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PARTICIPATORY TECHNOLOGY GAP ASSESSMENT FOR SMART MOBILITY: EVIDENCE FROM SIX PILOT TERRITORIES

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Abstract

The deployment of Intelligent Transport Systems (ITS) is central to advancing smart and sustainable mobility, yet many cities still struggle to align technological readiness with planning capacity and societal needs. This paper presents a participatory methodology for technology gap assessment applied in six pilot territories in the Adriatic–Ionian region. Using a Gap Analysis Tool across five domains—technical readiness, interoperability, scalability, sustainability impact, and user acceptance—the assessment, conducted with local Stakeholder Working Groups, identifies strengths in data-driven services and real-time passenger information, while revealing gaps in advanced traffic management, integrated fare systems, and user engagement. The findings show how participatory approaches help cities better understand readiness conditions and support evidence-based mobility transitions. Building on this socio-technical foundation, the paper also outlines the next research stage: a forward-looking exercise developing technology roadmaps and participatory pathways that translate identified gaps into scalable trajectories for next-generation ITS deployment.

Keywords*: Participatory assessment, Smart mobility, Intelligent Transport Systems, Key enabling technologies, Stakeholder engagement, Adriatic–Ionian region*

1 INTRODUCTION

Participatory approaches are increasingly recognised as key enablers for developing ITS solutions that more accurately reflect real mobility needs and everyday travel behaviour. Involving citizens and local stakeholders from the early stages of design enhances the relevance, usability, and acceptance of digital mobility services, ensuring that ITS innovations align with the lived realities of urban mobility rather than solely technological assumptions. Participation is therefore viewed not as an optional add-on but as a necessary component for aligning ITS deployment with societal needs, behavioural patterns, and local mobility priorities. Evidence from recent studies shows that including relevant stakeholders in the early phases of planning can contribute to more inclusive, transparent, and sustainable mobility outcomes, particularly when participation is embedded within decision-making structures rather than applied as a late-stage consultation [1,2]. Urban mobility planning guidance further emphasises that structured stakeholder engagement remains a cornerstone for the successful adoption and long-term integration of ITS measures into local mobility strategies [3].

Despite these benefits, several challenges persist. These include uneven representation of user groups, limited institutional capacity to facilitate participation, and gaps in translating stakeholder insights into final specifications. A specific challenge arises when the uptake of advanced Key Enabling Technologies (KETs) for ITS must be assessed from the stakeholders' perspective. This challenge is twofold: first, there is a need to establish an assessment scheme that encompasses the relevant KETs and links them to smart urban mobility dimensions—concepts that stakeholders recognise; and second, to appraise the uptake of these KETs in a way that reflects the views of diverse stakeholder groups. Addressing these issues is essential, given that KETs increasingly underpin the technological foundations of next-generation ITS, shaping opportunities for data integration, automation, and user-centred service delivery.

This paper presents an approach designed to address both of these challenges. For the purpose of technology gap assessment in smart urban mobility, a tailored methodology and a dedicated Gap Analysis Tool are devised. The methodology and the tool are applied to six diverse territories, each in the process of piloting different smart mobility solutions. The research forms part of a broader initiative to increase smart mobility uptake in the Adriatic–Ionian Region within the framework of the SMARTMOBAIR Project.

The paper is organised as follows. The next section sets the background and scope of the study. Section 3 presents the methodology, with the Gap Analysis Tool as the core instrument, while Section 4 provides the results and discussion. A separate fifth section outlines the next research stage: a forward-looking technology roadmap and participatory pathways that will extend this analysis and translate the identified gaps into actionable paths for next-generation ITS deployment and regional upscaling.

2 BACKGROUND AND THE SCOPE OF THE STUDY

2.1 Background

The digitalisation of urban mobility has positioned Intelligent Transport Systems (ITS) as central instruments for improving efficiency, accessibility, and sustainability in cities [4]. Smart mobility frameworks emphasise technologies such as real-time information, multimodal integration, connected infrastructure, and data-enabled service optimisation as core components of modern mobility ecosystems [5]. As these systems evolve, they increasingly depend on a constellation of digital, sensing, and connectivity technologies that determine the feasibility and sophistication of next-generation mobility solutions.

Despite widespread interest in smart mobility, the capacity of cities to absorb and operationalise these technologies varies substantially. Prior research shows that uneven digital infrastructure, fragmented data practices, institutional constraints, and diverse governance cultures produce significant disparities in ITS readiness across European territories [2, 6]. These differences are particularly visible in macro-regions such as the Adriatic–Ionian area, where variations in administrative capacity, mobility priorities, and technological maturity shape how cities approach the introduction and piloting of new mobility services. An in-depth analysis conducted across six territories—Gorizia (Italy), Koper (Slovenia), Niš (Serbia), Novo Sarajevo (Bosnia and Herzegovina), Rethymno (Greece), and Shkodra (Albania) shows marked variation in regulatory preparedness, funding capacity, digital infrastructure, and levels of public engagement [7]. While Koper and Rethymno exhibit stronger institutional support and more advanced digital systems, territories such as Shkodra, Novo Sarajevo, and parts of Niš face constraints including outdated regulations, fragmented governance, limited financial resources, and lower stakeholder awareness [7]. These contextual differences fundamentally influence how each territory approaches the design, introduction, and piloting of new smart mobility solutions. This context underscores the need for a participatory technology gap assessment that captures stakeholder-informed insights on the maturity and readiness of key enabling technologies for ITS deployment.

2.2 The Need for Technology Gap Assessment in Smart Urban Mobility

A growing body of literature stresses that the development and deployment of emerging mobility technologies should be guided by sociotechnical considerations rather than purely technical criteria [8]. In line with this perspective, smart urban mobility can be understood as “connectivity in towns and cities that is affordable, effective, attractive and sustainable” [8, p. 9].

Participatory technology gap assessment responds to this need by incorporating stakeholder perspectives into the evaluation of whether the technological and organisational prerequisites for adopting new ITS solutions are in place. Such assessments can highlight structural weaknesses, identify capacity-building needs, and support the prioritisation of technology pathways—particularly where advanced digital components underpin new mobility services. Crucially, participatory and co-creative approaches are recognised as essential for grounding technology assessment in local realities. Research across urban innovation and smart city domains shows that stakeholder involvement provides more accurate insights into feasibility, governance challenges, and implementation priorities [9]. Moreover, participatory mapping and stakeholder-informed diagnostic tools have been shown to enhance transparency and reveal readiness conditions that external benchmarking alone cannot capture [2]. In regions where diverse territories are piloting new mobility solutions, stakeholder-informed assessment becomes indispensable for understanding differences in technological readiness and informing future scaling strategies [3].

2.3 Scope of the Paper

Building on this background, the scope of the paper is twofold:

(1) to situate KET-related readiness within broader socio-technical and governance contexts relevant for smart mobility development, and

(2) to provide an analytical foundation for evaluating technological uptake from a stakeholder perspective.

This framing establishes the basis for the methodological approach presented in the following section and informs the next research stage, which will develop a forward-looking technology roadmap and scenario exercise aimed at translating identified gaps into participatory actionable pathways for next-generation ITS deployment.

3 METHODOLOGY

The methodology applied in this paper builds on the structured technology gap assessment framework developed for the six Adrion-Ionian pilot territories, combining a maturity-based self-assessment model with a participatory data collection process. The approach consists of two interconnected phases: conceptualisation and operationalisation: translated into a practical Gap Analysis Tool (GAT) designed to evaluate the maturity of Key Enabling Technologies (KETs) relevant for smart urban mobility.

3.1 Conceptual Foundations

The methodological design is anchored in self-assessment (SA) principles derived from Total Quality Management (TQM), where improvement is guided not by compliance against fixed benchmarks but through reflective comparison between current practice and an aspirational maturity level. This approach supports internal learning, structured progress, and organisational capacity building—conditions essential for deploying ITS in heterogeneous territorial settings. Its relevance is reinforced by earlier applications of TQM tools in mobility planning, such as Petrovic & Vidović’s [10] work on supporting mobility shifts in Serbian cities and assessing opportunities for transferring EU practice, as well as Petrovic et al.’s [11] audit schemes for sustainable urban mobility planning with focus on institutional assessment of road transport safety. Positioned within this research stream, the methodology adopted here leverages TQM's reflective logic to assess KET-related readiness in a participatory and locally informed manner.

3.2 Operationalisation Through the Gap Analysis Tool (GAT)

The conceptual model is operationalised through the Excel-based Gap Analysis Tool (Figure 1), applied uniformly across all six territories.

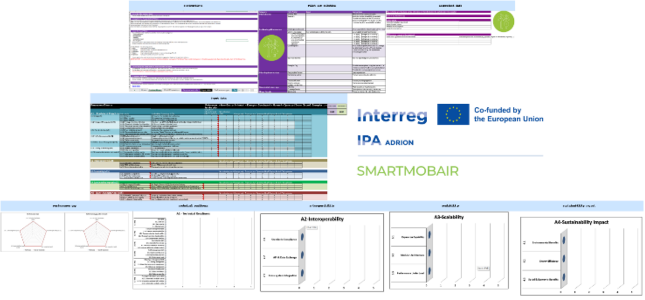


Fig. 1 *Gap Assesssment Tool-layout [12]*

The tool evaluates the maturity of relevant KETs and associated functionalities across five thematic areas:

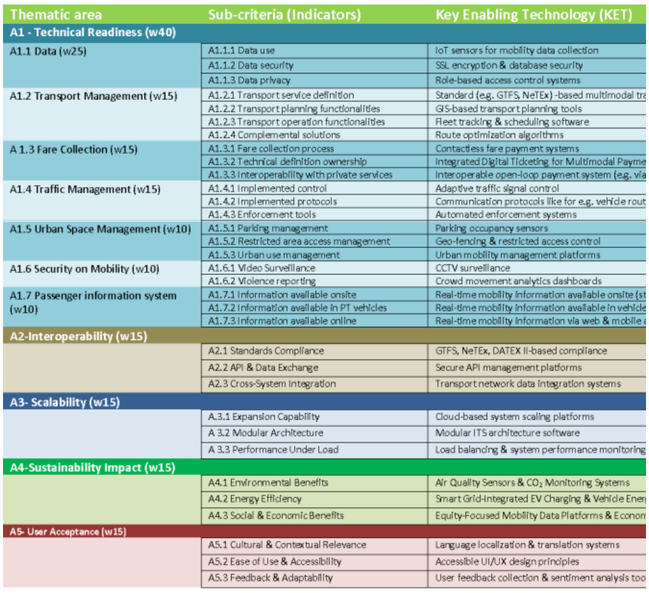
1. Technical Readiness
2. Interoperability
3. Scalability
4. Sustainability Impact
5. User Acceptance

These domains reflect major European smart mobility frameworks—the ITS Directive (2023/2661), the Sustainable and Smart Mobility Strategy, and the European Strategy for Data—as well as findings from earlier analytical work on data availability, governance, and regulatory conditions [7].

The association between Key Enabling Technologies (KETs) and the indicators in the Gap Analysis Tool (GAT) was developed through an evidence-informed, function-oriented process supported by multiple rounds of consultations with technical experts and external stakeholders. Three key sources informed the construction of the assessment structure as a whole—including its dimensions, sub-dimensions, and KET mappings: 1) the World Bank Smart Mobility Toolkit from 2023 [13], which offers practical guidance on smart mobility components and readiness conditions; 2) the JRC Public Transport Research and Innovation Report from 2021 [14], which highlights socio-technical enablers such as interoperability, accessibility, and user acceptance; and 3) study of Paiva et al. from 2021 [15], who synthesise how digital technologies (IoT, AI, cloud systems, and data platforms) underpin specific operational capabilities in smart mobility systems.

Despite these valuable references, the field still lacks a comprehensive and holistic framework that systematically links enabling technologies to system-level readiness factors. To address this gap, each KET was aligned with the relevant GAT subdomains based on: 1) its functional contribution to a specific capability (e.g., IoT for real-time data flows in "Data Use"); 2) its demonstrated relevance in international deployment cases and recommended practice (e.g., cloud systems for modular architecture), and 3) its compatibility with established standards and interoperability frameworks (e.g., GTFS, NeTEx, DATEX II). This structured logic ensured that the resulting analytical framework is coherent, operationally grounded, and transferable across diverse territorial contexts.

The GAT comprises 33 indicators linked to specific KETs (Figure 2).



Thematic area	Sub-criteria (Indicators)	Key Enabling Technology (KET)
A1 - Technical Readiness (w40)		
A1.1 Data (w25)	A1.1.1 Data use	IoT sensors for mobility data collection
	A1.1.2 Data security	SSL encryption & database security
	A1.1.3 Data privacy	Role-based access control systems
A1.2 Transport Management (w15)	A1.2.1 Transport service definition	Standard (e.g. GTFS, NeTEx) -based multimodal tra
	A1.2.2 Transport planning functionalities	GIS-based transport planning tools
	A1.2.3 Transport operation functionalities	Fleet tracking & scheduling software
	A1.2.4 Complemental solutions	Route optimization algorithms
A 1.3 Fare Collection (w15)	A1.3.1 Fare collection process	Contactless fare payment systems
	A1.3.2 Technical definition ownership	Integrated Digital Ticketing for Multimodal Payme
	A1.3.3 Interoperability with private services	Interoperable open-loop payment system (e.g. via
A1.4 Traffic Management (w15)	A1.4.1 Implemented control	Adaptive traffic signal control
	A1.4.2 Implemented protocols	Communication protocols like for e.g. vehicle rout
	A1.4.3 Enforcement tools	Automated enforcement systems
A1.5 Urban Space Management (w10)	A1.5.1 Parking management	Parking occupancy sensors
	A1.5.2 Restricted area access management	Geo-fencing & restricted access control
	A1.5.3 Urban use management	Urban mobility management platforms
A1.6 Security on Mobility (w10)	A1.6.1 Video Surveillance	CCTV surveillance
	A1.6.2 Violence reporting	Crowd movement analytics dashboards
A1.7 Passenger information system (w10)	A1.7.1 Information available onsite	Real-time mobility information available onsite (st
	A1.7.2 Information available in PT vehicles	Real-time mobility information available in vehicle
	A1.7.3 Information available online	Real-time mobility information via web & mobile a
A2-Interoperability (w15)		
	A2.1 Standards Compliance	GTFS, NeTEx, DATEX II-based compliance
	A2.2 API & Data Exchange	Secure API management platforms
	A2.3 Cross-System Integration	Transport network data integration systems
A3- Scalability (w15)		
	A.3.1 Expansion Capability	Cloud-based system scaling platforms
	A 3.2 Modular Architecture	Modular ITS architecture software
	A 3.3 Performance Under Load	Load balancing & system performance monitoring
A4-Sustainability Impact (w15)		
	A4.1 Environmental Benefits	Air Quality Sensors & CO_2 Monitoring Systems
	A4.2 Energy Efficiency	Smart Grid-Integrated EV Charging & Vehicle Ener
	A4.3 Social & Economic Benefits	Equity-Focused Mobility Data Platforms & Econom
A5- User Acceptance (w15)		
	A5.1 Cultural & Contextual Relevance	Language localization & translation systems
	A5.2 Ease of Use & Accessibility	Accessible UI/UX design principles
	A5.3 Feedback & Adaptability	User feedback collection & sentiment analysis too

Fig. 2 *Thematic areas, associated sub-criteria (indicators) and associated KETs [12]*

Indicators within the Technical Readiness domain are more numerous, reflecting the centrality of core ITS subsystems. The tool produces radar charts and thematic bar charts that visualize appraisal results and support interpretation but are not intended for inter-city ranking. Each indicator is scored using a six-level maturity ladder (0–5), distinguishing between non-existent development, conceptual formulation, early preparation, piloting, implementation, and continuous optimization (Table 1).

Table 1: Maturity scale used in the Gap Analysis Tool – Description of levels [12]

Maturity Level	**Description**	**Interpretation**
0 – Non-Existent	No technology exists	The technology **does not exist** yet.
1 – Initial	Concept only (early stage)	The technology is **in the concept stage**—there are discussions, early ideas, or references in planning documents, but no development has started.
2 – Emerging	Prototype tested (Technology validated, TRL 4-5)	The technology has been **tested in a controlled environment** (e.g., simulations or laboratory trials), but there has been no real-world application.
3 – Developing	Operational in pilots	The technology has been **tested in real-world conditions, but in a limited scope**—such as within a pilot project or a single segment of the transport system.
4 – Mature	Deployed widely (TRL 6-7)	The technology is **adopted across the entire city** and integrated into the overall transport system.
5 – Optimized	Fully optimized & continuously improved	The technology is **in full deployment** and optimization—fully implemented, operational, and in continuous improvements.

This structure draws inspiration from the Technology Readiness Level (TRL) framework developed by the European Commission for assessing innovation maturity, particularly in complex and infrastructure-intensive sectors such as energy and mobility [16].

3.3 Participatory Data Collection

A defining feature of the methodology is its participatory implementation, whereby data collection involves three actor groups:

- Technical Partners (TPs)-urban mobility experts,
- Institutional Implementation Partners (IIPs)-pilot territories, and
- Local Stakeholder Working Groups (SWGs).

This collaborative structure ensures that the maturity assessment reflects not only documented technological deployment but also practitioner experience, operational constraints, and local knowledge relevant for preparing and piloting smart mobility solutions.

The SWG are formed on the basis of a well-thought-out methodology. It begins with a structured process of stakeholder mapping and engagement designed to ensure that all actors relevant to the pilot—either through institutional authority, operational responsibility, or experiential knowledge—are systematically involved. Each pilot territory identifies stakeholders based on their influence, level of interest, and the expected impact of the specific smart mobility intervention, covering public authorities, service providers, user groups, and civil society. Beyond formal requirements, emphasis is placed on inclusiveness and representativeness, ensuring that groups such as youth, persons with disabilities, and local associations are considered when relevant to the pilot. Once identified, stakeholders are invited to join the SWG. In this stage transparent communication and early dialogue help align expectations, bring out potential concerns, and build the trust necessary for co-creation. This preparatory stage establishes a shared understanding of local conditions and user needs, which is essential for the consistent and context-sensitive assessment of technological maturity.

Operationally, SWGs follow iterative consultations, supported by standardised templates, that enables continuous refinement of insights and collaborative problem-solving throughout the research lifecycle: from design to implementation and evaluation. The sequence of minimum five meetings—ranging from background definition to discussion of pilot design, revision, mid-term assessment, and final results—ensures that stakeholder input is systematically integrated into both data collection and decision-making. A key methodological element is the feedback loop: issues identified in earlier meetings are explicitly revisited, and revised proposals are presented together with justifications for accepted or rejected suggestions. So far 13 meetings have been organised throughout the pilot territories involving about 70 stakeholders representatives.

Stakeholder Working Group (SWG) meetings served as the primary data-collection mechanism for GAT. Prior to each session, participants received preparatory materials and the Excel-based tool to ensure familiarity with the assessment structure. Given the technical nature of the Key Enabling Technologies (KETs), concise explanations and practical examples were prepared in advance to support a shared understanding and facilitate consistent appraisal. A methodological challenge in such settings is that the analyst must not only collect stakeholder judgments but also guide the group toward a consensus on the maturity level. Here, the presence of technical experts plays an essential role: they clarify technologies from an implementation perspective and help elicit accurate inputs by drawing attention to existing—but not always widely recognised—systems.

This dynamic was evident in Niš. For example, some SWG participants were initially unaware that certain APIs were already embedded within the vehicle-tracking system but not yet activated. A similar issue emerged in the environmental sensing subdomain. Initial responses from several SWG members suggested that air-quality sensing infrastructure was “non-existent,” primarily because these systems are not yet integrated into traffic-management planning and related platforms. However, the City of Niš operates a functional network of monitoring stations measuring PM_{10}, NO_2, SO_2 and O_3 in line with national regulations, with real-time data published through the Serbian National Air Quality Network. These data have already been used in transport-related analyses—most notably in the study by Živković et al. [17], which applies COPERT methodology to estimate traffic-related emissions in Niš, demonstrating the direct relevance of the sensing infrastructure for mobility-linked assessments. Earlier analyses of traffic-induced pollution in Niš (e.g., [18]) further confirm the operational use of these monitoring systems. In addition, the formally adopted Air Quality Plan for the Territory of the City of Niš (2023–2028) [19] relies on this monitoring network as the basis for environmental assessment and planning. Taken together, these elements show that the sensing infrastructure is active and analytically relevant, even if not yet embedded within smart-mobility systems, thus justifying a Developing maturity classification for the KET Air Quality Sensors & CO_2 Monitoring Systems.

3.4 Alignment with the scope of the paper

This methodological design directly supports the paper’s twofold scope:

(1) situating KET-related readiness within broader socio-technical considerations; and

(2) providing a stakeholder-informed analytical foundation for evaluating technological uptake.

It also establishes the basis for the next research stage, which will extend the analysis into a technology roadmap and scenario exercise, translating identified gaps into actionable pathways for next-generation ITS deployment.

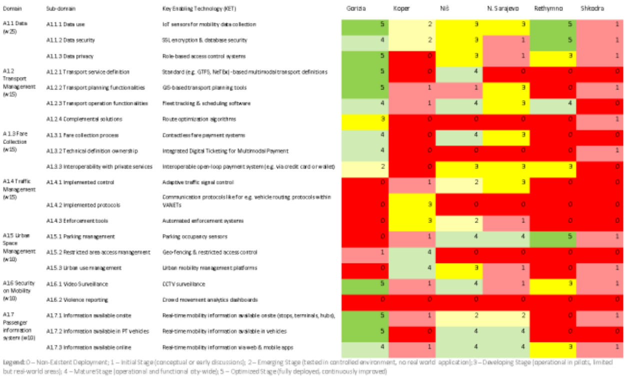
4 RESULTS AND DISCUSSION

A condensed synthesis of the technology gap assessment is presented here. The assessment covers six pilot territories, each oriented towards a specific ITS pilot solution: Public service on call in the Municipalities of Turriaco and Sagrado (Gorizia); Retractable bollards equipped with automatic licence plate recognition (Koper); E-cadastre for public transport and smart bus stops (Niš); Monitoring and management system for micromobility flows (Novo Sarajevo); Smart parking stations for personal bicycles (Rethymno); and a modular traffic data-monitoring system for bus transport (Shkodra).

This section synthesises the dominant cross-territorial patterns and socio-technical conditions that shape the feasibility of advanced ITS deployment, integrating evidence from the Gap Analysis Tool (GAT) and the Stakeholder Working Group (SWG) consultations. Complete analytical results, and territory-specific diagnostics are provided in [12].

Indicators within the Technical Readiness domain (A1) are more numerous and granular, reflecting the centrality of core ITS subsystems. The remaining four domains—Interoperability, Scalability, Sustainability Impact, and User Acceptance (A2–A5)—are treated jointly as cross-cutting enablers, as they capture transversal capabilities that condition whether technically functional ITS components can operate coherently, integrate with wider systems, and scale over time.

Across the six territories, Technical Readiness (A1) exhibits marked variability, with numerous indicators lying between Non-Existent and Developing (Figure 3).



Domain	Sub-domain	Key Enabling Technology (KET)	Gorizia	Koper	Niš	N. Sarajevo	Rethymno	Shkodra
A1.1 Data (w25)	A1.1.1 Data use	IoT sensors for mobility data collection	5	2	3	3	5	1
	A1.1.2 Data security	SSL encryption & database security	4	2	3	1	5	1
	A1.1.3 Data privacy	Role-based access control systems	5	0	3	1	3	1
A1.2 Transport Management (w15)	A1.2.1 Transport service definition	Standard (e.g. GTFS, NeTEx) -based multimodal transport definitions	5	0	4	0	0	0
	A1.2.2 Transport planning functionalities	GIS-based transport planning tools	5	1	1	3	0	1
	A1.2.3 Transport operation functionalities	Fleet tracking & scheduling software	4	1	4	3	4	0
	A1.2.4 Complemental solutions	Route optimization algorithms	3	0	0	0	0	1
A 1.3 Fare Collection (w15)	A1.3.1 Fare collection process	Contactless fare payment systems	4	0	4	3	0	0
	A1.3.2 Technical definition ownership	Integrated Digital Ticketing for Multimodal Payment	4	0	0	0	0	1
	A1.3.3 Interoperability with private services	Interoperable open-loop payment system (e.g. via credit card or wallet)	2	0	3	3	3	0
A1.4 Traffic Management (w15)	A1.4.1 Implemented control	Adaptive traffic signal control	0	1	2	3	0	0
	A1.4.2 Implemented protocols	Communication protocols like for e.g. vehicle routing protocols within VANETs	0	3	0	0	0	0
	A1.4.3 Enforcement tools	Automated enforcement systems	0	3	2	1	0	0
A1.5 Urban Space Management (w10)	A1.5.1 Parking management	Parking occupancy sensors	0	1	4	4	5	1
	A1.5.2 Restricted area access management	Geo-fencing & restricted access control	1	4	0	0	0	0
	A1.5.3 Urban use management	Urban mobility management platforms	0	4	3	1	0	1
A1.6 Security on Mobility (w10)	A1.6.1 Video Surveillance	CCTV surveillance	5	1	4	1	3	1
	A1.6.2 Violence reporting	Crowd movement analytics dashboards	0	0	0	0	0	0
A1.7 Passenger information system (w10)	A1.7.1 Information available onsite	Real-time mobility information available onsite (stops, terminals, hubs),	5	1	2	2	0	1
	A1.7.2 Information available in PT vehicles	Real-time mobility information available in vehicles	5	0	4	4	0	0
	A1.7.3 Information available online	Real-time mobility information via web & mobile apps	4	1	4	4	3	1

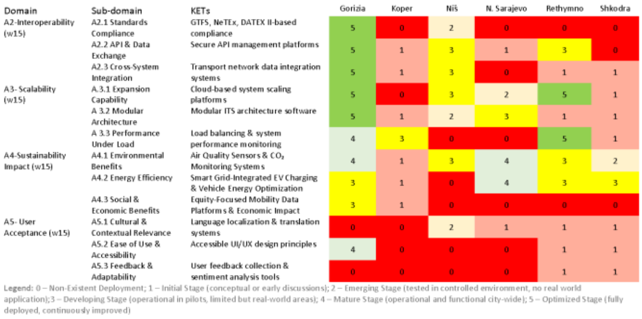
Legend: 0 – Non-Existent Deployment; 1 – Initial Stage (conceptual or early discussions); 2 – Emerging Stage (tested in controlled environment, no real world application); 3 – Developing Stage (operational in pilots, limited but real-world areas); 4 – MatureStage (operational and functional city-wide); 5 – Optimized Stage (fully deployed, continuously improved)

Fig. 3 *Technical Readiness of Smart Mobility KETs Across Territories [12]*

Within A1.1 Data, basic datasets are present, yet the uptake of key enabling technologies (KETs)—including IoT-based data acquisition, SSL-secured storage, and role-based access control—is inconsistent, constraining real-time data reliability, data protection practices, and secure information flows. In A1.2 Transport Management, several territories operate fleet-tracking or GIS-supported tools, but more advanced KETs such as GTFS/NeTEx-compliant multimodal service definitions, optimisation algorithms, and scheduling software remain marginal, limiting functional integration. A1.3 Fare Collection shows similarly uneven adoption: isolated contactless solutions exist, while open-loop interoperable payment systems, essential for integrated mobility ecosystems, are almost entirely absent.

A1.4 Traffic Management is dominated by conventional signal control, with negligible deployment of adaptive signal control, VANET-based communication protocols, or automated enforcement systems, indicating early-stage digitalisation. A1.5 Urban Space Management demonstrates low maturity: while basic parking occupancy systems exist, advanced KETs such as geofencing modules and urban mobility management platforms are rarely applied. In A1.6 Security on Mobility, CCTV coverage is widespread, yet higher-order digital capabilities—most notably crowd analytics and incident-detection dashboards—are largely absent. A1.7 Passenger Information Systems show uneven real-time service availability, with several territories relying on static or partially updated information.

The cross-cutting enablers (A2–A5, Figure 4) reveal a predominantly low level of maturity across the region. An exception within this otherwise low-performing cluster is Gorizia, which demonstrates comparatively higher maturity across several cross-cutting enablers—particularly in standards compliance, environmental KET deployment, and aspects of scalability. Interoperability (A2) remains weak due to partial implementation of GTFS, NeTEx, and DATEX II and limited availability of secure, well-documented APIs, sharply restricting cross-platform data exchange and hindering future MaaS integration. Scalability (A3) is constrained by non-modular ITS architectures, minimal use of cloud-based expansion frameworks, and insufficient performance validation under increased load. In Sustainability Impact (A4), environmental and energy-related KETs—such as air-quality monitoring systems, CO₂ sensors, and smart-grid-integrated EV charging—are present in several territories but insufficiently embedded in operational or planning workflows. User Acceptance (A5) is highly underdeveloped, with sporadic application of localised interfaces, accessibility-oriented UI/UX principles, and structured user-feedback mechanisms.



Domain	Sub-domain	KETs	Gorizia	Koper	Niš	N. Sarajevo	Rethymno	Shkodra
A2-Interoperability (w15)	A2.1 Standards Compliance	GTFS, NeTEx, DATEX II-based compliance	5	0	2	0	0	0
	A2.2 API & Data Exchange	Secure API management platforms	5	1	3	1	3	0
	A2.3 Cross-System Integration	Transport network data integration systems	5	1	3	0	1	1
A3- Scalability (w15)	A.3.1 Expansion Capability	Cloud-based system scaling platforms	5	0	3	2	5	1
	A 3.2 Modular Architecture	Modular ITS architecture software	5	1	2	3	1	1
	A 3.3 Performance Under Load	Load balancing & system performance monitoring	4	3	0	0	5	1
A4-Sustainability Impact (w15)	A4.1 Environmental Benefits	Air Quality Sensors & CO_2 Monitoring Systems	4	1	3	4	3	2
	A4.2 Energy Efficiency	Smart Grid-Integrated EV Charging & Vehicle Energy Optimization	3	1	0	4	3	3
	A4.3 Social & Economic Benefits	Equity-Focused Mobility Data Platforms & Economic Impact	3	1	0	0	0	0
A5- User Acceptance (w15)	A5.1 Cultural & Contextual Relevance	Language localization & translation systems	0	0	2	1	1	1
	A5.2 Ease of Use & Accessibility	Accessible UI/UX design principles	4	0	0	0	1	1
	A5.3 Feedback & Adaptability	User feedback collection & sentiment analysis tools	0	0	0	0	1	1

Legend: 0 – Non-Existent Deployment; 1 – Initial Stage (conceptual or early discussions); 2 – Emerging Stage (tested in controlled environment, no real world application);3 – Developing Stage (operational in pilots, limited but real-world areas); 4 – Mature Stage (operational and functional city-wide); 5 – Optimized Stage (fully deployed, continuously improved)

Fig. 4 *Cross-territorial comparison of Cross-Cutting Enablers for Smart Mobility [12]*

Despite these modest maturity levels, the findings must not be misinterpreted as evidence of insufficient technological capacity for pilot deployment. The assessment framework is intentionally designed to evaluate the entire ITS ecosystem—not only the technological subset required for pilot implementation. When the analysis is restricted to pilot-relevant KETs—such as real-time data capture, basic system integration, or digital service components—all territories demonstrate an adequate technological baseline for executing planned pilots. The lower scores in domains such as interoperability or scalability therefore reflect the structural prerequisites for medium- and long-term ITS upscaling rather than constraints to pilot feasibility. This distinction is essential: the methodology is structured not merely to verify pilot readiness but to support the development of technology roadmaps and scenario-based planning processes, where systemic maturity—not isolated system components—is the critical variable.

Overall, the results show that while foundational digital components exist across all territories, the systemic enablers required for integrated and scalable ITS ecosystems remain underdeveloped. SWG consultations further exposed discrepancies between stakeholder perceptions and actual technological conditions—e.g., cases where sensing or API capabilities were initially assessed as non-existent despite being operational but disconnected from mobility workflows. Such divergences highlight the analytical value of a participatory approach in revealing socio-technical readiness conditions that would remain invisible in exclusively technical audits. These findings form a robust empirical basis for the subsequent research stage, in which a forward-looking technology roadmap and scenario exercise will articulate development trajectories and regionally scalable pathways for next-generation ITS deployment.

5 FUTURE RESEARCH – TOWARDS TECHNOLOGY ROADMAPS AND PARTICIPATORY PATHWAYS

This section outlines future research by building on the two key elements from the paper's title—technology and participatory. We point toward possible directions for technology roadmapping based on the identified gaps, while also outlining how the next stages of the project will continue to follow a socio-technical approach through stakeholder and user involvement as we move toward pilot implementation.

5.1 Technology Roadmapping

The technology roadmapping activity builds upon the socio-technical evidence produced through the maturity assessment and adopts a structured analytical design aimed at transforming diagnostic findings into forward-oriented development trajectories. The methodological framework is articulated across three interdependent layers. The technology layer synthesises the maturity results by clustering Key Enabling Technologies according to their functional roles within ITS architectures, their interoperability attributes, and the infrastructural or organisational prerequisites they entail, in line with consolidated technology roadmapping principles [20]. The contextual layer links these technological configurations to governance capacities, regulatory conditions, operational practices, and broader institutional dynamics observed across the pilot territories, reflecting best-practice approaches in technology roadmap development. Finally, the temporal sequencing layer organises technologies into short-, medium- and long-term horizons through a structured appraisal of feasibility, required enabling conditions and expected systemic impact, consistent with scenario-informed roadmapping methods [21]. Taken together, these layers generate an integrated analytical foundation for delineating coherent, feasible and context-sensitive technological pathways.

Figure 5 illustrates the structured, multi-layer analytical workflow used to translate the diagnostic results of the maturity assessment into forward-looking development trajectories.

Inputs derived from technology maturity scores, functional KET analysis and contextual constraints are processed through interlinked analytical layers that consolidate technological clustering, dependency analysis and feasibility appraisal. Temporal sequencing defines short, medium- and long-term trajectories, while a final validation event ensures collective review and confirmation of the proposed pathways.

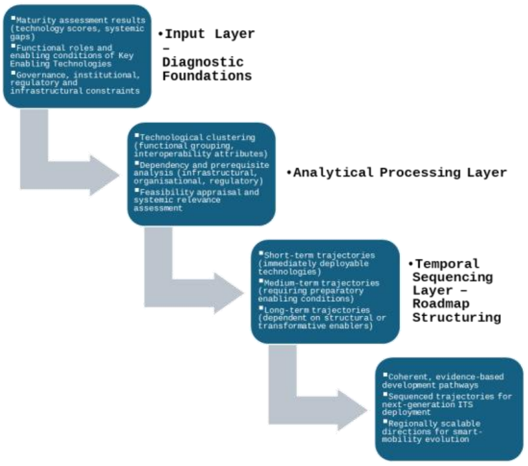


Fig. 5 *Methodological architecture of the technology roadmapping process*

To maintain methodological continuity with the participatory orientation of the overall project—but without replicating the iterative engagement used in the maturity assessment—the validation of the resulting roadmap will take place through a final collective review involving project partners and territorial representatives. This scientific dissemination and validation will serve to present the analytical clustering of technologies, discuss identified dependencies and enabling conditions, and validate the proposed sequencing of technological trajectories. The resulting roadmap thus operates as a structured transition model, integrating technological configurations, contextual feasibility and temporal structuring to support sequenced, evidence-based steps toward next-generation ITS ecosystems, as recommended in recent analyses of enabling technologies for smart mobility [15]. Rather than offering a deterministic projection, the methodology supports adaptive, multi-stage trajectories that align pilot implementation with longer-term, regionally scalable smart-mobility development pathways. In doing so, it provides a coherent bridge between the diagnostic findings of the maturity assessment and the forthcoming scenario exercise, reinforcing the socio-technical orientation that underpins the overall research design.

5.2 Participatory Pathways

The participatory pathways complement the technological work by ensuring that the development and implementation of the pilots remain closely connected to the expectations, needs, and behaviours of citizens and other relevant actors. During the pilot preparation and deployment stages, a series of regional and national seminars will facilitate structured dialogue among public authorities, operators, user groups, and civil-society organisations. These exchanges will support a shared understanding of the pilot objectives, practical requirements, and potential implications of the technological solutions being introduced.

In parallel, targeted user surveys will be carried out in each pilot territory to gather evidence on acceptance levels, perceived usability, accessibility considerations, and general attitudes toward the new mobility services. Survey findings, together with insights from the seminars, will form a continuous feedback loop that can inform adjustments to communication materials, user-facing components, and selected aspects of pilot design where relevant. In this way, technological advances throughout the project will not only inform public awareness and understanding but will also be shaped by the responses and preferences of end users.

The pilots themselves will provide the opportunity to observe user interaction with the new ITS solutions in real conditions. These observations will complement the survey data and stakeholder inputs, helping to identify potential barriers to use, aspects requiring further clarification, or features that may need refinement. By integrating these different sources of feedback, the participatory pathways aim to strengthen transparency, support informed decision-making, and ensure that the pilots reflect local mobility conditions and priorities.

Overall, this approach will enable a two-way relationship between technological development and public engagement, ensuring that the pilots evolve in a manner that is operationally feasible, understandable to users, and responsive to the social and institutional contexts of the participating territories.

6 CONCLUSION

This paper presented a participatory technology gap assessment applied across six Adriatic–Ionian pilot territories, offering a structured examination of ITS readiness with a particular focus on the core dimension of Technical Readiness, supported by a complementary analysis of cross-cutting socio-technical enablers. The findings show that while several foundational components of ITS—such as data collection infrastructures, transport management functions, passenger information systems, and elements of traffic and urban space management—are present or emerging in most territories, their maturity remains uneven and often limited to basic or intermediate levels. The cross-cutting enablers—interoperability, scalability, sustainability impact, and user acceptance—exhibit more systemic weaknesses, indicating that even where technical subsystems exist, the institutional and technological conditions needed to sustain integration and upscaling remain underdeveloped. Stakeholder consultations further revealed discrepancies between perceived and actual technological conditions, illustrating the analytical added value of participatory appraisal in revealing hidden capacities, clarifying misconceptions, and identifying readiness gaps relevant for both pilot deployment and broader ITS planning.

The contribution of the study lies in developing and operationalising an assessment framework that systematically links Key Enabling Technologies to functional ITS capabilities in a manner accessible to stakeholders and transferable across diverse urban contexts. By embedding this logic in the Gap Analysis Tool (GAT), the paper provides not only a diagnostic instrument but also a mechanism for continuous monitoring, enabling territories to track improvements over time, refine priorities, and align future development efforts with evolving technological and governance conditions. This capacity for repeated appraisal strengthens institutional learning and supports evidence-based decision-making beyond the pilot stage.

Nonetheless, several limitations should be acknowledged. Maturity assessments inherently depend on stakeholder judgement, which may be influenced by differences in technical familiarity, organisational perspective, or the visibility of existing systems. Although expert facilitation mitigated some of these effects, the resulting appraisals reflect context-specific interpretations that may evolve as systems mature. Moreover, the assessment focuses primarily on socio-technical readiness and does not explicitly address financial, regulatory, or behavioural determinants that also shape long-term ITS viability.

Looking forward, the next phase of research will extend the assessment through a technology roadmap and a scenario-based exercise that translate identified gaps into sequenced, realistic pathways for next-generation ITS deployment. In parallel, participatory pathways will deepen engagement with users and local actors, ensuring that technological development is responsive to lived mobility conditions and institutional realities. Together, these efforts will provide a coherent foundation for supporting pilot implementation while guiding a broader regional transition toward scalable, integrated, and user-aligned smart mobility system

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