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Public transport research and innovation in Europe

An assessment based on the Transport Research and Innovation Monitoring and Information System (TRIMIS)

Stepniak, M., Gkoumas, K., Marques dos Santos, F., Grosso, M., and Pekár, F.

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Contact information
Name: Ferenc Pekár
Address: European Commission, Joint Research Centre, Vie E. Fermi 2749, I-21027, Ispra (VA) — Italy
Email: ferenc.pekar@ec.europa.eu
Tel.: +39 0332 783925

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Contents

Abstract

The European Green Deal and its target for reducing emissions together with the New EU Urban Mobility Framework put public transport in the spotlight of EU mobility policies. Research and innovation is thus required in order to respond to these needs. This report provides a review of recent trends, challenges and achievements of European research and innovation initiatives in public transport. The report identifies relevant projects that focus on public transport, using the Transport Research and Innovation Monitoring and Information System (TRIMIS) database. It identifies main actors and trends in European public transport research and it discusses main areas of development in order to point out main achievements. It also presents future research needs and policy recommendations.

Acknowledgements

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Authors

Marcin Stepniak, European Commission, Joint Research Centre

Konstantinos Gkoumas, European Commission, Joint Research Centre

Fabio Marques dos Santos, European Commission, Joint Research Centre

Monica Grosso, European Commission, Joint Research Centre

Ferenc Pekár, European Commission, Joint Research Centre

Executive summary

The report presents an analysis of the research and innovation in public transport in Europe. The report assesses European Union projects funded under H2020 Framework Programme as well as nationally funded projects started since 2014. It uses the Transport Research and Innovation Monitoring and Information System (TRIMIS) database to identify relevant projects which have public transport in their scope. The report provides a review of recent trends, challenges and achievements of European research and innovation initiatives in public transport.

Policy context

The European Green Deal has set a very ambitious target of emissions reduction, which has a considerable impact on mobility and transport. The goal of EU Sustainable and Smart Mobility Strategy is to ensure modal shift towards more sustainable transport modes, namely public transport and active modes. In order to achieve that, European urban areas need a modern, green, inclusive, and more resilient EU transport. Finally, the New EU Urban Mobility Framework, published in 2021, also emphasises the importance of public transport, acknowledging serious challenges it faces in order to match those high expectations. These challenges, and the related research and innovation needs, can be grouped into subthemes covering digitalisation, reduction of emissions, public transport planning and management, safety, infrastructure development as well as readiness for the deployment of connected and automated mobility.

Key conclusions

The quantitative and qualitative analysis of relevant public transport projects identified the main actors, trends and achievements. Key conclusions are:

— Even though public transport has a central role in EU policy and strategic documents and is key to achieve the objectives of the Green Deal, it is in the main scope of only 114 out of nearly 2700 H2020 transport projects included in TRIMIS database;

— Main topics investigated in the identified projects cover public transport planning and management, digitalisation and digital innovations as well as emissions reduction and electrification of transport;

— The research and innovation effort in H2020 is in line with the most important challenges set out in the EU Urban Mobility Framework;

— Future research and innovation initiatives should concentrate on fostering an inclusive, safe, affordable and sustainable public transport for all transport users offering seamless integration with new and shared mobility services and thus contribute to a larger share of public transport in user choices. Public transport electrification and future-proof infrastructure settings should contribute to a more efficient transport system and significant emissions reduction too. Automated and connected mobility should be developed and tested under different environmental, infrastructure and social conditions.

Main findings

Using the TRIMIS database we identified **163 projects** which have public transport is in their scope, including 114 European (including 110 H2020 projects) and 49 national projects started since 2014. The thorough analysis of works carried out within those projects and their progress beyond the state of the art enable to define 12 main areas of development and for each of them we identified the following main achievements:

1. **Mobility as a Service and public/private mobility integration**
    - Real-world demonstrations of Mobility as a Service implementation
    - Development of technical and non-technical frameworks for Mobility as a Service integration
2. **Accessibility and inclusiveness of public transport**
    - Real-world testing of innovative measures to improve accessibility and address inclusiveness
    - Decision support system to address women's needs in mobility and transport
3. **Involvement of local authorities and other stakeholders**
    - Developing and implementing collaborative processes to address local mobility challenges

- Collection of innovative solutions for local transport authorities

4. **Development and testing of new mobility solutions through Living Laboratories**
    - Development of demonstration measures for reorganisation of public transport networks
    - Development of guidelines for integration of shared mobility services into public transport
5. **Geolocation for public transport applications**
    - Improved precision of geolocation signal from users and vehicles from GALILEO-equipped smartphones
    - Implementation and tests of indoor and outdoor positioning systems
6. **Data collection, integration and analysis for improvement of public transport management**
    - Roadmap for city deployment of cooperative Intelligent Transport Systems
    - Detailed and multidimensional anonymised origin-destination matrices for transport planning
7. **Smart ticketing services and cross-border mobility**
    - Development of a technical systems for cloud-based smartcard data
    - Development of methods and simulation tools for intermodal transport solutions
8. **Effective urban rail transport infrastructure**
    - Development of automated inspection and maintenance devices and systems for rail infrastructure
    - Development of a low-cost system for railway telecommunication infrastructure
9. **Infrastructure for electrified public transport**
    - Feasibility studies of wireless charging in public transport
    - Demonstrations of various charging concepts (e.g. overnight or opportunity charging)
10. **Retrofitting buses**
    - Development of retrofitting kits to convert a bus into a full electric vehicle
    - Implementation of retrofitting processes to reduce pollution
11. **Fuel cell bus**
    - Development of fuel cells with a higher lifespan
    - Deployment of fuel cell buses in selected case studies
12. **Autonomous buses and shuttles**
    - Test pilots of autonomous vehicles in public transport
    - Research on required changes in planning and procurement for deployment of autonomous buses

Other main findings include:

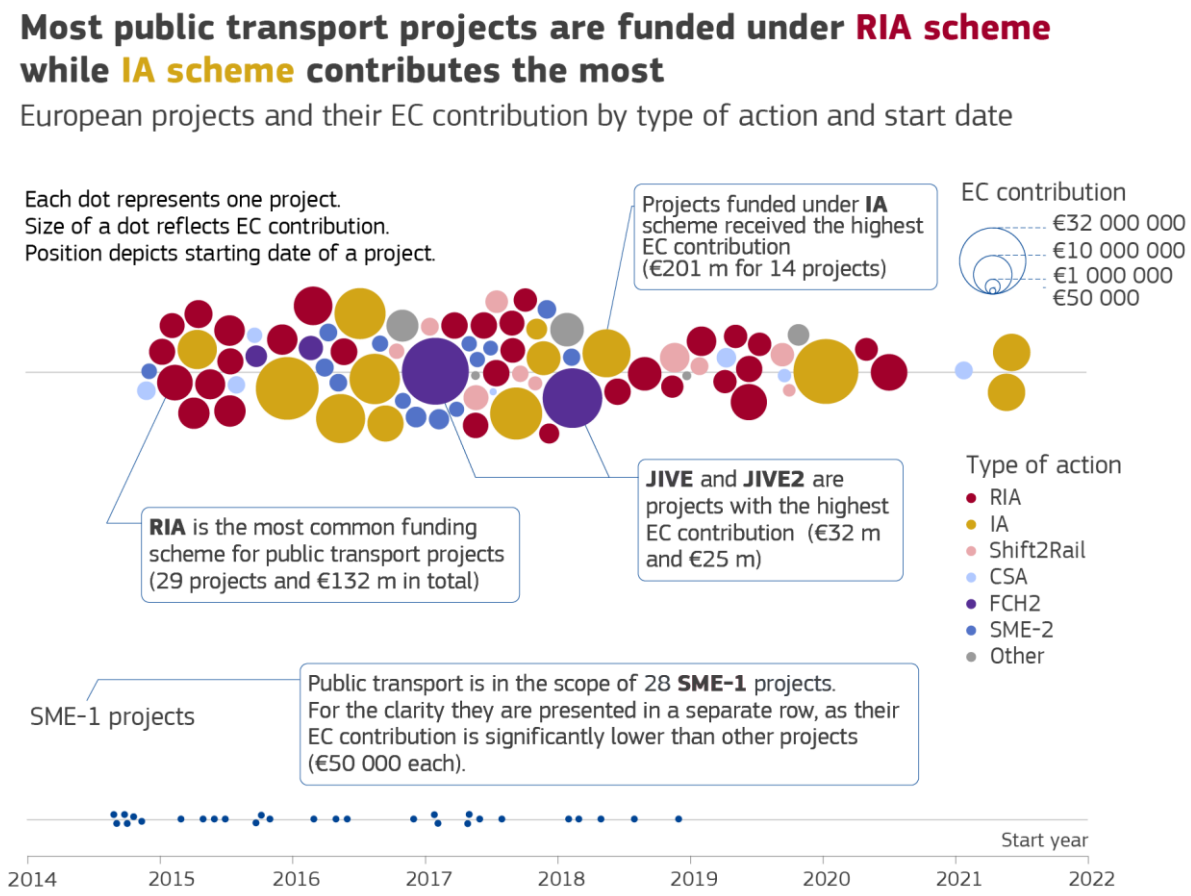
— the **highest total funding was directed through Innovation Actions** (IA) funding scheme (€201 m), however **the highest number of projects are funded under Research and Innovation Actions** (RIA; 29 projects);

— **Spanish organisations are the most active in European R&I public transport projects** in terms of total received EC contribution, number of projects they participate or led;

— more than half of the projects cover **Smart mobility and services** STRIA roadmap (92 out of 163); they also received the highest funding out of all STRIA roadmaps (€240 m);

— most of the identified projects focus on **public transport management and planning**, **digitalisation** as well as **emissions reduction**. Other three identified subthemes (connected and automated mobility, safety and infrastructure) received significantly less attention.

Figure Public transport research and innovation European projects by source of funding



RIA – Research and Innovation Action; IA – Innovation Actions; Shift2Rail - Shift2Rail Joint Undertaking; CSA - Coordination and Support Actions; FCH2 - Fuel Cells and Hydrogen Joint Undertaking 2; SME - Small and Medium-sized Enterprises Instrument;

Source: TRIMIS and CORDIS

Related and future JRC work

Since 2017 TRIMIS reports cover a wide range of the transport-related analyses on research and innovation initiatives in Europe. The content of TRIMIS reports covers all seven Strategic Transport Research and Innovation Agenda roadmaps, particular transport modes (airborne, waterborne, rail and road transport) as well as specific, transport-related topics, like new and emerging transport technologies or research and innovation in car sharing. A forthcoming TRIMIS report will focus on transport R&I in a specific urban context.

Quick guide

Section 1 provides the context of the report, introduces TRIMIS and presents the aims and structure of the document. Section 2 describes the detailed methodology and projects selection procedure. Section 3 sets the content of the report in the wider European policy and research context. Section 4 visually summaries quantitative analyses and focuses on main trends in recent European public transport research and innovation initiatives. Section 5 presents qualitative assessments of the relevant research and innovation projects focusing on the main achievements of these projects. The final section 6 concludes with the identification of the future research needs and policy recommendations.

1 Introduction

The era of the European Green Deal (European Commission, 2019) and its ambitious target of emissions reduction creates new conditions for urban mobility. The New EU Urban Mobility Framework (European Commission, 2021a) specifies these challenges putting public transport in the spotlight. Public transport, together with active mobility is expected to play a crucial role in making mobility more environmentally sustainable, inclusive, safe and innovative.

In order to achieve these ambitious aims, research and innovation (R&I) efforts in a broad spectrum are required. Achievement of reduction of emissions largely depends on fostering electrification of transport, implementation of alternative fuels, development of supporting infrastructure and supporting a shift to more sustainable transport choices, including public transport and active mobility. Improvement in transport management should orientate agencies and local authorities on making public transport more inclusive, safer, involving a wide range of various stakeholders into the planning and evaluation processes. Finally, the new digital solutions are essential to further improve quality of service, making it more affordable and safe and support management of public transport systems. All of these should be achieved having in mind a progressing automation of transport and upcoming connected and autonomous vehicles.

The **main aim** of this report is to provide a context and information about main trends, challenges and achievements of European R&I initiatives in public transport sector and to give recommendations on the focus of future R&I initiatives. The report uses the **Transport Research and Innovation Monitoring and Information System (TRIMIS) database** in order to identify all relevant projects which focus on public transport. TRIMIS has been developed by the European Commission's Joint Research Centre (JRC) under the Horizon 2020 Work Programme 2016-2017 on Smart, Green and Integrated transport (European Commission, 2017; Tsakalidis et al. 2020). and continued under the Horizon 2020 Work Programme 2018-2020 (European Commission, 2020a). It is an integrated transport policy-support tool which operates as a knowledge management system offering open-access information about transport-related R&I initiatives in Europe and beyond. TRIMIS contains a continuously expanded database which includes nearly 9000 R&I projects. TRIMIS collects data on European projects and projects funded from national sources, coming from Member States (MS) and associated countries and others. In the presented analysis we focus on European as well as national projects funded since 2014.

In the next section (section 2) we describe the detailed methodology and projects selection procedure. In the section 3 we present a brief summary of the main EU strategic documents relevant for public transport followed by an overview of the state-of-the-art of the public transport research. In this section we list key challenges which public transport currently faces. Then we set the scene for the review of main trends in public transport R&I in the scope of European projects (section 4) and to facilitate the identification of key achievements of evaluated projects (section 5). The final section (section 6) presents achieved results in the context of future research needs.

2 Methodological approach and structure of the report

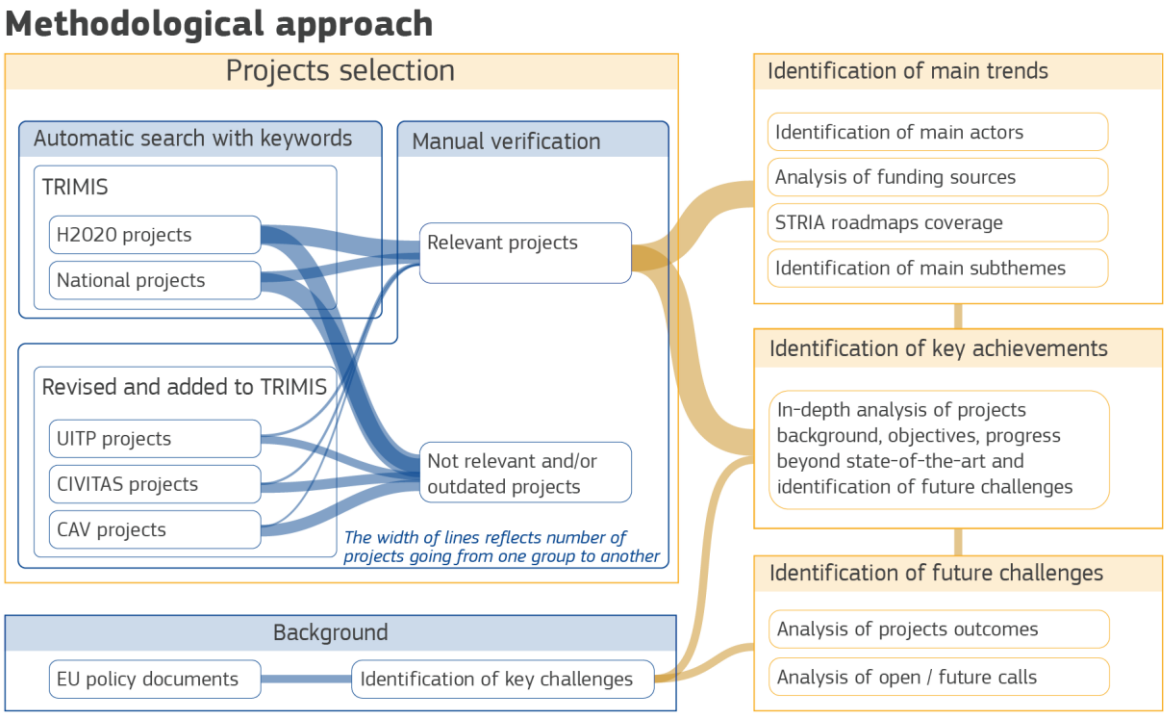
This report reviews recent R&I projects with public transport in their scope. The report is based on the TRIMIS project database, enriched by projects available from other sources. It includes almost 9 000 transport related R&I projects funded by European Commission (EC) as well as by MS and third countries. In this study, we focus on Horizon 2020 Framework Programme for Research and Innovation (H2020) projects which target public transport, along with projects funded by MS which started since 2014. We applied automatic search for projects in TRIMIS database using pre-selected keywords. The keywords include: public transport, transit, urban rail, tram, trolleybus, subway, metro, underground and bus. In the second step we manually checked and verified the list of projects, in order to ensure the selected ones are relevant to public transport.

To enrich the analysis, we identified relevant R&I projects from other sources, and we subsequently added them to TRIMIS. These additional sources include:

- UITP projects – projects listed by Union Internationale des Transports Publics; the International Association of Public Transport[1];
- CIVITAS projects – projects implemented within the Initiative for sustainable and smart urban mobility a reality for all; projects under category Collective passenger transport & shared mobility[2];
- CAV projects - projects collected by The Knowledge Base on Connected and Automated Driving[3].

Once we identified projects, we reviewed them according to their relevance and implementation period. In total, we considered 163 projects, looking at their background, scope and achievements. The dataset with all selected projects is available via JRC Data Catalogue[4]. The details of the selection process, embedded in a general overview of the approach of the report, is schematically presented in Figure 1.

Figure 1. Methodological approach



UITP - Union Internationale des Transports Publics; the International Association of Public Transport; CIVITAS - CIVITAS Initiative for sustainable and smart urban mobility a reality for all; CAV – the Knowledge Base on Connected and Automated Driving.
Source: JRC, 2022

[1] https://www.uitp.org/resources/projects/)
[2] https://civitas.eu/projects
[3] https://www.connectedautomateddriving.eu/projects/findproject/
[4] http://data.europa.eu/89h/09905b32-c339-4a8c-b94f-ef65409c0e1f

The width of the blue lines reflects the number of projects coming from one group to another. The majority of projects included in the report are H2020 projects automatically derived from TRIMIS database (90 out of 163) followed by national projects (49) and the rest (24) from additional data sources (including 10 more H2020 and 4 other European projects). Note that some of the projects included in the supplementary lists were already identified in the TRIMIS database.

Based on the detailed description of identified projects, we discuss MS involvement, funding sources and the relevance of projects to particular Strategic Transport Research and Innovation Agenda (STRIA) roadmaps (see Section 4). Furthermore, we assigned the projects to one or more identified subthemes (management, digitalisation, emissions, connected and automated mobility (CAM), safety and infrastructure). This allows us to identify main actors, financial background and main trends in public transport R&I activities in Europe.

Then we present an in-depth analysis of projects, their descriptions, and outcomes, in order to identify the main areas of development (see Section 5). We describe them following the same structure: the introduction and problem statement which put the achievement in a broader spectrum, which is followed by performed work and actual achievements in the area. We conclude with identifying potential or future R&I needs.

Finally, we summarise the report focusing on future challenges, placing them in the context of the scopes of open and/or upcoming European projects' calls (Section 6). We aim to show the next steps in the public transport R&I in the context of identified challenges of the sector resulted from the main strategic European documents from Section 3.

3 Background and key challenges

3.1 Public transport in the scope of European strategic documents

The 2019 European Green Deal (European Commission, 2019) aims at a 90% reduction in greenhouse gas emissions by 2050. Transport currently accounts for a quarter of the EU's emissions, and this figure continues to rise as demand grows. Meeting this objective will require considerably increase of the uptake of clean vehicles and alternative fuels and fostering more sustainable transport in general. Furthermore, improving public transport is expected to help to drastically reduce pollution especially in cities. In order to foster this effort, the Commission established the EU Climate-neutral and Smart Cities Mission which aims to deliver at least one hundred climate-neutral and smart cities in Europe by 2030 (European Commission, 2021b).

In line with the objectives of the European Green Deal, the December 2020 'Sustainable and Smart Mobility Strategy' (SSMS) (European Commission, 2020b) and the accompanying action plan of 82 initiatives aims at achieving a modern, green, and more resilient EU transport system. Increasing the number of passengers travelling by rail and commuting by public transport and active modes will help achieve these goals.

The New EU Urban Mobility Framework (European Commission, 2021a) published in December 2021 puts public transport in the spotlight, together with multimodality, active and shared mobility. The strategy acknowledges that many challenges remain to achieve an efficient public transport service (also due to the high demand during peak hours that leads to a lower quality of service), but also the opportunity to set public transport as the backbone of Mobility as a Service (MaaS) platforms. Digitalisation (including multimodal information systems, real-time timetables and smart ticketing) and automation can play a key role in promoting public transport, while at the same time, coverage and accessibility should improve.

Box 1. Principal policy directions

Public transport has been in the spotlight of European transport and mobility strategic documents and policies since it is a key for reducing pollution in cities. Principal focus is to improve efficiency and accessibility and propose public transport as a viable alternative to individual travel. Digitalisation, automation and integration with MaaS schemes as well as active mobility (walking, cycling) will play a key role to achieve these goals.

The Commission's communication on the new EU Urban Mobility Framework groups the desired actions into nine main blocks (see Box 2 for the details). Even though only one of them explicitly refers to public transport (attractive public transport services, supported by a multimodal approach and by digitalisation), the topic is indirectly present in the description of others as well. The thorough review of Urban Mobility Framework initiatives enables to identify main needs in public transport R&I and group them into main subthemes. The first one is related to **digitalisation** and digital innovation, including issues related to data collection and analysis as well as innovative solutions such as smart ticketing or MaaS applications (action 7 and actions 1, 3 and 4). The second one covers everything which relates to the reduction of **emissions** and making public transport environmentally friendly and energy-efficient. This includes electrification, implementation of hydrogen and alternative fuels, etc. (action 8 as well as actions 1-4). The next one covers a broad topic of public transport **management**, including public transport planning, accessibility, user experience or inclusiveness of transport systems as well as involvement of various stakeholders into planning and decision-making process or testing via Living Laboratories (action areas 2, 7 and 9 together with actions 3, 4). Additionally, Urban Mobility Framework directs attention to **safety** (action 4 and in combination with active modes – action 5), **connected and automated mobility** (CAM, actions 7, 8 and 4) as well as to transport **infrastructure** development (action 1 and action 8).

Box 2. Action areas of the new EU Urban Mobility Framework

1. A reinforced approach to TEN-T urban nodes
2. A reinforced approach to Sustainable Urban Mobility Plans (SUMPs) and mobility management plans
3. Monitoring progress – sustainable urban mobility indicators
4. Attractive public transport services, supported by a multimodal approach and by digitalisation
5. Healthier and safer mobility: a renewed focus on walking, cycling and micromobility
6. Zero-emission city freight logistics and last-mile delivery
7. Digitalisation, innovation and new mobility services
8. Towards climate-neutral cities: resilient, environmentally friendly and energy-efficient urban transport
9. Awareness raising and capacity building

3.2 Key challenges in public transport research and innovation

The analysis of public transport within the European strategic documents, complemented by the review of the recent public transport research enable to identify the following topics as key areas of R&I:

Topics related to **public transport planning and management**:

1. Integration of MaaS into public transport in order to improve quality of service and reduce car ownership.
2. Ensure accessible, inclusive and equitable conditions for all and especially for vulnerable users.
3. Involvement of citizens in defining mobility strategies and regulations and implementing the mobility measures.
4. Development and testing of new mobility solutions through Living Laboratories.

Topics related to **digital solutions** for public transport:

5. Data collection, storage and analysis for improvement of public transport planning and quality of service.
6. Real-time information about the position of public transport vehicles for transport planning and for enabling flexible/service on demand.
7. Smart ticketing, in particular in the context of increasing the attractiveness of public transport through seamless intermodal and cross-border travel, integration between transport services and improving connectivity between rural, peri-urban and urban areas.

Topics related to public transport **infrastructure**:

8. Well maintained and technology enabled infrastructure, in particular for urban rail systems, to achieve an appealing experience and assure safe and efficient travelling.
9. Electrified public transport and solutions for charging stations to be able to achieve lower urban emissions.

Topics related to **vehicles** for public transport:

10. Retrofitting of existing bus fleet to reduce the burden on the operator's costs, as electrification of the public transport fleet requires high initial investments.
11. Hydrogen fuel cell busses implementation to reduce emissions of public transport.
12. Increased efficiency and personalisation of public transport system and improvement of user experience due to implementation of autonomous buses.

4 Main trends

In this section we describe the main trends in European public transport research. First, we investigate the involvement of particular EU MS in H2020 R&I projects (Figure 2) and we analyse the main sources of funding for such research. The latter considers both EU projects – analysing the type of action which provides funding for projects (Figure 3), as well as national ones, showing number of projects funded by particular MS (Figure 4). Further, we investigate the scope of selected projects, in order to identify how they relate to transport R&I priorities for decarbonisation of the European transport sector. We do so, by taking advantage of existing tags in TRIMIS database which enable to link projects to the seven STRIA roadmaps (Figure 5). Finally, we group selected projects into identified thematic groups in order identify main thematic areas on which implemented R&I projects focus (Figure 6).

Main takeaways about the **Member States participation in 110 H2020 projects** (Figure 2):

— **Spanish organisations are the most active in European R&I public transport related projects**, considering the number of projects they participate in (60), the number of projects they lead (24) or total received EC contribution (EUR 58 million, approximately);

— in terms of **received EC contribution**, German (EUR 56.6 million) and UK organisations (EUR 53.5 million) closely follow; The next are Belgian, Italian, French and Dutch organisations (EUR 30-40 million);

— in terms of **number of projects**, Italian organisations are on the second position (coordinators in 16 out of 52 projects they participate in). German organisations participated in 48 projects, while they led only 8 of them – Belgium and UK organisations led more projects, 12 and 15 respectively;

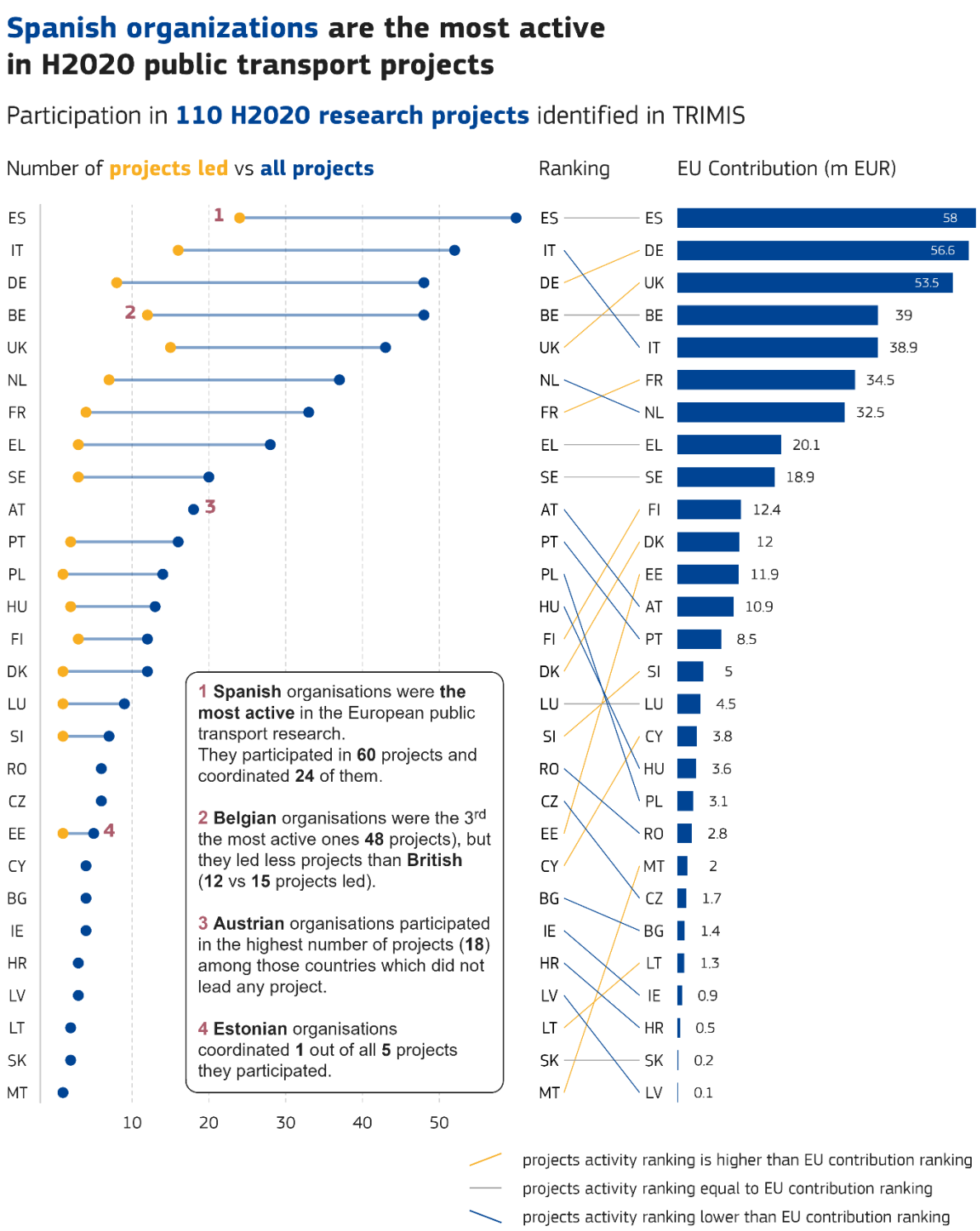
— **organisations from the three most active countries received almost 40% of all European funding** (EUR 168.1 million out of EUR 438.6 million) directed to the identified public transport related projects. It shows relatively high concentration of funding in terms to which countries the EC contribution is directed;

— the number of projects in which organisations from a country participate are more evenly distributed, so does the number of projects coordinated;

— **all EU27+UK countries have taken part in public transport related R&I projects**, and more than half have coordinated such projects. There is also quite high correlation between the scale of participation and coordination in R&I projects;

— the visible exception are Austrian organisations which have not coordinated any project despite the relatively high number of projects they participated in (18 projects). On the other hand, Spanish organisations have led 40% of projects they participated in, which underlines their leading role in the European public transport R&I initiatives.

Figure 2. Member States participation in H2020 research and innovation projects

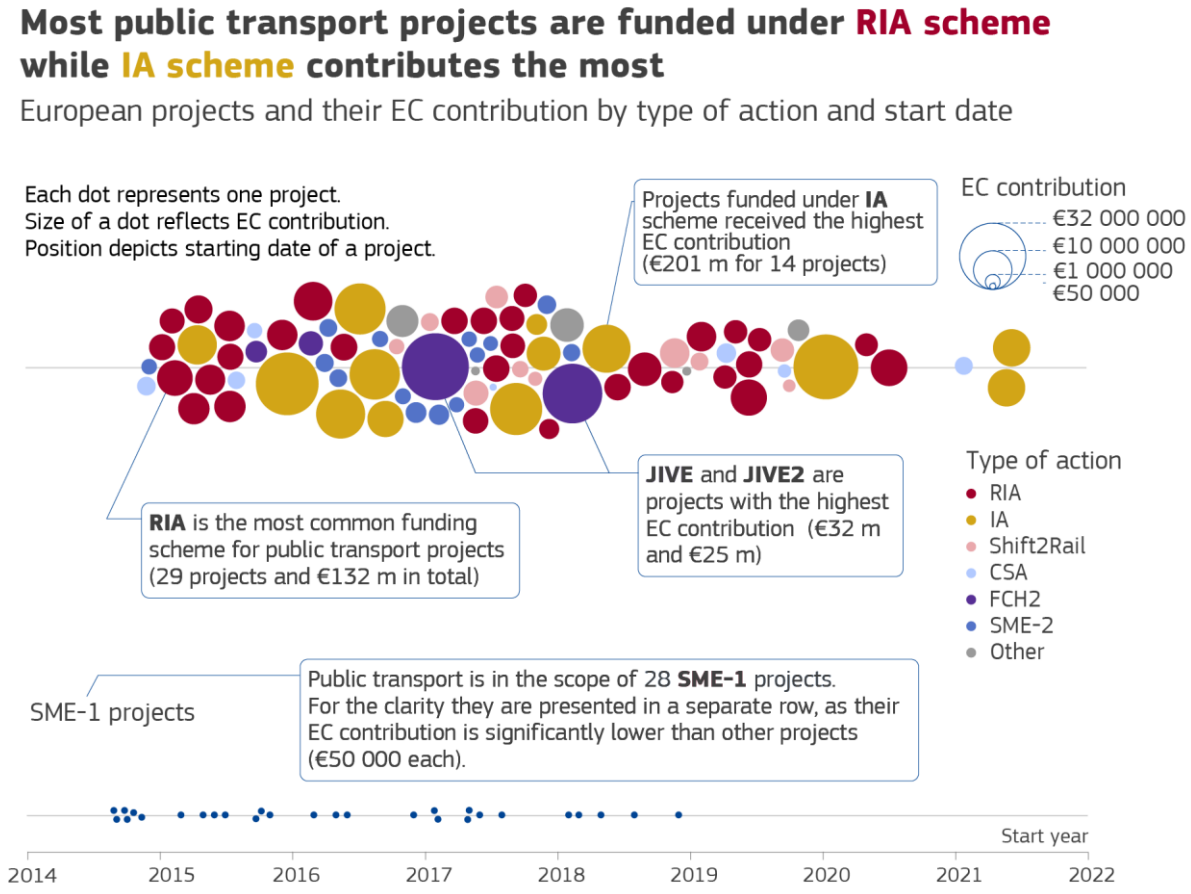


Source: TRIMIS and CORDIS

Figure 3 shows the distribution of funding sources of European and Figure 4 national public transport related R&I projects started since 2014. The Figure 3 presents the scale of EC contribution (the size of a dot) in 111 European projects (including 110 H2020 projects), which have public transport in their scope. The figure also indicates projects' starting date (position on x-axis) and type of action under which a project was funded (colour). Main takeaways:

- the **highest number of projects** (29) are funded under Research and Innovation Actions (RIA) funding scheme;
- the **total highest funding** was directed through Innovation Actions (IA) - more than €201 million;
- **the highest EC contribution** was granted to the JIVE and JIVE2 projects (both funded under Fuels Cells and Hydrogen 2 Joint Undertaking with total EC contribution of €32 million and €25 million) closely followed by SHOW project (IA, €30 million).
- the **most recent projects** are two funded under IA actions (MOVE21 and SCALE-UP, started on the 1st of May and 1st of June 2021, respectively).
- the **SME-1 projects**, due to their relatively low and equal funding (€50 000 of EC contribution), for the sake of clarity are presented on a separate line. 6 out of 28 projects included in the analysis started in the second half of the year 2014 and all of these projects started between 2014 and 2019;
- **Few of the SME-1 projects has been continued within SME-2** funding scheme (e.g. ELECTRIC_AXLE 2 or REBOOT projects).

Figure 3. Public transport research and innovation European projects by source of funding



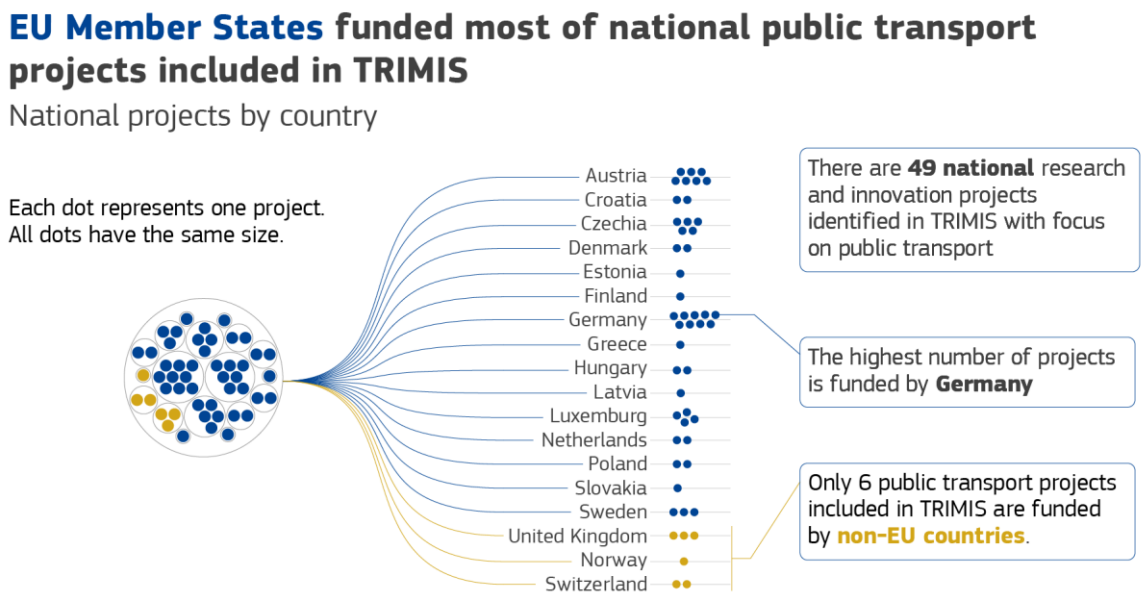
RIA – Research and Innovation Action; IA – Innovation Actions; Shift2Rail - Shift2Rail Joint Undertaking; CSA - Coordination and Support Actions; FCH2 - Fuel Cells and Hydrogen Joint Undertaking 2; SME - Small and Medium-sized Enterprises Instrument;

Source: TRIMIS and CORDIS

We also identified **49 public transport related national projects** in TRIMIS database (Figure 4):

- These projects are funded by 15 countries: 12 EU MS and 3 other countries;
- **The highest number of projects** are funded by Germany (9), then by Austria (7);
- Six projects are funded by **non-EU countries**: UK (3), Switzerland (2) and Norway (1);
- There is no visible correlation between number of projects funded from national sources and a country's activity in public transport related R&I activities. It can be related to the fact, that TRIMIS database covers national projects only partially, and the figures might not fully represent all nationally funded R&I projects.

Figure 4. Public transport research and innovation national projects



Source: TRIMIS

The next step of the analysis focuses on the scope of the identified projects. First, we check the number of R&I projects (both, European as well as national ones) which belongs to the particular STRIA roadmap (Figure 5). Considering the number of projects, we find that:

- **163 projects** have public transport in their scope;
- nearly half of the identified R&I projects (92) focuses on the **Smart mobility and services (SMO)**;
- **Network and traffic management systems** (NTM), **Transport electrification** (ELT), and **Cooperative, connected and automated transport** (CAT) groups between 27 and 40 projects, nearly three times less than SMO roadmap;
- the research areas of other STRIA roadmaps attract less attention, partly because the projects within other roadmaps have broader, not public transport specific scope and as such they fall beyond the scope of the report in hand.

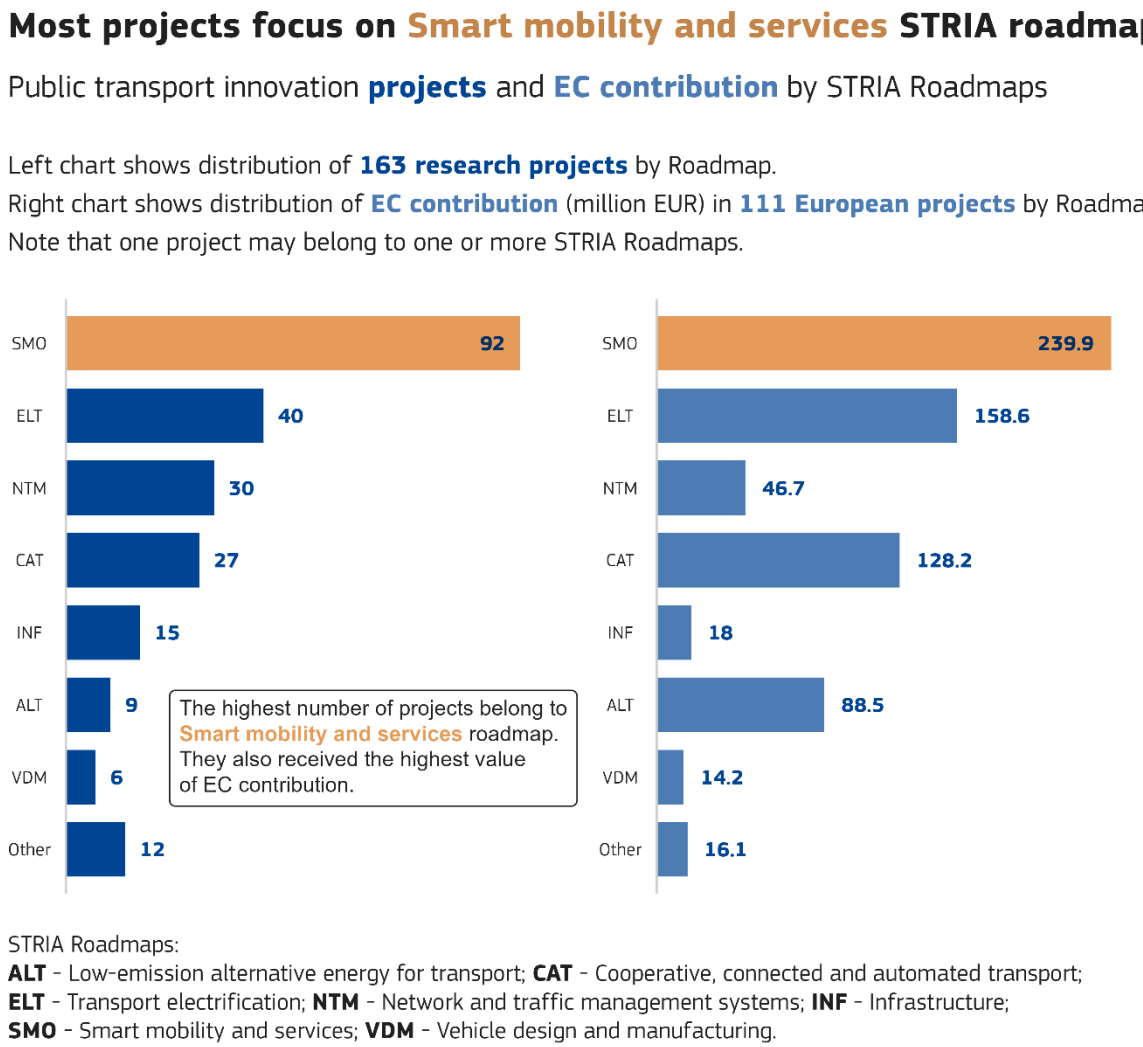
The distribution of **EC contribution in 111 European projects** is slightly different comparing to the number of projects:

- **SMO projects** similarly attract the highest share of EC contribution. They are followed by **ELT** and **CAT projects**;
- **Low-emission alternative energy for transport (ALT)** projects received the fourth most significant EC contribution. This is the consequence of the two Fuels Cells and Hydrogen Joint Undertaking 2 (FCH2) projects (JIVE and JIVE2) with a total contribution exceeding 60 million euro;

— **relatively low average budget of NTM projects** results in their lower total funding. It is approximately half of the ALT funding even though the number of projects is three times as big as ALT ones (30 versus 9, respectively);

— The scale of **funding is in line with the most important research challenges** as derived from EU Urban Mobility Framework described in section 3, namely management, which mostly fall within the scope of SMO, digitalisation (also SMO) and emissions (ELT and ALT).

Figure 5. Public transport research and innovation projects by STRIA Roadmaps



Source: TRIMIS and CORDIS

In order to confirm this conclusion we focus on main trends in public transport R&I activities by assessing an effort directed towards main identified subthemes (Figure 6). The definition of the subthemes follows the aggregation derived from Urban Mobility Framework action plans as presented in the section 3. The identified subthemes cover then the following areas:

— **management** – covers all topics related to public transport management and planning, including MaaS applications, accessibility, inclusiveness or studies on user experience;

— **digitalisation** – including data collection, management and analysis as well as innovative digital solutions for public transport (e.g. smart ticketing);

— **emissions** – covers all topics related to reduction of emissions, including hydrogen, electrification and alternative fuels;

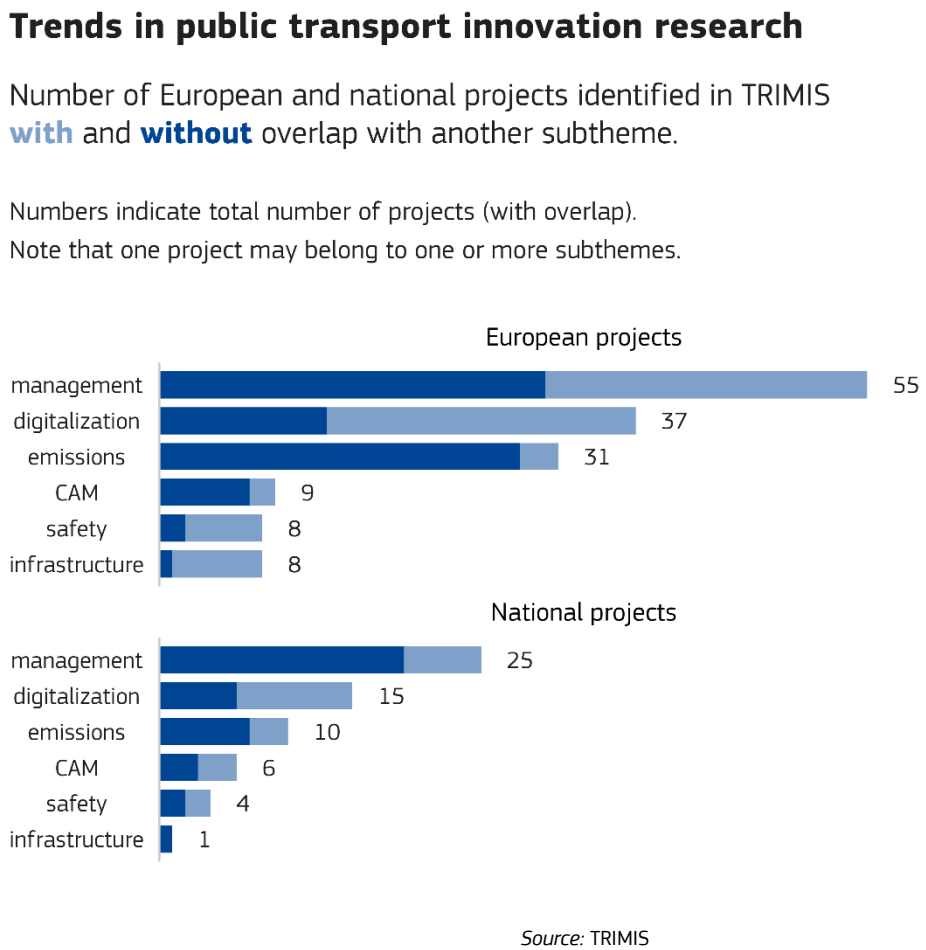
— **Connected and automated mobility (CAM)** – covers all topic related to connected and autonomous transport, e.g. autonomous shuttles, but also users' acceptance or operation systems and models;

— **safety** – including any R&I initiative towards increasing public transport safety and security, e.g. system of sensors and cameras, crash simulation tools and protocols etc.;

— **infrastructure** - covers project dealing with public transport infrastructure, e.g. maintenance and inspection, design in particular for needs of particular type users, railway tracks, etc.

Note, that since the scope of particular project may overlap between the identify subthemes, a project may be then assigned to one or more subthemes.

Figure 6. Public transport research and innovation projects by subtheme



Source: TRIMIS

Main takeaways:

— the highest number of projects (80) focused on **management** subtheme. Approximately half of European (30 out of 55) and 80% of national projects (19 out of 25) focuses exclusively on management subtheme, while the remaining overlap with another subtheme;

— the **digitalisation** and **emissions** are also in the scope of many projects (52 and 41 projects, respectively);

— the remaining three subthemes (CAM, safety and infrastructure) have attracted significantly less attention;

— **main R&I effort is line with the main objectives of the EU Urban Mobility Framework** and it focuses on improvement of management and planning, emission reduction and digitalisation. This applies to both European, as well as national R&I national projects included in the TRIMIS database.

5 Key achievements

This section presents key areas of public transport R&I and identifies key achievements in each of the areas. It also presents key issues of R&I and an outlook. The final section (5.13) summarises the main conclusions.

5.1 Mobility as a Service and public/private mobility integration

Mobility as a Service (MaaS) schemes have the potential to disrupt the way citizens and freight move in the future. MaaS will offer users mobility options as a viable alternative to own mobility and car ownership, combining transport infrastructures, travel information, payment services and more. Challenging car ownership can be achieved by offering one-stop shop MaaS platforms. This is a key to offer citizens an alternative that includes more sustainable public transport options.

Due to the implied challenges of public/private mobility integration, information handling and sharing, service interoperability and scalability requirements, specific actions to accelerate an appropriate and sustainable take off of MaaS solutions are needed. The IMOVE project investigated different roadmaps for MaaS. It analysed how heterogeneous stakeholders such as public sector entities (public transport authority, public transport operator, municipality) and private companies can work together for its uptake. The project focuses on the enhancement of the information technology tools to support business actors in the MaaS ecosystem. The Shift2MaaS project aimed to overcome the technical and non-technical barriers for the adoption of new integrated mobility platforms. It worked towards easing the process of integration with rail and supporting a major shift to collective transport.

IMOVE developed a framework of software enablers, Information and Communication Technologies (ICT) components integrating and enhancing the technological level of a MaaS. It put on the spotlight both, the supply and demand sides. The former focused on how the mobility offer portfolio of mobility services spreads across transport modes (public transport, shared mobility, railways) operated by various public and private operators and agencies. The latter covered how the users are willing to travel with ease in the most effective way according to the available options and their preferences. Shift2MaaS conducted pilot demonstrations in different cities. It evaluated the results, including the operator perspective, establishing a common methodology and set of relevant key performance indicators (KPIs) for assessing the success of the “technology enablers”. Real world data gathered from the demonstrations helped to improve solutions and understanding of possible bottlenecks in their implementation from policy, regulations, technology uptake and legacy systems readiness perspective. The UITP SPACE project aims to integrate on-demand shuttles, autonomous vehicles and robot taxis with the aim of substantial reduction of car ownership and to regain essential urban space in order to offer better mobility for all.

Eliminating data and interface standard incoherence (e.g., via the use of common APIs (Application Programming Interface) among the different operators) is key to the seamless integration of transport services. At the same time, profitability has to be assured for service providers within a context where public transport is often unprofitable.

5.2 Improve accessibility and inclusiveness of public transport

Personal mobility is paramount to society since it allows to access everyday activities such as education, healthcare, employment, and social activities. Nevertheless, various vulnerable groups may face difficulties in accessing these services which, in turn, can lead to the risk of social exclusion. One of the many obstacles they encounter concerns public transport since the limited accessibility may considerably affect the possibilities to engage in society. Likewise, people with disabilities including visually impaired people should be able to independently use public transport in a secure way and to orientate within complex public transport terminals. At the same time, current transport systems do not fully reflect specific needs of women, elderly or the youngest user groups.

The INCLUSION project addressed the challenges related to the accessibility of public transport, the inclusive mobility and equity, in peripheral, urban and rural areas. It defined new concepts and solutions applicable to inclusive mobility aided by ICT. The project conducted real life experiments in six pilot sites, implementing 15 innovative measures (for example using new app-based technologies for vulnerable user groups, or, redirecting lines accounting for the needs of rural commuters or accompanying parents). The INK 2016 project developed a system that combines real-time communication between vehicles of public transport and visually impaired people.

INCLUSION contributed to the improvement of accessibility offered by public transport systems in terms of trips involving connections to the public transport network. It focused on travel options to get to key services for vulnerable users and on increasing the number of trips made using public transport by vulnerable users. The project quantified targets measured by key performance indicators (KPIs), with data collected directly or through surveys on specific routes before and after interventions. The project reports concrete achievements for the different pilot projects. For example, it achieved 84% increase in bus trips by migrants on a public transport line in Florence, a 16% increase in children accompanied by parents using bus at least once a week for regular trips using a public transport line in the Rhein-Sieg pilot, and, 82% increase in passengers who make a connection to other public transport services in a rural area in Florence. DIAMOND applied a methodology based on a combination of a multi-level interdisciplinary analysis together with the development of a self-diagnosis tool and a decision support system, to enable a high-level understanding of women's needs in mobility and transport according to their specific characteristics.

The currently ongoing TRIPS project conducts research and evaluate existing accessibility and mobility services, elaborate on related digital and assistive technologies, design an index to measure mobility and provide case studies that demonstrate how mobility solutions designed by users with disabilities may provide inclusive urban transport for all.

Future research could focus on planning and technological solutions that will ensure accessibility and safety for vulnerable groups.

5.3 Involvement of local authorities and other stakeholders

The main challenge for local decision makers is to involve citizens and get their necessary acceptance when defining mobility strategies and regulations and implementing the mobility measures. Also, an organisational change is often necessary to create the conditions for the development and implementation of context specific sustainable transport measures. Many sectors (e.g., small privately owned businesses, and low-wage employees) may be neglected in the sustainable travel planning and their voice should be included in the decision-making process.

The CIVITAS ECCENTRIC project worked towards the improvement of public transport networks in peripheral areas (e.g. by speeding up core bus routes) and introduced new, integrated, and accessible shared mobility services complementing public transport. Cities-4-People underlined the importance of citizens in the co-creation process, with a focus on neighbourhood mobility. The project set up citizen mobility communities in five areas across Europe (Budapest, Hamburg, Istanbul, Oxfordshire and Trikala) and implemented five pilot programmes that address mobility challenges identified by the communities. SUNRISE addressed common mobility challenges at a neighbourhood level by developing and implementing collaborative processes in specific neighbourhoods, contributing to the principle of co-creation. The project embraced the principle of co-creation and developed a new, district-level governance approach, focusing on obtaining legal stability, financial support, technical assistance and on effective vertical integration (from neighbourhood to municipal to metropolitan level). The ongoing FastTrack project works on a suite of interlinking methods that provide local authorities with innovative interventions on areas of maintenance of transport fleets, ticketing systems, service integration and intermodality, accessibility for people with reduced mobility, new management and financing schemes. SCALE-UP aims to assist three European urban areas (namely Madrid in Spain, Antwerp in Belgium, and Turku in Finland) in becoming better connected and climate resilient while developing and operating complex and scalable multimodal transport systems. SUITS impact was on the working practices of local authorities, making them more efficient, adaptable and resilient, with increased engagement from citizens. SuMAC highlighted cases where workplace mobility planning can improve the environmental impact of commuting by employees from small organisations.

5.4 Development and testing of new mobility solutions through Living Laboratories

Living Laboratories (also called as Living Labs) are user-centred R&I projects which aim to integrate R&I processes in order to demonstrate and test innovation concepts in real-life settings. They use a dedicated physical space, mainly urban area, aiming to solve societal challenges involving multiple and diverse types of stakeholders. The learnt lessons may enable to implement proved successful solutions in other areas.

The CIVITAS Living Labs have covered a diverse types of urban areas: tourist, island cities (DESTINATIONS), port-cities (PORTIS) or suburban districts (ECCENTRIC). The activity of the projects covers multiple measures and innovative solutions which were designed, implemented and tested in one or many Living Labs organized in

participating cities. They cover general urban mobility solutions, however some of them are focusing in particular on public transport.

The outcomes of analysed projects include, among others: guidelines and technical description of the demonstration measures for reorganisation of public transport networks, integration of shared mobility services into public transport.

The public transport-related experiences from ECCENTRIC project were collected and disseminated through guidelines for reorganisation of public transport network. The guidelines contain a technical description of the demonstration measures including a description of the implementation process and the analysis of the main barriers and drivers of the reorganisation of public transport network. The Klaipeda's Living Lab developed and tested a new system for the prioritisation of public transport (PORTIS project). The Living Labs developed within DESTINATIONS project covers the topic of integration of public transport with flexible and tailored mobility services in tourist destinations. Finally, the ECCENTRIC project covered also in its research activities, the impact of COVID-19 on new mobility framework.

The ongoing MOVE21 project (started in May 2021) aims to deliver new, close to the ready for the market mobility solutions. These solutions cover wide range of areas, from monitoring of policies and governance and business models, up to solutions which support use of zero-emission electric or biofuel-based vehicles. In 2019, the European Commission's Joint Research Centre (JRC) set up the Future Mobility Solutions Living Lab (FMS-Lab) in Ispra (Italy) in order to engage citizens and relevant public and private players in the co-creation of innovative mobility solutions. The JRC Future Mobility Solutions Living Lab covers a wide range of innovative sustainable transport solutions, aiming to engage citizens and relevant public and private players in the co-creation of innovative mobility solutions. Examples include connected and autonomous vehicles (including vehicle connectivity and communication), mobility habits (pre- and post-Covid ones) or checking public's attitudes towards public transport. The JRC Living Lab targets also other mobility solutions (e.g. ad-hoc shared rides, door-to-door automated delivery, automated shuttles, robo-taxis, clean vehicle solutions), seeking opportunities with other mobility Living Labs for transferability, scalability and replication of the Living Lab results and processes.

5.5 Progress in data collection, integration and analysis for improvement of public transport management

The emerging data sources and increased capabilities for data collection, storage and analysis create new opportunities for improvement of public transport planning and quality of service. Public transport providers may use richness of data to conduct real-time analysis on how public transport system functions, detect its vulnerabilities and make immediate corrections. Precise, spatio-temporal data describe user behaviours and thus reflect their needs. On the other hand, an increased availability of data on public transport system offers multiple advantages for users, supports them in making informed decisions about their trips (e.g. route choice, selection of a departure time etc.).

All these developments create new prospects but also require further research and implementation effort to make them working for a well-being of the whole society. Several H2020 projects focuses on the involvement of advantages created by progress in data science for an improvement of public transport sector and they mostly concentrate on exploration of new possibilities, integration of new data sources into the existing procedures and development or improvement of analytical processes.

One of the progress areas is elaboration of detailed and as up-to-date as possible origin-destination (OD) matrices. SIADE SaaS project takes an advantage from smart card technology to extract this information. The conducted works enable to create very detailed anonymised OD matrices with multiple additional dimensions included (e.g. segmentation by day and time, occupancy level, fare group etc.). Further works tested and validated options to execute e.g. real time queries which further extend analytical and management potential.

Another area of development is the cooperative Intelligent Transport Systems (C-ITS) which provide opportunity for ITS systems to get access to data from other systems. Thus, each stakeholder is able to make better and more fact-grounded decisions. The CIMEC project collected use-cases for C-ITS and prepared the roadmap for city deployment of C-ITS.

The growing availability of new data sources, new technical capabilities and insufficient standardisation of data format create challenges for the nearest future of public transport sector. The MOMENTUM project plans to tackle the issue of development of new data analysis methods and implementation of new data sources in to the analytical process for better and more efficient transport models. This includes opportunities and threats

resulted from the future implementation of connected and autonomous vehicles. RIDE2RAIL project works on integration of various data sources on rail, ride-sharing and public transport in general to help users to compare and choose between multiple modes of transport in real time applying specific, user-defined criteria. DATA4PT aims to respond to the need of development and deployment of harmonized exchange standards which facilitate to implement union-wide multimodal travel information services.

5.6 Improving geolocation for public transport applications

In the area of geolocation, an important progress has taken place in the recent years. The real-time information about the position of a vehicle becomes available for public transport operators or local authorities as well as for passengers. Progress in the geolocation extends public transport services, enabling flexible routing and running the service on demand which is particularly important in the area with limited demand, e.g. low density, remote areas. Moreover, the progress in geolocation facilitates fleet management, transport planning or improve safety but it also makes planning a trip much easier for the users.

The existing obstacles related to the broad spread of geolocation and its further developments are related to, among others, limited availability in some areas and positioning errors. This is particularly the case of certain urban areas, e.g. deep urban valleys. The Galileo for Mobility project intends to tackle these issues by using the GNSS-Galileo technology and exploring how Galileo technology can benefit to urban mobility through the series of pilot projects.

The Galileo is the new European Satellite Navigation Satellite System launched in 2016. The project tested the Galileo technology in the context of taxi-sharing (Thessaloniki), combined mobility sharing service (e-bikes and cars in Paris; bike, scooter and car-sharing, public transport and taxi in Barcelona) and bus-on-demand service in a small town (Cervelló, near to Barcelona).

The conducted tests show improvement in the quality, stability and precision when using a GALILEO-equipped smartphone. In result, the geolocation signal provides more precise information about the location of users and vehicles. In consequence, the conducted research and implementation contributed to the improvement of the mobility options in the test areas.

The project ARIADNA continues working on the application of the European Global Navigation Satellite System (EGNSS) for urban mobility and for public transport in particular. It focuses on the next challenges, mostly related to the promotion of Galileo technology and its potential for improvement local mobility options.

Besides, works related to geolocation covered the areas of automated vehicle monitoring system (CELSO project), application of geolocated Wi-Fi data to automatically generate passengers' mobility flows (detailed origin-destination matrices; D3IMPACT project) or indoor positioning systems (GlobILS project), among others.

5.7 Smart ticketing services and cross-border traveling

Seamless intermodal travel and integration between transport services is key for increasing the attractiveness of public transport. Furthermore, travellers who wish to travel to a different country often are not familiar with local smartcard payment systems or even the cost of transport in general.

The solution to seamless cross-border travel lies in interoperable e-ticketing systems that exchange data and share information. The ETC project has developed technical systems and determined the required governance to take passenger and ticket information from a smartcard and places it in an 'account' on the cloud. With this solution traveling across borders and schemes is done seamlessly, enabling to use existing user's account.

The TRANSIT project is developing KPIs, mobility data analysis methods and transport simulation tools for evaluating the impact of innovative intermodal transport solutions with the aim to facilitate coordination of multimodal door-to-door trips.

The ticketing solution developed by ETC can lead to seamless travelling, resulting in greater use of public transportation and increased cooperation between transport authorities within Europe.

Standardisation and availability of data will be key for the smooth integration between different providers, and future research should focus to harness these aspects. Successful implementations should be collected and further explored in order to establish guidance for cities and metropolitan areas.

5.8 Effective urban rail infrastructure

Public transport relies on well maintained and technology enabled infrastructure to achieve an appealing experience and assure safe and efficient travelling. Inspection and tools for urban rail monitoring are important for minimising maintenance costs, optimising the use of resources and maximising network availability and reliability. Mechanical switches that enable the train to change tracks are subjected to repetitive impact collisions from the rolling stock that cause fatigue cracking which compromises their structural integrity. At the same time, the wireless coverage of the existing railway technological infrastructure does not fully comply with requirements for a large-scale use in support of the railway signalling.

The vmRail project combines sensor networks, computer simulation and signal processing to evaluate the state of railways and rolling stocks, simultaneously improving vehicle and track maintenance operations, ride safety, and passenger comfort. The SAFTInspect project developed a new, automated, ultrasonic inspection device for railway switches, that is able to detect with accuracy subsurface defects, avoiding their complete disassembly. The FAST-TRACKS project proposed a low cost telecommunication system, which, covering a functional gap in the railway radio telecommunication infrastructure.

vmRail aims to reduce maintenance costs of all the elements of the rail system, improve user experience through safer and more comfortable travel to the passengers. SAFTInspect focuses on reduction of delay of trains thanks to reducing the time required for inspection of rail crossings. It also aims to limit accidents related to train derailment caused by track switches. Benefits of the FAST-TRACKS system include improved safety and performance, increase of the track capacity, reduced running costs and improved reliability.

Future research will likely focus on technological solutions for monitoring and maintenance of urban rail infrastructure using digital technologies, including simulation tools and digital twins.

5.9 Infrastructure for electrified public transport

Electrified public transport is key to be able to achieve reduction of urban emissions. One of the barriers to wider take-up of electric mobility solutions is the energy infrastructure and the diverse hurdles around it. Due to the predominance of fossil fuel buses, charging infrastructure for public transport is still not completely developed or available. Therefore, there is a need to develop solutions for charging stations which are fast, cost effective and easily built making use of the existing public transport infrastructure.

Research in this area has focused on analysing feasibility of installation of charging stations without major modifications to the public transport infrastructure. It has also investigated the key enablers for fast and ultra-fast charging for buses, which are essential for a seamless public transport offer.

Results cover fast and smart charging solutions, with simulations to understand bottlenecks for charging demand. Innovative ideas include wireless charging, which can charge the bus when riding. In result, it reduces or even removes the need for a bus to travel back to station for charging. For example, ASSURED project studied the feasibility of introducing fast charging stations in the public transport infrastructure. The CEWET and CONCEPT projects researched the feasibility of wireless charging, with pilot trials expected in the future. The ELIPTIC project carried out demonstrators of different charging concepts, like overnight charging and opportunity charging.

Future challenges in the area include wide scale pilot implementation, to put the developed technologies to real test. They also include a development of new technologies which further decrease recharging times. Reduction of operational costs and cost of ownership are also challenges that require further exploration.

5.10 Retrofitting buses

Retrofitting of buses is an alternative solution to new electric buses, and can help reducing the burden on public transport operators, considering the high initial investment needs for the electrification of the public transport fleet.

To be able to achieve it, methodologies and new technologies which can be easily adapted to a diverse architecture of diesel busses is needed. These conversion kits have as a main goal to transform a diesel bus into a more environmentally friendly solution, such as hybridisation, full electrification of use of alternative fuels. Part of the work done is not only in developing the new technologies, but assuring that they will be cost effective, as that is one of the main motivations for the research.

Projects have developed retrofitting kits that can convert a bus into a full electric vehicle (REBOOT project), while also exploring the use of in-wheel driven technologies (ELECTRIC_AXLE). In other cases, the retrofitting is carried out to convert highly polluting diesel buses into less polluting ones, such as hybrids or LNG, as is the case for the Thomson Controller project. In other cases, as in the EU-elabus4.0 project, the retrofitting process makes use of the chassis and structure of old malfunctioning busses, therefore it reduces waste from the sector.

Future challenges include bringing the solutions to higher readiness levels, and to scale up the technologies and to be able to deliver them at affordable market costs. The attractiveness and reliability of the solutions is a crucial factor for their market uptake.

5.11 Fuel cell bus

Hydrogen fuel cell busses are another option for reducing emissions of public transport. These busses use hydrogen as a main energy carrier, which is converted to electricity which, in turn, powers an electric motor. Its performance was demonstrated in different use cases, including in busses.

However, there are still many barriers before the wide-scale adoption of fuel cell busses. First of all, a higher maturity of fuel cell technologies is needed, followed by the appropriate infrastructure for liquid hydrogen refuelling. Moreover, the technology is still quite expensive to be deployed so costs needs to be reduced.

Projects have focused on developing fuel cells that have a higher lifespan, and thus guaranteeing a lower lifecycle cost for the buses. There has been research on refuelling capacity for hydrogen stations, taking into account the periodic need for refuelling of a bus fleet.

Achievements include fuel cells with a higher lifetime and increased reliability. They also include diagnostic methodologies. The Giantleap project has improved the reliability and lifetime of fuel cells, while also designing a fuel cell range extender for battery buses. Further, the NewBusFuel project has created a design methodology which accommodates hydrogen refuelling stations for use with public transport systems. Within the context of the JIVE and JIVE 2 projects, fuel cell buses have been deployed across multiple European cities, while gathering data for future research on best practices.

Future challenges include the need to improve the hydrogen refuelling infrastructure, and close technological gaps which hamper wider scale deployment. For this purpose, more urban pilots are necessary.

5.12 Autonomous buses and shuttles

Autonomous buses are a promising solution for improvement of public transport. They can provide more efficient and personalised public transport system, with centralised on-demand systems. Thus, they can improve user experience and lead to higher public transport use. Nonetheless, there are still many barriers for the implementation of autonomous buses and shuttles. Technology still needs further improvement to be competitive, safe and ready to be used. Additionally, there are still regulatory barriers that impede full deployment of autonomous buses in most countries or cities. Finally, user acceptance is still an obstacle that needs to be addressed.

In this context, projects have worked on improvement of different types of technologies used for autonomous vehicles and deploy them in urban conditions in order to carry out tests and improve the knowledge base for regulatory institutions. Achievements include the implementation of multiple test pilots throughout Europe, where users can get a first-hand experience with autonomous buses and learn about their advantages. This is the case for the SHOW and AVENUE projects, which carry out test pilots in various European cities. These projects advanced the stated of the art of the technology and improved software for the deployment of autonomous vehicles. Further, some projects focused on the verification, validation and deployment (e.g. SHOW), while others concentrate on identification of barriers and obstacles for wide adoption (AVENUE) of autonomous buses. The FABULOS project has researched not only the technologies for autonomous shuttles, but also how planning and procurement should evolve when autonomous buses are deployed.

Future challenges include the development of testing protocols to ensure safety and technical performance, while improving the operational characteristics of the vehicles themselves (e.g. faster speed, improved routing, integration with other transport modes)

5.13 Summary of the key achievements

5.13.1 Public transport planning and management

1. Mobility as a Service and public/private mobility integration
    - Real-world demonstrations of Mobility as a Service implementation
    - Development of technical and non-technical frameworks for Mobility as a Service integration
2. Accessibility and inclusiveness of public transport
    - Real-world testing of innovative measures to improve accessibility and address inclusiveness
    - Decision support system to address women's needs in mobility and transport
3. Involvement of local authorities and other stakeholders
    - Developing and implementing collaborative processes to address local mobility challenges
    - Collection of innovative solutions for local transport authorities
4. Development and testing of new mobility solutions through Living Laboratories
    - Development of demonstration measures for reorganisation of public transport networks
    - Development of guidelines for integration of shared mobility services into public transport

5.13.2 Digital solutions for public transport

5. Geolocation for public transport applications
    - Improved precision of geolocation signal from users and vehicles from GALILEO-equipped smartphones
    - Implementation and tests of indoor and outdoor positioning systems
6. Data collection, integration and analysis for improvement of public transport management
    - Roadmap for city deployment of cooperative Intelligent Transport Systems
    - Detailed and multidimensional anonymised origin-destination matrices for transport planning
7. Smart ticketing services and cross-border mobility
    - Development of a technical systems for cloud-based smartcard data
    - Development of methods and simulation tools for intermodal transport solutions

5.13.3 Public transport infrastructure

8. Effective urban rail transport infrastructure
    - Development of automated inspection and maintenance devices and systems for rail infrastructure
    - Development of a low-cost system for railway telecommunication infrastructure
9. Infrastructure for electrified public transport
    - Feasibility studies of wireless charging in public transport
    - Demonstrations of various charging concepts (e.g. overnight or opportunity charging)

5.13.4 Vehicles for public transport

10. Retrofitting buses
    - Development of retrofitting kits to convert a bus into a full electric vehicle
    - Implementation of retrofitting processes to reduce pollution

11. Fuel cell bus
    - Development of fuel cells with a higher lifespan
    - Deployment of fuel cell buses in selected case studies
12. Autonomous buses and shuttles
    - Test pilots of autonomous vehicles in public transport
    - Research on required changes in planning and procurement for deployment of autonomous buses

6 Conclusions

Public transport has changed considerably during the years, affected by the introduction of innovative ICT technologies, new business models and different transport management systems. These are clearly reflected in the topics tackled under H2020 and national R&I projects. Still, transport users face several and not negligible challenges during their daily mobility. To this aim, targeted transport R&I underpinned by policy action can act as an enabler to improve transport and mobility.

In light of the previous key finding and looking at future transport priorities, as set out in the European Green Deal, the Sustainable and Smart Mobility Strategy and the new EU Urban Mobility Framework, some areas of further investigation which would help addressing public transport challenges are indicated below.

- The accessibility improvement has to be accomplished in a way that public transport does not leave anyone behind. Thus, on the hand, future R&I initiatives should concentrate on evaluation of current performance (transport accessibility, volume of passengers, user satisfaction), mapping users' needs and improve planning in order to meet those needs. On the other, they should focus on fostering an **inclusive, safe, affordable and sustainable public transport for all transport users**, including tailored approaches for vulnerable groups. Future research should identify specific mobility needs of women, children and teenagers, as well as of people with disabilities. Their needs should be consulted and addressed within public transport policy frameworks. The geographical dimension should be also considered, taking into account the needs of people from peri-urban and at rural areas as well.
- Improve the **transport accessibility to and by public transport**. The measurement of the level of user satisfaction should be incorporated into the planning and evaluation processes. Further, the research should focus on the investigation of dependencies between public transport and active travel modes, with particular focus on multi-modal hubs and accessibility to infrastructures. Feedback activities on public transport utilisation and satisfaction should be promoted to foster active users and citizen participation in transport urban planning activities.
- Gather and analyse the **needs, challenges and expectations of citizens and stakeholders** fostering their role in decision-making processes by means of innovative participatory processes, co-creation methods, living labs and hubs for innovative participative governance.
- Promote the **seamless integration with new and shared mobility services** (e.g. micro mobility including bike/scooter sharing, demand responsive transport, car-pooling or car sharing) as well as MaaS type of service in existing or new infrastructure settings. These solutions should be investigated both in urban and non-urban areas, trying to exploit their potential benefit also in rural or non-densely populated areas.
- Exploit the **collection, storage and analysis of public transport data** and the use of **simulation tools** which will support the creation of science-based indicators. These should lead to the development of a common planning, monitoring, reporting and verification framework, which could be used by European cities. Data collection should cover different transport user groups, looking at mobility patterns, behaviours and needs. The efficient dissemination of the collected data would increase public transport use and greatly support users' informed decisions (e.g. about route choice, applicable fare etc.). In the end, that should lead to a modal shift towards more sustainable modes and reduction of the use of private cars.
- Support the implementation of **learning, replicability and scaling-up of solutions** by helping cities to learn from other experiences and to tailor their approach in order to develop customized public transport policy framework using Sustainable Urban Mobility Plans concept and guidelines. The launch of large-scale pilots should be promoted deploying those R&I solutions that foresee scaling-up and replication in other cities.
- Asses the development and the deployment of **electric, automated and connected buses** under different environmental, infrastructure and social conditions. This would allow for more precise operational and ownership costs estimations which deserves additional research in the future, leading towards more efficient transport and reduction of emissions.

This list could be expanded further as new societal and mobility challenges may arise. Nonetheless these indications are aligned with the topics included in relevant Horizon Europe calls both from the Climate Neutral and Smart Cities Mission and from the Horizon Europe, Pillar II-Global Challenges and European Industrial Competitiveness and Cluster 5 on Climate, Energy and Mobility.

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List of abbreviations and definitions

ALT	Low-emission alternative energy for transport
API	Application Programming Interface
CAM	Connected and Automated Mobility
CAT	Cooperative, connected and automated transport
CAV	Knowledge Base on Connected and Automated Driving
C-ITS	Cooperative Intelligent Transport Systems
CSA	Coordination and Support Actions
EC	European Commission
EGNSS	European Global Navigation Satellite System
ELT	Transport electrification
EU	European Union
FCH2	Fuels Cells and Hydrogen Joint Undertaking 2
FMS-Lab	Future Mobility Solutions Living Lab
GNSS	Global Navigation Satellite Systems
H2020	Horizon 2020 Framework Programme for Research and Innovation
IA	Innovation Actions
ICT	Information and Communication Technologies
INF	Transport infrastructure
ITS	Intelligent Transport Systems
JRC	European Commission's Joint Research Centre
KPI	Key Performance Indicator
MaaS	Mobility as a Service
MS	Member States
NTM	Network and traffic management systems
OD	Origin-Destination
R&I	Research and innovation
RIA	Research and Innovation Action
Shift2Rail	Shift2Rail Joint Undertaking
SME	Small and Medium-sized Enterprises Instrument
SMO	Smart mobility and services
SSMS	Sustainable and Smart Mobility Strategy
STRIA	Strategic Transport Research and Innovation Agenda
SUMP	Sustainable Urban Mobility Plans
TRIMIS	Transport Research and Innovation Monitoring and Information System
UITP	Union Internationale des Transports Publics; the International Association of Public Transport
VDM	Vehicle design and manufacturing

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