DITM WHITE PAPER

From mobility to system

Why digital infrastructure is the real breakthrough

Digital Infrastructure for Future-proof Mobility

Project information

Project period
1 October 2022 – 1 October 2026

Project partners
ElaadNL · ELEO · Geomaat · Infiniot · InQuisitive · Monotch · NKL · NXP · Siemens · Sioux · TNO · TomTom · TU/e · VDL ETS · V-tron

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Brainport Development, RAI Automotive Industries NL, TNO

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Digital Infrastucture for Future-proof Mobility

About this publication

The Digital Infrastructure for Future-proof Mobility (DITM) project brings together industry, knowledge institutes and public authorities to develop and validate the digital infrastructure needed for the next generation of mobility.

This publication presents the project's vision, results and lessons learned through two complementary whitepapers.

Digital Infrastructure for Future-proof CCAM
Towards connected, cooperative and automated mobility through Key Enabling Technologies, shared data and validated use cases.

Digital Infrastructure for Future-proof Energy in Mobility
Grid-aware charging infrastructure for reliable, secure and scalable electrification.

Funded by the European Union
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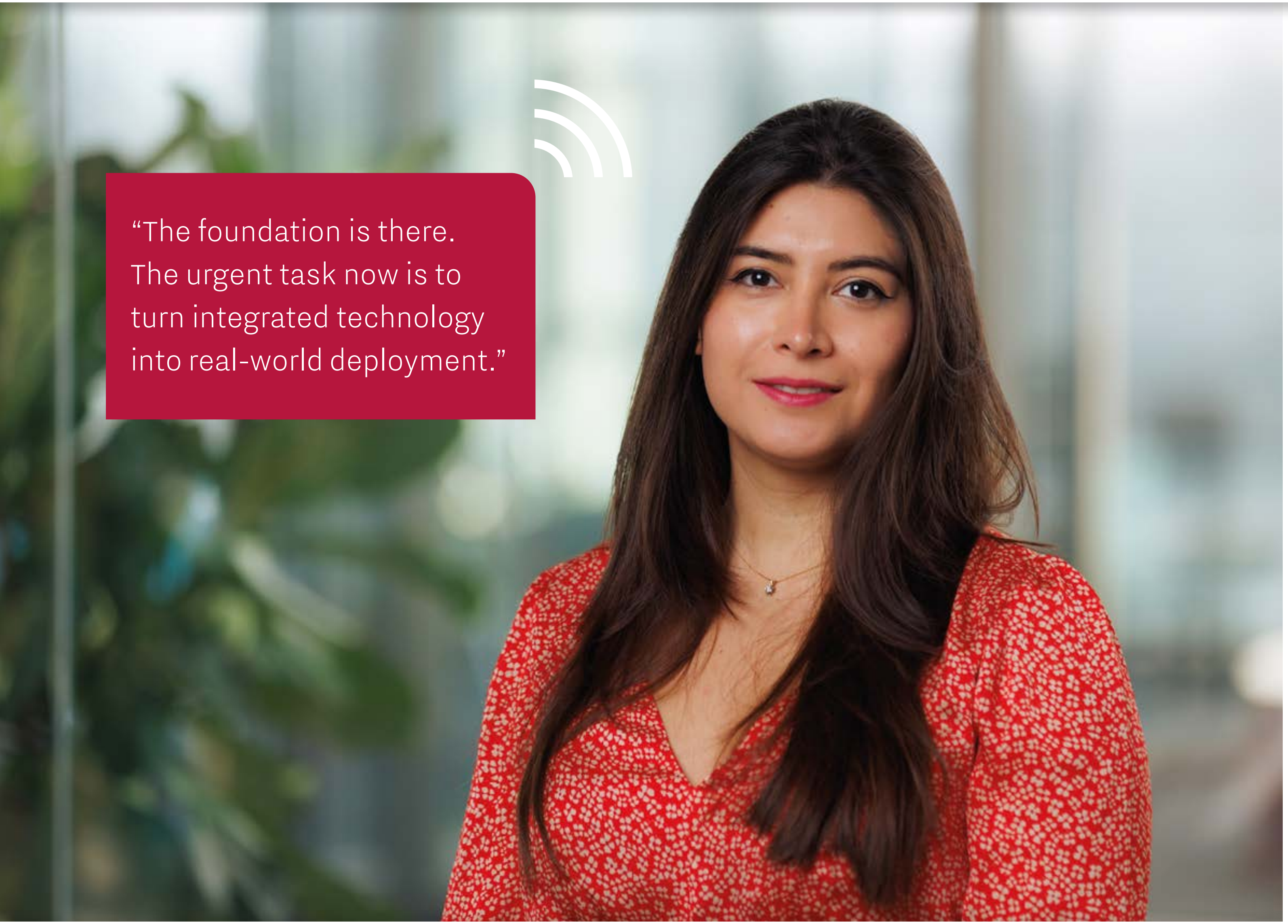


Foreword

Europe is entering a decisive phase in the transition towards clean and connected mobility. The technologies are advancing rapidly, but the challenge is no longer technology alone. The challenge is to integrate mobility, energy and digital infrastructure into systems that are reliable, scalable and ready for deployment.

That ambition has driven the Digital Infrastructure for Future-proof Mobility (DITM) project from the very beginning.

Over the past four years, DITM has brought together companies, knowledge institutes and public authorities to develop, connect and validate the Key Enabling Technologies that will shape tomorrow’s mobility system. Together, we have demonstrated how digital infrastructure can enable vehicles, infrastructure, energy systems and operational platforms to work together in concrete use cases.

The real breakthrough is not the development of individual technologies. It is the integration of technologies, data, infrastructure and organisations into a system that works reliably in practice.

That is also why DITM matters beyond this project. The Brainport region continues to grow, bringing new challenges for accessibility, sustainability and quality of life. Initiatives such as the Brainportlijn illustrate the ambition to create smarter mobility solutions for the region, while DITM provides part of the technological foundation needed to make that future possible. At the same time, the project strengthens the innovative capacity and competitiveness of Dutch and European industry.

The two whitepapers that follow capture the knowledge, experience and lessons generated throughout DITM. Together they show what has been achieved, what has been validated and where further work is needed to move from successful demonstrations to large-scale deployment.

I hope these publications will not only document the results of DITM, but also inspire the next generation of collaboration, innovation and implementation.

Ana Alanís
Programme Manager Smart Mobility, Brainport Development
Project Lead, Digital Infrastructure for Future-proof Mobility (DITM).

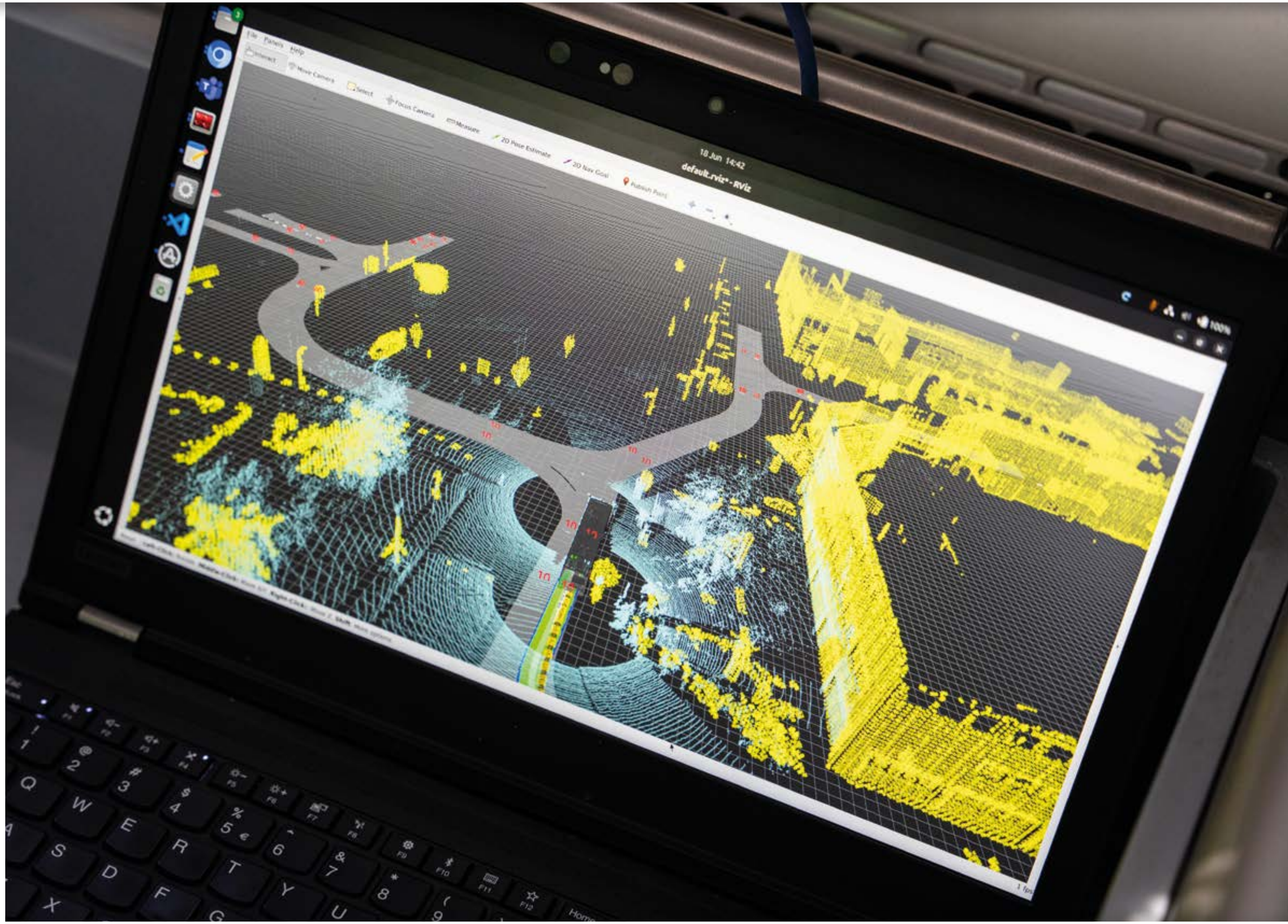
Core message
The DITM project does not present digital infrastructure as another isolated infrastructure project. Its distinctive contribution is the creation of an open, public-private ecosystem in which mobility, energy and data can be connected through Key Enabling Technologies, shared standards, secure data exchange and validated use cases. The result is not a completely finished system ready for immediate large-scale rollout, but a tested pathway from promising components to coordinated deployment.

Europe is investing heavily in the future of mobility and energy. Electric vehicles, automated driving, smart charging, data spaces, digital twins and intelligent infrastructure are all moving forward. Yet progress remains slower and more fragmented than the underlying technologies suggest it could be.

One reason is that mobility and energy transitions are often still treated as separate. Vehicles become smarter, but depend on physical and digital infrastructure that is not always ready to interact with them. Charging infrastructure expands, but must operate within an electricity grid that is increasingly constrained. Data is generated everywhere, but is not always shared in ways that are reliable, trusted, timely or usable for automated decisions.

DITM - Digital Infrastructure for Future-proof Mobility - starts from a different premise. The future of mobility will not be defined by the vehicle alone, nor by the grid alone. It will be shaped by the system that connects vehicles, infrastructure, energy assets, service providers and public authorities in a coordinated, secure and scalable way.

That is why the DITM approach is not simply about building more infrastructure. It is about defining and testing the digital layer that allows existing and newly developed technologies to work together. This includes high-definition maps, lane-level localization, secure communication channels, standardized data-sharing environments, remote operations, simulation and validation tooling, smart charging concepts and governance arrangements for data ownership and system responsibility.



High definition sensing

EnergyPod

An ecosystem approach with a sharper edge

Many mobility programmes rightly emphasize the importance of ecosystems. DITM's added value is that it makes this ecosystem operational. It brings together private and public partners, industry and knowledge institutes, mobility and energy stakeholders, and connects them through a shared technical architecture rather than through ambition alone.

The project has advanced Key Enabling Technologies and tested their dependence on digital infrastructure. In the mobility domain, this includes data-sharing environments, localization technologies, HD maps, map production and delivery pipelines, trusted 5G communication, software-defined vehicle concepts, remote operations, and SIL/HIL/digital-twin validation. In the energy domain, the same system logic applies to the coordination between charging operators, fleet operations, battery storage, grid constraints and prioritization mechanisms.

This matters because the challenge is neither just organizational nor just technological. The core technologies are available in many areas, but integrating them into a reliable system remains complex. DITM shows that coordination is possible, while also making clear that deployment requires further validation, standardization, governance and investment.

The role of digital infrastructure

In the context of these whitepapers, Digital Infrastructure for Future-proof CCAM and Energy refers to the integration of advanced digital technologies within mobility and energy networks to create an interconnected ecosystem. This ecosystem uses securely shared data, trusted communication, digital representations of physical assets and intelligent control mechanisms to improve connectivity, optimize performance, strengthen resilience and enable sustainable operation.

In practice, digital infrastructure consists of elements such as high-definition maps, real-time traffic and infrastructure data, secure communication networks, data-sharing environments, digital twins, validation tools and interfaces between mobility and energy systems. Within DITM, these elements were implemented and tested in concrete use cases rather than described only as concepts.

The point is not that every element of the system needs to be connected to every other element. The point is that the relevant actors and assets in a specific use case can exchange trustworthy information at the right time, under the right conditions, and in a form that allows automated or semi-automated decisions. For example, an automated vehicle on a depot can use a digital map, localization methods and a yard-management backend to decide whether to go to a charger, a wash bay, a maintenance area or a waiting position. An intelligent speed assistance system can combine camera recognition, HD maps and authoritative road-operator data to determine the correct speed at lane level. A smart-charging system can coordinate charging demand with grid capacity and operational priorities.

Two whitepapers, one transformation

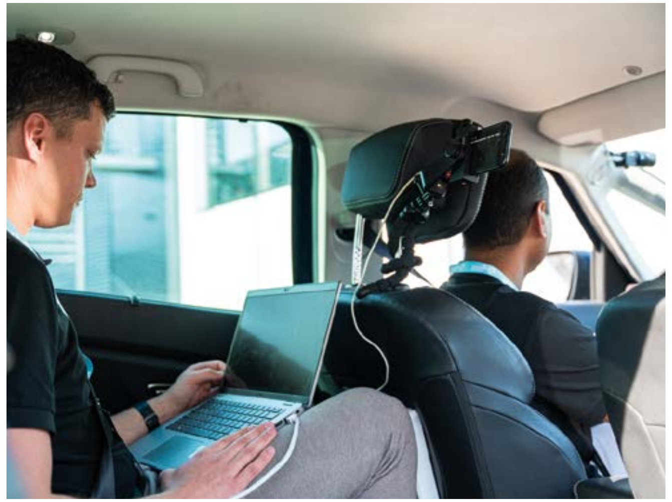
The two whitepapers that follow should be read as complementary parts of the same transformation.

The CCAM paper

Explains how Cooperative, Connected and Automated Mobility (CCAM) can move from isolated vehicle functions to coordinated system behaviour. It shows how use cases such as yard automation, Green Light Optimized Speed Advisory, Intelligent Speed Assistance and lane-level navigation rely on Key Enabling Technologies and digital infrastructure.

The energy paper

Explains why electrification cannot be solved only by adding chargers or reinforcing the grid. It shows how concepts such as smart charging, energy buffering, energy hubs and prioritization can turn mobility-related electricity demand into a more flexible, manageable and economically relevant part of the energy system.



CCAM demonstration

The connection between the two is important, but it should not obscure the focus of each paper. The CCAM paper concentrates on vehicle technologies, data exchange, maps, localization and validation. The energy paper concentrates on the interaction between charging demand, grid capacity, energy assets and operational control. This introduction provides the bridge between them.

From components to coordinated use cases

The DITM logic can be summarized as a chain of traceability. Societal challenges create the need for new mobility and energy capabilities. These capabilities require concrete use cases. The use cases depend on Key Enabling Technologies. Those technologies need a digital infrastructure to exchange data, validate decisions and operate across organizational boundaries. Only then can system-level impact become credible.

SYSTEM CHALLENGE	USE-CASE DIRECTION	KEY ENABLING TECHNOLOGIES	WHAT DIGITAL INFRASTRUCTURE ADDS
Safer and more reliable automated mobility	Yard automation and assisted public-road operation	Localization, HD maps, robotization interfaces, remote operation, SIL/HIL validation	A shared operational environment in which vehicle, depot systems and mission planning can exchange trusted data
Better use of existing road capacity	GLOSA, lane navigation and infrastructure-to-vehicle services	Traffic-light data, variable-message-sign data, secure 5G, NDS.Live, data spaces	Timely information flows between physical infrastructure, cloud services and in-vehicle functions
More robust speed and lane decisions	Intelligent Speed Assistance with lane-level context	Traffic-sign recognition, lane-level HD maps, authoritative road-operator data, sensor fusion	A way to combine multiple sources and assess confidence instead of relying on a single input
Grid constraints and rising electricity and power demand	Smart charging, buffering and energy hubs	Charging control, prediction and prioritization modules, fleet scheduling, grid-capacity data	Coordination between mobility operations and energy availability instead of uncoordinated charging demand

What DITM has shown - and what it has not yet shown

DITM has shown that connected, cooperative and automated functions can be implemented in controlled demonstrations and that the underlying digital infrastructure can connect vehicles, data platforms, infrastructure and operational systems. It has also shown that hybrid architectures are needed: sensor-based, backend-based and direct-communication approaches each have different strengths, costs, security profiles and deployment timelines. Robust deployment will often require combinations of these approaches rather than a single preferred paradigm.

At the same time, these results should not be overclaimed. Controlled demonstrations are not the same as large-scale deployment. Moving from pilot environments to real-world implementation requires further work on validation, reliability, safety, cybersecurity, standardization, governance, investment models and organizational responsibilities. DITM's contribution is therefore best understood as a tested foundation for deployment, not as a finished deployment programme.

The strategic opportunity

The strategic question is no longer whether mobility and energy will become more digital, connected and automated. They already are. The question is whether Europe can shape this transformation through open standards, public-private collaboration and trusted infrastructures, or whether it will fragment into local solutions and proprietary platforms that are difficult to scale.

The Netherlands, and Brainport in particular, has strong ingredients for a leading role: automotive and mobility expertise, high-tech systems knowledge, public-private collaboration, energy-transition urgency and a dense innovation ecosystem. DITM adds a practical route: develop Key Enabling Technologies, integrate them through an open digital architecture, validate them in use cases, and translate the results into deployment roadmaps for mobility, energy and adjacent markets such as logistics and defense.

The next step is not to choose between technology and governance. It is to develop both together. Technology must keep advancing, especially where reliability, safety, security and scalability are concerned. Governance must mature at the same time, especially around data ownership, standards, responsibilities and investment. Only their combination can turn promising innovations into a future-proof system.

DITM Vehicles

DITM consortium

Project note
The DITM project is enabled by the Dutch Ministry of Infrastructure and Water Management (I&W). DITM is funded by the European Union - NextGenerationEU and DITM partners. Project period: 1 October 2022 - 1 October 2026. More information on the DITM project and its partners: a.alanis@brainportdevelopment.nl

Digital Infrastructure for Future-proof CCAM

Towards connected, cooperative and automated mobility through Key Enabling Technologies, shared data and validated use cases

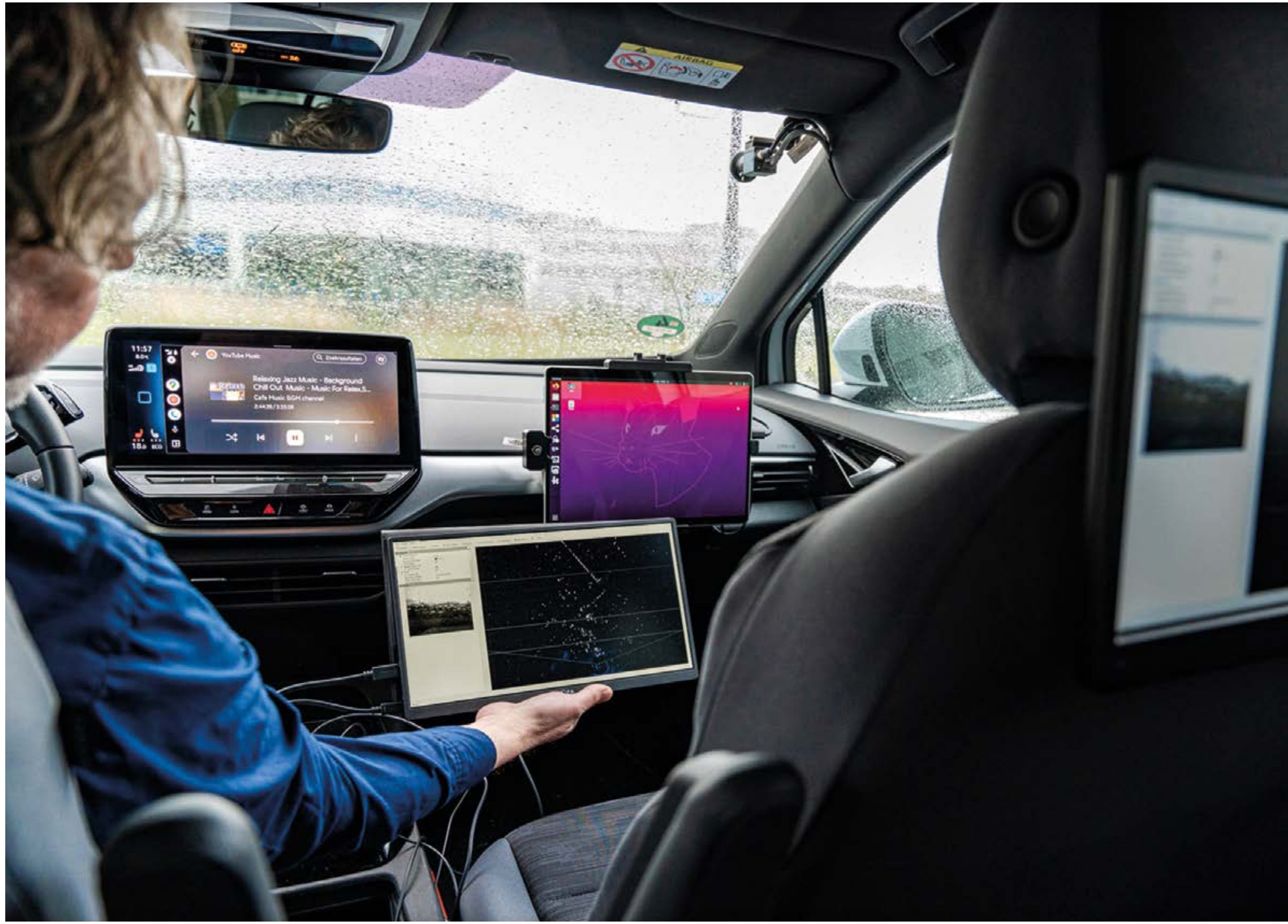
Executive summary

Mobility is entering a phase in which individual innovations are no longer enough. Vehicles, infrastructure, maps, cloud services, public authorities, logistics operations and energy systems increasingly depend on one another. DITM shows how an open public-private ecosystem can connect these layers through Key Enabling Technologies and digital infrastructure. The project has demonstrated feasibility in controlled use cases, while also showing that large-scale deployment requires further work on validation, governance, standards and investment.

The mobility system is changing faster than the structures around it. Electrification, automation, connected services and software-defined vehicles are advancing rapidly. At the same time, congestion, road-safety stagnation, grid constraints, workforce shortages and pressure on public infrastructure create a need for solutions that operate beyond the level of individual components.

The central insight of DITM is that the next step in mobility is not simply a smarter vehicle, a smarter road or a better app. It is the ability to connect vehicles, infrastructure, data platforms and operational systems into a coordinated environment. That environment must be technically reliable, secure, interoperable and governable. It must also be realistic about the difference between controlled demonstrations and large-scale deployment.

DITM - Digital Infrastructure for Future-proof Mobility - was created to explore and test that environment. A Dutch consortium of mobility industry partners and knowledge institutes jointly developed a system architecture for digital infrastructure. Within this architecture, partners advanced technologies such as localisation, traffic services, digital mapping, secure and automated data exchange, vehicle automation, remote operations and validation tooling. The goal is to accelerate the adoption of scalable Cooperative, Connected and Automated Mobility (CCAM) and to prepare for its interaction with a reliable energy system.



Sensing

Automated yard manouvering

A system under pressure

The challenges facing mobility are familiar, but their combined effect is often underestimated. Urbanisation puts pressure on infrastructure that was not designed for current levels of intensity. Electrification is essential, but it creates additional dependencies on an already constrained electricity grid. Driver shortages affect logistics and public transport operations. Road safety improvements have slowed, while serious injuries remain a concern. At the same time, digital services and automated functions raise expectations about reliability, comfort, efficiency and accessibility.

Each challenge can be addressed individually with targeted measures. Together, they require a system response. More charging points will not solve mobility-related grid constraints if charging remains uncoordinated. Automated vehicles cannot reach their full potential if they rely solely on onboard perception and lack trustworthy environmental data. Traffic services remain limited if data cannot be exchanged across organisational boundaries. The issue is therefore not a lack of innovation, but the difficulty of combining innovations into a safe, reliable and scalable system.

This is where digital infrastructure becomes essential. It is not a generic IT layer added to mobility afterwards. In the context of this whitepaper, digital infrastructure for future-proof CCAM refers to the integration of advanced digital technologies within mobility and energy networks to create an interconnected ecosystem. This ecosystem leverages shared data and innovative solutions to enhance connectivity, optimise performance, improve sustainability, and strengthen resilience across mobility and energy systems. A set of digital technologies, standards, data-sharing environments, communication services, maps, digital twins and validation tools allows mobility actors and assets to coordinate their behaviour.

What DITM adds

DITM's distinctive contribution is not that it claims to have solved challenges in mobility as a whole. Its contribution is more precise: it demonstrates how Key Enabling Technologies can be combined, tested and connected through digital infrastructure in representative CCAM use cases. This creates traceability from technical development to operational value.

The project, therefore, does more than promote an ecosystem approach. It operationalises such an ecosystem through cross-sector collaboration between private companies, public authorities, knowledge institutes and service providers.
It also shows that integration itself is a technological challenge. While many core technologies already exist, combining them into reliable use cases requires work on data reliability, synchronisation, safety validation, cybersecurity, standards and governance.

In practice, DITM's mobility work concentrates on three interacting domains: vehicle technologies, digital infrastructure and tooling. Each domain matters on its own, but the value lies in their mutual reinforcement.

1. Vehicle technologies

Vehicle technologies in DITM were advanced for both public-road and private-yard environments. The work includes vehicle robotisation, the development and implementation of automated driving functions, localisation and sensor fusion, and the specification of software interfaces and architecture design.
A software-defined vehicle separates software capabilities from hardware constraints, making it easier to update functions, integrate services and adapt behaviour to new data sources.

Vehicle robotisation allows the vehicle to accept setpoints from Advanced Driver Assistance Systems (ADAS) and Autonomous Driving (AD) functions. The advantage of DITM is that this is done in the context of already homologated vehicles (the VDL CITEA platform), which makes re-homologation easier: a road authority can accept the delta with regard to the previously checked platform.

On public roads, novel localisation technologies were developed to support precise vehicle positioning. Feature-matching techniques use lane markings and landmarks such as lamp posts and traffic signs to achieve decimeter-level accuracy in real-world conditions. A proof-of-concept radar-based method was developed to detect, classify, and position environmental features, thereby increasing its relevance for current-generation vehicles. Inputs are combined via multi-sensor fusion, enabling the system to select the most reliable localisation source at any given moment.

On private yards, DITM worked on vehicle automation in controlled yet operationally relevant environments, such as bus depots. Here, vehicles must interact with depot systems and execute missions such as moving to a charger, stopping at a wash bay, entering a maintenance area or waiting for a new deployment. Because public-road reference features are often absent or less useful in depots, localisation can switch to sensor configurations suitable for enclosed spaces, including scan-matching techniques based on a lidar point-cloud map. When automated functions are unavailable or degraded, the same robotisation interface can support handover to a teleoperator.

2. Digital infrastructure

Digital infrastructure enables these vehicle technologies to operate beyond isolated demonstrations. For yard automation, a vehicle can receive a high-definition digital representation of the depot environment, determine where it is allowed to drive, and interact with a yard-management backend that determines operational priorities. The backend may know whether charging capacity is available, whether the wash bay is free, whether the vehicle should go to maintenance, or whether sensors need cleaning before a new mission.

For the public-road domain, DITM advanced the delivery and updating of HD maps through standardised open protocols such as NDS.Live. Open industry standards reduce vendor lock-in and support rapid iteration in open-innovation ecosystems. The project explored ways to connect mapping processes from the road infrastructure asset management domain with those of automated mobility. Publicly available mapping data, mobile-mapping outputs, satellite imagery, and vehicle observations can all help reduce the time between a real-world change and an updated map.

For Intelligent Speed Assistance (ISA), the applicable maximum speed is determined by combining multiple sources of information. These include state-of-the-art traffic-sign recognition, lane-level HD maps, road-operator data and variable-message-sign information. The goal is not to replace one source with another, but to increase robustness by combining them and assessing confidence. This is especially relevant for dynamic situations where lane-level context matters.

Data sharing was implemented through Eclipse Dataspace Components, aligning with emerging European standards for trusted data exchange. Through this data space approach, semi-static and dynamic information can be supplied to vehicles. Semi-static data includes legally applicable maximum-speed values. Dynamic data includes Green Light Optimised Speed Advice (GLOSA) messages from traffic-light controllers, as, for example, communicated through variable message signs. Trusted communication channels, including a dedicated 5G slice, were used to increase reliability and cybersecurity in selected demonstrations.

This does not mean that every mobility function should use the same communication paradigm. DITM points instead to hybrid architectures. Sensor-based approaches can provide immediate local benefit through onboard or roadside perception. Backend-based approaches can aggregate, fuse and distribute information through cloud services and cellular networks. Direct communication can provide short-range, low-latency exchange when necessary. Robust CCAM deployment will depend on selecting and combining these approaches based on use-case requirements, cost, security, scalability and time-to-value.

3. Tooling and validation

A critical part of DITM is the tooling needed to validate new technologies before deployment. The project used several methods for single-vehicle components, such as Software-in-the-Loop (SIL), Hardware-in-the-Loop (HIL), digital twins, and cybersecurity testing, aligned with safety-of-the-intended-functionality thinking.

Societal impact is based on macro simulations. Using digital twins, it's possible to test recognition and classification functions with synthetic datasets and validate robotisation components before physical deployment, thereby translating technical progress into broader network-level and societal-impact assessments.

This validation layer is essential because technical feasibility in a controlled demonstration does not translate to safe, robust deployment at scale. Digital twins and virtual validation environments help bridge the gap from desk-based design and development, via validation before demonstration in a controlled environment, to deployment at scale. Many of the tools developed or used in DITM are now integrated within the Mobility Applied Research Quarter (MARQ), creating a consistent environment for further experimentation, validation and deployment preparation.

Digital simulation environment at MARQ

DITM use cases: from technology to impact

The Key Enabling Technologies developed in DITM are best understood through the use cases in which they were combined. The use cases are not merely examples at the end of the project. They are the mechanism through which the value of digital infrastructure becomes visible.

USE CASE	OPERATIONAL GOAL	KEY ENABLING TECHNOLOGIES	DEMONSTRATION RESULT / REMAINING STEP
Yard Automation	Automated depot operation for public-transport vehicles, including mission execution and interaction with depot systems.	Vehicle robotisation; automated driving stack; HD maps; digital twins; accurate absolute and relative localisation; teleoperation; integration with logistics backends.	Automated demonstrations showed how a vehicle can be integrated with a yard-management backend. Next step: move from controlled demonstrations to operational validation with safety cases, reliability targets and integration into real depot workflows.
GLOSA	Enable vehicles to receive traffic-light information and adapt speed to reduce unnecessary stops and improve flow.	Cybersecure communication; trusted 5G slice; data-quality assessment; lane-level localisation; data exchange from physical intersection controllers; simulation and validation.	Intersections in the Helmond test environment were upgraded to deliver trusted GLOSA messages. Next step: broaden interoperability, followed by scaling system implementation to OEMs and Tiers and integrating it with a multi-channel approach, including 5G and DSRC.
Intelligent Speed Assistance	Determine the applicable speed at lane level, including dynamic information such as variable message signs.	Traffic-sign recognition; lane-level HD maps; authoritative road-operator data; variable-message-sign feeds; data-sharing interfaces; sensor fusion; confidence assessment.	A connected data source combines static and dynamic maximum-speed information with in-vehicle perception. Next step: further validate under diverse road conditions and define how we make sure we flag conflicting messages back to the original data sources.
Lane Navigation	Provide lane-level guidance and contextual navigation that can adapt to real-world changes.	NDS.Live map delivery; automated feature extraction; change-detection services; lane-level localisation; software-defined vehicle architecture; perception-enhanced user interface.	Map production and delivery processes were improved to reduce reality-to-map time and support lane-level navigation. Next step: integrate the map delivery pipeline into automotive hardware and add additional map layers using the same processes developed in DITM, but for specific use cases.

A more detailed example: Yard Automation

Yard automation illustrates the DITM logic particularly well because the use case requires vehicle automation, digital infrastructure, and operational governance simultaneously. A bus in a depot does not simply need to drive itself. It must know where it is, where it is allowed to drive, what mission has priority, whether a charger or wash bay is available, and what to do if an automated function is degraded.

The digital infrastructure provides the vehicle with an HD map of the depot environment, supports localisation through scan matching, and links the vehicle to a backend system that manages missions. That backend can connect to operational data: the end of a bus route, the next planned deployment, charger availability, maintenance needs, cleaning requirements or queueing positions. Remote monitoring and teleoperation provide a fallback and oversight mechanism. The added value of DITM lies in integrating these elements into a single traceable system rather than demonstrating autonomous driving in isolation.

This example also shows why claims about deployment should be nuanced. The demonstration proves that the combination of architecture and technology can work in a controlled environment. Large-scale use requires operational reliability, cybersecurity, human oversight, responsibility allocation, integration with existing depot systems and the business case for fleet operators.

Teleoperation as a fallback mechanism

AI, software-defined vehicles and map updates

AI, software-defined vehicles and map updates Artificial Intelligence should not be treated as a generic promise. Within the DITM context, AI is relevant where it supports perception, classification, decision-making and map updates. For example, real-time observations from vehicles and infrastructure can help detect changes in the road environment. Before such data can be used, however, it requires careful engineering: filtering, quality assessment, confidence scoring and integration into map-production workflows. Raw data is not yet a reliable infrastructure.

AI is core to the map updates. DITM has created pipelines that combine public data with private vehicle domains. With ecosystem interactions between partners typically working for government (like Geomaat - doing mobile mapping, feature extraction, and HD map generation according to public standards) and automotive (like TomTom, performing feature integration and data aggregation to semantics applicable in automotive), DITM pushes raw data into reliable infrastructure development.

This connects directly to software-defined vehicles. As vehicle functions become more software-based and better connected to cloud and edge services, new capabilities can be deployed more flexibly. But the same trend increases dependence on standards, cybersecurity, update mechanisms and validation methodologies. Digital infrastructure is therefore both an enabler and a control layer: it allows new functions to emerge while creating the conditions for trust and safety.

From demonstration to deployment

DITM demonstrates that connected, cooperative and automated mobility can operate within an integrated digital ecosystem. Vehicles, infrastructure, data platforms and operational systems can interact in real time in selected use cases. But deployment at scale is not effortless. It requires deliberate alignment in three areas.

1. Architectural alignment. Systems must be interoperable, based on open industry standards and able to exchange data across organisational boundaries. DITM's work with standards such as NDS.Live and dataspace implementations provides a basis, but broader adoption is needed. DITM has shown it's possible, so the next step is to embed these results more permanently and in a financially viable setting.

2. Validation alignment. Software, hardware, digital twins, and real-world testing must be combined to produce credible safety and performance evidence. The step from TRL-6 demonstrations to operational deployment requires proof under more diverse conditions and further integration with the relevant (back-end) systems and deployment environment.

3. Governance and investment alignment. Data ownership, responsibilities, cybersecurity, liability, public-private collaboration and investment models must be defined alongside the technology. From this technology perspective, digital infrastructure should be treated as a shared system asset, not as an add-on to physical infrastructure.

This also clarifies DITM's role in the next phase. The project does not shift the problem onto the government after the technology is completed. Instead, it points to a public-private roadmap in which industry, research organisations, service providers and public authorities continue to develop and validate the architecture together. That roadmap should remain as open as possible to avoid vendor lock-in, be robust enough for safety-critical applications, and be scalable for deployment in mobility, logistics, and adjacent markets such as defence.

Next steps for innovation and deployment

The next stage should build on the work already done while addressing the remaining gaps. The following priorities emerge from the DITM results:

- Deepen technical validation of Key Enabling Technologies, including localisation, map-update pipelines, data-quality assessment, cybersecurity, remote operations and sensor-fusion methods and work towards the deployment of some of them.

- Develop at least one use case into a fully elaborated deployment pathway, including KPIs for safety, reliability, operational efficiency, data latency, localisation performance, map update time, and cost-benefit assumptions. For example, a public transport pre-deployment pilot could be the next step, as that should increase Automated Yard manoeuvring from TRL6 to TRL8.

- Strengthen data space governance by clarifying data ownership, access rights, responsibilities, trust mechanisms and alignment with European cloud-edge and data-sharing architectures. Include who is hosting the platform in this governance scheme.

- Explore how the developed technologies would fit other domains as well, including the defence industry.

- Keep the mobility focus sharp. Although energy demand and supply remain strategically important in the mobility domain, the key focus must remain on CCAM, including vehicle automation and driver support technologies, maps, localisation, data exchange and validation.

What DITM has shown

The future of mobility will not be achieved by individual innovations alone. It will depend on the ability to connect those innovations into a system that is technically reliable, operationally useful, secure, validated and governable. DITM has shown how such a system can begin to work: by integrating Key Enabling Technologies, adopting open standards, exchanging trusted data, testing with digital twins, shifting to software-defined vehicles and evaluating representative use cases.

The next challenge is to turn this foundation into a deployment. That means continuing technological development, not declaring it finished. It also means developing governance, standards and investment models at the same pace. If the Netherlands and Europe succeed in doing both, the digital infrastructure can become the backbone of future-proof mobility.

Digital Infrastructure for Future-proof Energy in Mobility

Grid-aware charging infrastructure for reliable, secure and scalable electrification

Digital Infrastructure for Future-proof Mobility

Executive summary

The electrification of mobility is accelerating, especially in heavy-duty transport, logistics and public transport. That progress depends on a charging infrastructure capable of meeting substantial power demand. At the same time, the Dutch electricity grid is increasingly constrained. Grid congestion is therefore both a capacity problem and a coordination problem: the available grid must remain reliable, while mobility operators need enough energy at the right time to keep vehicles in service.

DITM - Digital Infrastructure for Future-proof Mobility - addresses this challenge through grid-aware charging infrastructure. The project does not claim that grid expansion is unnecessary, nor that all barriers are merely organisational. Instead, it shows how technical integration, standardised communication and operational coordination can make better use of available grid capacity while protecting grid stability.

The central concept in the energy work is the EnergyPod: an integrated system combining charging stations, a Battery Energy Storage System (BESS), an Energy Management System and interfaces with grid, mobility and market actors. The EnergyPod receives information about grid capacity and constraints, combines this with operational charging needs and energy-market information, and translates it into control actions for chargers, storage and other assets. The key insight is therefore that capacity, flexibility and control must be orchestrated together. For grid-constrained locations, such as depots, logistics hubs and heavy-duty charging plazas, this can create a practical route to electrification that would otherwise be delayed, restricted or impossible. The EnergyPod delivers an integrated solution to this challenge.

The electrification of mobility is no longer a distant ambition. More kilometres are driven electrically every year, in passenger transport as well as in buses, trucks and logistics operations. This shift is essential for a sustainable mobility system, but it also creates a new dependency: mobility increasingly relies on an electricity grid that is itself undergoing a profound transition.

The pressure is most evident at charging locations with high, concentrated power demand. Direct Current (DC) chargers for buses and heavy-duty vehicles operate at significant power levels. A logistics charging plaza or public transport depot can require hundreds of kilowatts and, in some cases, megawatt-scale capacity. When multiple sites are connected to the same constrained part of the distribution grid, their cumulative impact becomes a serious strain on the available capacity and a reliability issue.

DITM focuses on this practical question: how can charging infrastructure for future mobility remain operational in a congested electricity system while also respecting its limits? The answer explored in the project is grid-aware charging infrastructure: a digitally connected and controllable system that combines prediction, standardised communication, local energy storage and operational prioritisation.

EnergyPod

Renewable energy causes fluctuations in the electricity grid

A grid under pressure

For an uninterrupted supply, the electricity grid must remain balanced. At any moment, the amount of electricity supplied to the grid must match the amount consumed. The grid frequency is the visible indicator of this balance: in Europe, the system is designed around 50 Hz. A frequency below 50 Hz indicates insufficient supply; a frequency above 50 Hz indicates overproduction. Large deviations can threaten the stability of the system.

At the same time, the energy system is becoming more decentralised. Solar and wind power add clean generation, but their output depends on weather and time of day. More electricity is consumed, less energy is supplied by natural gas, and more renewable generation is connected across the system. This creates a stronger need to align demand, supply and grid capacity.

Grid congestion occurs when the electricity grid cannot transport all requested electricity from generation locations to consumption locations, or when generated electricity cannot be fed into the grid. This can happen on different voltage levels. The high-voltage, medium-voltage and low-voltage grids work together like a hierarchy of highways, regional roads and local streets. A constraint at one level can affect the others.

Two forms of congestion are relevant. Consumption congestion occurs when demand exceeds available transport capacity. Generation congestion occurs when more electricity is produced than the grid can absorb. Both forms matter for mobility. Charging creates additional demand, while local renewable generation and storage can help, but only if they are coordinated with grid conditions.

At certain moments, it is becoming increasingly likely that available generation will not be sufficient to meet demand, particularly during peak periods or under constrained network conditions.

Why mobility needs grid-aware charging

The traditional answer to grid congestion is grid reinforcement. This remains necessary. However, reinforcement is slow, costly, and, in many places, not available quickly enough to keep pace with electrification. For mobility operators, waiting for new capacity can delay the transition to electric fleets. For grid operators, granting unrestricted capacity in constrained areas can increase operational risk.

This creates a specific challenge for charging plazas, bus depots and logistics hubs. Mobility cannot simply stop when the grid is constrained. Vehicles must be charged in time for their next mission, route or delivery schedule. At the same time, charging behaviour must remain within the limits set by the grid operator. Grid-aware charging is a way to reconcile these two requirements.

In the DITM approach, the charging system is linked to the load and constraints of the electricity grid. The goal is to allow as much useful charging as possible while preventing or mitigating congestion. This is not only a matter of organisational agreement but also a matter of software and hardware. It requires a technical architecture capable of receiving grid information, securely interpreting it, integrating it with operational needs, and controlling local assets accordingly.

What DITM adds in the energy domain: the EnergyPod

The relevant system elements are those that make a reliable and secure energy supply possible for electric mobility. The DITM contribution is integrating these elements into a practical architecture for grid-aware charging.

The central building block is the EnergyPod. It is a specific system that buffers energy in a Battery Energy Storage System (BESS) and responds to grid demand and capacity parameters. It is designed for charging infrastructure in which vehicle demand, grid constraints, and operational planning must be managed together.

The work combines several Key Enabling Technologies and integration steps. These include a grid-load prediction module, standardised and secure communication between grid operators and EnergyPod through OpenADR (Open Automated Demand Response), a Priority Module that optimises charging and storage decisions, and the integration of charging stations, battery storage and metering into one controllable system. The distinctive value lies in the way these components interact.

The EnergyPod demonstrates the need for a system in which Distribution System Operators (DSOs) and Transmission System Operators (TSOs) can manage energy consumption for charging infrastructure at charging plazas.

SYSTEM ELEMENT	ROLE IN THE ENERGYPOD ARCHITECTURE
Charging stations	Deliver energy to vehicles and receive control instructions about charging power and timing.
Battery Energy Storage System (BESS)	Buffers energy locally, supports charging when grid import is limited, and can absorb energy when capacity or local generation is available.
Energy Management System / Priority Module	Converts grid limits, operational needs and market signals into control actions for chargers, storage and other assets.
Grid operator interface	Communicates available capacity, import limits and congestion signals to the EnergyPod in a structured, secured and automated way.
Operational planning interface	Provides information about vehicles, charging sessions, fleet planning, state of charge, deadlines and service requirements.
Market and balancing interface	Provides pricing, nominations and potential flexibility or balancing information through a Balancing Service Provider or Balance Responsible Party, where applicable.

EnergyPod

The EnergyPod architecture

The EnergyPod consists of three layers. The first is the physical layer: charging stations, BESS, grid connection, and possible local generation, such as photovoltaic panels. The second is the control layer: hardware and software that run the Energy Management System and execute control commands. The third is the interface layer: communication links with the grid operator, the Charge Point Operator (CPO), the Public Transport Operator or fleet operator, and market actors such as a Balancing Service Provider (BSP) or a Balancing Responsible Party (BRP).

The system distinguishes itself through the combination of hardware, software and operational intelligence. The hardware creates flexibility, especially through battery storage. The software determines how that flexibility should be used. The interfaces ensure that decisions are based not only on local charging demand but also on grid conditions and operational priorities.

For the grid operator, the EnergyPod creates a controllable connection. Instead of treating a charging plaza as a fixed load that always draws power when vehicles are connected, the grid operator can communicate limits that the system must respect. For the mobility operator, the EnergyPod creates continuity. When direct grid import is restricted, the BESS can supply additional energy to keep charging sessions going, as long as sufficient stored energy is available.

This means the EnergyPod balances availability and usage. It does not merely reduce consumption. It makes charging demand controllable by combining grid import, storage, charging schedules and operational deadlines. In favourable conditions, it can charge vehicles and storage. In constrained conditions, it can reduce grid imports and use stored energy to minimise operational disruption.

Data exchange: what the digital infrastructure actually carries

The digital infrastructure in this whitepaper is not a generic IT layer. It is the set of data connections, standards, security measures and control interfaces that allow the EnergyPod to operate. The exchanged data is specific and operational: available grid capacity, expected transformer load, import limits, vehicle charging needs, state of charge, charger status, battery state, local generation, energy prices, nominations and possible flexibility requests.

For a public-transport depot, for example, vehicles and fleet systems may provide the current state of charge and the energy required for the next route. The fleet operator or planning system may provide arrival and departure times, operational priorities and charger availability. The grid operator provides the capacity boundary that must not be exceeded; this takes precedence over all other inputs. The Priority Module combines these inputs into a charging plan and revises that plan when conditions change.

This is where the integration between the grid operator, CPO and mobility operator becomes critical. The CPO operates the charging infrastructure and needs to execute charging sessions reliably. The mobility operator needs vehicles ready in time. The grid operator needs the site to remain within grid constraints. The EnergyPod provides the local control logic that coordinates these requirements rather than handling them in isolation.

EnergyPod system overview

Prediction module and OpenADR

A central part of the DITM approach is predicting grid load. In the project, a machine-learning model was trained on actual data such as historical transformer load, weather data and general load profiles. For each transformer or relevant grid asset, the model must learn the local load profile under different conditions. A validation set is used to assess the quality of the model. Because the tested transformers were congested only for limited periods, fictional congestion scenarios were also used to validate the control concept.

The prediction module estimates the available headroom on the grid. In operational terms, this can be expressed as the import capacity available to the EnergyPod per 15-minute interval for the next day. This day-ahead view allows the charging system to plan before congestion occurs, rather than only reacting when the grid is already under stress.

In DITM, communication of grid constraints is based on OpenADR, an open standard for automated and secured communication between controlling systems and energy management systems. In this architecture, the controlling side is represented by a Virtual Top Node (VTN), operated by or on behalf of the grid operator. The receiving side is represented by a Virtual End Node (VEN), integrated into the EnergyPod.

The grid operator can use OpenADR to communicate import limits to the EnergyPod. In DITM, this can be done day-ahead, aligned with planning cycles, and can also support acute congestion signals when needed. The relevant signal is an absolute power limit for a defined time interval. Once received, this limit becomes an operational boundary: the EnergyPod must ensure that total grid import does not exceed it during the specified period.

OpenADR is therefore not a general-purpose data exchange mechanism. Its role is specific: communicating capacity constraints or control events in a standardised and automated way. Compliance can be verified through metering at the grid connection point, while the EnergyPod can provide feedback on the execution of signals. The use of an open standard supports vendor neutrality and scaling across multiple sites and operators.

The Priority Module: how constraints become actions

The Priority Module is the core decision-making component of the EnergyPod. It is a type of Energy Management System that gathers information from the grid, charging operations, fleet planning, local assets and energy-market actors. It then determines which control actions should be sent to chargers, the BESS and other assets.

The module does not optimise a single variable. It must balance several conflicting requirements. The first priority is to respect grid constraints, including congestion parameters and import limits from the grid operator. The second is to safeguard the operational plan: vehicles must be charged sufficiently and on time for their next use. The third is to use available flexibility efficiently, for instance by charging when energy prices are favourable or by making spare flexibility available through a BSP when this does not conflict with grid and operational requirements.

In practice, the module works as a rolling optimisation process. It translates a changing set of inputs into a feasible plan, executes that plan, and recalculates when new information arrives. This is essential because the system is dynamic: photovoltaic production can deviate from forecasts, vehicle arrivals can change, chargers or assets can become unavailable, and grid constraints can be tightened or relaxed.

This priority order is important. The EnergyPod is not primarily a tool for energy trading. Its main purpose within DITM is to enable charging infrastructure to operate in a grid-constrained environment. Commercial optimisation and the valorisation of flexibility can be relevant, but only within the boundaries set by grid reliability and mobility operations.

The same logic also explains the value of the BESS. The battery is not merely an add-on. It is the asset that gives the Priority Module room to manoeuvre. When grid import is limited, the BESS can supply part of the charging demand. When capacity is available, the BESS can be recharged. When renewable generation would otherwise be curtailed or unused locally, storage can help align supply and demand.

PRIORITY	INPUT	TYPICAL ACTION BY THE PRIORITY MODULE
1. Grid constraints	Import limits, congestion signals, available headroom and metered grid connection data.	Keep total grid import within the allowed boundary; curtail or shift charging where necessary; use BESS to support charging when grid import is limited.
2. Operational continuity	Vehicle arrival and departure times, required state of charge, active charging sessions, route or mission planning, charger availability.	Allocate charging power to vehicles that need it most urgently; maintain minimum service levels; re-plan when the fleet's needs change.
3. Energy and flexibility value	Energy nominations, price signals, BESS state of charge, local generation and possible BSP/BRP flexibility opportunities.	Charge storage or vehicles when capacity is available; use stored energy during constrained periods; offer flexibility only when compatible with the grid and operational priorities.

The planning cycle

The interaction between operational planning and energy planning is best understood as a rolling 48-hour process. On the day before the operation, fleet planning, expected charging demand, asset availability and grid forecasts are combined into an initial plan. Around the same period, energy nominations to the BSP or BRP are prepared. Not all operational requirements are known at that moment, so the plan is based on the best available estimates.

When the grid operator communicates day-ahead import limits, the EnergyPod incorporates these limits into its planning. On the day of operation, the Priority Module compares the plan with real conditions. If actual photovoltaic production is lower than expected, if a vehicle arrives with less charge than planned, if a charger is unavailable, or if congestion becomes acute, the system recalculates. This leads to re-planning and execution: actual charging, battery charging or discharging, and possible curtailment.

After the operation, measurements and allocations are used for validation and settlement. This closes the loop. The same data can improve future predictions, verify compliance with grid limits and support the development of business cases for grid-aware charging infrastructure.

A representative workflow

STEP	WHAT HAPPENS	WHY IT MATTERS
1. Grid load is predicted	Transformer measurements, historical load data, weather data and load profiles are used to estimate available grid capacity for the next day.	The charging system receives a view of expected headroom before congestion occurs.
2. Limits are communicated	The DSO communicates import limits to the EnergyPod via OpenADR, specifying values for defined time intervals and potential acute congestion signals.	Grid constraints become machine-readable operational boundaries.
3. Operational needs are added	Fleet planning, vehicle state of charge, charging sessions and charger availability are provided by mobility and charging systems.	The system knows not only what the grid allows, but also what mobility operations require.
4. The Priority Module optimises	The module allocates power between grid import, BESS, chargers and possible local generation, respecting grid limits and charging deadlines.	Charging remains as useful as possible without exceeding the grid boundary.
5. Assets execute and report	Chargers, BESS and metering systems execute the control plan and provide feedback for compliance, re-planning and settlement.	The system becomes controllable, verifiable and scalable.

What needs to happen next

The DITM work shows that grid-aware charging infrastructure can be designed as an integrated system, with the battery at its heart. The next phase is deployment and validation in real operational environments. This should not be framed as proof that technology is no longer a barrier. Although these challenges can be overcome, technical barriers remain, including cybersecurity, reliability, prediction accuracy, standard implementation, asset control, validation, and interoperability. At the same time, organisational and regulatory alignment is essential. In addition, developments in a broader EU context must also be taken into account. On 20 May 2026, the Smart Energy Expert Group and the Sustainable Transport Forum produced a joint report containing a set of recommendations to simplify data exchange for flexibility, smart charging, and bi-directional charging.

The most logical starting points are locations where the need is clear, and the operational environment is relatively controlled: bus depots, logistics hubs, heavy-duty charging plazas and other large charging locations in grid-constrained areas. The choice of locations should be driven by grid operators and site operators together, based on actual congestion needs, site suitability, and the potential to demonstrate value.

Several aligned steps are required. Grid operators need a structured way to communicate capacity and constraints. CPOs and mobility operators need charging systems that can respond without jeopardising operations. Standards such as OpenADR need to be implemented and updated consistently. The role of BESS and other flexibility assets needs to be reflected in contracts and business cases. Cybersecurity and trust must be treated as core design principles because manipulation of control data could affect both operations and grid stability.

For policymakers, the implication is that electrification policy and grid policy cannot be treated separately. More charging infrastructure is needed, but how it connects to the grid matters. Grid-aware charging can help make scarce capacity more usable, reduce the need for avoidable reinforcements and allow mobility electrification to proceed in locations where unrestricted grid capacity is not available in the short term.

Charging must become more predictable and flexible

The electrification of mobility increases the strategic importance of charging infrastructure, but it also exposes the limits of the electricity grid. Grid reinforcement remains necessary, but it cannot be the only answer. In grid-constrained areas, charging must become more predictable, controllable and flexible.

DITM's EnergyPod provides a concrete architecture for that shift. It combines charging stations, BESS, prediction, OpenADR-based communication, and a Priority Module into a single coordinated system. The prediction module estimates grid load and available headroom. OpenADR translates limits into standardised control signals. The Priority Module converts those limits, together with operational and market information, into charging and storage actions.

The result is a system that responds first to grid parameters while still considering the needs of mobility operators, CPOs, and market actors. This can help make charging infrastructure available where electrification would otherwise be slowed down by congestion, connection delays or limited grid capacity.

The next step is not a general call for more coordination, but a practical deployment agenda: test EnergyPod-like architectures at suitable grid-constrained charging sites, validate their performance, clarify roles and contracts, and scale what works. That is how digital infrastructure can turn grid-aware charging from a promising concept into a foundation for future-proof electric mobility.

Digital Infrastructure for
Future-proof Mobility