DITM WHITE PAPER

Digital Infrastructure for Future-proof Energy in Mobility

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

Digital Infrastructure for Future-proof Mobility

Project information

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

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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.

Whitepaper 1

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

Whitepaper 2

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

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.

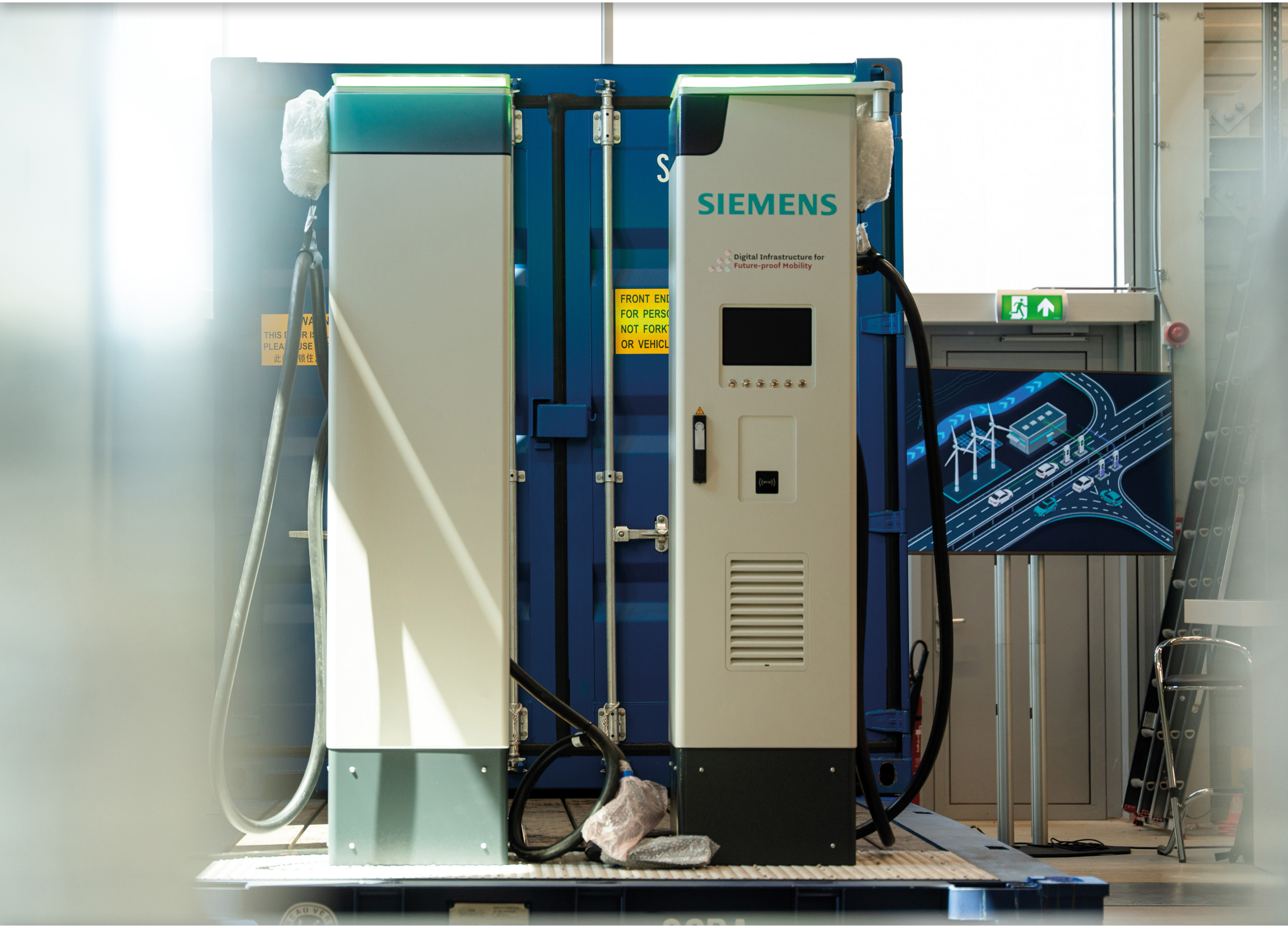
DITM - Digital Infrastructure for Future-proof Mobility - addresses this challenge through grid-aware charging infrastructure. The project does not claim that grid expansion is unnecessary, nor that all barriers are merely organisational. Instead, it shows how technical integration, standardised communication 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.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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

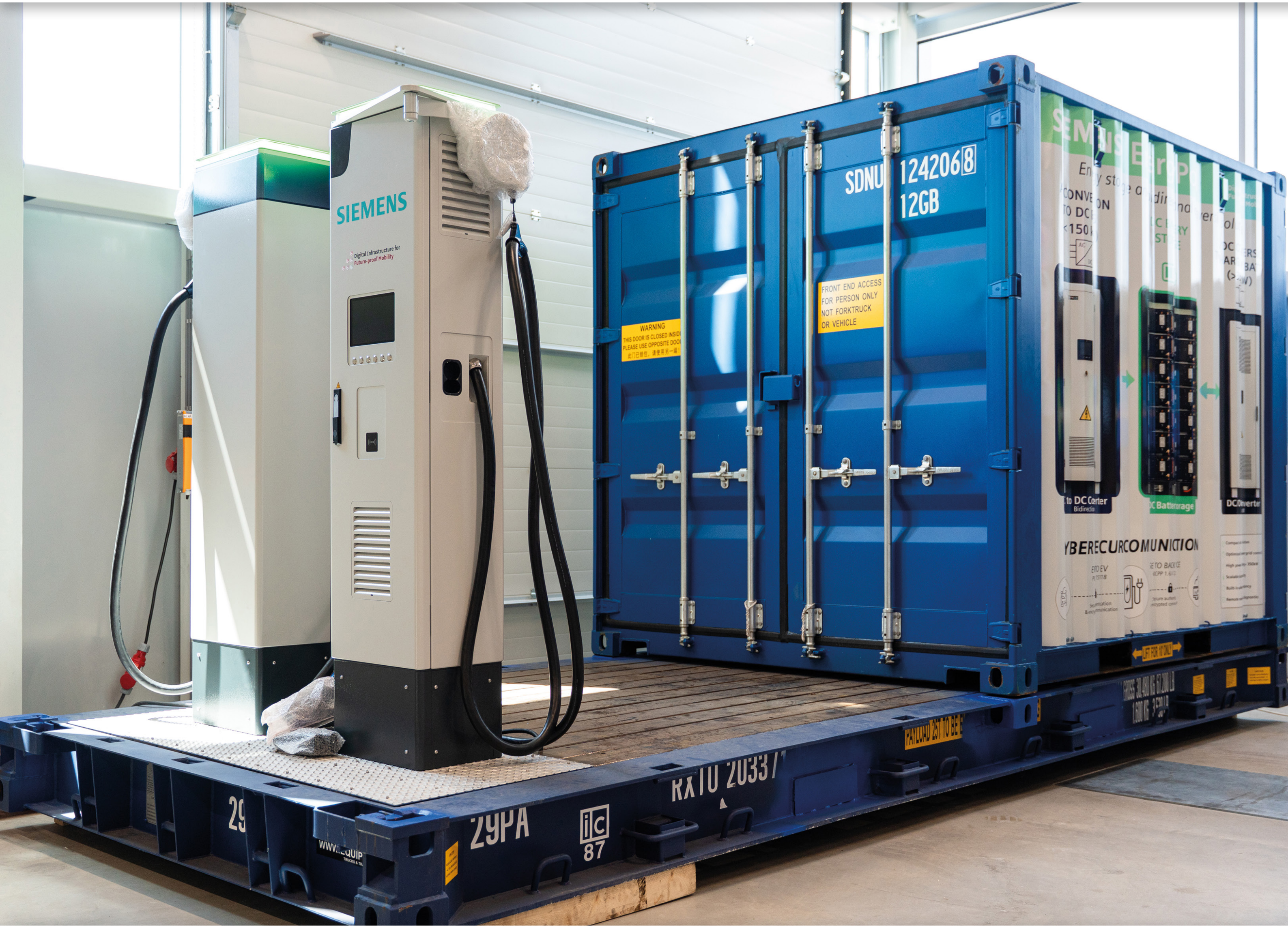
The relevant system elements are those that make a reliable and secure energy supply possible for electric mobility. The DITM contribution is integrating these elements into a practical architecture for grid-aware charging.

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.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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.

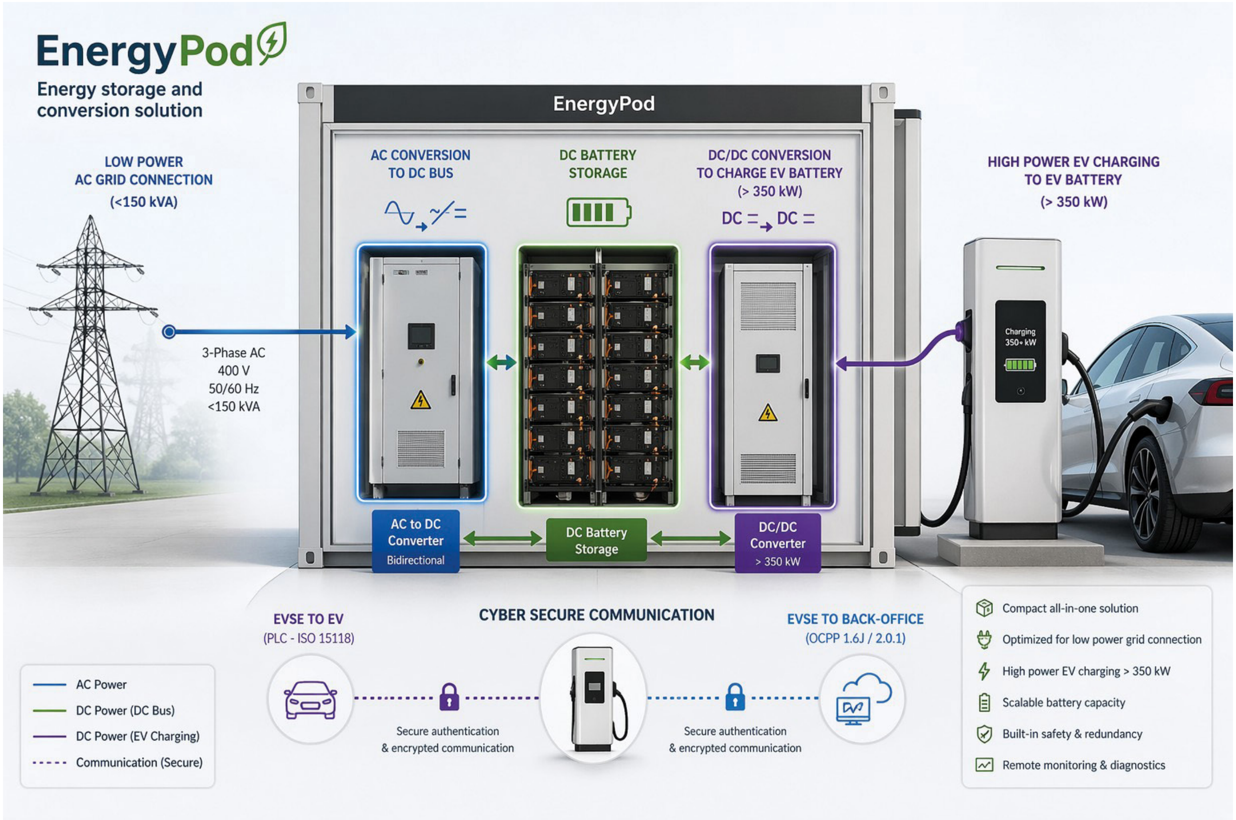
This means the EnergyPod balances availability and usage. It does not merely reduce consumption. It makes charging demand controllable by combining grid import, storage, charging schedules and operational deadlines. In favourable conditions, it can charge vehicles and storage. In constrained conditions,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

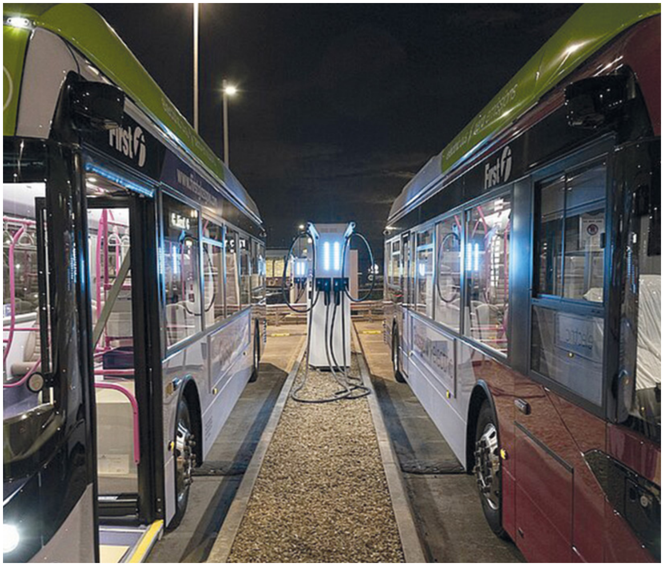
This priority order is important. The EnergyPod is not primarily a tool for energy trading. Its main purpose within DITM is to enable charging infrastructure to operate in a grid-constrained environment. Commercial optimisation and the valorisation of flexibility can be relevant, but only within the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

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