Innovation Strategies and Research Trends for Connected, Cooperative and Automated Mobility in Europe

Carolin Zachäus[1(✉)] and Stephane Dreher[2]

[1] Department European and International Business Development, VDI/VDE Innovation + Technik GmbH, Steinplatz 1, 10623 Berlin, Germany
carolin.zachaeus@vdivde-it.de

[2] Department Innovation & Deployment, ERTICO – ITS Europe, Avenue Louise 326, 1060 Brussels, Belgium
s.dreher@mail.ertico.com

Abstract. Exploring the forefront of innovation strategies and research trends, the future of connected, cooperative, and automated mobility (CCAM) in Europe promises to revolutionize the transportation landscape, paving the way for sustainable, efficient, and inclusive transportation systems [1]. Therefore, this chapter discusses the challenges and solutions for the deployment of CCAM technologies in Europe related in particular to coordination and cross sector stakeholder engagement. Despite the technical advancements and numerous Research and Innovation (R&I) and testing activities, multiple barriers remain, such as limited demand, lack of technical maturity, scattered research efforts, and inadequate demonstration and scale-up. The CCAM Partnership plays a crucial role in overcoming these obstacles by creating a unified, long-term R&I agenda. Under the umbrella of the CCAM Partnership 18 projects have been funded so far. The project objectives and thematic assignments corresponding to R&I priorities identified by the Partnership, are described in this paper. Furthermore, the role of the FAME project supporting the European CCAM ecosystem by fostering knowledge exchange, best practices, and international collaboration is highlighted. Finally, the CCAM ecosystem with respect to the R&I projects will be discussed.

Keywords: Connected and Automated Mobility · Autonomous Driving · Electronic Components and Systems · Innovation Policy · Research and Innovation Activities · CCAM Partnership

1 Introduction

Mobility and transport are vital to society, enabling economic and social life, yet they also impose significant costs, including pollution, accidents, and greenhouse gas emissions. The transport sector must significantly reduce its emissions to achieve EU climate goals, and the European Green Deal's success depends on sustainable transport [2]. As society moves towards sustainable and efficient mobility solutions, CCAM has emerged as a

G. Meyer and S. Beiker (Eds.): ARTSymposium 2022, LNMOB, pp. 79–90, 2023.
https://doi.org/10.1007/978-3-031-34757-3_8

crucial area of focus. CCAM solutions aim to provide user-centred, inclusive mobility while increasing safety, reducing congestion and emissions, and contributing to decarbonization. By seamlessly integrating novel mobility services with existing ones, they have the potential to enhance transport sustainability, safety and inclusiveness directly contribute to various policy goals, such as the United Nations Sustainable Development Goals, Vision Zero, the European Green Deal, Europe fit for the Digital Age, and the Smart and Sustainable Mobility Strategy. However, the problem drivers and technical maturity of CCAM solutions must be further advanced and proven.

Recognizing the necessity for collaboration in the development of technological solutions, the Horizon Europe Framework strategy emphasizes the importance of European Partnerships [3]. European Partnerships in the Horizon Europe framework are strategic, collaborative initiatives designed to address global challenges, enhance European competitiveness, and foster innovation. These partnerships are collaborative initiatives between the EU Commission and private and/or public partners that support research and innovation programs and significantly contribute to achieving EU political priorities. By pooling resources, expertise, and knowledge, European Partnerships drive impactful research and innovation, accelerating progress towards a more sustainable, inclusive, and prosperous future for Europe.

Besides emphasizing the importance of European Partnership, the Horizon Europe Framework strategy aims to improve the coherence of Partnerships, make them more open and transparent, and promote competitiveness and innovation, while fostering pre-competitive collaboration of stakeholders from the entire value chain, ensuring a holistic approach to address complex challenges, e.g. posed by CCAM.

This paper provides an overview of the topics and projects addressed in the first phase of the CCAM Partnership, focusing on the essential stakeholder interaction required for successful implementation. By examining the collaborative efforts and outlining the key areas of focus, we aim to provide insights into the current state of CCAM Research and Innovation strategies in Europe and highlight the crucial role that partnerships as well as Coordination and Support Actions (CSA) play in its development and deployment.

2 Research and Innovation Strategies in Europe

As society moves towards sustainable and efficient mobility solutions, CCAM has emerged as a crucial area of focus. CCAM solutions aim to provide user-centred, inclusive mobility while increasing safety, reducing congestion and emissions, and contributing to decarbonization.

Multiple problem drivers are remaining to achieve the successful deployment of these technologies, such as limited demand, underdeveloped solutions, scattered research and innovation efforts, and inadequate demonstration and scale-up. To tackle these challenges, a transformation in the mobility innovation process is crucial, with a focus on user engagement, strategic timing, and expanded outreach. The CCAM Partnership [4] plays a vital role in overcoming these obstacles, facilitating the swift adoption of CCAM technologies and services across Europe by creating a unified, long-term research and innovation agenda that incorporates various stakeholders in a coordinated, holistic approach. This partnership ultimately supports Europe's position as a leader in safe and

sustainable road transport through the advancement of automation. Launched in 2021, the European CCAM Partnership has the main objectives to better align EU R&I efforts in the field of CCAM and develop and implement a coherent long-term agenda to coordinate investments in R&I and pre-deployment. The second phase of the partnerships focusses on implementing large-scale demonstrations of inclusive and user-oriented CCAM solutions for people and goods across Europe by 2030.

Partnerships should however not work in silos, as several challenges they address are connected and in particular, for transport the wider impacts or all related technologies should be looked at. Emphasizing a collaborative approach between different partnerships and missions, the CCAM Partnership, the 2ZERO Partnership [5], and the Cities Mission [6] have jointly launched a common research call to broaden the EU perspective and enhance cooperation across various mobility domains and urban-related topics.

The calls primary objective is to develop cutting-edge mobility solutions catering to the needs of both people and cities while aiming for climate neutrality by 2030. Through collaboration with local authorities, citizens, and stakeholders, the projects funded in the frame of this call will create transferable solutions that merge electrification, automation, and connectivity in passenger and freight transport. These solutions should be economically viable, modular, adaptable, and applicable across cities committed to achieving climate neutrality.

Moreover, the project will bolster capacity among local authorities, users, and mobility systems providers, accelerating the adoption of shared, smart, and zero-emission solutions. It will also aid in formulating implementation plans for local and regional transport authorities to replicate innovative smart mobility solutions and associated infrastructure in cities beyond the project's reach.

Another development strongly discussed in the European CCAM ecosystem is the promotion of a software defined vehicle (SDV) platform. The increasing importance of software and hardware in vehicles, as they become more electric, autonomous, connected, and service-oriented, has led to a rapid rise in software complexity. This development calls for enhanced standardization and reuse through a software platform, which encompasses the operating system and middleware layer. European companies, facing intense global competition and talent shortages in automotive software, often encounter fragmented efforts.

A pre-competitive European collaboration could expedite cooperation and result in an open SDV platform, initiated by the Electronic Components and Systems Partnership (KDT) and spearheaded by leading EU stakeholders and concentrating on non-differentiating aspects [7]. This approach would help conserve resources and focus investments on competitive solutions. The platform aims to establish common architecture building blocks (modules), supported by development tools for prototyping and testing, centering on the hardware abstraction layer within a comprehensive SDV architecture.

3 Research Landscape in Europe (Stakeholder and/or Projects)

The European Union has a long legacy of funding research and innovation activities in CCAM. Intense funding with the launch in 2016 of a specific call on "Automated Road Transport" in the Horizon 2020 Programme provided over €300 million in funding up to 2020 in four research fields, namely: Networking, Coordination & Support; Infrastructure, Connectivity and Cooperative Systems; Driver Assistance Systems and Partial Automation; and Highly Automated Road Transport. EU research funding has continued in the Horizon Europe programme for 2021–2027 under the umbrella of the CCAM Partnership. So far, 18 projects have been funded in the frame of the Horizon Europe Programme in CCAM. Each project is assigned to one of the seven clusters, which structure the activities of the CCAM Partnership (Fig. 1).

Fig. 1. Cluster structure of the CCAM Partnership, organizing the necessary R&I actions to support large-scale demonstration essential to advance towards deployment readiness.

The interlinked CCAM cluster structure illustrates the connections between specific R&I actions and the Partnership's objectives to advance CCAM solutions and prepare them for large-scale deployment.

The successful deployment of CCAM relies among other things highly on its societal benefits and user adoption. To achieve this, development, deployment, and regulation must be based on understanding specific needs, impacts, and costs. Cluster 6 addresses user needs and societal aspects in various ways, such as focusing user-centric technologies, guiding transport system integration, addressing user needs in key enabling technologies, and offering feedback on societal aspects in Living Labs. Socio-economic and environmental impacts will be assessed to understand CCAM's contributions to safety, accessibility, equity, and environmental goals. Tools will be provided for user-centered solutions that effectively contribute to societal targets and regional CCAM uptake. Concrete actions will be performed in the following projects, which have started in September 2022.

MOVE2CCAM - MethOds and tools for comprehensive impact Assessment of the CCAM solutions for passengers and goods [8] explores the impact of CCAM passenger and freight solutions by defining use cases, business models, and KPIs through

co-creation with a multi-system network of actors. It develops a system dynamics-based impact assessment tool to evaluate the effects of CCAM interventions on various aspects, considering European region specifics and different actors' needs. The project delivers impact evaluation frameworks, KPIs, policy recommendations, and recommendations for Sustainable Urban Mobility Plans (SUMP).

SINFONICA - Social INnovation to FOster iNclusIve Cooperative, connected and Automated mobility [9] aims to develop strategies, methods, and tools to engage CCAM users, providers, and stakeholders in understanding their needs and concerns related to CCAM. It co-creates decision support tools for designers and decision-makers to enhance seamless and sustainable CCAM deployment, ensuring inclusivity and equity for all citizens.

Besides the understanding of user needs and societal aspects, the advancement of vehicle technologies for sensing and safety systems (cluster 2), alongside with key enabling technologies (cluster 5) are crucial to enhance CCAM solutions.

Cluster 2 "Vehicle technologies" aims to develop safe, efficient, and effective solutions for highly automated vehicles in Europe's future mobility and transport system. Cluster 2 focuses on environmental perception and safe decision making to ensure safe interactions with other road users, provide protection in emergencies, and maintain occupants' comfort and well-being. This requires multiple sensing devices and systems interacting within a "Sense-Think-Act" process for effective decision-making.

AWARE2ALL - Safety systems and human-machine interfaces oriented to diverse population towards future scenarios with increasing share of highly automated vehicles [10] addresses new safety challenges posed by highly automated vehicles in mixed traffic by developing innovative passive and active safety and Human Machine Interface (HMI) systems. It proposes a universal safety framework for HMI, building on results from previous projects and focusing on the variety of the population.

EVENTS - ReliablE in-Vehicle pErception and decisioN-making in complex environmenTal conditionS [11] aims to create a robust and self-resilient perception and decision-making system for autonomous vehicles (Avs) to handle unexpected situations. The project focuses on three use cases: Interaction with Vulnerable Road Users (VRU), Non-Standard and Unstructured Road Conditions, and Low Visibility and Adverse Weather Conditions.

ROADVIEW - Robust Automated Driving in Extreme Weather [12] develops an in-vehicle system for advanced environment and traffic recognition, prediction, and decision-making under various conditions, including harsh weather. The project integrates a cost-effective multisensory setup, sensor noise modeling, collaborative perception, and testing through simulation-assisted methods.

Cluster 5 "Key enabling technologies" supports the whole mobility system, focusing on AI, Big Data, and cybersecurity for vehicle technologies, integration, and validation, extending their application beyond individual vehicles. It fosters cooperation among stakeholders from various technology areas and industries, aiming for safe and secure operation of vehicles and mobility systems.

AI4CCAM - Trustworthy AI for CCAM [13] will develop an open environment for integrating trustworthy AI models for VRU behavior anticipation in urban traffic conditions, focusing on road safety and user acceptance.

AITHENA - AI-based CCAM: Trustworthy, Explainable, and Accountable [14] will research explainable AI in CCAM development and testing frameworks, focusing on data, models, and testing.

CONNECT - Continuous and Efficient Cooperative Trust Management for Resilient CCAM [15] addresses security and safety convergence in CCAM by assessing dynamic trust relationships and defining a trust reasoning framework, enabling cyber-secure data sharing and trustworthy outsourcing of tasks.

SELFY – SELF assessment, protection & healing tools for a trustworthY and resilient CCAM [16] aims to increase CCAM ecosystem safety, security, robustness, and resilience by developing a toolbox of collaborative tools focusing on situational awareness, data sharing, resilience, and trust. These tools will operate individually or cooperatively to manage protection, response, and recovery decisions locally or globally in response to cyber threats or hazards.

Integrating the overall transport system ensures safe human-machine interaction and supports traffic, fleet management, and physical and digital infrastructure requirements. In this regard, Cluster 4 "Integrating the vehicle in the transport system" advances physical and digital infrastructure, connectivity, and cooperation to enhance fleet and traffic management systems for CCAM vehicles. Hereby, Cluster 4 focuses on providing digital information, developing connectivity and communication solutions, delivering cybersecurity and data sharing approaches, while addressing user needs and societal expectations. Those developments are aimed to enhance safety and efficiency as well as interoperability, ensuring seamless mobility across various operators and service providers.

AUGMENTED CCAM - Augmenting and Evaluating the Physical and Digital Infrastructure for CCAM deployment [17] aims to advance the readiness of physical, digital, and communication infrastructure for large-scale deployment of CCAM solutions. It will develop and evaluate physical, digital and communication infrastructure (PDI) supported solutions in seven test sites across three European countries. AI, Big Data, and crowdsourced High Definition (HD) maps will enhance situational awareness, prediction, and actuation.

CONDUCTOR - Fleet and traffic management systems for conducting future cooperative mobility [18] focuses on designing and demonstrating advanced traffic and fleet management for efficient and globally optimal transport. It will build upon existing CCAM solutions, using dynamic balancing and priority-based management. The project will lead to reduced urban traffic, congestion, pollution, and improved quality of life.

IN2CCAM - Enhancing Integration and Interoperability of CCAM eco-system [19] aims to develop, implement, and demonstrate innovative CCAM services, providing benefits such as safety, environmental impact reduction, and inclusiveness. Physical, digital, and operational infrastructures will be enhanced to improve CCAM services and traffic efficiency. The project will be implemented in four lead Living Labs across Europe.

PoDIUM - PDI connectivity and cooperation enablers building trust and sustainability for CCAM [20] identifies and assesses connectivity and cooperation enablers for higher levels of automation, using facilities from three Living Labs in Germany, Italy,

and Spain. A multi-connectivity approach ensures the reliability, availability, and redundancy of the PDI system. The project focuses on integration, advanced environmental modeling, digital twins, and VRUs in the overall PDI.

Successful implementation of CCAM depends on societal acceptance and adoption, with safety assurance as a crucial factor for trust. Cluster 3 "Validation" provides procedures, methodologies, and tools for validating, verifying, and rating CCAM systems in terms of technology and human factors, establishing an EU-wide database of relevant scenarios for validation. These actions will help reduce the number of test kilometers needed for safety validation, ensure functional safety, and develop a harmonized simulation environment for virtual testing of CCAM functions and systems.

I4Driving - Integrated 4D driver modelling under uncertainty [21] aims to create an industry-standard methodology to establish a human road safety baseline for virtual assessment of CCAM systems. The project focuses on a multi-level, modular simulation library for human driving behavior and a cross-disciplinary methodology to account for uncertainties in human behaviors and use case circumstances.

SUNRISE - Safety assUraNce fRamework for connected, automated mobIlity SystEms [22] will develop and demonstrate a safety assurance framework for CCAM systems by addressing the needs of diverse use cases, defining a scenario-based database framework, generating CCAM test scenarios, preparing tools for comprehensive testing, and integrating functional safety and cybersecurity. The project will create building blocks for the framework, including harmonized safety assessment methodologies, a federated European scenario database framework, and a commonly agreed simulation framework.

With respect to demonstrating the maturity of the developed CCAM solutions, Cluster 1 "Large-scale Demonstration" focuses on implementing results from other clusters into pilots, FOTs, and Living Labs to support deployment readiness and final impact assessment. It builds on technologies and methods, integrates concepts in real-life conditions, aligns with societal needs and, aims for cross-sector collaboration, and provides feedback and lessons learned to the CCAM community.

MODI - A leap towards SAE L4 automated driving features [23] aims to identify and resolve barriers for SAE level 4 (L4) CCAM vehicles on the corridor from Rotterdam to Oslo, demonstrating solutions for logistic chains. The project emphasizes coordination to integrate CCAM into existing logistics operations and smart traffic management and creates detailed business models to demonstrate CCAM's profitability. It comprises five use cases, focusing on regulatory barriers and infrastructure on public roads.

ULTIMO - Advancing Sustainable User-centric Mobility with Automated Vehicles [24] aims to create an economically feasible and sustainable integration of Avs for Mobility as a Service (MaaS) public transportation and Logistics as a Service (LaaS) urban goods transportation. With a user-centric approach, it targets the deployment of 15 or more multi-vendor SAE L4 Avs per site in three European locations, operating without safety drivers. The project focuses on long-term sustainable impact on automated transportation, ensuring interoperability between stakeholders, and building on previous AV-demonstrator projects to maximize technical and societal impacts.

Finally, cluster 7 "Coordination" manages all CCAM stakeholders and aligns R&I activities, facilitating knowledge exchange to address the fragmentation of efforts and

lack of a coherent, long-term vision and strategy. It focuses on developing harmonized approaches, common methodologies, and tools to facilitate cross-sector collaboration as well as exchange of best practices and lessons learned.

FAME - Framework for coordination of Automated Mobility in Europe [25] has been established to support the CCAM Partnership and implement the activities of cluster 7, supporting collaboration among CCAM stakeholders for large-scale demonstrations and future scale-up of complete CCAM solutions. The project supports the European Commission and the CCAM Partnership's commitment to a long-term coordination framework for R&I and large-scale testing and evaluation activities in Europe. FAME will establish a stakeholder-validated European framework for testing on public roads, including a CCAM test data space, a common evaluation methodology, and knowledge exchange mechanisms. This framework will improve cooperation, consensus building, and data sharing, enabling comparability and complementarity of results across all testing and demonstration activities in Europe.

FAME interacts with a large stakeholder community, which extends beyond the CCAM Partnership, building on the wide network federated in the previous Coordination and Support Actions CARTRE [21] and ARCADE [22]. The project engages in particular with the international community through the Trilateral EU-US-Japan Working Group on Automation in Road Transportation and with EU funded and national R&I projects and initiatives to foster the exchange of knowledge, best practices and lessons learned and build consensus on future R&I needs. The EU wide Knowledge Base and networking tools from FAME are strongly supporting the CCAM Partnership in updating the Strategic Research & Innovation Agenda (SRIA) [26], in developing the future CCAM related Horizon Europe Work Programmes. Further support is done by monitoring the progress towards its objectives and KPIs. In addition to the support of the international Trilateral exchanges, networking tools maintained by FAME include the biennial EUCAD conferences and symposia, co-organized with the European Commission and the Partnership, as well as R&I projects and stakeholder concertation workshops, discussing specific challenges related to R&I and harmonization challenges and needs among experts.

The close cooperation with member States and cities is fundamental to gather information about national, regional or local initiatives in Europe. Thanks to the fruitful collaboration with the CCAM Platform between 2019 and 2021 in the frame of ARCADE, today more than half of the about 350 projects listed in the Knowledge Base are from Member States. In FAME, a collaboration has been initiated with the CCAM Partnership Member States Representatives Group (SRG). It is part of the current objectives of Cluster 7 to support the work of this group to exchange best practices and develop harmonized approaches enabling cross border testing. FAME is currently working with the SRG to collect requirements for testing activities (incl. Small-scale pilots, large-scale demonstration sites, and living labs) in all member states. This will form a basis to investigate the different approaches, commonalities and peculiarities across countries and prepare recommendations for mutual recognition, which will be part of the European Framework for testing on public roads.

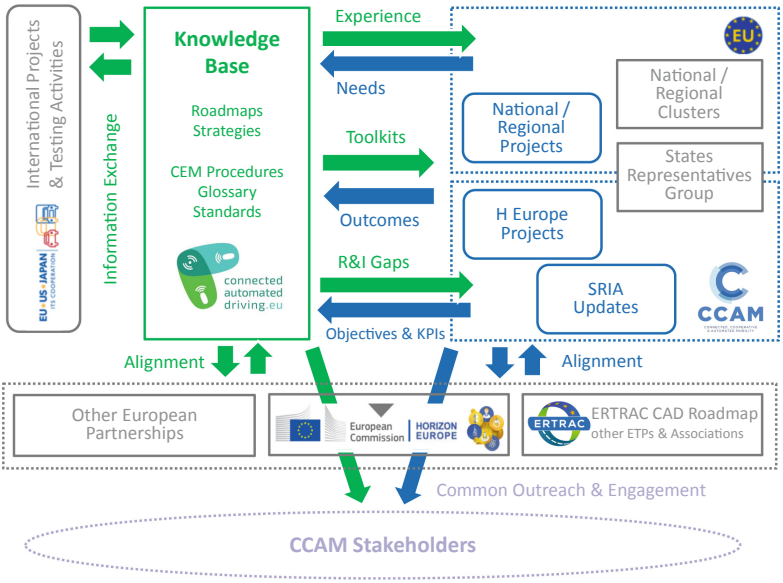

Fig. 2. FAME interaction with stakeholder ecosystem

The relationship FAME maintains with the stakeholder community is based on a win-win principle (see Fig. 2). On one side, FAME relies heavily on contributions from CCAM R&I projects, Member States, CCAM Partnership partners and the international network to carry out the tasks of collecting knowledge on ongoing activities, roadmaps, standards and common methodologies included in the Knowledge Base. Feedback from experts is also sought for the development of the Common Evaluation Methodology and related taxonomy. On the other hand. R&I project representatives and CCAM stakeholders can benefit from the experience of other projects when planning and setting up new research testing and demonstration initiatives. This bi-directional exchange will facilitate alignment and contribute in reducing overlaps or redundancies of R&I activities in Europe for a more optimized funding and coordination.

The CCAM stakeholder landscape is continuously expanding and encompasses a wide range of contributors from various sectors (Fig. 3). Key players include academia and research institutions, private industry and infrastructure providers, as well as national and regional transport authorities. The research sector, comprising universities and private research institutes, is the main driving force behind CCAM R&I projects in the framework of the CCAM Partnership under Horizon Europe. The automotive supply chain also plays a significant role, followed by physical and digital infrastructure providers. Regional and national transport authorities and stakeholder representation associations on European level contribute to the development of CCAM as well. However, public transport operators and the freight and logistics sector as well as civil society representative currently have a more limited role within the CCAM ecosystem.

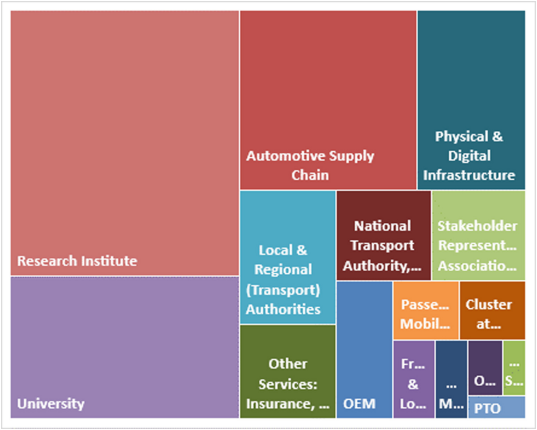

Fig. 3. Proportion of participation of different stakeholder types in CCAM project funded under the Horizon Europe framework, showing strong participation of research institutes (rose), universities (light purple), automotive suppliers (light red), physical and digital infrastructure (dark turquoise), local and regional (transport) authorities (light blue). Stakeholder representation associations on European level (light green), national transport authorities (dark red), other services (dark green) and OEMs (blue) are less represented in European R&I projects. Passenger mobility providers (orange), clusters at national level (brown), freight and logistics services (purple), national ministries (navy), civil society representation (green) and public transport operators (lavender).

Analyzing the research landscape via a network graph (Fig. 4), we can identify distinct connections within individual R&I projects, as well as key stakeholders who act as links between various R&I projects. The bigger the node, the higher the influence of the stakeholder within the research landscape. These so to say connectors are primarily research institutes in pink. European associations (grey), automotive suppliers (green), service providers (orange), and universities (black) also play significant roles. Notably, local and regional (transport) authorities, along with infrastructure providers, are not the primary connecting players, suggesting that the focus remains on developing solutions rather than implementing them.

The FAME project (pink) is strategically positioned at the center of the stakeholder network, incorporating a diverse range of stakeholder types that facilitate connections with other projects. Similarly, projects related to key enabling technologies (orange) and vehicle technologies (turquoise) are also placed closer to the center, signifying their central role in the network. Node with high centrality have a large influence on e.g. knowledge and information transfer within the network, under the assumption that the knowledge transfer follows the shortest paths. In contrast, projects associated with large-scale demonstrations (green), user-needs and societal aspects (red), and integration into the transport system (navy) are less centralized and have fewer connections. This indicates that these projects introduce new players, such as national and local authorities and societal representatives, into the network. However, it is worth noting that one project focusing on user needs and societal aspects is entirely disconnected from the rest, highlighting potential gaps in collaboration within the CCAM ecosystem.

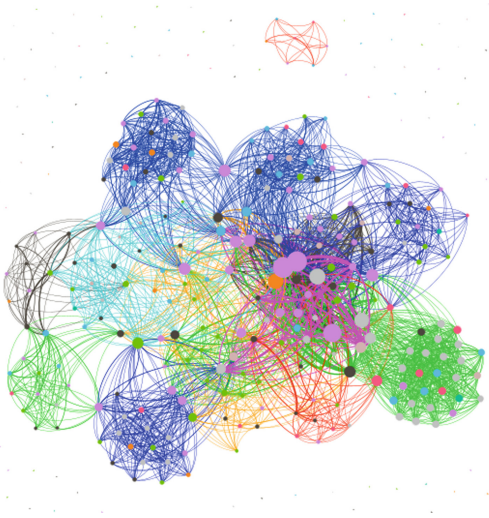

Fig. 4. Network graph, showing links between different stakeholders made through the participation in European CCAM projects. Links are colored with respect to the corresponding CCAM cluster. Knots are categorized with respect to the different stakeholder types. A few very prominent and central stakeholder act as interconnects.

4 Conclusions and Outlook

The successful deployment of CCAM technologies in Europe requires a coordinated and collaborative approach among various stakeholders, including academia, research institutions, private industry, and transport authorities. The CCAM Partnership, along with other partnerships and projects such as FAME, is essential in overcoming the challenges and facilitating the adoption of CCAM solutions.

Further alignment with other partnerships such as 2ZERO and the Cities Mission will enhance cooperation across different mobility domains and urban-related topics. Inclusion of additional stakeholders, apart from the usual suspects, can foster broader perspectives and innovative solutions. While many efforts have been made to align CCAM initiatives within Europe, there is still a need for increased focus and coordination. By fostering collaboration, standardization, and innovation across the European CCAM ecosystem, the CCAM Partnership aims to support Europe's position as a leader in safe and sustainable road transport through the advancement of automation.

Acknowledgements. The authors would also like to express their gratitude to the European Commission for funding this work through the Research and Innovation Action FAME, as well as thank the CCAM Partnership for close collaboration.

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