adriatic

RT4 ⇨ Integrated Land-sea Maritime and Spatial Planning

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Integrated Land-sea Maritime and Spatial Planning

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⇨ ABSTRACT

Spoke 8 – RT4 examines meteorological and climate-driven changes in the Upper Adriatic coastal territories, particularly in the Friuli Venezia Giulia region, where the alternation of fresh and salt waters, wetlands, and dry areas is increasingly uncertain. Focusing on interactions from sea to land and employing a “research by planning and design” approach, RT4 aims to support the development of sustainable, integrated mobility across marine, inland, and terrestrial networks, fostering a more resilient organisation of settlements and water- and land-based economies.

➔ INTRODUCTION

Drawing inspiration from the *EU Mission: Restore our Ocean and Waters* and its objective of integrating research and innovation, citizen engagement, and blue investments (European Commission, 2025), Spoke 8 develops and tests technologies and spatial solutions for the management, monitoring, and climate change adaptation of marine and coastal environments. The primary expected outcome is the provision of a Digital Twin (DT) concept for the North Adriatic, a highly demanding task for both theoretical and applied research.

Specifically, the core aim of Spoke 8 is to establish an interdisciplinary Research & Innovation framework, assessing the constraints and potentials of spatial data tools, scenario development, and multi-stakeholder processes to support the climate transition in the Upper Adriatic coastal and marine areas. Within this framework, the activities conducted by the University of Trieste and the University IUAV of Venezia focus on Research Topic 4 (RT4) – *Integrated Land-sea Maritime and Spatial Planning*.¹ The emphasis is on the coastal and lowlands, particularly in the Friuli Venezia Giulia region, which are characterised by an increasingly uncertain alternation of fresh and salt waters, wetlands, and dry areas.

In these contexts, interventions to divert river courses and reclaim land have occurred over time, from the fifteenth century onwards, with intensification during the twentieth century (Giannotti, 2025). Moreover, this narrow and compressed portion of the Mediterranean presents itself as a “solid” and “urbanised” sea (Couling, Hein, 2020), crossed by major European transport corridors, animated by flows of people and economies, and punctuated by port and logistics hubs of national and international significance (Venezia, Trieste, Koper, Rijeka). Today, a diverse set of conditions and uses here coexists with complex meteorological, climatic, and ecological dynamics, affecting human activities. Significant environmental resources, urban centres and dispersed settlement systems, collective facilities and services are exposed to multiple risks, the most prominent of which are flooding and hydrogeological instability. To ensure territorial resilience, the challenge is to explore new spatial and functional configurations and visions.

➔ MOVING ACROSS WATERS AND LANDS: A VIEW ON CLIMATE TRANSITION

RT4 examines ongoing dynamics looking from the sea towards the land, with attention to their evolving interactions. This standpoint is not entirely new; for decades, the EU has encouraged integrated approaches to coastal and marine planning and climate adaptation (Maragno *et al.*, 2020). Yet this shift still remains fragmented across multiple instruments and governance levels, with limited coordination among programmes, timelines, and actions (Marchigiani, 2024).

Alongside the reversal of viewpoint, RT4 places emphasis on sustainable and integrated mobility across the sea, inland waters, and land. The hypothesis is that by concentrating on this theme – seemingly narrow, yet capable of rethinking the ways in which territories are organised and accessed – the impacts of meteorological and climate changes can be addressed, both in responding the short-term urgency of emergencies and in managing longer-term processes of structural transformation. This raises important issues: how to ensure the adaptation of settlements, infrastructure networks, and transport services, while guaranteeing accessibility to and between facilities; if and how these territorial systems can support more resilient water- and land-based economies, ranging from tourism to logistics and agricultural production.

¹ For the University of Trieste (Lead partner of Spoke 8), the scientific coordinator of RT4 is Elena Marchigiani (spatial planner and urban designer); participants are: Ludovico Centis, Alvise Pagnacco, Federico Vascotto (spatial planners and urban designers), and Stefano Graziani (photographer). For the University IUAV of Venezia, participants are: Francesco Musco (coordinator of the local unit), Barbara Gasparini di Gaetano, Emanuel Giannotti, Davide Longato, Giulia Lucertini, Maria Manfroni, Denis Maragno, Vittore Negretto, Michela Pace, Nicola Romanato, Elisa Scattolin, Maria Chiara Tosi, Luca Velo (spatial planners and urban designers), Daniele Bigolin (ecologist), Sebastiano Fabbrini (architectural historian), and Stefania Tonin (economist).

In the face of energy crisis and growing environmental impacts, the intent is to demonstrate the feasibility of transition toward sustainable mobility – not only for commercial purposes, but also for daily life and commuting – while addressing a range of strategic challenges for the future of the Upper Adriatic coastal zones: climate adaptation and decarbonisation; protection of biodiversity and fragile ecosystems; and improved conditions of liveability in increasingly “amphibious” contexts.

From RT4 perspective, adopting transition as a key concept means moving beyond a defensive stance that seeks to preserve territory at all costs – for instance, by erecting barriers to maintain the *status quo* or by prolonging unsustainable land-use models such as mechanical reclamation. Instead, the assumption is that transition requires approaches that lay the groundwork for new geographies and ecologies, renewed relationships between landscapes and ways of life, and processes of eco-territorialisation and reterritorialisation (Magnaghi & Marzocca, 2023). In today’s context of profound uncertainty – where attempts to map and measure the effects of climate change are constantly revised – the notion of transition draws on the concept of *mouvance* (Berque, 2016), reinterpreting territorial planning as an evolutionary process shaped by inseparable ecological, economic, and social dynamics.

➔ THICK AND DESIGN-ORIENTED DESCRIPTIONS: APPROACH AND FIELDS OF ACTIVITIES

The challenge of RT4 is both ambitious and complex: to develop analytical and design strategies that respond to increasing vulnerabilities by reimagining the spatial organisation of the coastal areas of the Upper Adriatic, particularly those of Friuli Venezia Giulia. Work unfolded through an iterative process of interpretative explorations, including cartographic inquiries, critical analyses of spatial dynamics and land uses, and reconstructions of the images conveyed by planning tools as well as by institutional and non-institutional actors. The objective was to produce “thick descriptions” (Geertz, 1973) of spaces, practices, and activities, paying close attention to the multi-directional and layered relations among diverse human and non-human agents. Operating within an “inexhaustible virtuous circle between interpretative and design-oriented research” (Palermo, 1992, p. 240), this process enabled the gradual identification of “transitional” themes and sites, with sustainable marine and inland mobilities along water routes, and their interplay with land-based networks, emerging as drivers for envisioning future scenarios and project strategies. To support the construction of the DT, the research also engaged with the critical assessment of institutional datasets (primarily regional), their potentials and limitations.

Adopting this approach, and in collaboration with the other RTs within Spoke 8, RT4 structured its work into five tasks: 1) investigating territorial structures and dynamics, together with the multiple impacts of climate change; 2) identifying gaps and prospects in spatial strategies, plans, and projects, at national, regional, and local levels; 3) collecting data on mobility demand and supply; 4) proposing spatial planning visions and site-specific design explorations, pilot projects, and guidelines emphasising integrated mobility; and 5) developing technologies for both monitoring climate change-related effects and the environmental impacts of mobility and other human activities, in order to support the assessment and revision of planning strategies and actions (Marchigiani *et al.*, 2025).

All activities were sustained by strong synergies with two complementary funding streams provided by Spoke 8, in line with RT4 overall objectives.

The most substantial was allocated to “Cascade Calls” (CCs), launched by the University of Trieste for networks of local enterprises in the north-eastern regions and provinces (Veneto, Friuli Venezia Giulia, Trento, and Bolzano), as well as for research institutions and companies in southern Italy. Aimed at fostering solutions with a high degree of technological innovation, four projects were funded during the summers of 2023 and 2024 to advance RT4 fifth task (iNEST, 2025).

Under the CCs call targeting southern Italy, “MERCIE. Eco-sustainable Models for Integrated and Inclusive Collaborative Urban Regenerations of the Land-Sea System” proposes

the development of a Collaborative Spatial Decision Support Tool and its implementation into a demo of an innovative DT. This tool is designed to guide actions towards integrated and resilient maritime and terrestrial systems. Using both satellite and *in-situ* data, and Machine Learning models, “M.A.R.A.N.O. Monitoring Environment, Aquatic Resources and Online Nautical Systems” and “F.A.S.T. Fluvial Analytical Scanning Technologies” create technological platforms to monitor the impacts of climate change and their interactions with ecological systems and navigability conditions, focusing respectively on the Marano and Grado lagoon and a section of the Litoranea Veneta waterway. Finally, “L.A.G.U.N.A.S. Localisation of Avifauna for a Sustainable Netcentric Urban Environmental Management” aims to deliver an innovative prototype capable of collecting and integrating data from multiple sources on the state of the Venice lagoon, monitoring air traffic and its impacts on avifauna, and supporting new sustainable transport solutions.

A second stream of funding was allocated to “Young Researchers” (YRs) from the Universities of Trieste and IUAV. The three selected research programmes address several operational topics related to the first four tasks of RT4. “*Deluge. Visualising the Unthinkable*” entails a couple of operations: the creation of a photographic documentation of cultural and environmental assets under radical changes due to climate transition; and the development of a methodology to assess economic losses in the real estate sector (Centis, 2025). “Ecopublica. The Eco-Public Network as a Framework and Project for Climate Change Adaptation in the Upper Adriatic Coastal Territories” focuses on mapping ecological networks, infrastructures related to active mobility, collective services, and initiatives promoted by institutions and third-sector actors, assessing their capacity to influence local social, economic, and ecological changes (Fabbri *et al.*, 2025; Velo *et al.*, 2025). “MOBIPLAN-FVG. Mobility and Sustainable Planning at the Land-Sea Interface of Friuli Venezia Giulia” is organised into two main axes: the analysis of territorial governance processes aimed at building synergies between spatial (land and maritime) planning and the understanding of climate vulnerability; and the construction of scenarios for territorial transformation and sustainable mobility, supporting integrated and participatory planning processes (Giannotti *et al.*, 2025).

The following paragraphs summarise the principal operational outputs of RT4, in connection with the results of YRs-funded projects.

➔ SPACES AND ACTIVITIES: EXISTING ISSUES EXACERBATED BY GROWING VULNERABILITIES

From the Po Delta to Muggia and the Slovenian border, the Italian Upper Adriatic coast is increasingly exposed to meteorological and climatic pressures, which exacerbate conflicts between existing land uses and ecologically valuable areas.

To better define the geographical field of observation, an initial set of maps was produced to illustrate structuring settlement systems, landscapes, environmental assets, as well as land, marine, and inland water infrastructures and transport services. These maps clarify the “depth” of the coastal strip, whose inland boundary is set by the main infrastructural corridors – the A4 motorway, the state/regional road 14, and the railway – running parallel to the shoreline at an average distance of 20 to 40 kilometres. Along these corridors, a “chain” of urban centres of varying size is connected by roads extending to the sea, serving tourist resorts as well as port and logistics hubs. Within this framework, the pronounced heterogeneity of the Upper Adriatic coast can be categorised into four main sectors: i) the Trieste and Julian Karst, characterised by distinctive rock formations and specific climatic and geomorphological conditions; ii) the low plain from Monfalcone and the Timavo estuary to Jesolo and Cavallino, a biodiversity-rich area where reclaimed lands alternate with wetland and lagoon systems; iii) the polycentric urban network centred on Venice, a dynamic, densely urbanised zone facing the lagoon with major

transport infrastructures; and iv) the Po Delta, an agricultural landscape increasingly affected by drainage demands and land subsidence.

RT4 focused deeper investigations on the Friuli Venezia Giulia region, particularly the low plains of the eastern sector ii), between the Timavo and the Tagliamento rivers (Fig. 1).

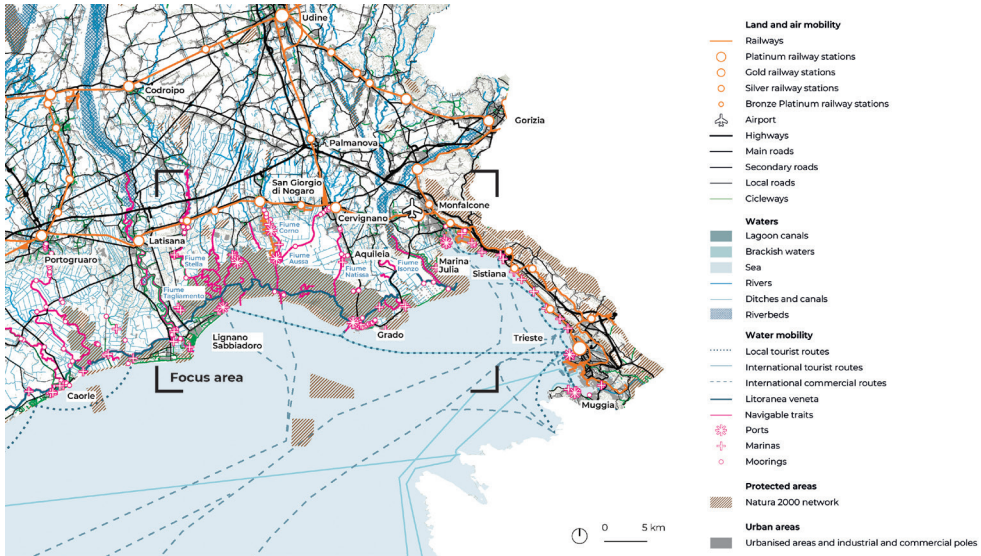


Figure 1

Friuli Venezia Giulia and the focus on the low plains.

Elaborated by: L. Centis, F. Vascotto. Sources: <https://idt2.regione.veneto.it/>; <https://eaglefvg.regione.fvg.it/eagle/main.aspx?configuration=guest>; <https://emodnet.ec.europa.eu/en>; <https://www.regione.fvg.it/rafv/cms/RAFVG/ambiente-territorio/tutela-ambiente-gestione-risorse-naturali/FOGLIA203>; <https://www.rfi.it>

This area was considered representative of the varied conditions found in transitional landscapes between land and water: environments that provide key ecosystem services (such as the Marano and Grado lagoon, wetlands and protected areas); seaside resorts (from Lignano Sabbiadoro to Grado and Marina Julia); small and medium-sized historic towns (e.g., Aquileia); port and industrial settlements (Monfalcone and Porto Nogaro); extensive reclaimed lands intersected by artificial navigable canals; and alpine- and spring-fed rivers that are partially navigable (Tagliamento, Stella, Aussa and Corno, Natissa, and Isonzo).

Today, these territories are home to approximately 124,000 residents, just over 10% of the Friuli Venezia Giulia population (ISTAT data 2024). Population levels, however, rise markedly during spring and summer, generating environmental pressures as well as traffic congestion issues. Mobility in the area remains predominantly dependent on private road transport, with only seasonal maritime services available. The strengths and weaknesses of these services became evident in summer 2022, when prolonged drought-induced wildfires devastated the Karst woodlands. With both the motorway and railway closed, sea transport emerged as the sole means of rapidly restoring connectivity to coastal and lowland areas; however, its limited capacity and timetables – designed for tourism and leisure – proved insufficient.

Building on these considerations, the second phase of the research examined the spatial distribution of climatic and meteorological vulnerabilities and their socio-economic impacts. The Upper Adriatic, recognised as a climate change hotspot (Tuel & Eltahir, 2020), faces alarm-

ing projections from regionalised IPCC scenarios, further exacerbated by studies combining sea-level rise with storm surges and vertical land motion. By 2050, recurrent annual flooding in areas such as Grado could reach 140-168 cm, with local variations in peak intensity (Spadotto *et al.*, 2025). Additional hazards are expected from the interaction of these dynamics with anthropogenic pressures. Intensified precipitation heightens the risk of river flooding and erosion. Rising temperatures and prolonged droughts worsen the effects of unregulated groundwater extraction, urban heat islands, and leaks in water infrastructure. Soil desertification diminishes biological and economic productivity, particularly in forestry and agriculture. Combined processes of drought, evapotranspiration, sea-level rise, and land subsidence further drive saltwater intrusion, severely affecting human and non-human habitats and ecosystems.

In this context, RT4 developed further cartographic representations. By integrating regional datasets, satellite imagery, and geostatistical methods, they overlay key vulnerabilities associated with sea-level rise, riverine and coastal flooding (Regione Autonoma Friuli Venezia Giulia, 2023a), and urban heat islands. Spatial analyses also mapped existing protective infrastructure; the resulting picture, based on the Digital Terrain Model (DTM) (Tarquini *et al.*, 2023), is stark. Between the Timavo and Tagliamento river mouths, coastal elevations fall to about -2 m a.s.l. (-4 m in irrigation channels), while embankments rise only to +2 m with a narrow safety margin against projected sea-level rise (Fig. 2).

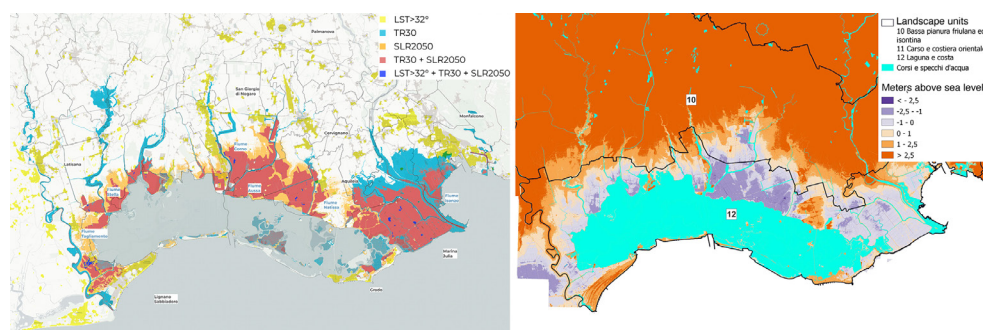


Figure 2

On the left, overlapping climate hazards. LST: Land Surface Temperature (proxy of heat island effects, above 32°); TR30: flood-prone areas with a return period of 30 years; SLR2050: inundated area according to 2050 sea level rise projections. Elaborated by: N. Romanato. Sources: <https://www.usgs.gov/landsat-missions/landsat-8>; https://sigma.distrettoalporientali.it/geoportal/catalog/search/resource/details.page?uuid=abdda%3A2021_12_21_tiranti_tr_30_2007_60_ce; <https://doi.org/10.1016/j.jquascirev.2016.12.021>. On the right, Digital Terrain Model (DTM). Landscape units are those defined by the Piano Paesaggistico Regionale of Friuli Venezia Giulia. Elaborated by: D. Longato. Source: <https://irdat.regione.fvg.it/CTRN/ricerca-cartografia>.

Moreover, flood-prone areas with a 100-year return period overlap with zones projected to be inundated by 2050 sea-level rise, carrying serious impacts on real estate and land use (Fig. 3). Temporary river flooding may not directly destroy ecosystems or economic activities but can disrupt their functioning, leading to indirect losses (e.g., businesses cut off from transport routes). In contrast, sea-level rise may cause permanent flooding, eroding sandbanks and agricultural land. Urban heat islands further amplify heatwave impacts, stressing people and ecosystems in built-up areas. These hazards also affect mobility networks and services, both through direct disruptions (e.g., flooded roads, interrupted public transport) and indirect effects on users (e.g., heat stress for cyclists in unshaded areas).

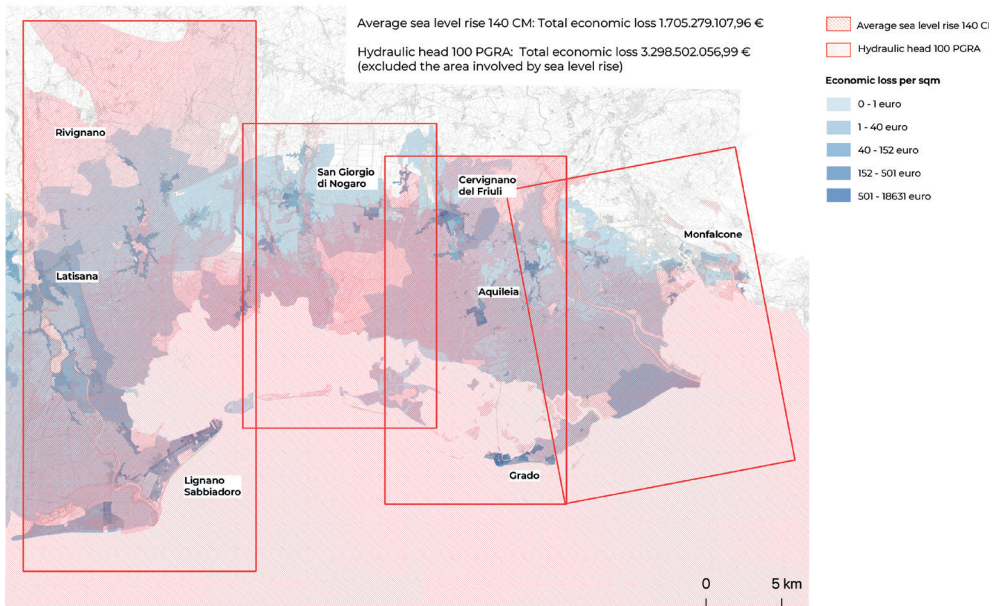


Figure 3

SLR2050 and TR100. The intensity of the blue areas marks lower or higher economic loss in terms of real estate value (Diluvio YRs project). Elaborated by: L. Centis, A. Pagnacco, F. Vascotto. Sources: <https://www.istat.it/notizia/basi-territoriali-e-variabili-censuarie>; <https://www.agenziaentrate.gov.it/portale/schede/fabbricatiterreni/omi/banche-dati/quotazioni-immobiliari>; <https://distrettoalpiorientali.it/piano-gestione-acque/piano-gestione-acque-2021-2027>; <https://www.ipcc.ch/report/sixth-assessment-report-cycle>; <https://doi.org/10.13127/tinitaly/1.1>.

► PLANNING TOOLS: AN INCOMPLETE FRAMEWORK, WITH SOME PROMISING PROSPECTS

In recent years, progress has been made in developing European and national directives and strategies for climate transition and marine and coastal governance. Analysis of spatial planning instruments for the Upper Adriatic and the Friuli Venezia Giulia region enabled RT4 to assess their themes, synergies, and gaps.

Building on the EU Strategy on Adaptation to Climate Change (European Commission, 2021), Italy adopted its National Adaptation Plan in 2023 (MASE, 2023). The Plan specifies several types of actions for coastal zones: seven “soft” (awareness, monitoring, planning, financial tools), ten “green” (ecosystem conservation, natural defences, wetlands, resilient crops), and nine “grey” (technological and architectural innovations, reinforcement of embankments, managed retreat, artificial barriers, elevation of infrastructure). In Friuli Venezia Giulia, however, the drafting of a regional strategy and plan to operationalise these measures has only recently begun.

In parallel with the National Adaptation Plan, and referring to the EU directive on Maritime Spatial Planning (European Union, 2014), Italy approved its Maritime Spatial Plans (MSPs) in 2024. These instruments establish objectives to promote cross-sectoral and multi-scalar governance in maritime planning (MIT, 2024). For Friuli Venezia Giulia, specific indications are included in the MSP for the Adriatic Sea, Sub-area A/1. Planning Units define maritime uses and their links with onshore facilities, seeking to balance port development and shipbuilding with pollution reduction, fisheries and aquaculture, and the presence of marine and terrestrial protected areas with coastal landscape conservation, heritage restoration, and archaeological safeguarding. The resilience of coastal tourism is linked to flood and erosion protection and to integrated systems of sustainable maritime and land mobility. At this stage, MSP implementation depends on regional territorial and landscape planning (Carella *et al.*, 2024).

In the region Friuli Venezia Giulia, however, the drafting of the Territorial Governance Plan, launched in 2021, has not yet produced documents showing the concrete spatial articulation of these topics (Regione Autonoma Friuli Venezia Giulia, 2025). Conversely, the Regional Landscape Plan, approved in 2018, gives specific attention to the coastal zone, providing guidelines for its resilience (Regione Autonoma Friuli Venezia Giulia, 2018). Nonetheless, these remain broad orientations, whose implementation requires complex negotiations to align local town plans with the regional plan. Of greater operational relevance is the proposal by municipalities of Integrated Landscape Projects, developed jointly with the regional administration to support the creation of three “Strategic networks”: ecological, cultural heritage, and slow mobility. Indeed, increasing attention to the relationships between sustainable mobility and the “green” and “blue” networks is emerging as one strong driver of supra-municipal planning processes, particularly in Friuli Venezia Giulia, where governance operates only at regional and local levels due to the absence of Provinces. The recently approved Regional Cycling Mobility Plan is the first to address the coastal zone from an integrated land-sea-inland waters perspective (Regione Autonoma Friuli Venezia Giulia, 2022). Its strength lies in outlining an overarching “territorial project”, which includes repurposing cycle routes along rivers flowing into the sea and the Grado and Marano lagoon, developing boat navigation, and converting disused railways into cycling paths. However, the Plan does not consider the impacts of climate change on its proposed actions and strategies.

To date, at the local level, only some municipalities – Latisana, Lignano, Staranzano, Duino-Aurisina, and Trieste – have adopted a Sustainable Energy and Climate Action Plan. In parallel, public works continue to follow predominantly short- to medium-term, maintenance-oriented approaches. The effectiveness of the National Recovery and Resilience Plan (PNRR) remains to be assessed; however, this same pattern is reflected in the regional PNRR funds allocation, particularly under Mission 2, “Green Revolution and Ecological Transition”, and in projects targeting land and water protection. In coastal areas, flood and hydrogeological risk management is largely addressed through local interventions, such as restoring damaged infrastructure and maintaining irrigation networks in reclamation zones (Regione Autonoma Friuli Venezia Giulia, 2023b).

In response to these limitations, numerous Interreg Italy-Croatia and Italy-Slovenia projects have developed climate adaptation observatories and scenarios, planning guidelines, and tools and actions to support integrated coastal and marine management, the protection of *Natura 2000* sites and wetlands, ecosystem service evaluation, sustainable tourism and agriculture, intermodal transport linking cycling and waterways. These initiatives have established a knowledge base involving regional authorities, universities, and coastal municipalities, demonstrating their potential as a first step toward broader-scale planning. A notable example is the Wetland Area Contract for the Marano and Grado lagoon, initiated with a Statement of Intent by the Comunità di Riviera Friulana in 2021 (Giannotti, Tosi & Velo, 2024). The main limitation, however, is that these projects often remain poorly integrated into standard regional and local planning tools.

➔ MULTIPLE MOBILITIES: REFRAMING DEMAND AND SUPPLY

In Friuli Venezia Giulia, the growing emphasis on sustainable mobility – particularly cycling – reflects the region’s position along major international cycle routes, the steady rise in cycle tourism, and the associated economic benefits. However, sustainable mobility should not be limited to cycling or seasonal flows alone. Given the dense network of natural and artificial waterways in the Upper Adriatic coastal areas, integrating inland and maritime navigation could offer a valuable alternative to road and rail transport for everyday use. Yet, aside from the year-round passenger link between Trieste and Muggia, water connections remain limited to seasonal routes: between Trieste, Sistiana, Monfalcone, and Grado; between Lignano, Grado, and Marano across the lagoon; and between Grado and Aquileia along the Natissa.

To address these limitations and explore the potential for enhanced water-land interactions, RT4 examined mobility demand and supply at the interregional scale, encompassing both leisure movements – by tourists and city users – and residents’ daily commuting patterns. The study involved several cartographic analyses: mapping “nodes” of collective equipment and existing mobility infrastructure and services (road, rail, and waterborne) (Fig. 4); identifying “attractor poles” where such equipment concentrates and analysing their seasonal shifts in location and intensity; and finally, assessing their accessibility in spatial and temporal terms (“isochrones”), including the functionality of intermodal hubs and both land- and water-based transport services (Fig. 5). For short-range travel between hubs, bicycles and private cars were considered the primary modes of transport (Maragno & Romanato, 2025a).

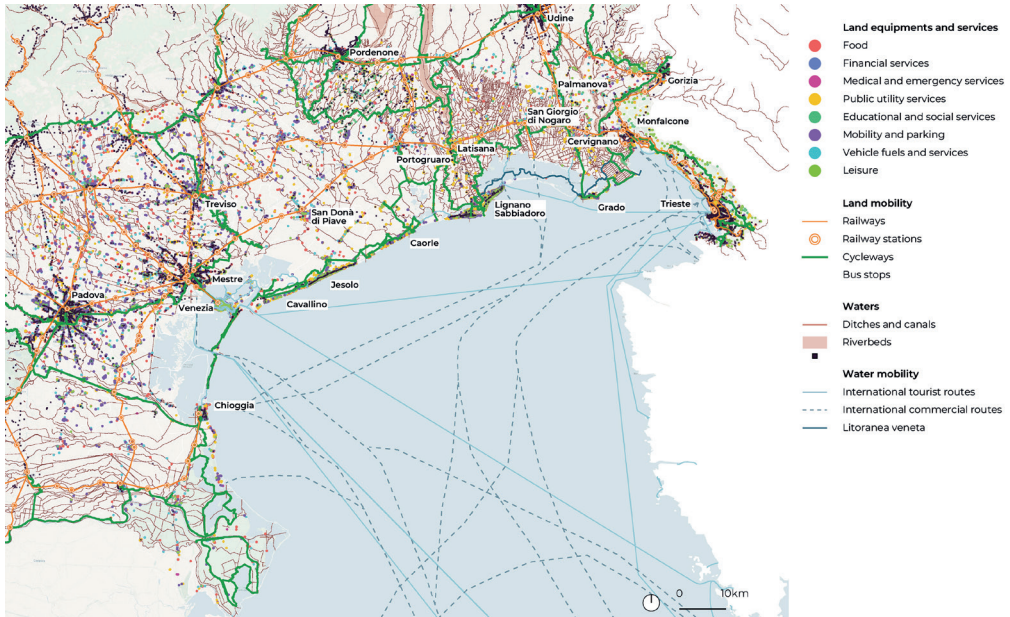


Figure 4
Upper Adriatic. Nodes and mobilities. Elaborated by: D. Maragno, N. Romanato.
Source: (Marchigiani et al., 2025, p. 150).

However, regarding these issues, the lack of regional databases was particularly evident. A key output of RT4 was therefore the development of a methodology for constructing a new database: real-time updatable, fully open source, and compatible with regional GIS systems. Mobility nodes representing residents’ and tourists’ movements – including economic activities, facilities, and collective services as destinations – were identified and georeferenced using Application Programming Interface protocols and OpenStreetMap tags. Seasonal clustering of these nodes into attractor poles was analysed using a Kernel Density Estimation algorithm, with radii of 5 km for services and production areas and 10 km for ports and landing places. Finally, “isochrone” maps – areas defined by different travel times from the poles during high- and low-demand seasons – were generated using OpenRouteService Tools, a plugin integrated in the QGIS environment (Maragno & Romanato, 2025b).

Equally important were the insights gained from analysing spatial relationships among attractor poles, which highlighted key challenges for designing integrated land-sea-inland water mobility systems. Such systems should become more isotropic, responsive to daily movements, operational

throughout the year, and resilient to flooding risks. Achieving this requires better coordination of maritime and river transport routes and services, extensive use of navigable canals, and the expansion of the cycling network linking settlements to attractor poles. The final phase of RT4 activities focused on addressing these challenges.

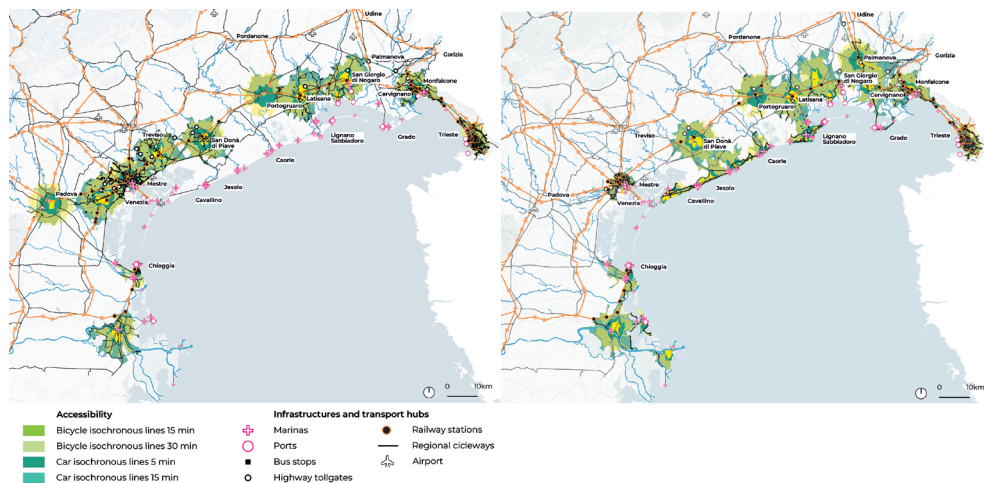


Figure 5

Upper Adriatic. Isochrones and poles. On the left, season of low demand; on the right, season of high demand (below).

Elaborated by: D. Maragno, N. Romanato. Sources: <https://idt2.regione.veneto.it>; <https://eaglefvg.regione.fvg.it/eagle/main.aspx?configuration=guest>; <https://emodnet.ec.europa.eu/en>; <https://openrouteservice.org>; <https://www.openstreetmap.org>.

➔ EXPLORING THE POSSIBLE: TRANSECT PLANNING AND PILOT PROJECTS

Beyond the Gulf of Trieste, where Karst morphology and limited watercourses restrict intermodal connections to a narrow coastal strip, RT4 identified several inland waterways and associated “territorial transects”. Focusing on these areas offers a basis for climate transition strategies that integrate multiple transport modes and leverage sea and river navigability as structuring principles.

The concept of “transect” has recently gained prominence as a tool for spatialising resilient, environmentally sensitive projects. It facilitates the analysis of complex interactions between spatial structures, ecological systems, and human activities in the context of climate transition (Han, 2021; Innocenti & Musco, 2023). This approach is particularly useful in bridging sectoral gaps, linking Maritime Spatial Planning, Integrated Coastal Zone Management, and Climate Adaptation Planning with Flood Risk Management and river basin-scale planning required by EU flood risk and water directives (European Union, 2007, 2020).

RT4 recognised four strategic territorial transects, connected by the interregional transversal axis of the Litoranea Veneta; they extend from the sea through the Marano and Grado lagoon and along partially navigable stretches of the main regional rivers (Fig. 6).

From east to west, the first transect encompasses the final stretch of the Isonzo river and the Monfalcone conurbation, where agriculture, leisure facilities, and extensive port and logistics areas coexist, often in tension, with wetlands and fragile ecological reserves. A canal network, constructed during Fascist reclamation works, offers potential for extending the Litoranea Veneta toward the Valentinis canal, which already accommodates a seasonal maritime service from Trieste.

The second transect follows the 15 km-long tract of Natissa, linking the UNESCO World Heritage site of Aquileia with the lagoon and the island of Grado, an ancient harbour and current seaside re-

sort. Both serve as nodes for seasonal maritime transport, though the connection to Aquileia is limited in scope and largely oriented to tourism.

The third transect is organised around the Corno and Aussa rivers. The Corno connects to Porto Nogaro's industrial zone, while the Aussa extends towards Torviscosa and the inland intermodal hub of Cervignano. Despite its strategic potential, this latter corridor has been underrepresented in regional planning, and the land between the rivers remains highly vulnerable to flooding and the long-term effects of industrial pollution.

Finally, the fourth transect lies at the lagoon's western edge around Lignano Sabbiadoro, a major seaside destination. It is intersected by two rivers: the Stella, historically a Roman transport route and now ecologically significant, and the Tagliamento, largely unmodified except for its lower embankments. During the summer, maritime access includes a ferry crossing the Tagliamento to Bibione, while recreational boating is particularly active along the Stella near the lagoon.

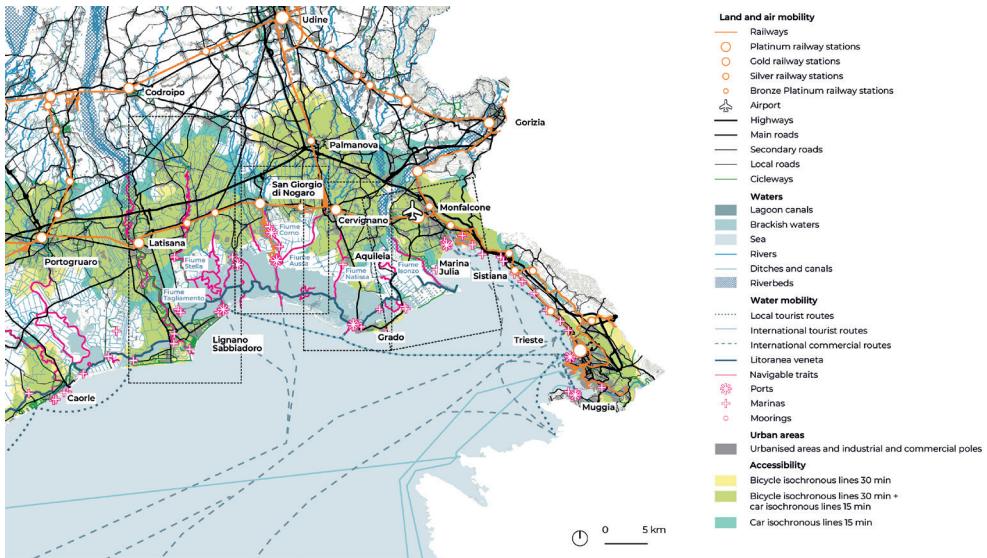


Figure 6

Friuli Venezia Giulia. The four marine-riverine transects. Isochrones indicate conditions that persist in the seasons of low and high demand. Elaborated by: L. Centis, D. Maragno, N. Romanato, F. Vascotto. Sources: <https://eagle.fvg.regione.fvg.it/>; <https://openrouteservice.org/>; <https://www.regione.fvg.it/ravfg/cms/RAVFG/ambiente-territorio/tutela-ambiente-gestione-risorse-naturali/FOGLIA203>.

Building on this framework and guided by the recent EU regulation introducing integrated measures for the restoration of terrestrial, coastal, and freshwater ecosystems (European Union, 2024), RT4 adopted a “research by design” methodology. An urban planning laboratory at the University of Trieste (A.Y. 2023-24) and a masterclass involving researchers and PhD students from the Universities of Trieste and IUAV (September 2024) facilitated dialogue with local authorities through dedicated field surveys and meetings, while exploring territorial regeneration and climate adaptation. The proposed strategies encompass integrated sea-river-land transport systems and intermodal hubs, ecological networks, blue- and greenways for slow mobility, conversion of low-yield crops to wetland-compatible uses, urban desealing, and phytoremediation of contaminated areas (Fig. 7).

The final phase of the research focuses on a detailed pilot project along the Grado-Aquileia transect. In collaboration with RT2 and RT3, a potential electric-boat route is under study, extending

from the current seasonal public transport dock at Monfalcone (Valentinis Canal), through the lagoon to Grado, and upriver to Aquileia. The project also identifies strategic sites and interventions to support the short- and medium-term transition: the urban frontage of Grado on the lagoon and the sea, where measures for flood defence and the guided natural expansion of beaches and wetlands are being explored; the areas at the entrance and exit of the road bridge across the lagoon, where park-and-ride facilities are proposed to reduce private car traffic on the increasingly flood-prone island; and the transformation of a former railway corridor into a dedicated cycle path or public transport line, connecting Aquileia (and its river dock) with the Cervignano rail hub to the north, and with the new park-and-ride facilities and Grado to the south (Fig. 7).

Although current investigations focus on the Italian side, the strategies and projects developed by RT4 are conceived as prototypes for wider application. To this end, they are translated into guidelines to support local administrations in: i) analysing land- and water-mobility potential under climate-related threats; ii) defining priorities and integrating strategic interventions into territorial plans and projects; and iii) monitoring progress to enable the adaptation of planning and design to transition dynamics.

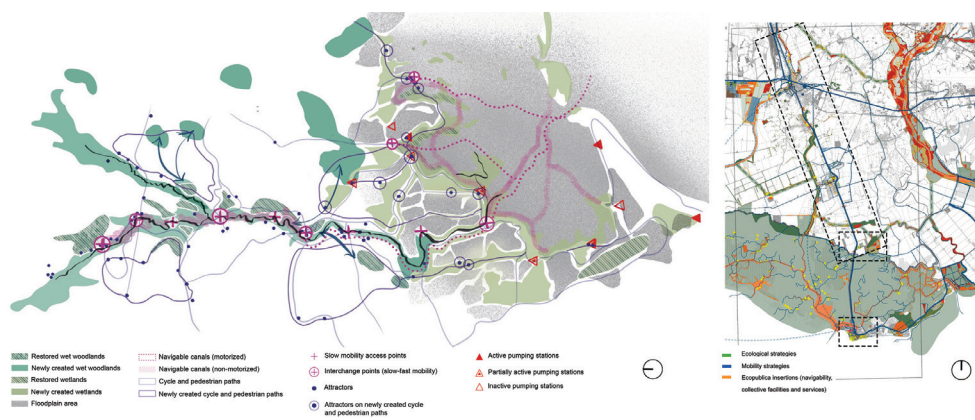


Figure 7
On the left, the transect concerning the Stella and Tagliamento Rivers. Design Scenario (Masterclass, September 2024). Elaborated by: E. Ceschin, V. Mancini, A. Moretti, I. Trabucco. On the right, the transect concerning the Natissa river. Pilot project strategic map (Ecopublica and MOBIPLAN-FVG YRs projects). Elaborated by: B. Gasparini di Gaetano, E. Scattolin.

➔ CONCLUSIONS

In spatial planning, research suggests that under climate transition, territorial transformations are often “over-determined”, with multiple, individually plausible tendencies collectively exceeding what is needed to explain past dynamics or guide future development (Secchi, 2003). Addressing this complexity requires interdisciplinary collaboration, diverse cognitive strategies, and scenario-building to clarify conditions, trajectories, and potential outcomes. A Digital Twin (DT), conceived as a tool for constructing, discussing, and assessing alternative scenarios, can support this process through “what if” analyses and evaluations. From a planning perspective, developing a DT is not a mechanical, deductive task; it involves formulating precise, sometimes contrasting project hypotheses, whose spatial visualisation and evaluation can strengthen and refine planning instruments. RT4 activities provide concrete outputs towards this goal.

From a transition perspective, RT4 planning and design explorations radicalise hypotheses and solutions to enable a comprehensive rethinking of ecological, economic, and social systems (Viganò,

2023). They identify strategic contexts and pilot areas for territorial projects, conceived as opportunities for shared planning across institutional levels, better responsive to local community needs. These projects aim to foster the integration of currently fragmented domains – spatial and landscape planning, transport and mobility, climate adaptation, and the management of marine and coastal spaces – into coherent frameworks that can support discussion and co-design with public administrations and civil society. Parallel to this, the detailed analyses conducted by RT4 not only help territorialise proposed solutions but also build a catalogue of existing spatial datasets, highlighting opportunities for their harmonisation and further development. Many datasets are produced by different institutional bodies for varying purposes and are often outdated due to time- and cost-intensive collection processes, limiting real-time representation of ongoing changes and climate- or human-driven pressures. In the mobility sector, RT4 demonstrates how such gaps can be addressed through innovative, open-source applications of GIS and AI, enabling new forms of analysis and assessment.

These results, however, represent only a first step. The activities undertaken so far highlight the need for greater integration and synthesis of diverse approaches, together with enhanced cross-fertilisation of knowledge across disciplines and stronger collaboration between the social sciences and the fields of science, technology, engineering, and mathematics (SSH and STEM). More structured synergies between Spoke 8 outputs should therefore be pursued beyond the duration of iNEST, with the aim of establishing a stable, integrated Research & Innovation stream among all partners in the near future.

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