Requirements and Specification of the Operational Fleet Management Support Tools

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Executive Summary

The Charging Energy Hub (CEH) project aims to accelerate the electrification of logistics transport by addressing financial, legal, and organizational barriers. The project integrates charging infrastructure, battery storage, and renewable energy into existing electricity networks, and the project use cases include both public and private charging locations. This report is part of Work Package (WP) 2 and outlines the requirements and interfaces for digital assets later developed in WP3.

This report, Deliverable 2.4, defines the initial requirements and interfaces for two tools: the Fleet Planning Tool (FPT) and the Digital Twin of the Vehicle (DTV). These tools aim to predict and plan fleet charging activities, supporting flexible charging sessions and dynamic vehicle scheduling thereby attributing to CEH's overarching objectives to provide more sustainable and cost-effective solutions to charge electric vehicles. The document serves as input for subsequent tasks in the project, including the development of:

- vehicle digital twins (T3.2),
- dynamic congestion-aware charger control (T3.3) and
- AI-based optimization of fleet and charge planning (T3.4).

Firstly, functional requirements are defined. The functional requirements are linked to the general functional requirements as defined in WP1 and are further refined based on conversations with project partners and end-users. This way, specific requirements are defined for the FPT and the DTV. Additionally, in case of the public-charging UC, requirements for a charge-time estimation digital twin (DTC) are defined. Next, context diagrams are presented for the operational tools, indicating how the tools connect to one another and to other systems such as the Energy Management System (EMS) and the Charge Station Management System (CSMS). These interfaces are further detailed by listing protocols, messages and signals per interface. Lastly, a protocol is presented that will be used in the communication of power-profiles.

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Definitions

Term	Definition
API	Application Programming Interface
CEH	Charging Energy Hub
Charging Profile	Detailed representation of the power consumption of an electric vehicle over time.
CSMS	Charging Station Management System
CPMS	Charging Plaza Management System
DTV	Digital Twin of the Vehicle
EMS	Energy Management System
ETA	Estimated Time of Arrival
FPT	Fleet Planning Tool
OCPP	Open Charge Point Protocol
OCPI	Open Charge Point Interface
PTD	Planned Time of Departure
Route	Series of waypoints that form a series of trips throughout the day. A route does not include charging.
Route leg	A subsegment of a route indicated by a start and stop location
SoC	State-of-Charge of the battery
TMS	Transport Management System
UC	Use Case
Vehicle status	Snapshot of the vehicle state. For example: timestamp, position, speed, etc.
WP	Work Package

1. Introduction

The Charging Energy Hub (CEH) project is aimed at accelerating the electrification of logistic transport in the Netherlands by overcoming financial, legal, and organizational barriers. The project focuses on integrating charging infrastructure, battery storage, and renewable energy into existing electricity networks. As visualized in Figure 1, the figure is subdivided in ten Work Packages (WP's), including three Use Cases (UC's), where innovations will be validated and demonstrated. This report is part of the architecture description of WP2 by describing the requirements and interfaces of the part of the digital assets developed in WP3. These assets will later be demonstrated both in a private-charging UC, WP6, and a public-charging UC, WP7.

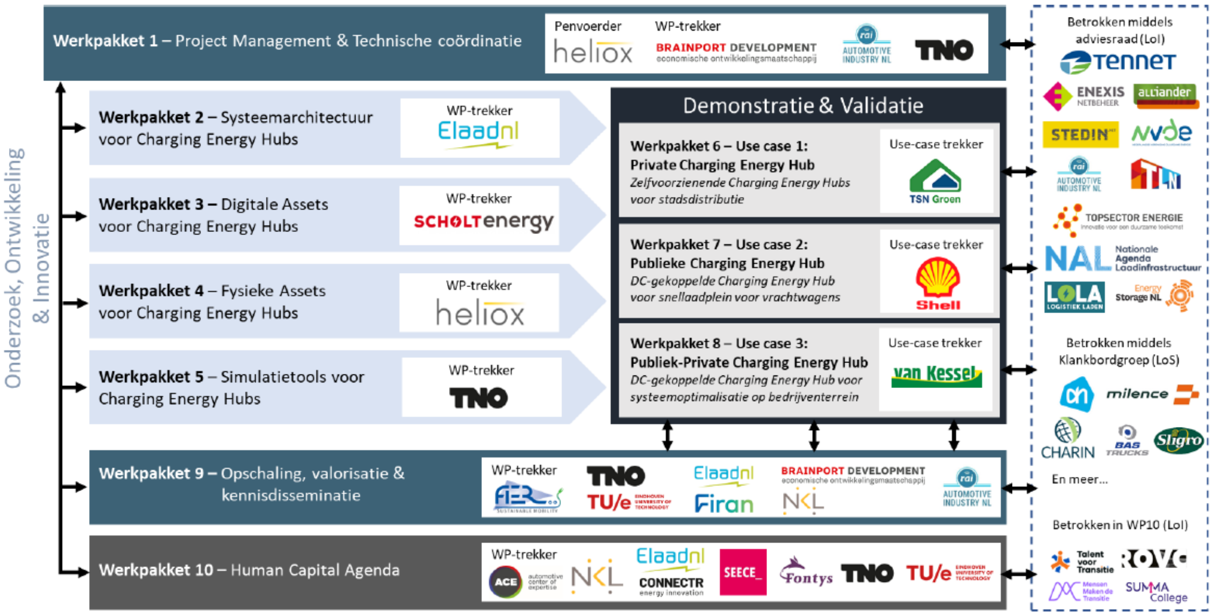

Figure 1: Overview of the WP-structure of the CEH project [1].

Providing charging opportunities to vehicles is one of the key functionalities of a CEH. In order to predict, plan, and control the vehicle fleet charging activities in a way that supports the high-level goals of the CEH, a set of operational fleet-management-support tools is developed. As described in Section 1.3.4 of D2.1 [2], these tools support flexible charging sessions and dynamic scheduling of the vehicles. The toolset includes the Fleet Planning Tool (FPT) and the Digital Twin of the Vehicle (DTV). Where in D2.3 [3] the interfaces for these tools are identified on a high level, they are specified in more detail here.

This document describes the requirements and specified interfaces of fleet management support tools, developed withing the CEH project. Thereby, this report functions as input to:

- T3.2, the development of vehicle digital twins,
- T3.3, the Active, Dynamic Congestion-Aware Charger Control and
- T3.4, the AI-based optimization of fleet and charge planning.

The requirements and interfaces described in this document are those as defined in the first year of the CEH project. During development and demonstration of the principles described here, changes in the details surrounding the interfaces are expected. Nevertheless, this document provides a solid first guideline on the requirements and specification of the fleet managements support tools and thereby functions as input to following deliverables in the project that specify the functional designs and API's.

This report is structured as follows: First, Section 2, describes the functional requirements of the operational fleet management support tools, which are linked to the functional requirements of the CEH. Next, in Section 3, the interfaces of the individual tools to each of the connecting software systems are described. Furthermore, in Section 4, a standard for power-profile communication is proposed, which can be part of this interfacing. Lastly, conclusions are provided in Section 5.

2. Requirements - Operational Fleet Support Tools

This section describes the formulated requirements of the operational fleet management support tools. The requirements are the result of interactions between the authors of this deliverable report, which represent both the developers of the fleet support tools, as well as the developers of the Energy Management Systems (EMS) and the end-users of the use-cases. First, in Section 2.1, a link is made to the general CEH requirements. Next, in Section 2.2, the resulting functional requirements are described and motivated for the digital twin of vehicle and vehicle planning.

2.1 Link to generic CEH requirements

The general requirements of the CEH system are described in D1.2.1 [4]. Based on the text of these requirements, there are seven requirements that relate to the fleet support tools discussed in this report: Req-1020, Req-1040, Req-1130, Req-1520, Req-1760, Req-1810, and Req-1870. For purpose of completeness, these requirements are repeated in the tables below, where they are subdivided in requirements related to the fleet planning, in Table 1, and requirements related to the DTV, Table 2. In these tables, the priority column indicates whether the requirement is considered; to be a 'must-have', to be realized in the CEH project (high), or a 'nice-to-have', to be realized if possible (medium). Low priority requirements are not mentioned in this deliverable.

Table 1: Excerpt from D1.2.1 : Requirements mentioning or relating to 'fleet planning'.

ReqID	**Has Parent**	**Requirement** ***Rationale***	**Value**	**Priority**
Req-1020		The CEH shall increase the grid's max capacity by 20% by optimising energy supply and demand Rationale: Goal is to optimise the grid's supply and demand to avoid power peaks and its results	20%	Medium
Req-1040	Req-1020	The CEH shall use optimising software (SW) algorithms to ensure optimal operation time of vehicles and lowest energy cost price possible using actual measurements Rationale: Software implementation to do the logic		Medium
Req-1130	Req-1040	The CEH shall have an energy consumption forecasting to predict renewable production, fleet planning, congestion and local energy flows based on current and historical data. Rationale: To improve the accuracy of energy predictions and enhance operational efficiency.		High
Req-1520	Req-1040	The CEH shall adjust, while there are unexpected deviations due to failure or error in forecast, the energy scheduling (fleet charge planning or energy consumer schedule) Rationale: mitigate on unexpected behaviour Logistics Service Provider (software)		Medium

Table 2: Excerpt of D1.2.1: Requirements mentioning or relating to 'digital twin'.

ReqID	**Has Parent**	**Requirement** ***Rationale***	**Value**	**Priority**

Req-1760	Req-1810	The digital twin shall receive up to date information from the fleet charging scheduler Rationale: to calculate with demand Knowledge Institutes		Medium
Req-1810		The CEH shall have a digital twin energy management interface Rationale: digital twin will be input for the CEH Maxem Energy Solutions B.V.		High
Req-1870	Req-1810	The digital twin shall predict charging energy demand with a 5% better accuracy than rule based methods Rationale: to improve on accuracy of prediction	5%	High

2.2 Digital Twin and Vehicle Planning Requirements

Based on conversations between algorithm developers, energy management system developers, and the end-users of the use-cases, additional requirements are formulated. The additional requirements can be categorized in:

1. Requirements for the DTV, see Table 3,
2. Requirements for the charge-time estimation digital twin in a public charging hub context, see Table 4 and
3. Requirements for the FPT, see Table 5.

Table 3: New functional requirements related to the Digital Twin of the Vehicle (DTV).

ReqID	Has Parent	Requirement ***Rationale***	Value	Priority
Req-2900	Req-1810	The CEH vehicle digital twin upon receiving the vehicle status and vehicle route, shall send, within a 95% confidence bound (2 sigma), the Estimated Time of Arrival (ETA) prediction of the vehicle at the CEH, to the vehicle fleet planning Rationale: Adherence to planning (constraints), charge block reservations, trading windows	+/- 95%	High
Req-2920	Req-2900	The CEH vehicle digital twin upon vehicle ETAs excession, shall alert the fleet planning optimizer Rationale: To allow for dynamic replanning if planned vs predicted values are (too much) out of synch		Medium
Req-2930		The CEH vehicle digital twin upon receiving the vehicle status and vehicle route, shall predict, within a 95% confidence bound (2 sigma), the remaining energy, in kWh, required to complete the route towards it next charge event Rationale: The required remaining kWh directly influences the fleet planning	+/- 95%	High
Req-2950	Req-2930	The CEH vehicle digital twin upon indicating too low vehicle SoC to reach arrival, shall alert the fleet planning optimizer Rationale: To allow for intervention regarding alternative charge planning along route		High
Req-2960	Req-2950	The alert must include future position of the vehicle along the route at the time the vehicle is expected to breach the low-SoC threshold		Medium

		Rationale: This allows the platform to show the estimated location that the vehicle breaches the threshold and command vehicle to charge earlier along the route.		
Req-2970	Req-2920, Req-2950	The operator shall configure the alert thresholds through an API Rationale: To avoid 'false positives' and to denote planning safety buffer for a carrier regarding min. Battery SoC.		Medium

Table 4: New functional requirements related to the charge-time estimation digital twin.

ReqID	**Has Parent**	**Requirement** ***Rationale***	**Value**	**Priority**
Req-2980		The CEH charge-time estimation digital twin, when connected to a charger, shall send an estimated remaining charging power profile within a 95% confidence bound, at least every 15 minutes. Rationale: Knowing when a vehicle might ask for reduced power will result in in-/decreased optimization space	15 min	Medium
Req-3000		The CEH charge time prediction digital twin shall provide, assuming full available requested power, an estimated time to the required SoC, within a 95% confidence bound, at least every 15 minutes Rationale: Knowing when a vehicle might ask for reduced power will result in increased optimization space	15 min	Medium
Req-3020	Req-3000	The prediction shall not consider constraints enforced by the EMS, but rather predicts the profile in case a 'greedy charging' strategy would be pursued. Rationale: Each vehicle, will request a different power, possibly as function of SoC. In practice the EMS defines what the charger-side maximum charging capacity is, this is out-of-scope here.		Medium

Table 5: New functional requirements regarding Fleet Planning Tool (FPT).

ReqID	**Has Parent**	**Requirement** ***Rationale***	**Value**	**Prio**
Req-3040	Req-1130	The CEH vehicle Fleet Planning Tool shall prescribe the estimated Time of Arrival (ETA) and planned time of departure (PTD) of each charging vehicle for use in charge planning execution / EMS Rationale: This data enables the EMS to assess optimal charging profiles as well as available flexibility to valorise at flex markets		High
Req-3050	Req-1130	The CEH vehicle fleet planning or Transport Management System (TMS) shall provide the required SoC at departure for use in charge planning execution / EMS Rationale: The SoC is a measurable indication of the amount of energy the vehicle will charge from the CEH.		High

3. Interfaces

The operational fleet management support tools are communicating with different systems in the Charging Energy Hub. In this chapter, the interfaces from the FPT and the DTV to these other systems are described. Most notably, the connection to the Energy Management System (EMS) and the Charging Station Management System (CSMS) are detailed. Where possible, links to D2.3 [3] and specifically Section 3.7.5 of D2.3, are supplied.

3.1 Context Diagrams

First, the context of operational tools is mapped in a context diagram. This is done separately for the private charging use-case, as will be demonstrated in WP6, and the private charging use-case, as demonstrated in WP7.

3.1.1 Use-Case Description: Private Charging

In WP6 of the CEH project, a private charging energy hub is considered. The tasks in this use-case related to fleet management support will be about testing and validating the tools for real-time planning and energy forecasting. By means of a cloud-based platform and APIs, real-time vehicle data will be retrieved and combined with the planning to ensure optimal deployment of vehicles and the energy required.

The context diagram is displayed in Figure 2. The figure shows the digital twin software in the center, which is hosted on the digital-twin platform. From the digital twin, there are interfaces to the user and to third party data (e.g. vehicles fleet management portal). Most significant is the interface between the DTV and the FPT. The FPT will schedule the routes of different vehicles, based on the logistic assignment from the Transport Management System (TMS). Both during this planning activity, as well as during operation of the vehicle, the FPT will forward route- and vehicle information to the digital twin of the vehicle (DTV). Based on this information, the DTV will return estimates of the predicted SoC at arrival and arrival time to the FPT, including an uncertainty indication of the estimated values. If a route is predicted to be infeasible, the DTV returns an alert. The FPT will use this information to determine and optimize the (updated) vehicle planning, defined by arrival- and departure times, and departure SoC’s, and communicate this to the EMS and CSMS of the charging energy hub.

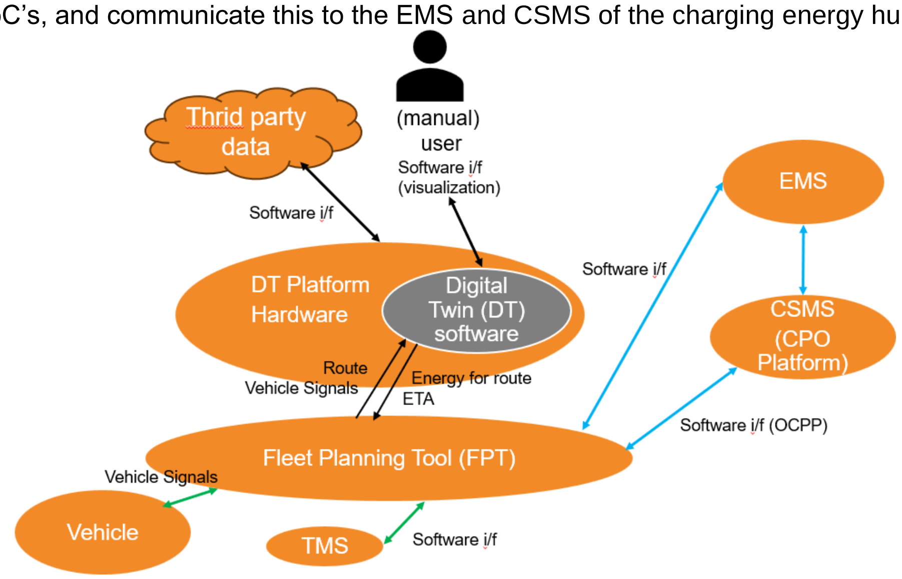

Figure 2: Context diagram of the Digital Twin and the FPT for the private charging use-case. Overview does not show the full context of the CEH.

The connection between FPT and EMS and CSMS is more extensively described in D2.3 [3], where also a Charging Plaza Management System (CPMS) is introduced. In Figure 2, the Charging Plaza Management System and the Charging Plaza are considered part of respectively the EMS and the CSMS systems. This particular choice ensures the overviews here remain central to the fleet-management-support tools. In addition, in the case where the EMS-provider and the CSMS-provider are the same party, as is the case in UC6 of the CEH project, the functionalities of the CPMS might be embedded in the EMS and CSMS systems.

3.1.2 Use-Case Description: Public Charging

In WP7 of the CEH project, a public charging energy hub will be realized. A DTV will be implemented to support the operation of the public charging energy hub. The digital twin provides estimated data points for short-term optimization purposes, including ETA vehicle arrival at charging station and estimated initial SoC at charger arrival. In absence of a FPT, the data is fed directly to the EMS of the CEH, which can use this information to predict the flexible energy capacity available and valorize on this. The required vehicle signals to feed the DTV could be challenging to obtain, as the vehicle operators are not necessarily project partners. Alternatively the DTV might be demonstrated using data from simulation data.

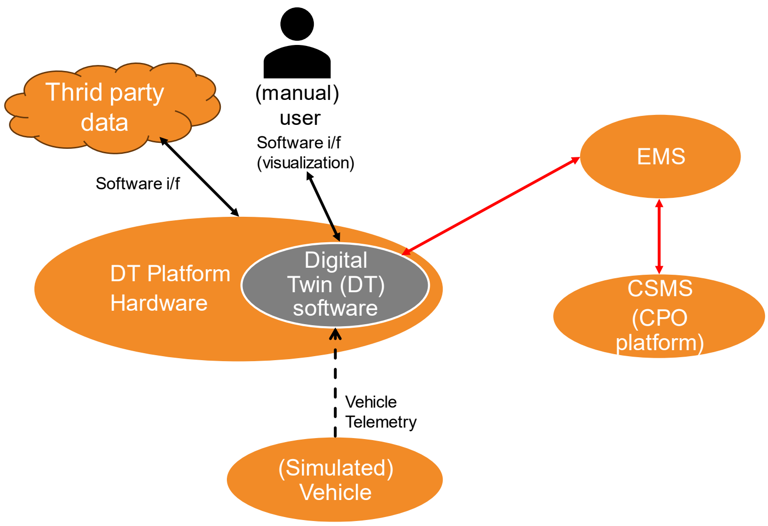

Figure 3: Context diagram of the Digital Twin for the public charging use-case.

3.2 Interface: Digital Twin – Fleet Planning Tool

This section describes the interface *I_DigitalTwin* between the Fleet Planning Tool (FPT) and Digital Twin for Vehicles (DTV) as defined in the main architecture in D2.3 [3]. In the implementation, this interface is a group of interfaces between the FPT and the DTV.

The FPT is responsible for planning the route between waypoints. This route will be communicated to the DTV, which will then estimate its energy consumption and Estimated Time of Arrival (ETA).

The functions of this interface are:

- **vehicleRoute**: supply a route to the DTV that needs to be evaluated.
- **vehicleStatus**: supply the DTV with near-real-time vehicle data (on regular time interval)
- **vehiclePrediction**: supply the FPT with energy consumption and ETA predictions for both day-ahead planning and near-real-time trip status.

3.2.1 Sequence diagram

A route is initialized in the DTV with the *vehicleRoute* call. After starting the route, the FPT repeatedly publishes *vehicleStatus* to the DTV, and receives asynchronous responses, until the end route *vehicleStatus* is published. This is visualized in the sequence diagram in Figure 4.

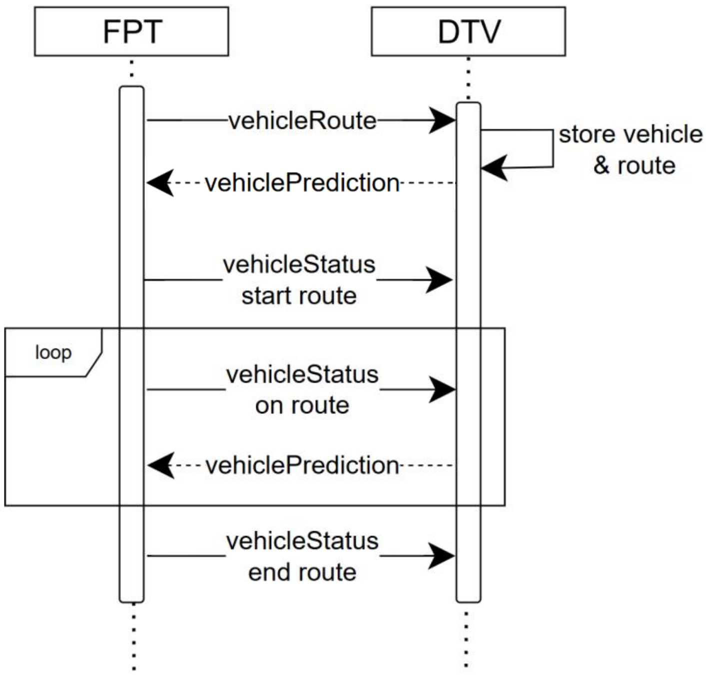

Figure 4: Sequence diagram of the interface *I_DigitalTwin*.

3.2.2 Functional requirements

This section lists the functional requirements of the DTV.

3.2.2.1 vehicleStatus

The FPT sends vehicle status updates to the DTV at a fixed interval, e.g. once every 5 minutes, and on important events, such as trip start/stop. The purpose of this interface is to provide data for updating the internal state of the DTV. For the complete message content, see Table 6.

Table 6: *vehicleStatus* message.

Symbol	**Unit**	**Description**
vehicleId	n/a	Unique ID of a vehicle
routeId	n/a	The unique ID identifying the route
sentTimestamp	ISO 8601	Timestamp when the status message was sent
vehicleRouteStatus	enumeration	starting route, on route, ending route
vehicleSignals	n/a	Time series of vehicle signals, with a minimal sampling rate of 0.1Hz. For example:
- position & heading	WGS84	Timeseries position
- speed	km/h	Timeseries speed signal
- stateOfCharge	%	Timeseries battery State of Charge
- AmbientTemperature	degC	Timeseries Ambient Temperature
- HV Battery Current	A	Timeseries current
- HV Battery Voltage	V	Timeseries voltage
- HV Drivetrain Current	A	Timeseries current
- HV Drivetrain Voltage	V	Timeseries voltage

3.2.2.2 vehicleRoute

The FPT requests the DTV for an energy and feasibility estimation of a planned route. The FPT provides the message *vehicleRoute* as described in Table 7.

Table 7: *vehicleRoute* message.

Symbol	**Unit**	**Description**
vehicleId	n/a	Unique ID of a vehicle
(vehicleType)	Car/Bus/Truck	Vehicle Type (CEH scope is limited to Trucks)
routeId	n/a	The unique ID identifying the route
vehicleHVBatteryCapacityGross	kWh	The gross capacity of the HV battery
vehicleHVBatterySoCMin	%	The minimum allowed SoC level of the HV battery
vehicleRouteStartSoC	%	SoC at start of the route
vehicleRouteEtAAlert	ISO 8601	EtA limit
route		Series of:
- routeSegmentStartLocation	WGS84	Starting location
- routeSegmentEndLocation	WGS84	Ending location
- routeSegmentStartDateTime	ISO 8601	Date and time of start of the route
- routeSegmentEndDateTime	ISO 8601	Date and time of end of the route
- routeSegmentWayPoints	WGS84	Series of coordinates that are part of the route, with the purpose of making the route definition unique.
- vehicleGrossWeight	kg	Total weight of the vehicle

The DTV responds with a *vehiclePrediction* message which is specified in Section 3.2.2.3. Constraints for loading/unloading goods at a route waypoint can be modelled as a route segment with equal start/stop, but non-zero duration.

3.2.2.3 vehiclePrediction

The DTV provides the FPT with the information provided in Table 8

- as response to *vehicleRoute*
- at regular time intervals, during operation of the vehicle, i.e., while repeatedly receiving *vehicleStatus*.

Table 8: *vehiclePrediction* message.

Symbol	Unit	Description
routeId	n/a	The unique ID identifying the route
vehicleId	n/a	Unique ID of a vehicle
routeEnergyEstimation	kWh	Estimated energy required for remaining part of the route
- *routeEnergyEstimationLowerBound*	kWh	Lower bound of the 95% confidence interval of the energy consumption estimate
- *routeEnergyEstimationUpperBound*	kWh	Upper bound of the 95% confidence interval of the energy consumption estimate
routeETAEstimation	ISO 8601	Estimated ETA for ending the route
- *routeETALowerBound*	ISO 8601	Lower bound of the 95% confidence interval of the ETA
- *routeETAUpperBound*	ISO 8601	Upper bound of the 95% confidence interval of the ETA
routeAlert		-
- *type*	enumeration	Alerts including: - SoC - ETA
- *location*	WGS84	Location where alert is triggered
- *remainingDuration*	seconds	Duration between alert and arrival
- *remainingDistance*	meters	Distance between alert and arrival

3.3 Interface: Fleet Planning Tool – EMS

The FPT requires high-level the following from the EMS at regular intervals which are detailed out in the functional requirement specifications:

- Cumulative energy available for charging for 15 minutes intervals for the next 48 hours rolling
- On submitting a day ahead planning, the feasibility in terms of cumulative energy
- Real-time alerts:
    - Requested cumulative energy required for planned charging is not available
- Charging infrastructure: charge point properties
- Real-time updates on smart charging profiles applied to charge points

The EMS requires the following from the FPT:

- Charge point, arrival and departure times, power requirements, arrival and departure and SoCs for individual vehicles for the day ahead
- Real-time updates on arrival and departure times and SoCs for individual vehicles during the day

- Vehicle characteristics:
    - Battery gross capacity
    - Maximum charging power

Prospected protocols:

- **Custom:** alerting EMS>FPT, and vehicle characteristics FPT>EMS
- **VDV 463** [5]**:** charger/vehicle planning
- **Custom** (inspired on OSCP): EMS grid capacity constraints forecast

3.3.1 Sequence diagram

The sequence diagram in Figure 5 describes the communication between FPT and EMS.
Solid lines represent synchronous communication, and dashed lines asynchronous. The loop indicates that the FPT regularly optimizes the planning. If there are changes, then the EMS will be updated with the changes.

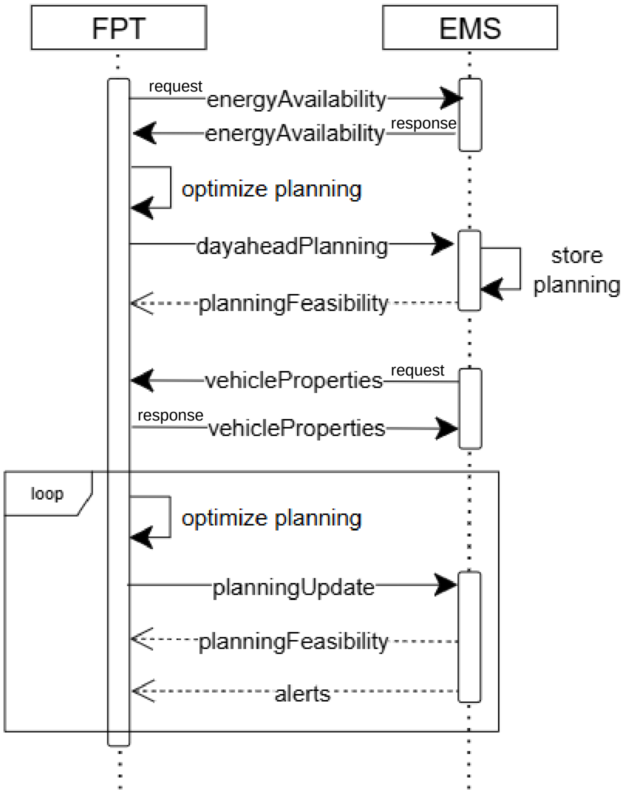

Figure 5: Sequence diagram of the interface between the FPT and the EMS.

3.3.2 Functional requirements

This section describes the functional requirements of the interface between the FPT and the EMS, consisting of the messages *energyAvailability*, *dayAheadPlanning*, *planningFeasibility*, *vehicleProperties*, *planningUpdate*, and *alerts*.

3.3.2.1 energyAvailability

Prediction of the available total energy for the coming 48 hours, as specified in Table 9 and Table 10. Blocks are per 15-minute interval.

Table 9: *energyAvailability* request message.

Symbol	Unit	Description
locationID	n/a	Unique ID of a Charging Energy Hub location
startTimestamp	ISO 8601	
stopTimestamp	ISO 8601	

Table 10: *energyAvailability* response message

Symbol	Unit	Description
locationID	n/a	Unique ID of a Charging Energy Hub location
energyAvailabilityBlocks	kWh	Combined energy availability prediction for the CEH. Available kWh per 15 minute block, with start and stop timestamp, for coming 48 hours.

3.3.2.2 dayAheadPlanning

The FPT sends a day ahead planning (24hr) to the EMS, see Table 11. Upon start of executing the planning, the EMS will be updated if a planning change has occurred. The EMS will receive SoC and use gross battery capacity to calculate energy usage in kWh.

Table 11: *dayAheadPlanning* message

Symbol	Unit	Description
sentTimestamp	ISO 8601	Timestamp when the message was sent
planningID	n/a	Unique ID of a planning
revisionID	n/a	Unique ID of the planning revision
vehiclePlanning		
- *vehicleID*	n/a	Unique ID of a vehicle
- *arrivalTimestamp*	ISO 8601	Planned arrival timestamp
- *arrivalStateOfCharge*	%	Planned arrival gross battery SoC
- *departureTimestamp*	ISO 8601	Planned departure timestamp
- *departureStateOfChargeDesired*	%	Planned desired departure SoC
- *departureStateOfChargeMinimum*	%	Planned minimum departure SoC
- *minimumPower*	W	Minimum power limit on the charge session

3.3.2.3 planningFeasibility

A planning feasibility will be sent from the EMS to the FPT, as in Table 12. A feasibility will be sent at least once for every update, and upon important changes.

Table 12: *planningFeasibility* message

Symbol	Unit	Description
sentTimestamp	ISO 8601	Timestamp when the message was sent
planningID	n/a	Unique ID of a planning
revisionID	n/a	Unique ID of the planning revision
statusCode	enumeration	0 = OK 1 = Infeasible
statusDetails	n/a	Message describing the cause of infeasibility

vehicleStatus (array)	Series of:	
- *vehicleID*	n/a	Unique ID of a vehicle
- *statusCode*	enumeration	Status code for identifying infeasibility cause.
- *statusDetail*	text	Message describing the cause of infeasibility
- *actionCode*	enumeration	Enumeration identifying the action taken in response to the infeasibility. For example: 0=OK, 1=throttled, 2=stopped
- *actionDetail*	text	Message describing what action is taken as result of infeasibility. For example: Power limited to X kW.

3.3.2.4 vehicleProperties

Vehicle properties are required for mapping SoC to kWh in the EMS. Sycada has an existing API [6] for this purpose which shall be extended. It should be possible to get properties for:

1. All vehicles
2. A list of vehicleID

The request and response messages are defined in Table 13 and Table 14, respectively.

Table 13: *vehicleProperty* request message

Symbol	Unit	Description
vehicleID list (optional)	n/a	Unique ID of a planning

Table 14: *vehicleProperty* response message

Symbol	Unit	Description
properties		
- *vehicleID*	n/a	Unique ID of a planning
- *batteryGrossCapacity*	kWh	Gross capacity of the battery
- *maximumChargingPower*	kW	Maximum charging power

3.3.2.5 planningUpdate

Send changes since last planning publish.

Table 15: *planningUpdate* message

Symbol	Unit	Description
sentTimestamp	ISO 8601	Timestamp when the message was sent
planningID	n/a	Unique ID of a planning
revisionID	n/a	Unique ID of the planning revision
vehiclePlanning		
- *vehicleID*	n/a	Unique ID of a vehicle
- *arrivalTimestamp*	ISO 8601	Planned arrival timestamp
- *arrivalStateOfCharge*	%	Planned arrival gross battery SoC
- *departureTimestamp*	ISO 8601	Planned departure timestamp
- *departureStateOfChargeDesired*	%	Planned desired departure SoC
- *departureStateOfChargeMinimum*	%	Planned minimum departure SoC

3.3.2.6 alerts

Alerts are pushed from the EMS to FPT upon events, see Table 16.

Table 16: *alerts* message

Symbol	Unit	Description
timestamp	ISO 8601	Timestamp of the event
eventCode	n/a	Unique code for the event
planningID	n/a	Unique ID of a planning
vehicleID (optional)	n/a	Unique ID of the vehicle

3.4 Interface: Fleet Planning Tool – CSMS

The FPT requires the following from the CSMS:

- Chargers and their properties
- Real-time status updates on charger status
- Real-time updates on smart charging profiles applied to charge points
- Receive and respond to authorisation requests
- Receive charge session details during charging

Prospected protocols:

- **OCPI** [7]**:** charging infrastructure and smart charging profiles
- **Custom**: relay of charge session details

3.4.1 Sequence diagram

This section presents the following sequence diagrams:

- **Figure 6 Left:**
  - Charge session authorization
- **Figure 6 Right:**
  - Receiving infrastructure properties
  - Assigned charge profile for planning optimization
  - Receive charge session details

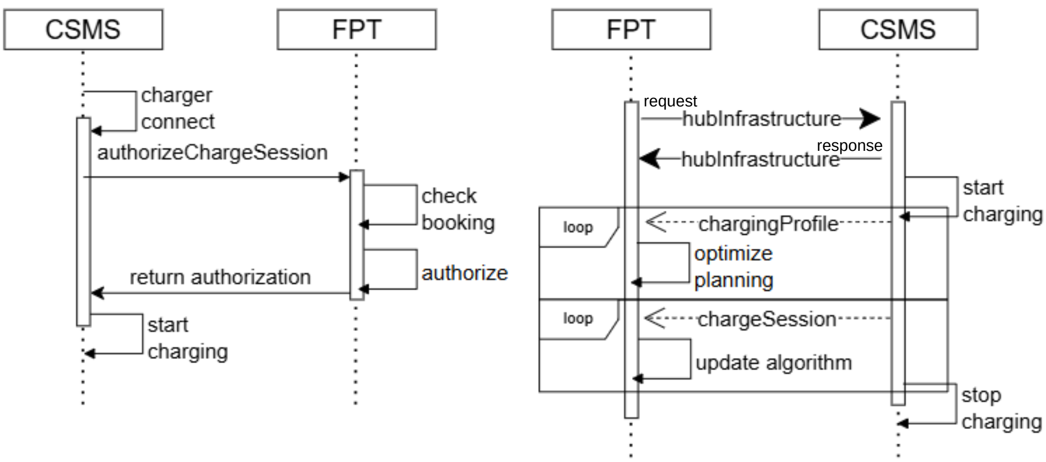

Figure 6: Sequence diagram of the interface *I_FleetMng*, between the FPT and the CSMS.

3.4.2 Functional requirements

This section describes the requirements of the FPT – CSMS interface, including *hubInfrastructure*, *chargeSession*, *chargeProfile*, and *authorizeSession*.

3.4.2.1 hubInfrastructure

The FPT fetches the location data using OCPI 2.2.1 Locations module, with including data specified in Table 17. The CSMS pushes status data defined in Table 18 to the FPT.

Table 17: data included in GET *hubInfrastructure*

Symbol	Unit	Description
ChargerID	-	Timestamp when the message was sent
Capacity	kW	Actual current on charger outlet
Connectors - Max current - Max voltage - Connector type - Power type	 A V - -	Connector object according to standard.
cumulativePower	kWh	Cumulative power transfer on charger outlet
Status	enum	Status enumeration according to standard.
Status schedule	-	Status schedule according to standard.

Table 18: data included in charger status and status schedule updates

Symbol	Unit	Description
ChargerID	-	Timestamp when the message was sent
Status	enum	Status enumeration according to standard.
Status schedule	-	Status schedule according to standard.

3.4.2.2 chargeSession

The CSMS sends detailed charge session information to the FPT for charge session duration prediction. OCPI Sessions does not expose the required data as listed in Table 19.

Table 19: *chargeSession* message

Symbol	Unit	Description
Timestamp	ISO 8601	Timestamp when the message was sent
current	A	Actual current on charger outlet
voltage	V	Actual voltage on charger outlet
cumulativePower	kWh	Cumulative power transfer on charger outlet

Maxem has a Measurement Module extension for OCPI for meter data. This facilitates all data that is exposed over OCPP. The CSMS relays the data every time it received from the charger (OCPP meter values) to the FPT.

3.4.2.3 chargeProfile

The CSMS sends charging profiles it applies to chargers, to the FPT. It uses OCPI 2.2.1 *ChargingProfiles* module [7]. See section 14.3.7: Example of the Receiver (typically the CPO) sending an updated ActiveChargingProfile. In this standard, the ChargingProfile type is defined as in Table 20: OCPI 2.2.1 *chargingProfile* class.

Table 20: OCPI 2.2.1 *chargingProfile* class [7]

Property	Type	Description
start_date_time	DateTime	Starting point of an absolute profile. If absent the profile will be relative to start of charging.
duration	int	Duration of the charging profile in seconds. If the duration is left empty, the last period will continue indefinitely or until end of the transaction in case start_date_time is absent.
charging_rate_unit	ChargingRateUnit	The unit of measure.
min_charging_rate	number	Minimum charging rate supported by the EV. The unit of measure is defined by the chargingRateUnit. This parameter is intended to be used by a local smart charging algorithm to optimize the power allocation for in the case a charging process is inefficient at lower charging rates. Accepts at most one digit fraction (e.g. 8.1)
charging_profile_period	ChargingProfilePeriod	List of ChargingProfilePeriod elements defining maximum power or current usage over time.

3.4.2.4 authoriseSession

OCPI 2.2.1 *Tokens* module [7]: CSMS sends real-time authorisation request to FPT. FPT checks against planning, including booking, and responds to this request. Only when charging is allowed, the CSMS can start a transaction.

3.5 Interface: Digital Twin – EMS in a public charging context

In the context of a public charging hub, customers are free to arrive and charge their vehicles at the hub at a moment of their choosing, given there are chargers available. Therefore, the fleet planning is not in direct control of the Charge Point Operator (CPO). Even in a situation where a booking system is considered, allowing customers to reserve a specific timeslot and a specific charger power in advance, the responsibility of timely arriving – or arriving at all - at the hub and charging the vehicle lies with the customer, who is the vehicle/fleet operator. To this end, the Fleet Planning Tool (PT) activities are not applicable in this use case.

3.5.1 Added value of the Digital Twin

Even though controlling the vehicle is outside scope of the public charging use case, there could be value in predicting both the driving and charging behaviour of the vehicles attending the public charging hub.

3.5.1.1 Predicting the driving process

In the situation that remote telemetry data of the vehicles is available, a digital twin of the vehicle (DTV) could predict the time of arrival (EtA) and SoC at arrival to provide to the EMS with hard limits:

- A limit on the maximum total energy a vehicle will request = (SoC_full-SoC_arrival)
- A limit on start time of charging, which might be later than the start of the reserved timeslot.

This predictive information would provide greater flexibility to the EMS to control the flow of energy within the CEH. Note that this information can only be provided in case certain telemetry data, as discussed in Section 3.2.2 are available for the vehicles attending the public charging hub. In case these data are not available, the DTV might be demonstrated using historic data, or synthetic data originating from a high-fidelity model.

3.5.1.2 Predicting the charging process

Once a vehicle is connected and charging, a Digital Twin Charger (DTC), as specified in Req-2980 – Req-3020, in Section 2.2, could provide additional flexibility to the EMS, by predicting the

- future vehicle-requested charging power as function of time
- the minimum expected charging duration to go to 100% SoC.

Both these estimations will assume 'greedy charging', e.g., the vehicle is charged as fast as possible, without power limitations imposed by the EMS. Nevertheless, these estimation give an indication of the flexibility within the predefined reservation slot of a vehicle attending the public charging hub, and might therefore be useful to the EMS.

3.5.2 Sequence diagram – Charge Time Estimation

Upon initiation of a charging session, the CSMS will inform the EMS, which will pass through the *chargeSession* message, as previously described in Section 3.4.2.2, to the Digital Twin for charge time estimation (DTC).

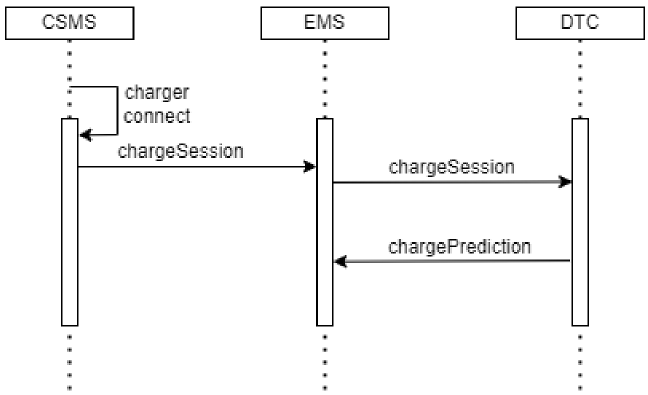

Figure 7: Sequence diagram of the interface between the Digital Twin for Charge time estimation and the EMS.

3.5.3 Functional Requirements

The high-level functional requirements of the charge-time estimation digital twin are listed in Table 4. The functional requirements regarding the interface are listed here. The minimum communication interval of this message is at least ~15min. The DTC will respond with *chargePrediction*, containing the information as in Table 21.

Table 21: functional requirements of *chargePrediction*.

: Symbol	Unit	Description
chargeSessionID	n/a	ID of charging session
Timestamp	ISO 8601	Timestamp when the message was sent
timeToFull	seconds	Estimated duration till 100% SoC
timeToFullUncertainty	seconds	95% Conficene bound of *timeToFull,* indicated by the number of seconds +/- the provided estimate.

predictedPower	Profile as in Section 4.	Predicted charging profile

3.6 Scenario-based Analysis – Task 3.3 and Task 5.3

In addition to the operational contexts, described in Section 3.1, the digital twin tool is also used in simulations. Simulations allow for the evaluation of different scenarios, thereby facilitating control algorithm development, such as T3.3, and studies on the impact of changing logistic operations on the operation of the CEH, such as T5.3. Each of these will briefly be discussed below.

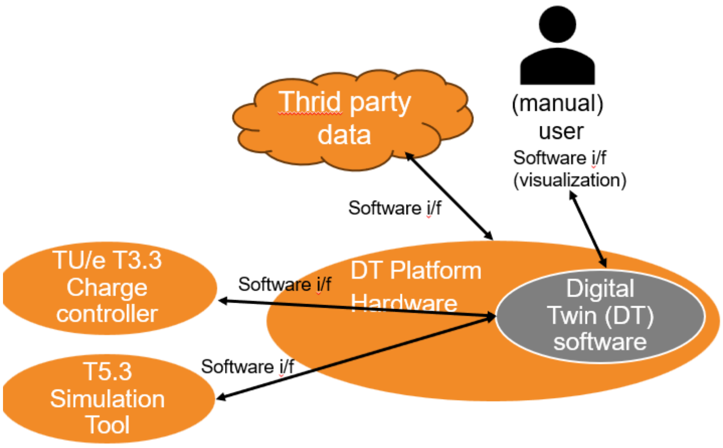

Figure 8: Context diagram for scenario-based analyses.

3.6.1 Relation to T3.3 - Dynamic Congestion-Aware Charger Control

Taks 3.3 is aimed at the development of novel control strategies for the chargers at the CEH. In order to develop these algorithms, and test these in a realistic simulation environment, a model of the CEH with DTV in the loop could be realized. The interface specified in Section 0 allows for this though the DTV's response with a *vehiclePrediction* to *vehicleRoute*, even if no operational vehicle status is supplied.

The controller of T3.3 relies on a data-driven predictive model of the charging demand (SOC required, time of arrival/connection and departure/disconnection). Therefore, ideally, the vehicle routes used as inputs for the scenario-based tool produce vehicle predictions (SOC required, time of arrival and departure) that are similar to the data used to create the predictive model and controller of T3.3. Starting from the same vehicle routes, this tool could simulate realistic variations of the vehicle predictions, e.g., an event that increases the SOC required of all vehicles for the rest of the day. With this approach, the predictive controller is tested on predicting the effect of these perturbations in the demand, and its ability to adapt its predictions to improve the control decisions. As comparison, a baseline or omniscient controller can be build using vehicle predictions from the DTV instead of the prediction model.

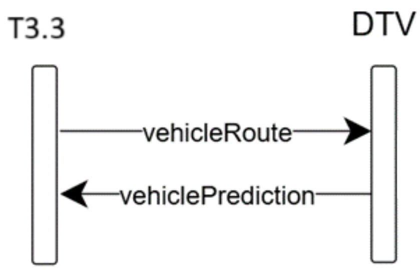

Figure 9: Sequence diagram for T3.3 simulations.

3.6.2 Relation to T5.3 – Simulation Tools for Logistic Operations

Task 5.3 is aimed at the simulation of the operation of the CEH with changing and logistic operations. This way, the CEH can be tested in scenario's that might not occur during the demonstrations. Additionally, this allows for analysis of the effect of possible future changes in the logistic operation or the vehicle fleet.

In this scenario-based analysis, the goal is to – as much as possible – use the same interfaces as during operation, which are described in Sections 3.2 - 3.5. Specifically for the digital twin, the interface, described in Sections 3.2, with or without vehicle data. In case there is (historical) vehicle data available, the sequence diagram as in Figure 4, might be used. In case there is no vehicle data, the digital twin might be used as an 'offline' model, according to the sequence diagram below.

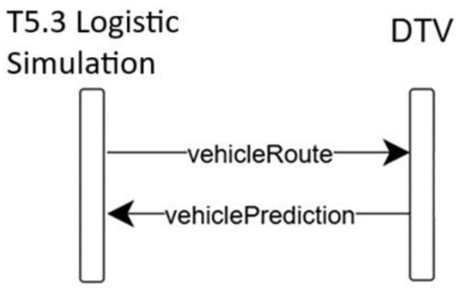

Figure 10: Sequence diagram for T5.3 logistic simulations.

4. Standard format for charging profiles to provide insight into energy and power demand

4.1 Charging Profiles and Standardized Communication

A charging profile is a detailed representation of an electric vehicle's power consumption and charging behavior over time. It includes key variables such as charge rate, duration, and energy levels. A charging profile can convey three different types of information:

1. **Charging limits** – what the vehicle is allowed to charge.
2. **Charging profiles** – the actual charging schedule.
3. **Meter values** – what has been charged.

To effectively communicate energy and power levels, it is recommended to use a standardized, structured, and straightforward format.

4.2 Standardized Communication Protocols

4.2.1 Demand Response Signaling – OpenADR

For defining how much power a vehicle (or fleet) can use, Demand Response (DR) signals are best to be communicated via OpenADR 3.0[1]. OpenADR provides a standardized method for sending energy availability signals, allowing charging stations and energy management systems to adjust their power demand accordingly.

Specifically, OpenADR 3.0's Demand Response Signals (EiEvent) enable real-time and scheduled power adjustments based on grid conditions. This protocol is widely adopted by large Distribution System Operators (DSOs) in the Netherlands.

4.2.2 Charging Profile Execution – OCPP

When specifying how a vehicle and charger should follow a charging profile, which is the primary focus of CEH and this inventory, the Open Charge Point Protocol (OCPP) is the industry standard. Versions OCPP 1.6, 2.0.1, and 2.1[2] are already widely implemented by Charge Point Operators (CPOs), especially those participating in CEH.

The ChargingProfiles feature in OCPP allows operators to send charging schedules to chargers, ensuring vehicles charge within defined power limits and time frames. Additionally, OCPP 2.0.1 introduces Smart Charging enhancements, improving flexibility in handling dynamic energy demands.

[1] https://www.openadr.org/openadr-3-0
[2] https://openchargealliance.org/protocols/open-charge-point-protocol/

4.2.3 Communicating Meter Values

For cases where only the actual energy and power consumption of a specific vehicle needs to be shared, as described Section 3.5.3, ElaadNL recommends using a lightweight JSON format:


```
{
  "profiles": [
    {
      "vehicle_id": "Vehicle123",
      "profile": [
        {
          "start_time": "2024-12-03T08:15:00Z",
          "end_time": "2024-12-03T08:30:00Z",
          "power_min": 200,
          "power_avg": 600,
          "power_max": 700,
          "energy_kwh": 150
        },
        {
          "start_time": "2024-12-03T08:30:00Z",
          "end_time": "2024-12-03T08:45:00Z",
          "power_min": 50,
          "power_avg": 400,
          "power_max": 400,
          "energy_kwh": 100
        }
      ]
    }
  ]
}
```


It is recommended to use ISO 8601 for time formatting. The example assumes 15-minute intervals, but if a different granularity is needed, it can be adjusted. For any time interval it should be possible to communicate the energy charged based on the metervalue readings. From this, one can derive the average power consumption during the interval. If available, the minimal and maximal power that was consumed during the interval could be optionally communicated as well.

It is recommended to use ISO 8601 for time formatting. The example assumes 15-minute intervals, but if a different granularity is needed, it can be adjusted. Since this appears to involve a prediction, communicating only the average power makes sense. For actual realized values, additional metrics such as minimum, average, and maximum values, as demonstrated.

5. Conclusions and next steps

This report, D2.4, sets the requirements of the operational fleet managements support tools in the Charging Energy Hub (CEH) project and specifies the interfaces that these software systems have. Specifically the Fleet Planning Tool (FPT) and the Digital Twin of the Vehicle (DTV) are highlighted. The interfaces are generic, yet also applicable to the project use cases. This report thereby provides input to the development of the tools in T3.2, T3.3, and T3.4, and the specifications of the API's in T2.9.4 and T2.10.1.

Based on the seven relevant functional requirements from D1.2.1, new functional requirements are defined through group discussions. The new requirements are subdivided in

- 6 requirements for the DTV,
- 3 requirements for a Charge-Time-Estimation Digital Twin (DTC),
- 2 and requirements for the FPT.

The new functional requirements are linked to the general CEH requirements of D1.2.1 [4].

For each of these tools sequence diagrams are developed, indicating the context of the operational tools. The distinction is made between a private CEH, where planning of the vehicle is a possibility, and thus the FPT is applicable, and a public CEH, where the vehicles arrive at-will. In this latter case, a charge-time-estimation digital twin communicates directly with the Energy Management System (EMS). Based on these context diagrams, interfaces are defined between the DTV - FPT, FPT – EMS, FPT – Charging Station Management System (CSMS), and DTV – EMS. Lastly, the DTV supports the option to perform offline simulation, which is applicable for scenario-based analysis, such as in T3.3 and T5.3 of the CEH project.

Lastly, this document proposes a communication standard for the communication of power and energy profiles.

6. References

[1] C. Consortium, “Nationaal Groeifonds 3 - Charging Energyhubs - Bijlage B - Uitwerking per Werkpakket,” 2023.

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[7] Open Charge Alliance, “Open Charge Point Interface 2.2.1,” Open Charge Alliance, 2023.

[8] openADR Aliance, “openADR 2.0 and 3.0 Specification,” [Online]. Available: https://www.openadr.org/specification. [Accessed 29 January 2025].

[9] Open Charge Alliance, “Open Charge Point Protocol 2.0.1,” 2024.