Storage capacity sharing over virtual neighborhoods of energy ecosystems

H2020 LCE-01-2016: 731285

WP 5 – SHAR-Q added value services based on collaboration business models

D5.4 Services for optimal charging of e-vehicles

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Editor's Note

This document is divided in two parts. Through this file you will find both parts, but in SHAR-Q website and for communication activities we will shared them separately. Between the two parts we are including a blank page.

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Research and Innovation Action

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D5.4 Services for optimal charging of e-vehicles PART I

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Executive Summary

The scope of this deliverbale is to analyse the development of the e-mobility related added value services which enable the monitoring/management of charging infrastructures as well as the realisation of advanced smart charging concepts towards the business objectives and e-mobility use cases identified in D2.5 “SHAR-Q collaboration business models and business requirements” [SQD25]and D5.1 “SHAR-Q Added Value Service Definitions”[SQD51SQD51SQD51SQD51SQD51SQD51SQD51SQD51SQD51SQD51SQD51SQD52], respectively.

The AVS layer, which lies on the top of the SHAR-Q platform, aims to link consumer/prosumer and energy stakholders by offering monitoring and management capabilites decoupled from the implemented technologies. The added value services serve different energy sectors such as e-mobility users, Charging Point Operators (CPO), Emobility Service Providers (EmSP), system and market operators. The *Customer oriented services* are mainly scheduling services targeting individual or collaborative customers (producers/ consumers/ prosumers) aiming to optimize their energy portfolio based on their available resources and the wholesale electricity prices. *Grid and market oriented services* are the ones which exploit the spatial and time demand flexibility offered by Electric Vehicles (EV) and they offer the aggregated flexibility capacity to serve network or market operational needs.

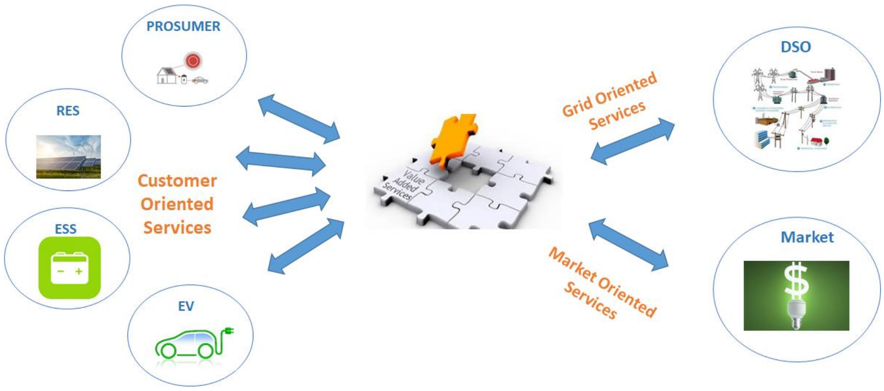

Figure I. Added Value Services targeting energy sectors

In this deliverable, two generic types of added value services were developed: one service for offering PV monitoring services (PVs are considered as non controllable distributed energy sources within the SHAR-Q project) and one service for offering e-mobility services. The PV monitoring service refers to RES producers or prosumers. The emobility services can be either exploited directly from EV users or prosumers in order to enjoy advanced e-mobility services aiming to optimize their individual portfolio or as an enabling software solution for CPOs offering asset management services or for EmSPs offering advanced smart charging mechanisms towards grid/market objectives.

The overall architecture with the respective components is illustrated in Figure II. The architecture is divided in two major layers: the Service one where Service Providers expose their Added Value Services (AVS) to SHAR-Q and the Infrastructure layer where smart energy components exist and can be exploited by the AVS for monitoring & management purposes. The communication path between the service layer and the infrastructure one is established, operated and maintained by the SHAR-Q platform as it is analysed in detail in SHAR-Q D4.2 “Collaboration Web components” and D4.3 “Open Interoperability Gateway API”.

Generally, each SHAR-Q added value service comprises four layers:

- **Communication layer** which is responsible for handling the incoming/outgoing requests/actions/events from/to SHAR-Q platform

- **Business layer** includes the business logic of the added value services that lies on the service layer. The data from the communication layer is forwarded to the business layer where the added value services process it based on the respective business rules and policies.
- **Data layer** is responsible for retrieving/storing data from/to the database. It abstracts all the functionalities enabling the access to the data stores
- **Representation layer** is responsible for implementing and exposing the user interface and for enabling the user interaction with the added vale service

The integration of a smart energy component into the SHAR-Q platform requires the development of a respective adapter. The technical and functional requirements of such adapters depend on the characteristics and specifications of the local infrastructure.

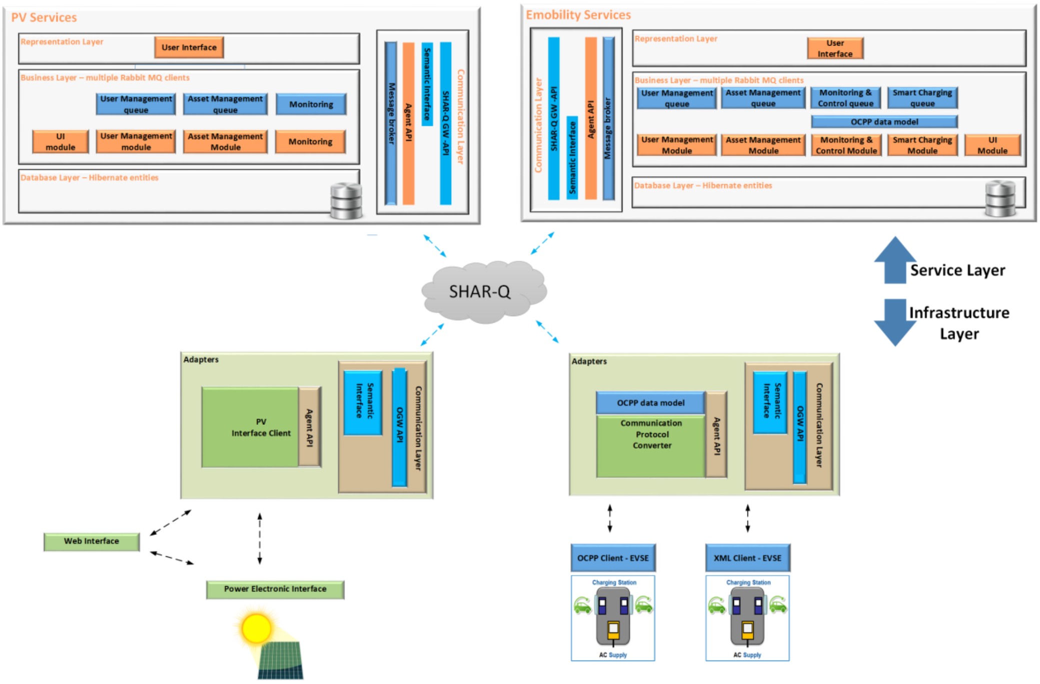

Figure II Overall architecture for optimal charging of electric vehicles

The interaction of the end-users with the added value services is realized through the service's user interface. This UI visualizes the monitoring data for each energy component and allows users to express their preferences and to request more personalized services. Indicative examples from the whole services' process chain with the respective UI screenshots are available in this document for better understanding of the service exploitation.

More specifically the services which are developed and analysed in this document are:

- PV related services:.
  - Monitoring service: The scope of the PV monitoring service is to collect, store and visualize the measurments of the operational parameters of the contracted PVs. The measurments are collected in 15 minutes interval (Figure III)

  - Production forecasting service: The scope of the PV forecasting service is to provide historical and day-ahead forecast production data. The PV production forecast is retrieved from the climate and meteorological service developed in SHAR-Q D5.2 "Meteorological services for RES & climate services" [SQD52] (Figure IV)

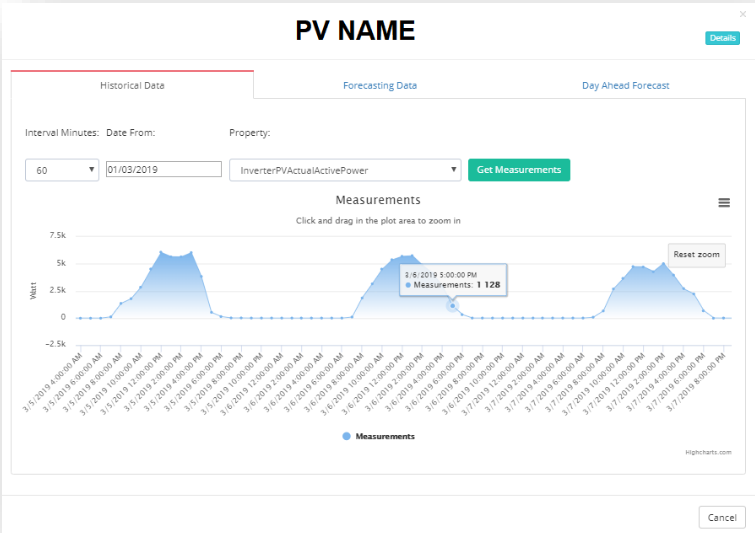

Figure III Indicative graph of historical monitoring PV data

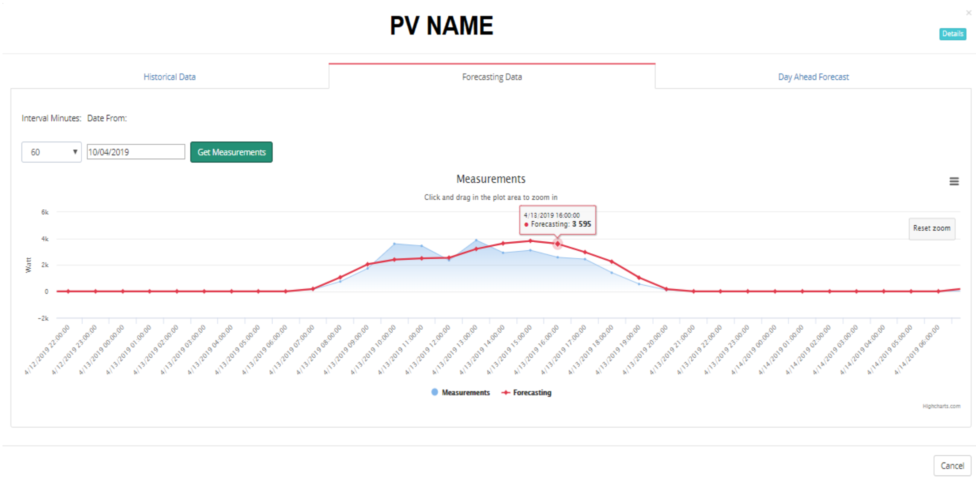

Figure IV Diagram of historical PV forecast data in AVS user interface

- Emobility related services
  - Monitoring and management of charging infrastructures: The emobility service monitors the overall operation of the charging infrastructures and every change in their operation is reported and stored in the service's database
  - EV user management enabling users to plug-in to charging stations using an RFID card or requesting personalised smart charging services.

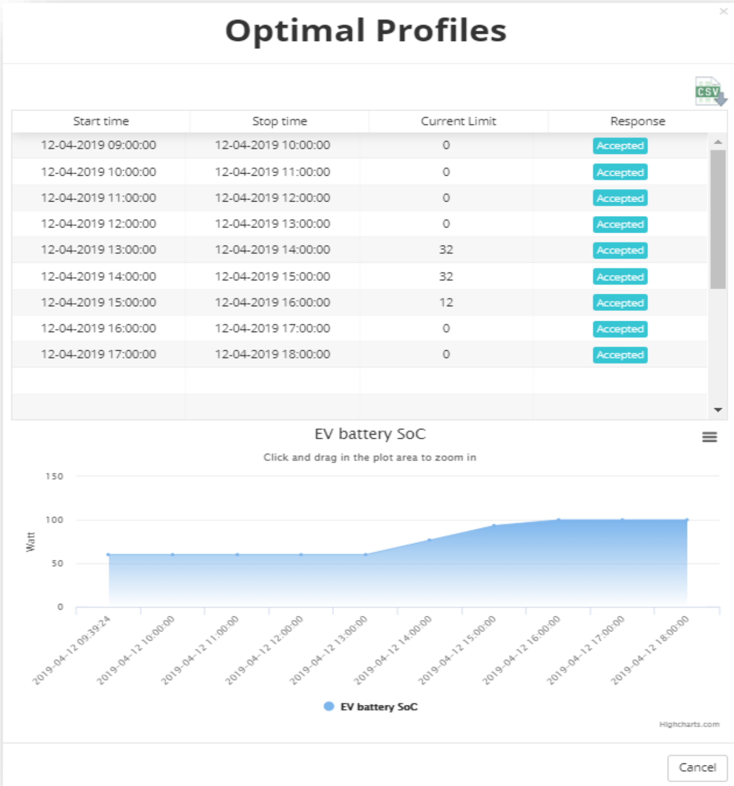

Figure VII Indicative EV management output for charging cost minimization

- Ancillary service provision to distribution system Operators: The aim of this service is to offer ancillary services to the distribution system Operators in order to support the network operation. The EU distribution system Operators suggest implementing flexible grid capacity contracts which allow for higher charging available capacities when the grid consumption is low, whereas the available capacity decreases during periods of network stress.

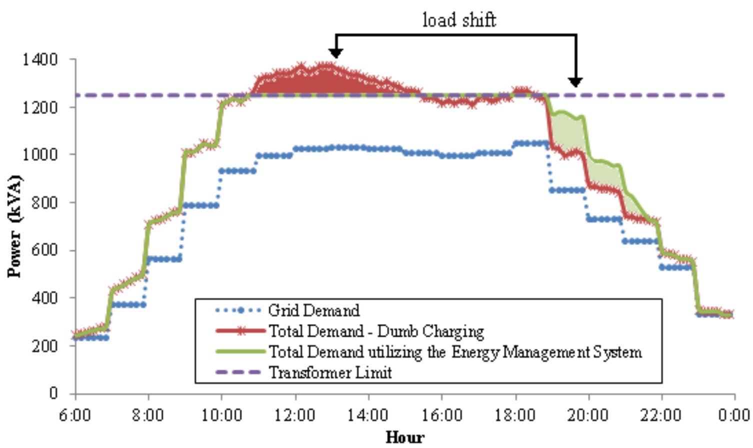

Figure VIII Charging load shedding mechanism for avoiding network equipment overloading

- Optimal EV market participation: The market-oriented smart charging dictates two pre-conditions: the engagement of a specific ancillary capacity which should remain available during a specific time period and the partial or complete exploitation of the engaged ancillary capacity.

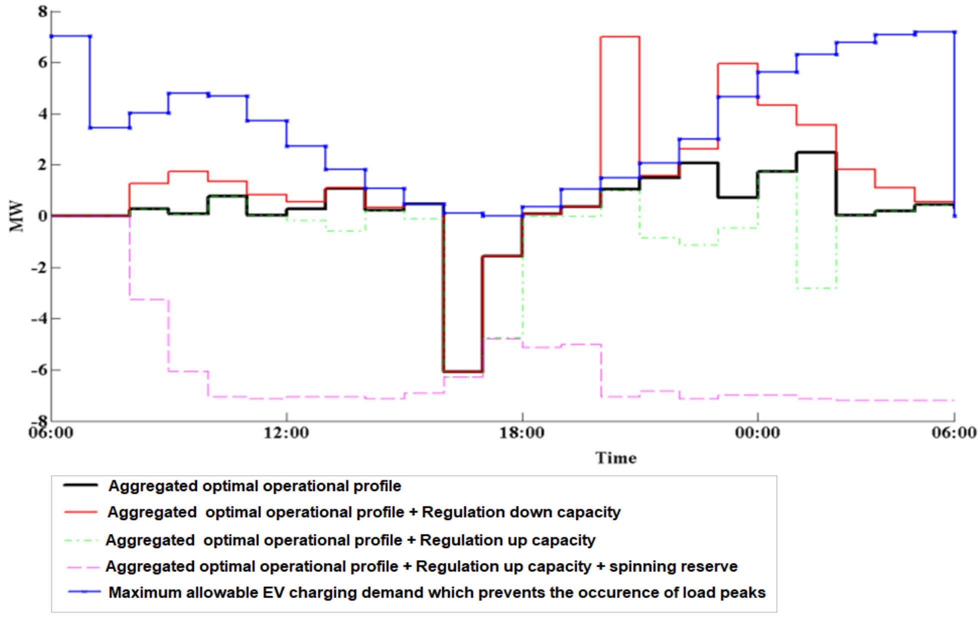

Figure IX Example of an optimal day-ahead EV scheduling mechanism

In Section 5, the document presents in detail the algorithms which realize the optimal smart charging for each service as well as indicative UI screenshots for better navigation through service functionalities.

The SHAR-Q AVS layer is the intermediate between end-users and regulated energy stakeholders, i.e. emoblity actors, system operators and market operators. In this respect new business opportunities are raised for the e-monility related actors aiming to offer innovative and advanced e-mobility services towards increasing EV users' e-mobility experience. Section 6 of this document analyses the new challengies and opportities for the e-mobility stakeholders, i.e. EV users, e-mobility service providers, system and market operators

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List of Acronyms and Abbreviations

Term	Description
EV	Electric Vehicle
DSO	Distribution System Operator
EVSE	Electric Vehicle Supply Equipment
AVS	Added Value service
PV	Photovoltaic
OGWAPI	Open Gateway API
ToU	Time-of-Use
RES	Renewable Energy Sources
CPO	Charging Point Operator
EmSP	Emobility Service Provider
OCPP	Open Charge Point Protocol
SoC	State of Charge

1. Introduction

1.1 Scope of the document

The scope of this deliverable is to describe the SHAR-Q Added Value Services (AVS) which were developed to serve the e-mobility business cases and needs as these were identified in D2.3 “Report on SHAR-Q regulatory framework”, D2.4 “SHAR-Q pilot surveying report” and D5.1 “SHAR-Q Added Value Service Definitions”[1].

The emobility services target different energy sectors such as e-mobility users, system and market operators. The *Customer oriented services* are mainly scheduling services targeting individual or collaborative customers (producers/ consumers/ prosumers) aiming to optimize their energy portfolio based on their available resources and the wholesale electricity prices. *Grid and market oriented services* are the ones which exploit the spatial and time demand flexibility offered by Electric Vehicles (EV) and they offer the aggregated flexibility capacity to serve network or market operational needs.

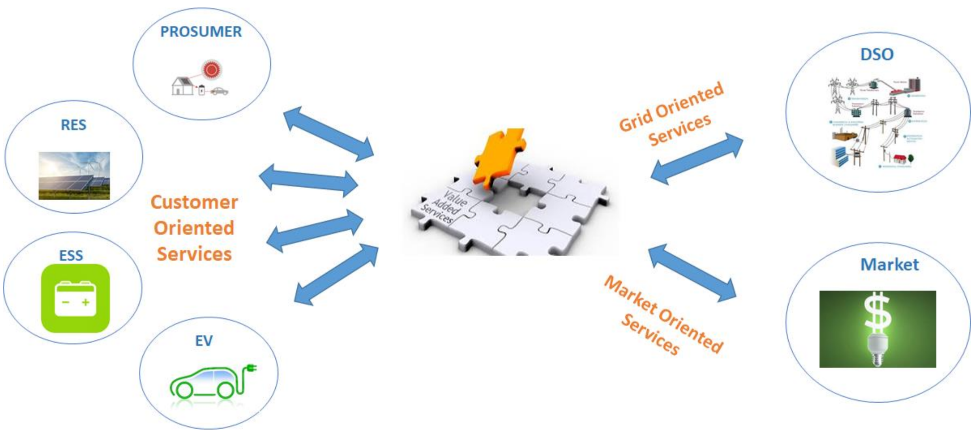


Figure 1 Added Value Services targeting energy sectors

In the following paragraphs, the developed emobility services will be analysed and presented in detail along with some indicative examples concerning their functionalities and interaction with the end-users.

1.2 Correlation with other SHAR-Q deliverables

The work in this deliverable is closely related to the one on other SHAR-Q deliverables, the information delivered in those documents should be considered when developing the AVS concerning the stakeholders’ and business requirements. Moreover, the development of AVS and their functionalities will provide useful input to other deliverables concerning mainly the pilot deployment and evaluation phase of the AVS. An illustrative representation of this correlation is presented in Figure 2.

More specifically, the following correlations exist:

- D2.6 *“SHAR-Q functional design document*”[SQD26]: It presents the functional and non- functional requirements dictated by the peer-to-peer data and information exchange among the AVS, SHAR-Q users and SHAR-Q platform. The implementation of the AVS poses specific requirements which should be considered in the SHAR-Q functional design

[1] Available online at http://www.SHAR-Qproject.eu/deliverables

- D2.7 "*Architecture of SHAR-Q technology components*"[SQD27]: It presents the principal components of the SHAR-Q architecture as well as their basic processes (registration, update, data exchange, etc.). The AVS is one of the principal components lying at the higher communication and logical layers.
- D3.1 "*Detailed specification of the SHAR-Q interfaces and semantic models*"[SQD31]: It presents the interfaces for communication between the SHAR-Q registered entities and defines the semantic model which enables a common language understanding.
- D4.2 "Collaboration Web Component"[SQD42]: It presents the SHAR-Q module which is responsible for handling collaborations among actors. An active collaboration agreement unblocks the communication path between AVS and smart energy components
- D4.3 "Open Interoperability Gateway API"[SQD43]: It presents the interface which is responsible for the data transfer between two collaborative peers in a semantic format. This data exchange can be bidirectional depending on AVS service needs.
- D5.1 "SHAR-Q Added value service definition"[SQD51SQD51]: It presents the functional and user requirements in respect to which the SHAR-Q AVS should be developed
- D5.2 *"Meteorological services for renewables & climate services"* [SQD52]*:* it presents the RES forecasting service which is exploited by the e-mobility AVS for the collaborative management of EV and Renewable Energy Sources (RES).
- D6.1 "SHAR-Q gateway adapters"[SQD61]: which are the link between the AVS and the smart energy facilities. The services that can be offered to users depend highly on the monitoring and management capabilities offered by the respective adapter.
- D6.5 "Report on integration of pilot with adaptive e-vehicle charging"[SQD65] which reports the real life experience from the pilot deployment of the emobility AVS
- D7.4 "Report on SHAR validation in the context of RES/EV synergy"[SQD74] which aims to validate the whole SHAR-Q solution within the context of a pilot site.
- D7.5 "Report on overall evaluation of UX and performance of SHAR-Q framework"[SQD75] which aims to capture user experience towards SHAR-Q solution.

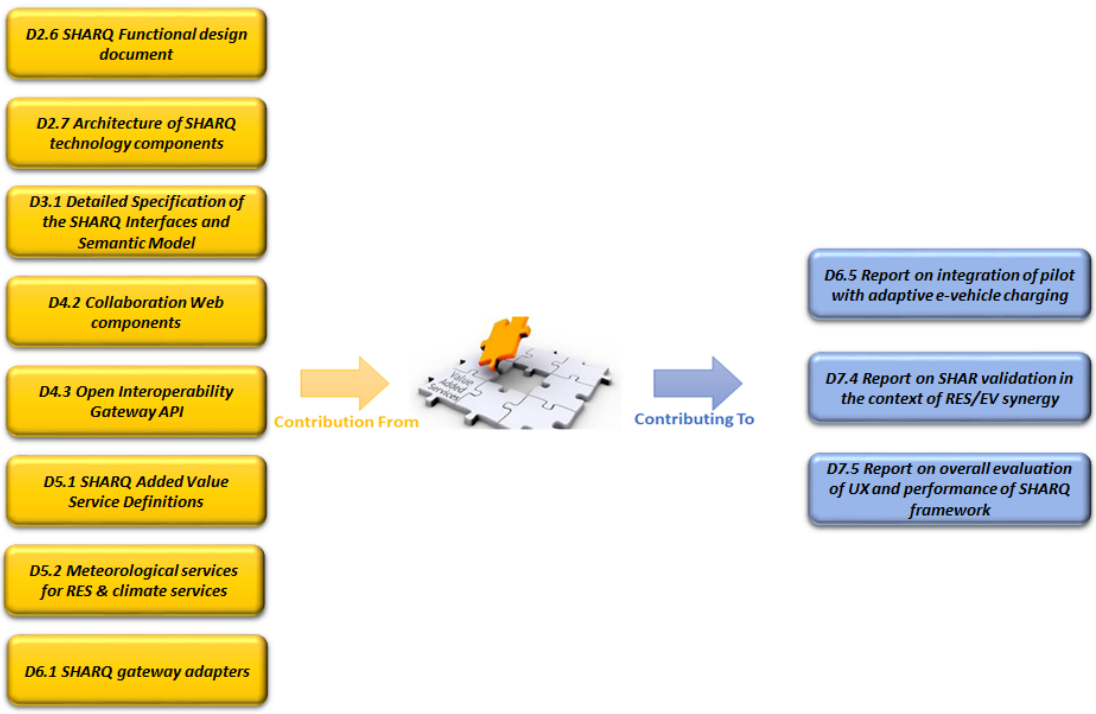


Figure 2 Correlation of this work with the one of other SHAR-Q deliverables

2. Architecture

2.1 Overall architecture design

The overall architecture for the optimal charging of electric vehicles is illustrated in Figure 3. The architecture is divided in two major layers: the Service one where Service Providers expose their Added Value Services (AVS) to SHAR-Q users aiming to serve a business objective and the Infrastructure layer where smart energy components exist and can be exploited by the AVS for monitoring & management purposes. The communication path between the service layer and the infrastructure one is established, operated and maintained by the SHAR-Q platform as it analysed in detail in SHAR-Q D4.2 “Collaboration Web components” [SQD42]and D4.3 “Open Interoperability Gateway API”[SQD43].

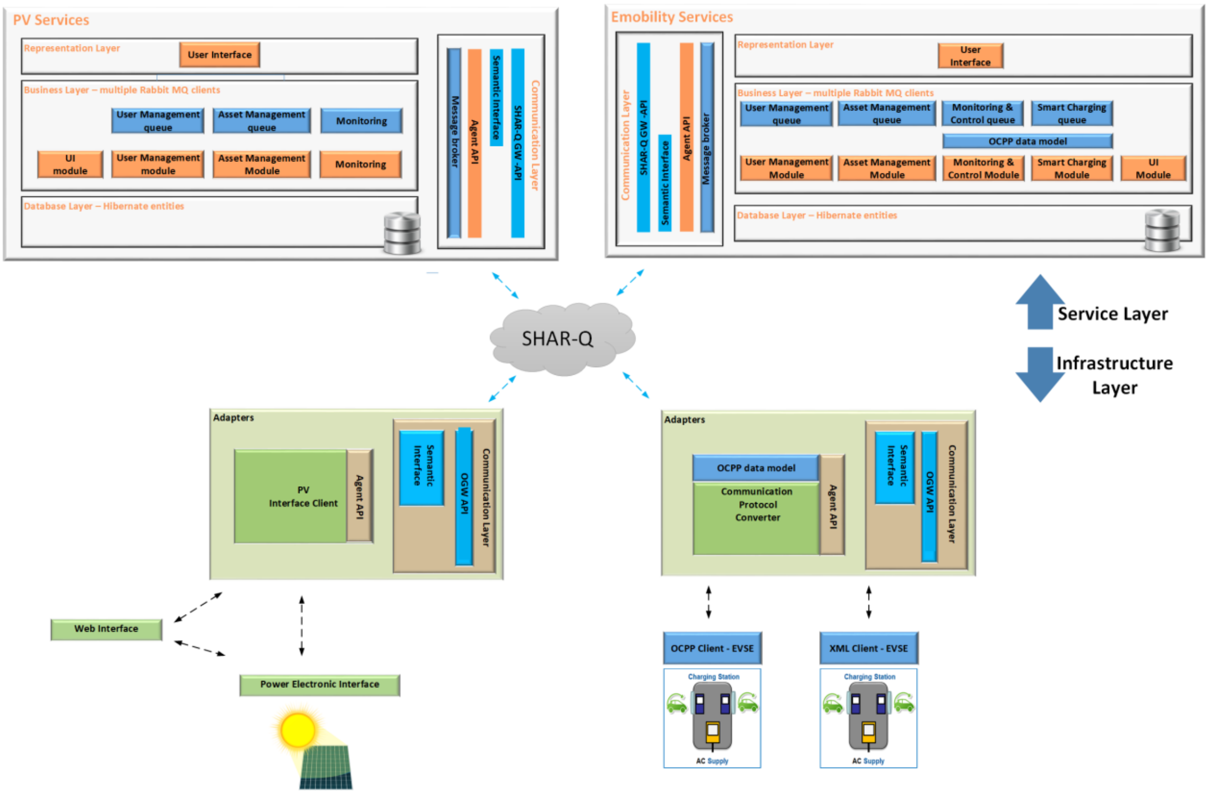


Figure 3 Overall architecture for optimal charging of electric vehicles

Generally, each SHAR-Q added value service comprises four layers:

- **Communication layer** which is responsible for handling the incoming/outgoing requests/actions/events from/to SHAR-Q platform
- **Business layer** includes the business logic of the added value services that lies on the service layer. The data from the communication layer is forwarded to the business layer where the added value services process it based on the respective business rules and policies.
- **Data layer** is responsible for retrieving/storing data from/to the database. It abstracts all the functionalities enabling the access to the data stores
- **Representation layer** is responsible for implementing and exposing the user interface and for enabling the user interaction with the added value service

The integration of a smart energy component into the SHAR-Q platform requires the development of a respective adapter. The technical and functional requirements of such adapters depend on the characteristics and specifications of the local infrastructure.

In the next paragraphs, the internal AVS layers as well as the respective adapters for the e-mobility related services will be analysed focusing mainly on the requested functionalities for serving the diverse business objectives defined in SHAR-Q D5.1 “SHAR-Q Added Value Service Definitions”[SQD51].

2.2 Added Value Services Layer

The added value services were developed in Java 1.8 using Spring Boot framework and they are running in NTUA’s local application server.

2.2.1 Communication Layer

The communication layer facilitates the information exchange between the AVS and the smart energy components. It comprises four components:

- ***SHAR-Q Open Gateway API (OGWAPI)*** enables the registration of a service to the SHAR-Q platform with a specific description presenting the offered functionalities. Moreover, the SHAR-Q OGWAPI facilitates the bidirectional data exchange between AVS and smart energy components by exposing specific REST API endpoints.
- ***Semantic interface*** enables the interoperable data exchange between services and heterogeneous smart energy infrastructure technologies with diverse communication protocols.
- ***Agent API*** has the knowledge of interfacing with the SHAR-Q platform either directly through the SHAR-Q OGWAPI or through the Semantic Interface. It is responsible for handling the incoming requests without having the knowledge to process them. Every incoming message is forwarded to the respective service module which is responsible and has the intelligence to process the request. Respectively, requests ordered by the added value services are communicated to the agent API and the latter one is responsible for transforming the initial request to the appropriate form which is afterwards forwarded directly to the OGWAPI or to the semantic interface.
- ***Message Broker*** facilitates the message distribution among the different service modules. The message broker that is exploited is the open source one named RabbitMq[2].

2.2.2 Business layer

The business layer incorporates all the business logic that is necessary for monitoring and managing smart energy components towards different business objectives. A micro-service oriented approach is adopted in the business layer where each module is responsible for executing a specific task. There are four main service categories:

- ***User Management Module***: This module is responsible for handling users and orgnanisations. In the SHAR-Q project there are three different organisations reflecting the three different pilot sites (Martim Longo in Portugal, Gussing in Austria and Rafina-Meltemi in Greece). Under each organization there are registered users who might be owners of energy infrastructure(s). Energy infrastructures, which are declared under the same

[2] https://www.rabbitmq.com/

organization at the service layer, can be treated in a collaborative way in order to achieve a business objective. Moreover, users are categorized in three groups:

- Simple Users ***are capable of registering their energy facilities to an added value service for monitoring and management purposes. Simple users can handle only the energy infrastructures that belong to their property.***

  - ***Pilot Managers*** are only capable of monitoring all the energy infrastructures that are registered to an added value service and belong to the same organization he/she is responsible for.

  - ***Administrator*** is the unique entity that has full monitoring and management capabilities of all assets irrespectively to which pilot they belong. This role will only be used for demonstration purposes.

- ***Asset Management Module:*** This module is responsible for retrieving and storing the technical specifications and the operational properties of all assets which can be monitored by the respective AVS. The technical specifications of an asset refer to the static characteristics of the energy infrastructure, which remain constant during the lifecycle of the asset, as well as to its registration parameters to the SHAR-Q platform. All technical specifications are dictated by the asset and their values cannot be modified by the AVS. The operational properties refer to the parameters reflecting the operational status of an asset at a specific time. Some operational properties of an asset can be modified by the AVS aiming to affect the operational behavior of an asset towards a business objective. The set of operational properties being available to an AVS depends on the local infrastructure API capabilities. The integration of new assets to the AVS as well as any updates or enhancements on existing ones are handled by this module.

- ***Asset Monitoring & Control Module:*** This module is responsible for periodically retrieving and storing the values of the operational properties which are exposed by all the assets registered to an AVS. For the project purposes, the monitoring time interval is set to 15 minutes. Moreover, this module enables the modification of the controllable properties of an asset. The control capabilities of this module do not serve any specific business objective, but they enable infrastructure owners to dynamically modify their asset's operational status according to their preferences.

- ***Smart Charging Module:*** This module is responsible for managing the registered charging stations in order to serve an e-mobility business objective. In SHAR-Q D5.1 "SHAR-Q Added Value Service Definitions"[*SQD51*], various use cases were defined to be served by the e-mobility AVS: i) minimizing the charging cost of an electric vehicle based on an electricity price scheme (dynamic pricing, ToU tariffs, etc.), ii) offering ancillary services to Distribution System Operator (DSO) in order to support grid operation and avoid violation of grid operational constraints, iii) EV participation in wholesale and ancillary services energy markets. Smart charging module serves the aforementioned use cases taking into consideration EV user's preferences and their mobility constraints.

- ***User Interface Module:*** This module is responsible for processing all the monitoring and management requests from the infrastructure owners. The monitoring data stored in the AVS database is formatted properly and it is exposed via REST API end-points. Users are capable of retrieving monitoring data either via the provided AVS user interface or via the REST API end-points. This module also accepts users' requests and, afterwards, it forwards them to the respective AVS modules which are responsible for processing and serving them.

2.2.3 Representation Layer

This layer is responsible for enabling the interaction between users and added value services. The user interface is offered by the Service Provider to the users in order to be able to monitor and manage their energy infrastructures. Only valid credentials provided by the Service Providers to each user can unlock the data access to energy infrastructures.

ReactJs library and ExpressJs framework were exploited for the development and deployment of the AVS user interface.

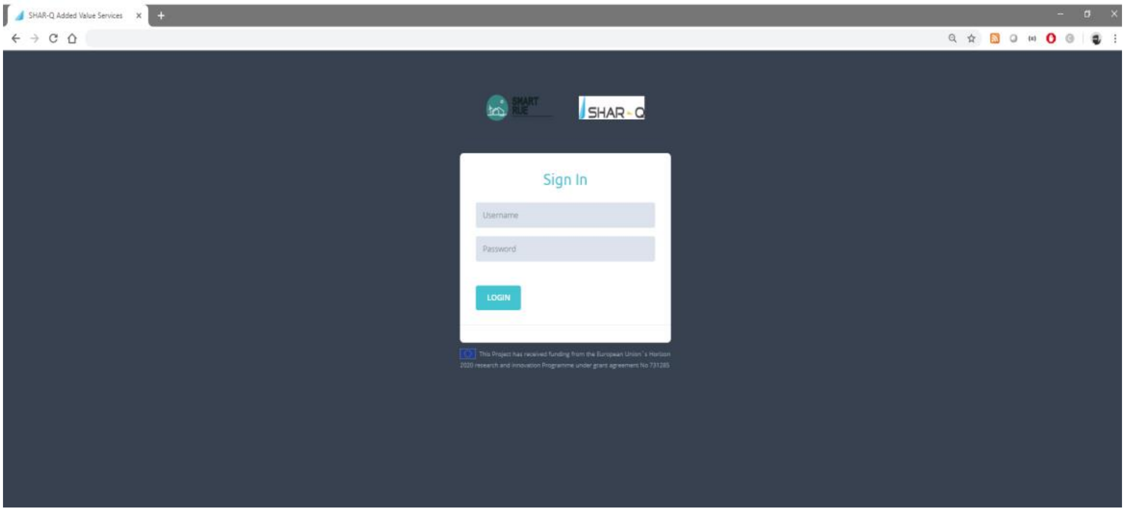


Figure 4 Login page of AVS user interface

2.3 Infrastructure Layer

The integration of a smart energy component into the SHAR-Q platform requires the development of an adapter at the infrastructure level. The adapters should be developed considering open protocols for the different infrastructure technologies. More details on the adapter development and deployment can be found in SHAR-Q D6.1 “SHAR-Q gateway adapters” [SQD61] and D6.5 “Report on integration of pilot with adaptive e-vehicle charging”[SQD65].

The monitoring and management capabilities offered by the infrastructure adapters affects consequently the services that can be offered by the respective added value service. In this respect, the following paragraphs present the capabilities offered by the developed SHAR-Q adapters for photovoltaics and charging stations which should be considered during added value service development and deployment.

2.3.1 Photovoltaics

The photovoltaics are considered as non-manageable energy components, thus, only monitoring services can be offered to PV owners. The technical and operational data which should be exposed by the SHAR-Q PV adapters are tabularized in Table 1. In case of single phase PV inverter the operational properties InverterPVActualActivePowerLx and InverterPVActualReactivePowerLx are ignored. In case of three-phase PV inverter, the InverterPVActualPower and InverterPVActualReactivePower properties refer to the three phase measurements.

Table 1 PV adapter requested properties

SHAR-Q PV Adapter Properties			
	Name	**Type**	**Unit**
Static	PvInstalledCapacity	Double	Wp
	Location	String	GPS
	Azimuth	String	Degrees
	Elevation	String	m
	ServiceLevel	String	-
Operational	InverterPVActualActivePower	Double	W
	InverterPVActualReactivePower	Double	W
	InverterAccumulatedActiveEnergyProduction	Double	Wh
	InverterConsumerActivePowerLoad	Double	W
	InverterGridActivePowerLoad	Double	W
	InverterPVActualActivePowerL1	Double	W
	InverterPVActualActivePowerL2	Double	W
	InverterPVActualActivePowerL3	Double	W
	InverterPVActualReactivePowerL1	Double	W
	InverterPVActualReactivePowerL2	Double	W
	InverterPVActualReactivePowerL3	Double	W
	Timestamp	Date	-

2.3.2 Charging Stations

Charging stations are considered as manageable components. Even though, it is the electric vehicle that offers the charging flexibility, the charging station is the facilitator for the smart charging implementation dictating the requested smart charging set-points or profile through the control pilot according to IEC 61851 specifications.

For the adapter development the open standard OCPP 1.6 protocol[3] is implemented. The majority of the commercially available charging stations are compliant with the OCPP standard and this is the reason for implementing an OCPP compliant adapter for the charging stations. More details on the charging station adapters can be found in SHAR-Q D6.1 SHAR-Q gateway adapters.

Apart from the management capabilities, the major difference between the PV and the charging point lies in the fact that PV is a passive component while charging station is an active one. Particularly, passive component means that the service should always request for the operational status or technical specificatins of a component. On the contrary, active components trigger a message whenever an operational status change is occurred. For this

[3] https://www.openchargealliance.org/

purpose, charging station adapter should allow bidirectional communication: data flow from the charging station to the added value service for monitoring purposes and from the added value service to the charging station for management purposes.

The operations which are supported by the implemented SHAR-Q adapter for the charging stations are presented in Table 2, with respect to the OCPP 1.6 standard

Table 2 Charging station adapter supported OCPP operations

Charging Station OCPP operations			
	Name	**Request type**	**Response Type**
Operations initiated by the Charging Point	Authorize	OCPP Authorize.req	OCPP Authorize.conf
	BootNotification	OCPP BootNotification.req	OCPP BootNotification.conf
	Heartbeat	OCPP Heartbeat.req	OCPP Heartbeat.conf
	StartTransaction	OCPP StartTransaction.req	OCPP StartTransaction.conf
	StopTransaction	OCPP StopTransaction.req	OCPP StopTransaction.conf
	StatusNotification	OCPP StatusNotification.req	OCPP StatusNotification.conf
	MeterValues	OCPP MeterValues.req	OCPP MeterValues.conf
Operations supported by the Charging point	Reset	json object	String
	RemoteStart	json object	String
	RemoteStop	json object	String
	SmartCharging	json object	jsonObject

3.AVS & Component integration in SHAR-Q platform

The integration of the AVS and the respective components in the SHAR-Q platform should follow the principles described in SHAR-Q D.2.7 “Architecture of SHAR-Q technology components” [SQD27]. The following sections describe the steps for registering and connecting the AVS as well as the smart energy components to the SHAR-Q platform.

3.1 Emobility AVS integration

With respect to the OCPP operations defined in Table 2, the thing description for registering the respective service to the SHAR-Q platform is presented in Annex I - 9.1

3.2 PV monitoring service integration

The thing description for registering the PV monitoring service to the SHAR-Q platform is presented in Annex I - 9.3

3.3 Charging infrastructure intrgration

With respect to the OCPP operations defined in Table 2, the thing description for registering a charging station to the SHAR-Q platform is presented in Annex I - 9.2.

3.4 PV infrastructure integration

The thing description for registering a PV to the SHAR-Q platform is presented in Annex I - 9.4 and 9.5 (for single and three phase PV inverters, respectively).

3.5 AVS – Energy component communication link establishment

After the successful registration of the AVS and the energy components to the SHAR-Q platform it is necessary to establish a communication link between them. This communcaiton link is realised as soon as a contract between the AVS and each smart energy component is established through the collaboration web of the SHAR-Q platform (SHAR-Q D4.2 “Collaboration Web components” [SQD42]) as shown in Figure 5.

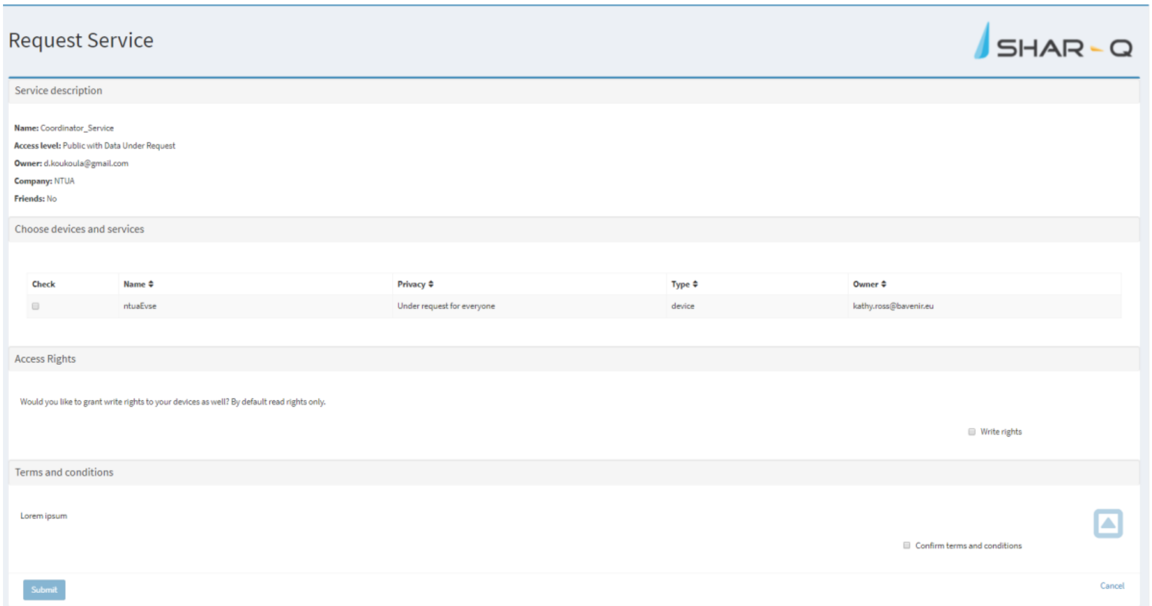


Figure 5 SHAR-Q contract request form – SHAR-Q collaboration web

4. PV monitoring service

4.1 Scope

The scope of the PV monitoring service is to collect, store and visualize the measurments of the operational parameters of the contracted PVs. The measurments are collected in 15 minutes interval. Moreover, the PV monitoring service offers day ahead PV production forecast.

4.2 PV integration into service

Given that there is a valid contract between the PV monitoring service and a PV, the registration of that PV to the service can be realized through the service user interface under the path Assets/Photovolatics. The user can add a new PV by completing the requested registration form in Figure 6.

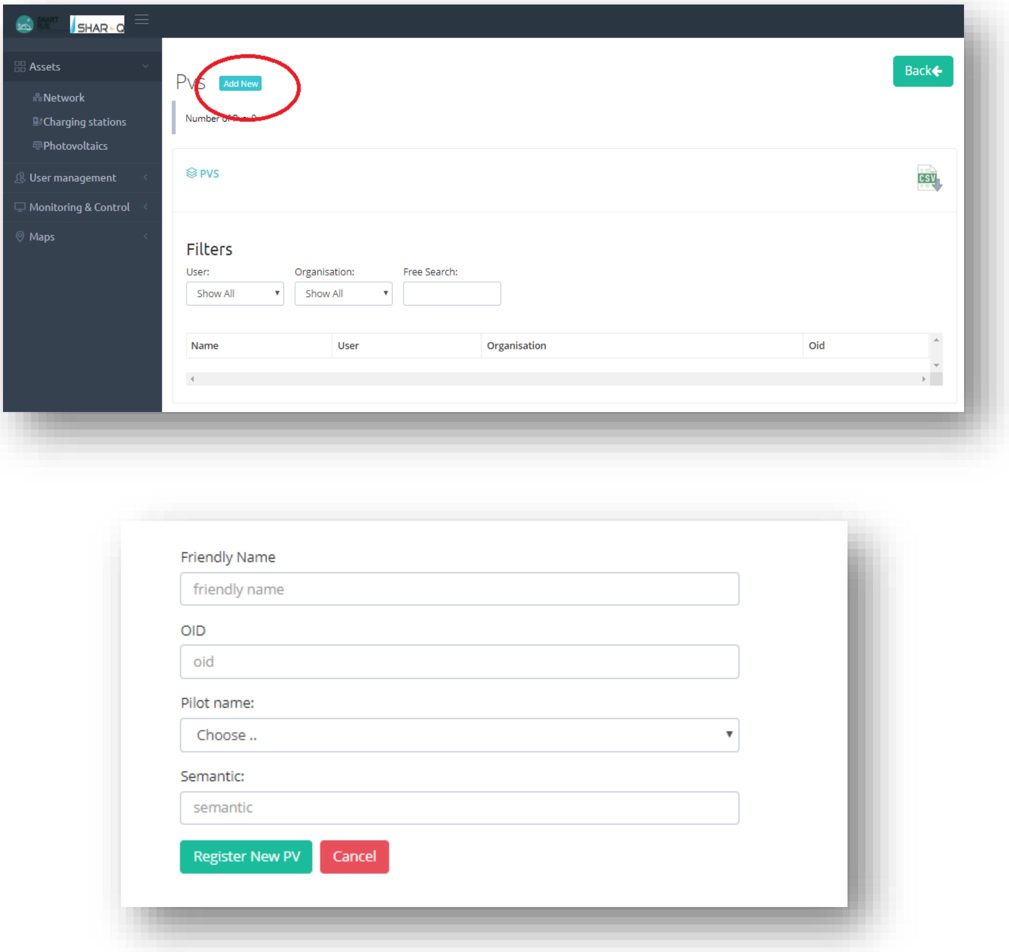


Figure 6 PV registration page in AVS user interface

The fields “oid” and “semantic interface” should be the same as the one declared during the PV registration in the SHAR-Q platform. This information is available in the SHAR-Q platform. User must declare a unique name for the registered PV as well as the pilot site where the PV is physically installed.

After the successful integration of the PV in service, the latter requests from the respective adapter the PV technical specifications and operational parameters. The technical specifications of the PV are visualized in Figure 7. Fields with gray background cannot be modified by the service and the respective data is dictated by the PV dapater. The set of the operational parameters is the one defined by the semantic interface version declared during PV registration in the SHAR-Q platform. As it is shown in Figure 8, the parameters are grouped in four categories based on two criteria: i) if the operational parameter is supported by the PV adapter or not and ii) if the operational parameter is blocked or not by the service Provider. The block/unblock of an operational parameter can only be ordered by the service Provider enabling the implementation of pricing policies for the exploitation of the service.

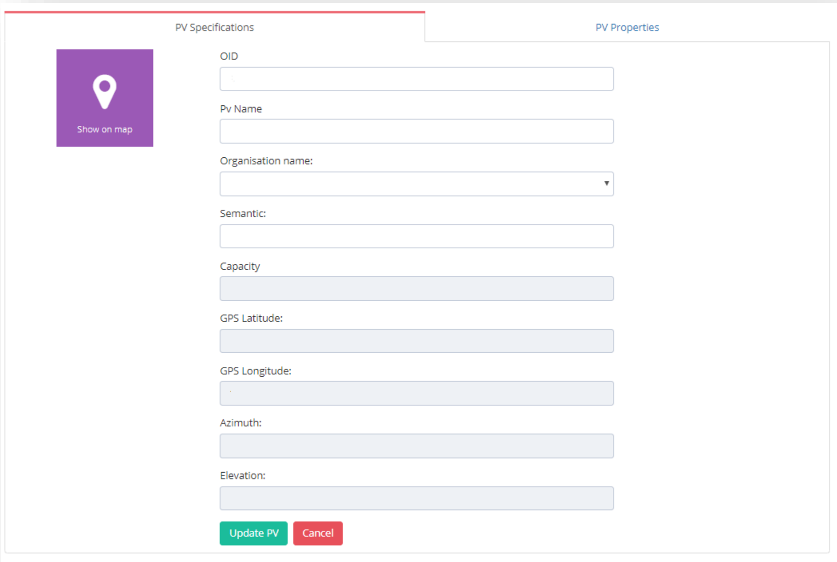


Figure 7 PV registration page in AVS user interface

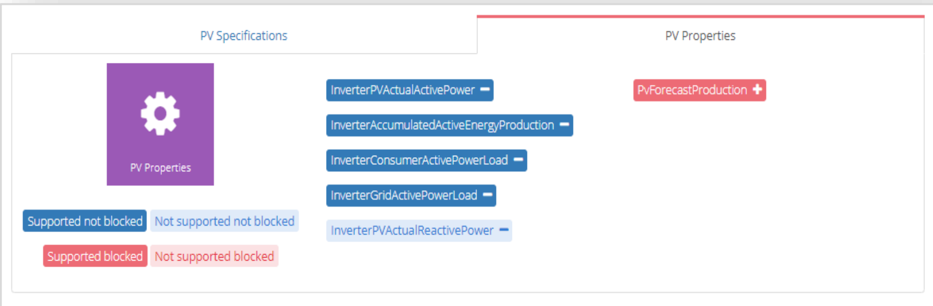


Figure 8 Properties (not) supported by the PV adapter and (not) monitored by the AVS

4.3 Monitoring of PVs

The PV operational parameters, which are supported by the PV adapter and they are under a bilateral monitoring agreement between the service Provider and the PV owner, are monitored periodically (i.e. 15 minutes interval). Infrrasctructure owners can access the historical data of the operational parameters of their PVs through the UI of the service, as it is shown in Figure 9. Users can select different data plotting intervals by selecting any option (i.e. 15 minutes – 1 hour) from the drop-down menu of the “Interval Minutes” as well as they can define the day since which they wish to retrieve monitoring data. From the “Property” drop-down field, users can select from the set of the available operational parameters the prefereable one for plotting.

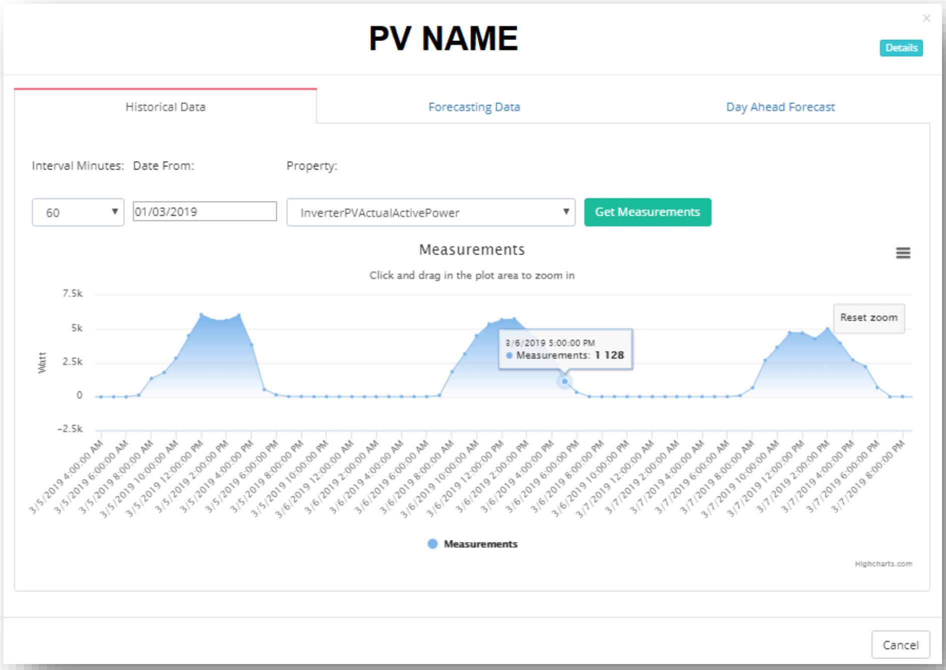


Figure 9 Diagram of historical PV monitoring data in AVS user interface

4.4 PV Production Forecast

The PV monitoring service offers day ahead PV production forecast. The PV production forecast is retrieved from the climate and meteorological service developed in SHAR-Q D5.2 “Meteorological services for RES & climate services” [SQD52. The interaction between the PV monitoring and the PV forecasting services, which operate under the resposniblity of different Service Providers, is realised through the SHAR-Q platform, as it is illustrated in Figure 10. The client of the forecasting service needs to provide some input parameters related to the PV infrastrucutre (azimuth, elevation, installed capacity and coordinates) and the forecast service outputs the respective weather and production forecast data for different time horizons (i.e. 1 - 9 days ahead) and time intervals (i.e. 10 minutes - 1hour).

An indicative example of the PV forecast call is presented below:

http://locahost:{port}/api/objects/{forecastServiceOid}/properties/pvForecast

Request:

Body Parameters:

```
{
    "input_azimuth":double,
     "input_inclination":double,
     "input_nominal_output":double,
     "coordinates"=double double,
     "token":"string"
}
```

Response:

json Object (SHAR-Q D5.2)

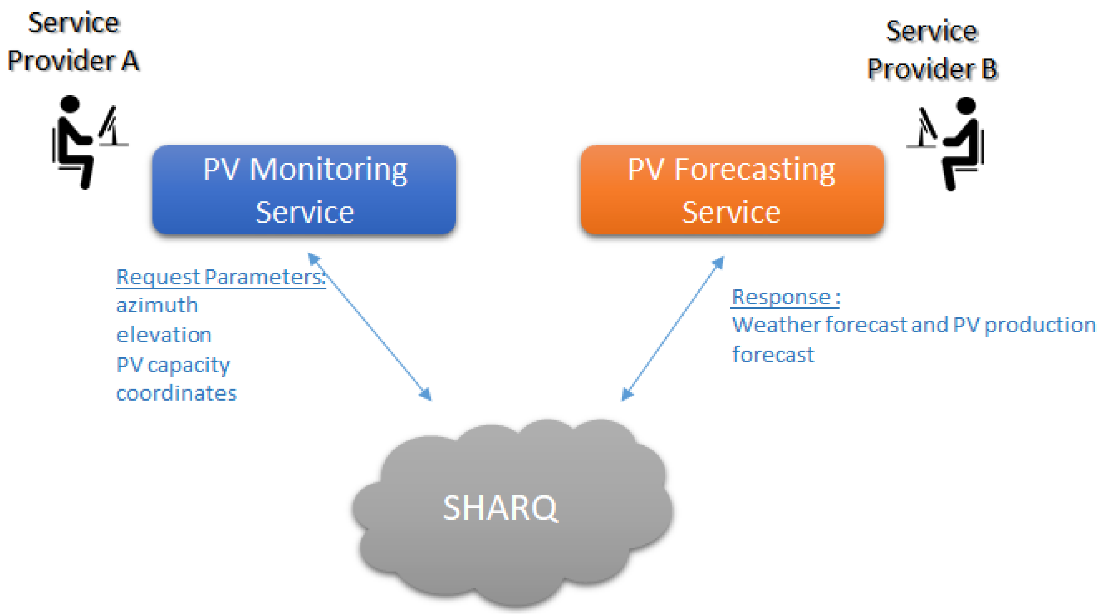


Figure 10 Interaction between AVS

The PV production forecast data is visualized in the AVS user interface as it is shown in Figure 11 & Figure 12. The historical forecast data is plotted in comparison with the real PV production data. Moreover, the latest PV production forecast data for the 24-hours ahead with time interval of 10 minutes is also exposed in the AVS user interface. The day-ahead PV forecast is updated in hourly basis.

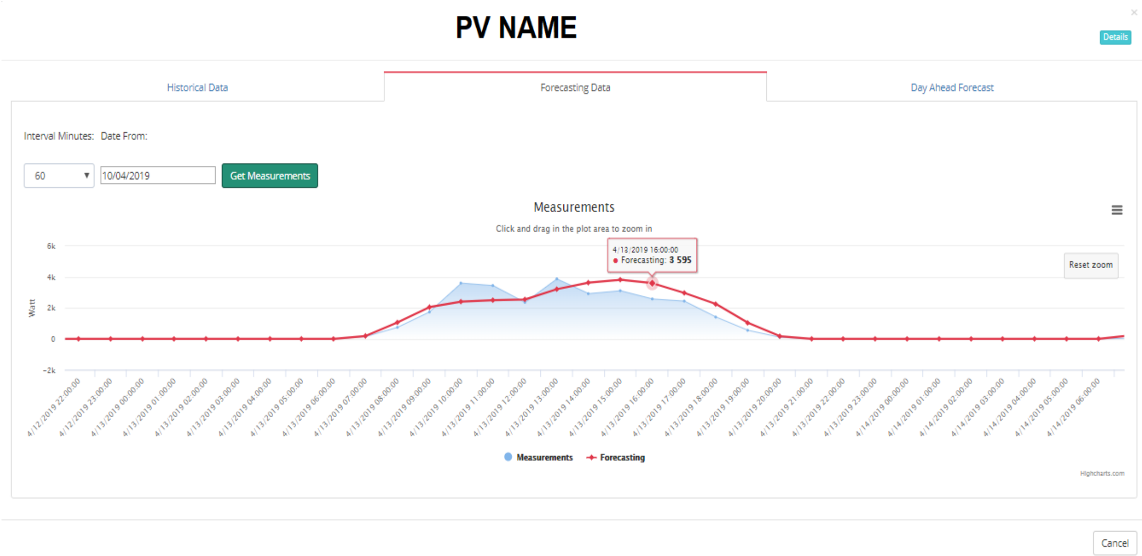


Figure 11 Diagram of historical PV forecast data in AVS user interface

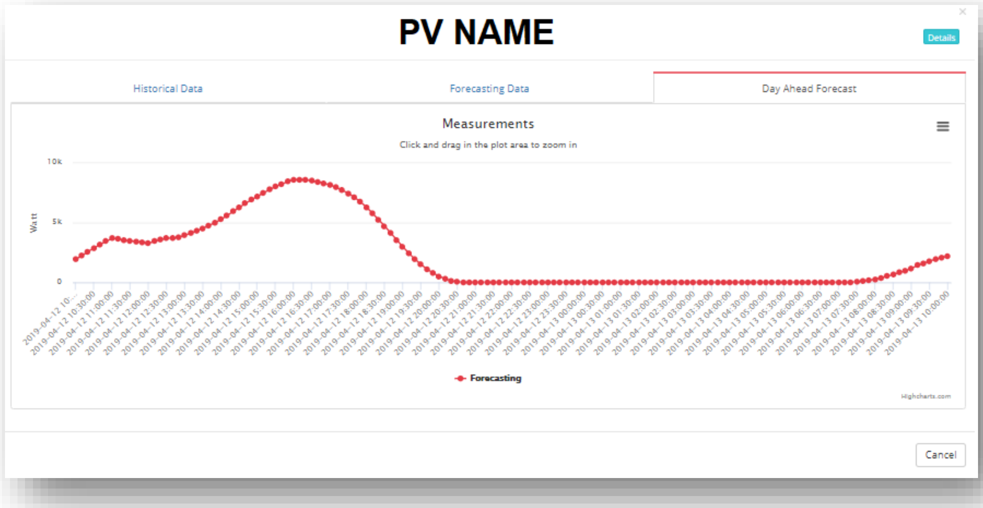


Figure 12 Diagram of day-ahead PV forecast in AVS user interface

4.5 Map visualization of the PVs

Users can track their infrastructures in a google map along with basic technical specifications (Figure 13). The infrastructure representation can be useful mainly to pilot managers in order to have a short (operational) representation of all the assets of their organisation.

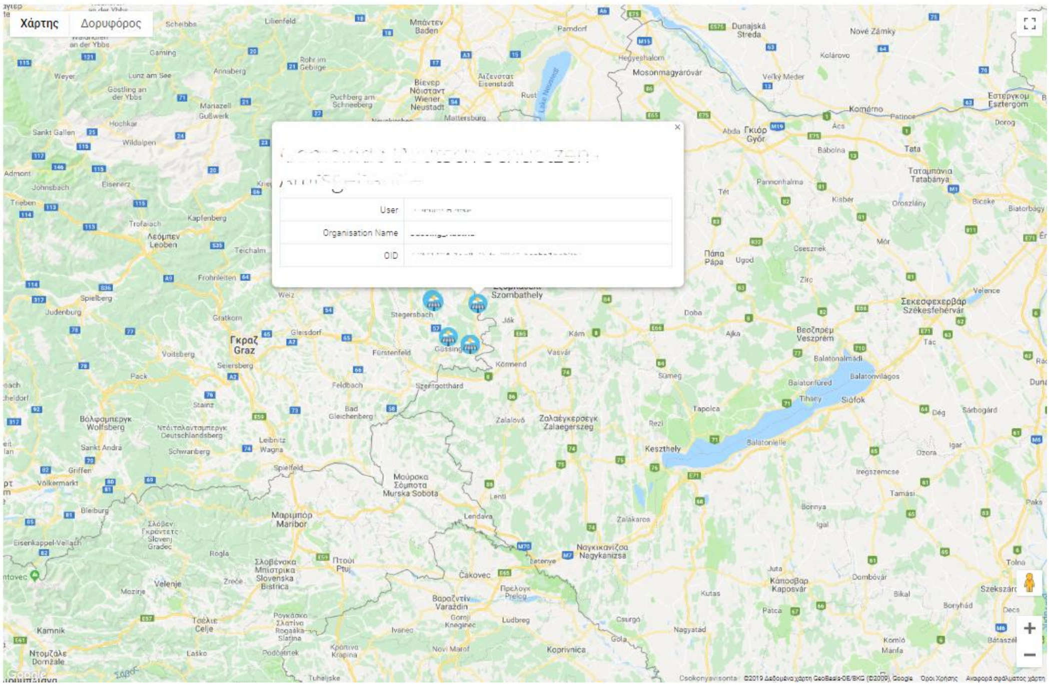


Figure 13 PV location in AVS user interface

5.E-mobility related services

5.1 Scope

The scope of the emobility service is to offer monitoring and management capabilities to different stakeholders similar to the ones offered by a Charging Point Operator. Furthermore, the emobility services offer personlised services to EV users, in respect to their preferences and their mobility restrictions, faclitating more efficient exploitation of the charging infrastructures and better user experience.

5.2 Service registration of charging stations

Given that there is a valid contract between a charging station and the emobility service in the SHAR-Q collaboration web, its registration to the service can be realized through the service user interface. The user should provide the technical specifications for the charging station (name, oid, vendor, energy meter details, coordinates, etc.) as well as data related to the electricity grid (i.e. feeder, substation, etc). The grid related data is exploited for offering grid oriented services. The respective registration form is illustrated in Figure 14.

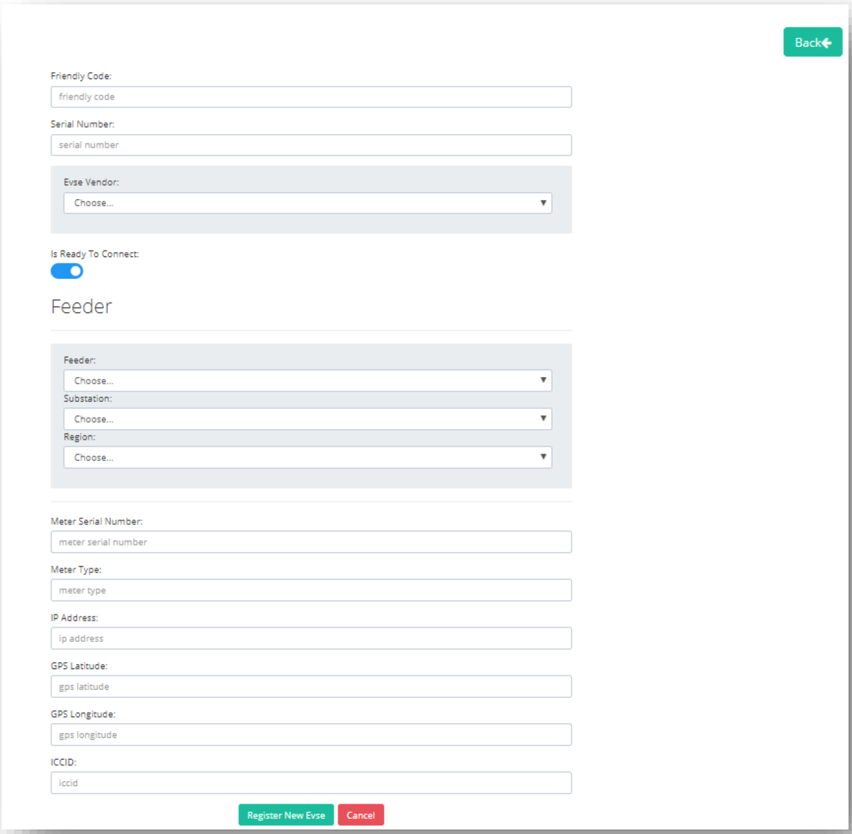
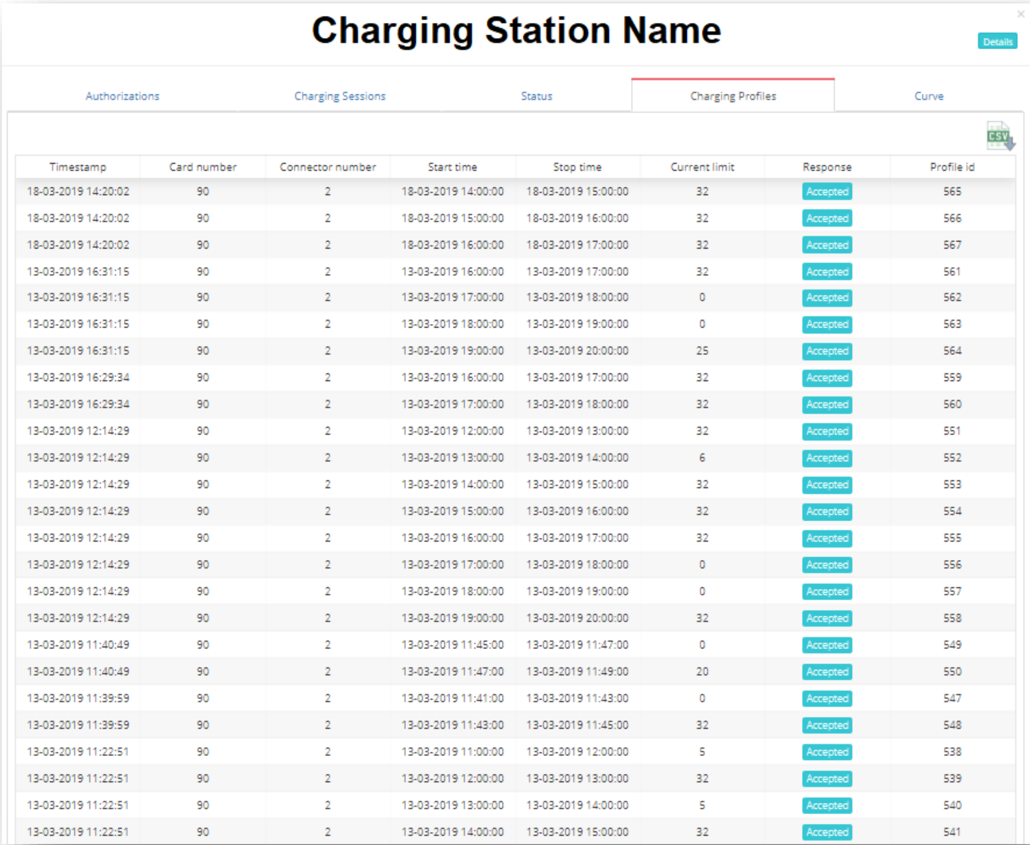


Figure 14 Charging station registration page in AVS user interface

5.3 Monitoring and Control of charging stations

The emobility service monitors the overall operation of the charging infrastructures and every change in their operation is reported and stored in the service's database. The monitoring data for better user experience are grouped in five catagories (Figure 15):

- **Status** which tabularizes all the operational status changes that occur in a charging station
- **Authorisation** which presents all users which requested access to a charging station
- **Charging session** which reports the details for all the charging sessions, i.e. user, charging station, connector, charging energy, charging duration.
- **Charging Profile** which reports all the smart charging profiles which were ordered to the charging station by the service (i.e user, station, connector, start time, stop time, current limit, charging station response)
- **Curve** which visualizes the charging demand of a charging station.



Charging Station Name

Details

Authorizations | Charging Sessions | Status | Charging Profiles | Curve

Timestamp	Card number	Connector number	Start time	Stop time	Current limit	Response	Profile id
18-03-2019 14:20:02	90	2	18-03-2019 14:00:00	18-03-2019 15:00:00	32	Accepted	565
18-03-2019 14:20:02	90	2	18-03-2019 15:00:00	18-03-2019 16:00:00	32	Accepted	566
18-03-2019 14:20:02	90	2	18-03-2019 16:00:00	18-03-2019 17:00:00	32	Accepted	567
13-03-2019 16:31:15	90	2	13-03-2019 16:00:00	13-03-2019 17:00:00	32	Accepted	561
13-03-2019 16:31:15	90	2	13-03-2019 17:00:00	13-03-2019 18:00:00	0	Accepted	562
13-03-2019 16:31:15	90	2	13-03-2019 18:00:00	13-03-2019 19:00:00	0	Accepted	563
13-03-2019 16:31:15	90	2	13-03-2019 19:00:00	13-03-2019 20:00:00	25	Accepted	564
13-03-2019 16:29:34	90	2	13-03-2019 16:00:00	13-03-2019 17:00:00	32	Accepted	559
13-03-2019 16:29:34	90	2	13-03-2019 17:00:00	13-03-2019 18:00:00	32	Accepted	560
13-03-2019 12:14:29	90	2	13-03-2019 12:00:00	13-03-2019 13:00:00	32	Accepted	551
13-03-2019 12:14:29	90	2	13-03-2019 13:00:00	13-03-2019 14:00:00	6	Accepted	552
13-03-2019 12:14:29	90	2	13-03-2019 14:00:00	13-03-2019 15:00:00	32	Accepted	553
13-03-2019 12:14:29	90	2	13-03-2019 15:00:00	13-03-2019 16:00:00	32	Accepted	554
13-03-2019 12:14:29	90	2	13-03-2019 16:00:00	13-03-2019 17:00:00	32	Accepted	555
13-03-2019 12:14:29	90	2	13-03-2019 17:00:00	13-03-2019 18:00:00	0	Accepted	556
13-03-2019 12:14:29	90	2	13-03-2019 18:00:00	13-03-2019 19:00:00	0	Accepted	557
13-03-2019 12:14:29	90	2	13-03-2019 19:00:00	13-03-2019 20:00:00	32	Accepted	558
13-03-2019 11:40:49	90	2	13-03-2019 11:45:00	13-03-2019 11:47:00	0	Accepted	549
13-03-2019 11:40:49	90	2	13-03-2019 11:47:00	13-03-2019 11:49:00	20	Accepted	550
13-03-2019 11:39:59	90	2	13-03-2019 11:41:00	13-03-2019 11:43:00	0	Accepted	547
13-03-2019 11:39:59	90	2	13-03-2019 11:43:00	13-03-2019 11:45:00	32	Accepted	548
13-03-2019 11:22:51	90	2	13-03-2019 11:00:00	13-03-2019 12:00:00	5	Accepted	538
13-03-2019 11:22:51	90	2	13-03-2019 12:00:00	13-03-2019 13:00:00	32	Accepted	539
13-03-2019 11:22:51	90	2	13-03-2019 13:00:00	13-03-2019 14:00:00	5	Accepted	540
13-03-2019 11:22:51	90	2	13-03-2019 14:00:00	13-03-2019 15:00:00	32	Accepted	541

Figure 15 Charging station Monitoring in AVS user interface

Furthermore, the operation of the charging station can be remotely controlled. The remote control actions which are available by the emobility service and they are supported by the charging stations are the following (Figure 16):

- **Reset:** restarting the controller of the charging station

- **Start charging session:** enabling users or charging station operator to plug in and charge their electric vehicle to a charging station via a mobile phone (without using RFID card).
- **Stop charging session:** enabling users to remotely stop a charging session and unlock the charging cable.
- **Firmware update:** enabling users to install to the charging stations the latest firmaware according to vendor's updates.

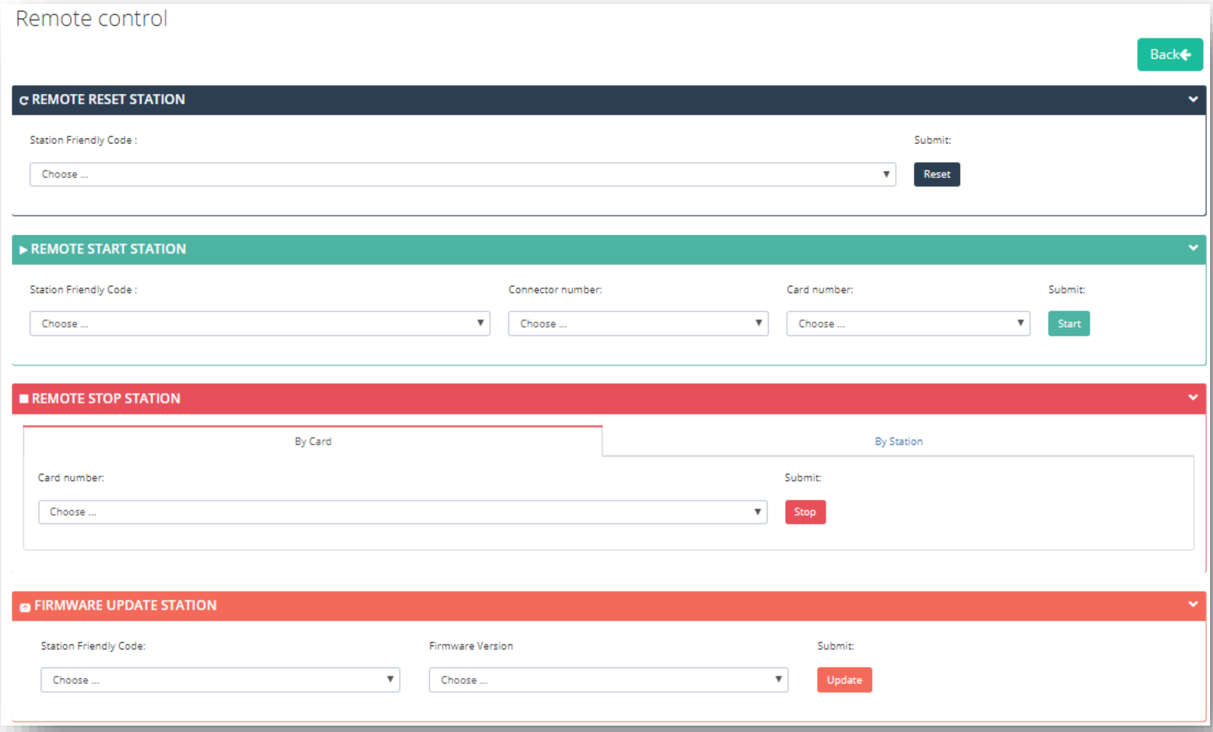


Figure 16 Remote actions initiated by the service Provider

Furthermore, the emobility service facilitates users ordering their prefereable smart charging profile which will be implemented during a specific charging session. Based on their charging energy needs and their mobility pattern, users can order their own set of charging profiles by defining the implementation period of each profile and the desirable charging current. Besides users' willingness for smart charging, smart charging capabilities can also be exploited by charging network operators (ex. parking areas, hotels) in order to avoid high charging peak demands due to EV charging synchronization. The respective form for requesting a charging profile is shown in Figure 17. Charging profiles which provoke current constraint violations are rejected by the charging station as invalid.

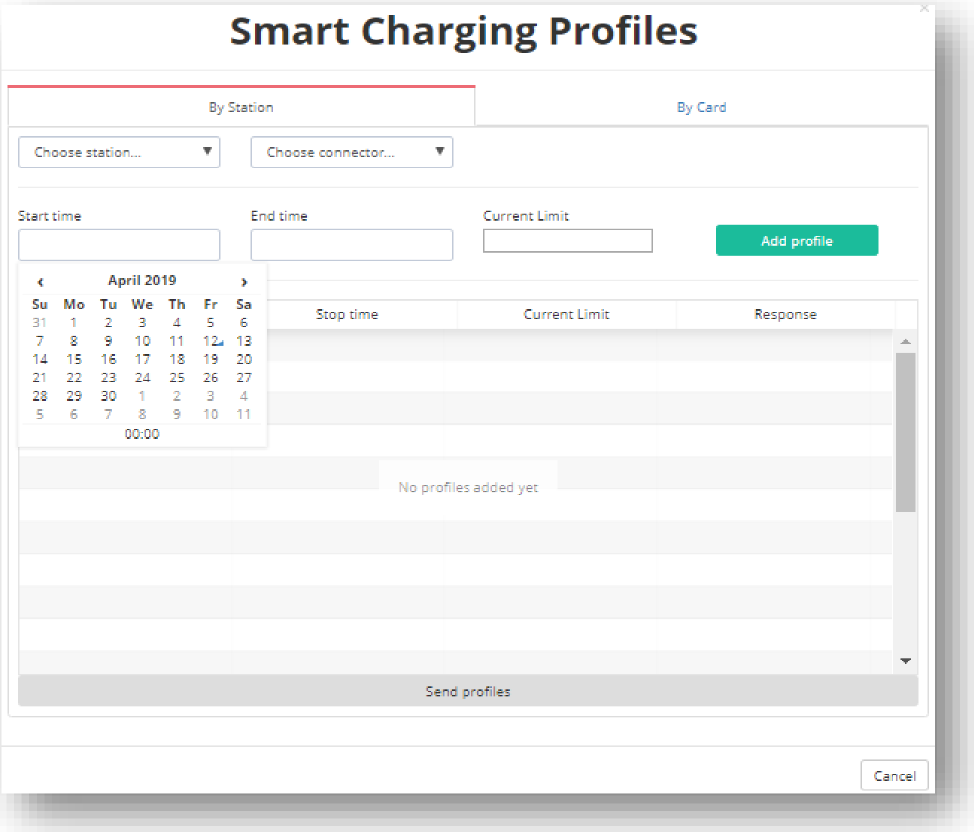


Figure 17 Smart charging profiles form in AVS user interface

The smart charging capabilities offered by the charging station can be exploited by the e-mobility service for offering more advanced services to different stakeholders, i.e. distribution system Operator, market Operator, balancing responsible parties, Aggregators, etc. In the following sections, advanced smart charging schemes are presented and analysed.

5.4 Cost Optimal Charging Service

The aim of this service is to minimize the charging cost in respect to an electricity pricing scheme (dynamic pricing, multiple-tarrif). The successful user authorization is a prerequisite for the implementation of the cost optimal charging service. As soon as the EV is plugged-in, the EV user can request from the service to charge its electric vehicle at the lowest energy cost by defining a set of technical (charging cable capabilities, EV battery capacity and charging status) and mobility (i.e. departure time) constraints. With repsect to the EV user's preferences and the predefined electricity prcing scheme, the service produces the optimal charging profile achieving the lowest charging cost. The charging profiles as well as the estimated battery state-of-charge are visualized in Figure 18. The mathematical formulation of the cost minimization service is as follows:

$$Min \sum_{t_{0,i}}^{t_{0,i}+T_i} p_t \cdot P_{ch,t}^{EV} \cdot \Delta t$$

s.t.

$$\sum_{t_{0,i}}^{t_{0,i}+T_i} P_{ch,t}^{EV} \cdot \Delta t - (1 - SOC_{in}) \cdot C_{bat} / C_{eff} \geq 0$$

$$P_{ch,t}^{EV} \leq P_{\ nomCS} \ \ \forall \ t = 1, \dots, T$$

where $\boldsymbol{p_t}$ is the pricing scheme, $\boldsymbol{P^{EV}_{ch,t}}$ is the optimal charging profile, SOC_{in} is the initial battery charging status, C_{bat} is the EV battery capacity, C_{eff} is the charging process efficiency, $P_{\ nomCS}$ is the maximum allowable charging current considering the operational constraints of the charging station, EV battery management system and charging cable.

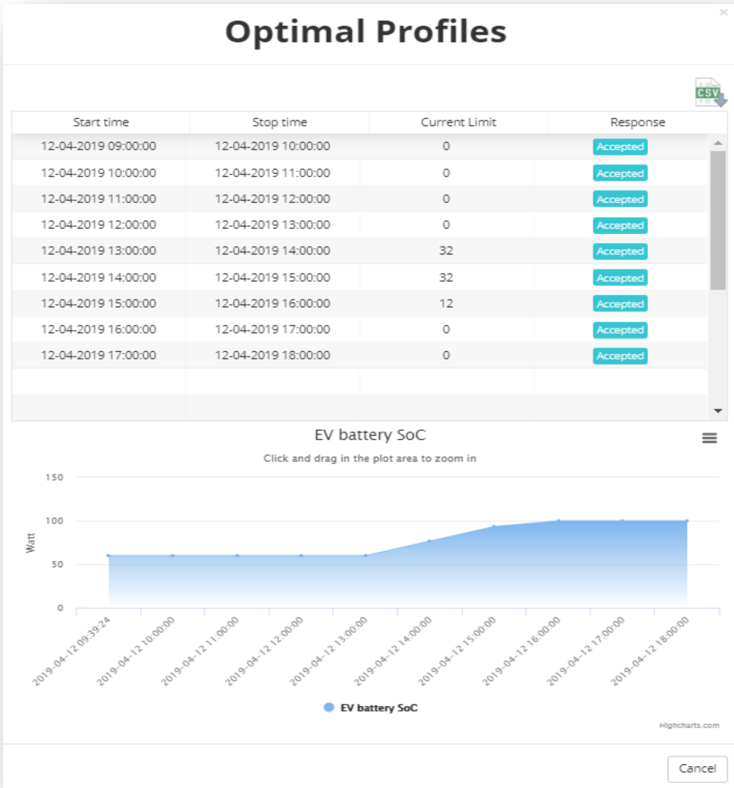


Figure 18 Cost optimal charging profile defined by the AVS

5.5 Grid oriented smart charging

The aim of this service is to offer ancillary services to the distribution system Operators in order to support the network operation. The common output of all grid-impact emobility analysis is the fact that the “plug-n-play” approach under high EV deployment scenarios will provoke high charging demand peaks due to the synchronization of the EV charging, especially when considering home charging. Such peak demands may result in costly premature grid reinforcements. Alternatively, smart charging concepts can be implemented in order to shift the charging demand to grid off-peak time periods.

This issue has already been identified by the majority of the EU distribution system Operators as a potential future network operational issue. Several schemes for avoiding charging peak demands have been proposed and analysed. In the E.DSO’s report named “European Distribution System Operators for Smart Grids”[4], the EU distribution system Operators suggest implementing flexible grid capacity contracts (Figure 19). The flexible grid capacity contracts allow for higher charging available capacities when the grid consumption is low, whereas the available capacity decreases during periods of network stress.

[4] https://www.edsoforsmartgrids.eu/wp-content/uploads/EDSO-paper-on-electro-mobility-2.pdf

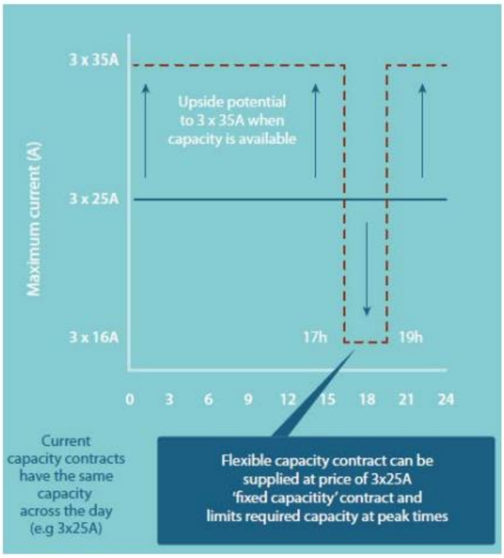


Figure 19 Example of flexible grid capcity contracts (Source:E.DSO)

In this respect, the developed grid-oriented service aims to optimally allocate the available charging capacity dictated by the distribution system operators to the plugged-in electric vehicles. The available grid capacity is provided by the distribution sytem operator as it is shown in Figure 20. In case that there is adequate avaialbel network capacity for serving all the plugged-in EVs, the whole fleet is charging at the maximum charging rate. In the opposite case, a charging load shedding mechanism should be activated such that the aggregated EV charging demand does not exceed the grid capacity. The load shedding mechanism is illustrated in Figure 21. The prioritization of the charging depends on the charging energy needs of the vehicle, the non-commuting period and the charging current constraints. In this respect, EVs with lower battery state-of-charge and shorter available charging period gain higher charging priority.

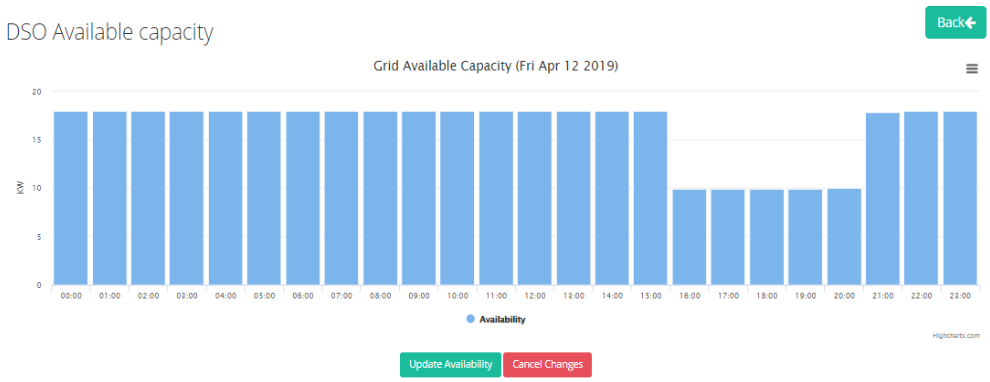


Figure 20 Indicative example of an available grid capacity profile defined by DSO

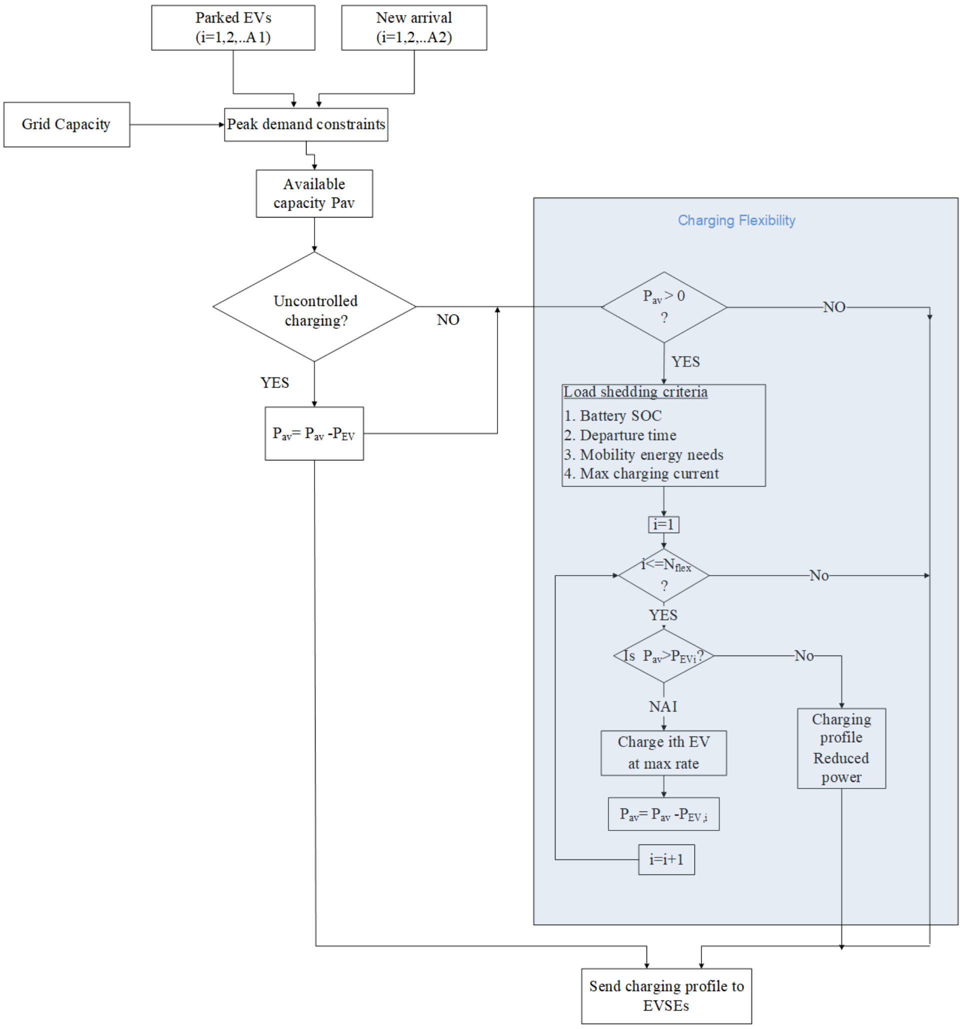


Figure 21 Charging load shedding mechanism

An indicative example of the grid oriented service is provided below for better understanding of the service operation.

A Medium to Low Voltage (MV/LV) transformer with nominal power 1250kVA supplying commercial load is considered. The commercial load supplied by the transformer presents a peak of approximately 1.1MW at 18:00 and quite a high demand during the morning and middle day hours, as illustrated in Figure 22.

It is assumed that the charging network infrastructure comprises charging stations with nominal power of 7.2kW and efficiency of 90%. The battery's SoC, when an EV plugs-in, is randomly defined (uniform distribution) between 20% and 40%. The battery capacity of each vehicle is considered equal to 24kWh. Furthemore, it is assumed that a total number of *180 charging sessions* occur during the examined period (24hours). The percentage of charging sessions occurring each hour of the day is illustrated in Figure 23. The probability of a charging session to occur during the time period from 9:00 to 16:00 is the highest one.

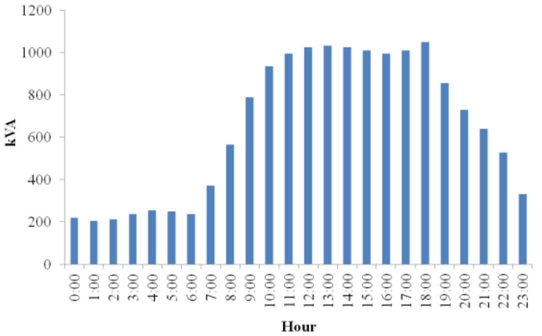


Figure 22 Commercial load curve for the examined transformer

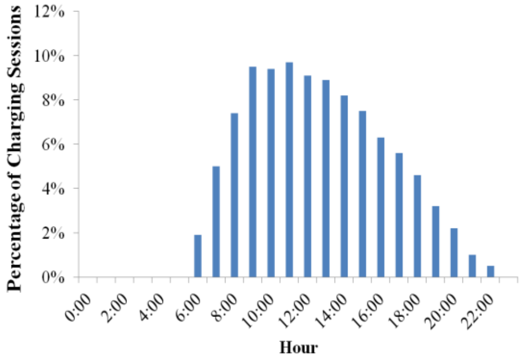


Figure 23 Charging sessions per hour

Based on the input parameters and the grid availability, the EV charging demand shifting is illustrated in Figure 24. The EV demand which exceeds the grid capacity limit (red coloured area) is shedded and shifted to off-peak hours (green area). Moreover, the number of occupied charging stations as well as the number of charging electric vehicles are illustrated in Figure 25.

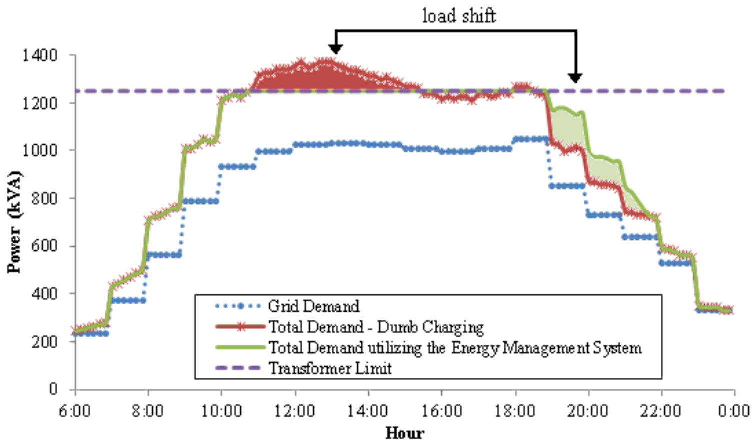


Figure 24 Total Demand of the examined transformer

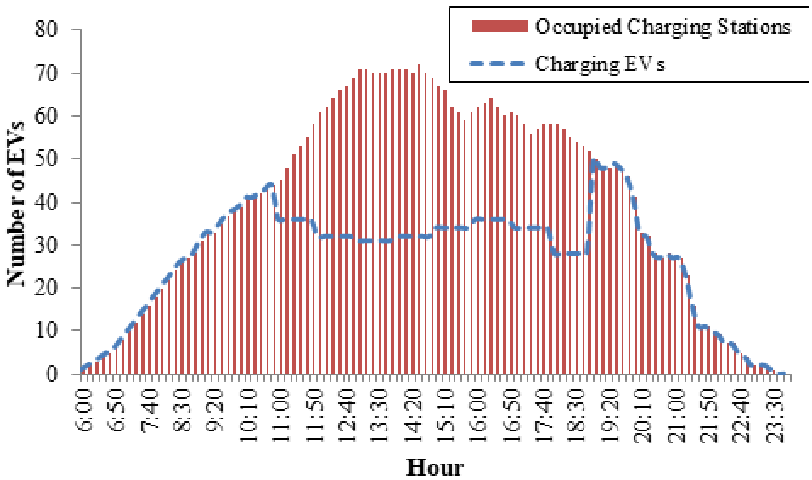


Figure 25 Occupied charging stations and charging EVs

5.6 Market Oriented smart charging

The market-oriented smart charging dictates two pre-conditions: the engagement of a specific ancillary capacity which should remain available during a specific time period and the partial or complete exploitation of the engaged ancillary capacity. In this respect, such kind of services should be capable of defining the optimal operational profile of the energy resources as well as the optimal ancillary capacity that can be offered to market stakeholder in respect to customers' preferences and restrictions.

The participation of electric vehicles into electricity grid can be realized only through the aggregation of their battery capacities, since current market capacity participation constraints does not allow their participation as individual units. Aggregators or E-mobility Service Providers are responsible for aggregating and optimizing the participation of electric vehicles into electricity grids. The objective of the market oriented service is to optimize day-ahead EV scheduling in order to maximize the aggregator's revenues. The output of the service is the optimal operational profile for each electric vehicle as well as the asymmetrical ancillary services capacities (regulation up/down and spinning reserve).

The day ahead optimal EV market scheduling is formulated as follows:

$$Max\ f = \sum_{t=1}^{T}\big(PRu(t)Ru(t) + PRd(t)Rd(t) + PRr(t)Rr(t)\big) + Mk\sum_{i=1}^{N}\sum_{t=1}^{T}\left(E\{FP_i(t)\}\right) - \sum_{i=1}^{N}\sum_{t=1}^{T}\big(E\{FP_i(t)\}P(t)\big) - \sum_{i=1}^{N}\sum_{t=1}^{T}\big(Deg_i(t)\big) \quad (B1)$$

$$Ru(t) = \sum_{i=1}^{N} MnAP_i(t)\ and\ Rd(t) = \sum_{i=1}^{N} MxAP_i(t) \quad (B2)$$

s.t.

$$h_{1,i,t} = POP_i(t)\big(1 - Plug_i(t)\big) = 0 \quad (B3)$$

$$h_{2,i,t} = MxAP_i(t)\big(1 - Plug_i(t)\big) = 0 \quad (B4)$$

$$h_{3,i,t} = MnAP_i(t)\big(1 - Plug_i(t)\big) = 0 \quad (B5)$$

$$h_{4,i,t} = RsRP_i(t)\big(1 - Plug_i(t)\big) = 0 \quad (B6)$$

$$h_{6,i} = SOC_i(1) - \sum_{t=1}^{T} Trips_i(t) + Ef_i\sum_{t=1}^{T}\big(E\{FP_i(t)\}Comp_i(t) - \rho_i(t)\big) - Mc_i = 0 \quad (B7)$$

$$g_{1,i,t} = \big(MxAP_i(t) + POP_i(t)\big)Comp_i(t)Ef_i + SOC_i(t) - Mc_i \le 0 \quad (B8)$$

$$g_{2,i,t} = (POP_i(t) - MnAP_i(t) - RsRP_i(t) - \rho_i(t))Comp_i(t)Ef_i + SOC_i(t) \ge 0 \quad (B9)$$

$$g_{3,i} = \sum_{\tau=1}^{t}(E\{FP_i(\tau)\}\,Comp_i(\tau) - \rho_i(\tau))Ef_i + SOC_i(1) - \sum_{\tau=1}^{t} Trips_i(\tau) - Mc_i \le 0 \quad (B10)$$

$$g_{4,i} = \sum_{\tau=1}^{t}(E\{FP_i(\tau)\}\,Comp_i(\tau) - \rho_i(\tau))Ef_i + SOC_i(1) - \sum_{\tau=1}^{t} Trips_i(\tau) \ge 0 \quad (B11)$$

$$g_{5,i,t} = \sum_{i=1}^{N} POP_i(t) - \frac{MxL - L(t)}{MxL - MnL}\sum_{i=1}^{N}\big(MP_i(t)Plug_i(t)\big) \le 0 \quad (B12)$$

$$g_{6,i,t} = Deg_i(t) - (POP_i(t) - MnAP_i(t)ExU(t) - RsRP_i(t)ExR(t)\big)\,DC_iComp_i(t)/Ef_i \ge 0 \quad (B13)$$

$$g_{7,i,t} = MxAP_i(t) + POP_i(t) - MP_i(t) \le 0 \quad (B14)$$

$$g_{8,i,t} = POP_i(t) - MnAP_i(t) + MP_i(t) \ge 0 \quad (B15)$$

$$g_{9,i,t} = POP_i(t) - MnAP_i(t) - RsRP_i(i) + MP_i(t) \ge 0 \quad (B16)$$

$$g_{10,i,t} = POP_i(t) + MP_i(t) \ge 0 \quad (B17)$$

$$g_{11,i,t} = MxAP_i(t) \ge 0 \quad (B18)$$

$$g_{12,i,t} = MnAP_i(t) \ge 0 \quad (B19)$$

$$g_{13,i,t} = RsRP_i(t) \ge 0 \quad (B20)$$

$$g_{14,i,t} = Deg_i(t) \geq 0 \qquad (B21)$$

The constraints in Eq. (B3)-(B6) express the EV operational limitation due to EV mobility. The EV batteries operational bounds are considered in Eq. (B7)-(B11). Eq. (B12) ensures that simultaneous charging does not affect the forecasted system peak load. Eq. (B13) refers to the battery degradation cost. The domain of definition of the decision variables is defined by Eq. (B14)-(B21). The term $\rho_i(\tau)$ is to account for the energy discharge from the battery due to the discharge efficiency and it is defined as $\rho_i(\tau) = Deg_i(t) \cdot (1 - Ef_i^2)/DC_i \cdot Ef_i$.

An indicative example of the day-ahead optimal EV scheduling follows.

An EV fleet of 10000 vehicles of types L7e and M1 is considered. The technical characteristics of the simulated EV fleet are shown in Table 3. For the traffic pattern of the EV fleet the following aspects are considered:

- 06:00-09:00: It is assumed that all EVs have fully charged their battery at 06:00. During this time period, it is considered that each EV makes one trip.
- 10:00-15:00: During this period it is assumed that EVs are parked and plugged-in. However, there is a random number of EVs that makes an additional trip during this period.
- 16:00-19:00: During this time period, it is considered that EVs return home and plug-in to the grid.
- 20:00-03:00: It is assumed that a random number of EVs unexpectedly departures, but all EVs are plugged-in after 03:00.
- 03:00-05:00: All EVs are connected to the grid. No unexpected departure occurs.

Based on the assumed traffic patterns, the number of plugged-in EVs at each hour is illustrated in Figure 26. Regarding the daily travelled distances (km), a normal distribution with a mean value of 40km and 5km deviation is considered. For the arrival and departure times, normal distributions with mean values 07:30 and 17:30, with half an hour deviation, are considered, respectively. The assumption of normal distribution for the travel distance and the arrival departure time is made. The proposed EV coordination methodology however can be implemented for different traffic profiles reflecting different mobility conditions and/or EV classes (bus, tracks) without affecting the performance of the proposed methodology.

Concerning the charging infrastructures, single-phase charging stations of Mode 2 are considered according to IEC 62196-1.

Table 3 EV fleet specifications

EV fleet characteristics			
	EV number	**Battery Capacity *(kWh)***	**Consumption *(kWh/km)***
Type A	500	53	0,127
Type B	2000	26	0,157
Type C	2000	30	0,14
Type D	2500	16	0,125
Type E	3000	24	0,21

The simulated market data for energy and regulation services is presented in Figure 27. In respect to the obovementioned input parameters and assumptions, the day ahead EV scheduling pfoile for the aggregated electric veihicles is shown in Figure 28.

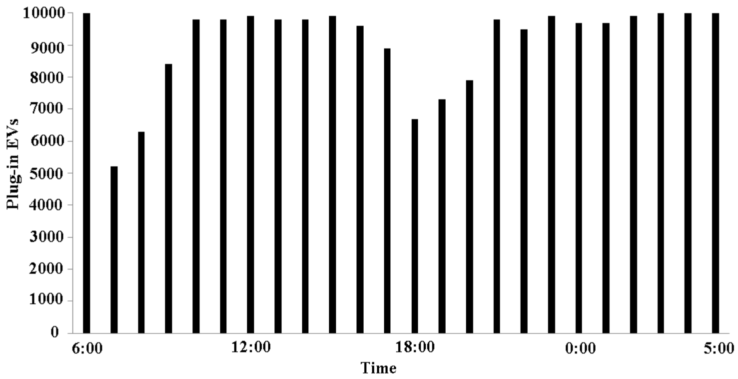


Figure 26 Number of plugged-in EVs in each hour of the day

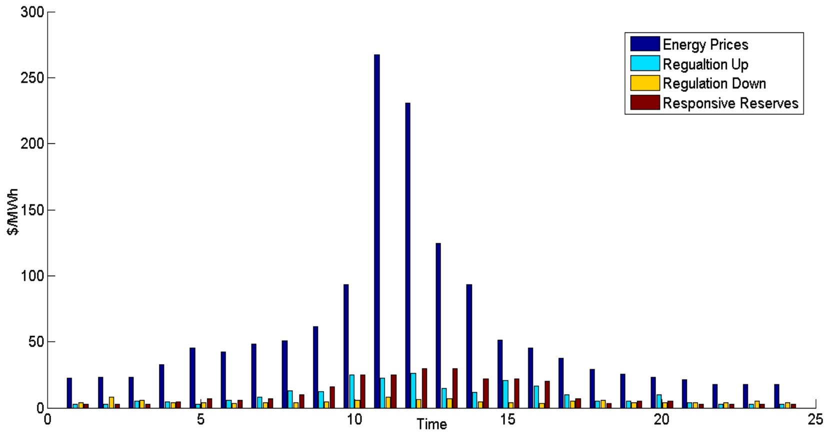


Figure 27 Market Energy prices

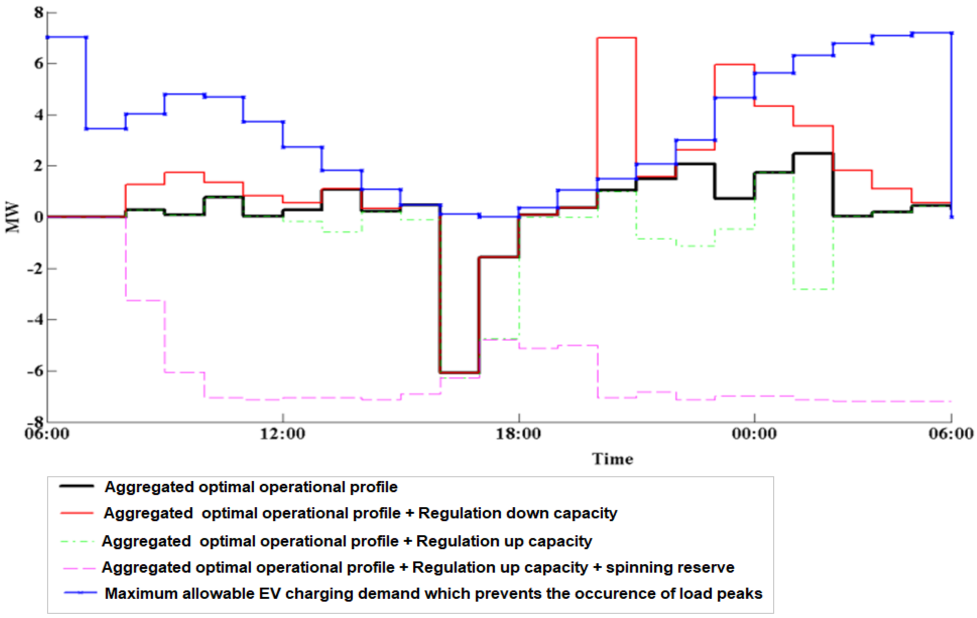


Figure 28 Optimal day-ahead EV scheduling

6. Business impact expected through the implementation of the service

The SHAR-Q AVS layer is the intermediate between end-users and regulated energy stakeholders, i.e. emoblity actors, system operators and market operators. The scope of the emobility service is to offer monitoring and management services to individual customers or to a number of customers forming a virtual neighborhood as well as to offer the aggregated energy flexibility of customers to support network and market operation.

6.1 Emobility services for end-users

One of the major pillars for the successful deployment of an e-mobility business is the user experience. E-mobility is a rapid growing concept for sustainable transportation which should prove its efficiency towards conventional transportation. In this respect, it is crucial that EV users are enjoying better transportation services. Even though multi-transport services is an upcoming need, the SHAR-Q project focuses mainly on the EV customers.

The SHAR-Q emobility services offer EV user the capability of exploiting the whole charging network that is under the services' responsibility with the use of a single RFID card. Different charging technologies, i.e. conductive or inductive infrastructures, fast or slow charging, etc., which are monitored and controlled by the SHAR-Q AVS, can serve the e-mobility needs of EV users wherever they plug-in their electric vehicle.

Enabling the EV connectivity though an RFID card allows users to select any e-mobility contract according to their willingness and needs. The SHAR-Q emobility service "transforms" any charging infrastructure to an energy hub where EV users can potentially buy energy from any energy supplier. Thus, SHAR-Q emobility service enables roaming services by establishing communication links with the energy suppliers for user management purposes.

Furthermore, the emobility service offers visualized representation of the status of the charging stations through a user-friendly user interface. Such a visualization allows users to search for the most convenient location for charging their electric vehicle in respect to their destination and charging station availability.

Apart from individual services, the SHAR-Q e-mobility service offers monitoring and management capabilities for organisations of end-users, such as the energy communities. The offered smart charging services facilitates the synergetic operation of local renewable energy sources and EV charging. The battery of electric vehicles is treated as an energy buffer which can be exploited for optimizing the overall operational electricity cost of one organisation.

6.2 E-mobility tool for service Providers

The emobility service can also be exploited as an enabling tool for offering asset management and/or e-mobility services. This tool can be utilized from the two regulated e-mobility actors: the Charging Point Operator (CPO) and the Emobility Service Provider (EmSP).

The asset and user management capabilities offered by the SHAR-Q emobility service can be exploited by charging infrastructure vendors which wish to offer a complete market product including hardware and software solutions. Moreover, energy suppliers who wish to extend their business portfolio with e-mobility activities can utilize this service in order to offer services to their end users. Additionally, parking facility Operators are also interested in integrated solutions which allow them to operate different charging technologies and charge EV users in respect to the service exploitation.

In this case, the operation of the CPO and the EmSP is unbundled, the EmSPs are not interested in operating and managing charging assets but they wish only to offer e-mobility services to EV users. In this respect, the SHAR-Q e-mobility service establishes a communication path with the EMSPs in order to provide them the required operational data of the charging network.

6.3 E-mobility services for DSOs

The integration of electric vehicles into distribution grids poses an additional load to the network demand curve. Depending on the EV deployment level and the charging policies, the secure and reliable operation of distribution networks might be affected. The traditional network planning and management principles dictates the design and development of distribution networks under the worst case scenario. However, the energy transition entails the exploitation of local flexible demand from DSOs towards more efficient and cost effective network planning and management.

The SHAR-Q e-mobility service facilitates the smart charging of electric vehicles such that the grid operational constraints dictated by the DSOs are not violated. Web interfaces offered by the SHAR-Q service facilitates the real-time interaction with the DSOs who dictate network operational constraints. Afterwards, the service manages the charging of electric vehicles such that the charging needs of electric vehicles are best served in respect to the EV users' preferences/mobility constraints and network operational conditions.

6.4 E-mobility tool for energy market participation

The current market operational framework does not allow the participation of electric vehicles as individual units, due to their limited battery capacity. Their participation can be realized through the aggregation of their battery capacities and their participation as a single entity. The battery aggregation and management of a fleet of electric vehicles can be realized by energy actors such as EmSPs or Aggregators.

The SHAR-Q emobility service offers the tool which allows EmSPs or Aggregators to optimize the market participation of electric vehicles into electricity markets. This tool optimizes the EV battery operation (charging/discharging profile) towards wholesale electricity market prices and it also defines the optimal bidding battery capacity for ancillary services (regulation up/down and spinning reserve). Moreover, this tool aims to maximize the profits or the EmSPs and Aggregators and offer competitive charging tariff schemes to end users.

6.5 PV monitoring Service as key enabler of EV/RES synergy

It is true that the correlation between RES production and EV charging demand offers several technical, financial and environemental benefits. The intermittent RES production provokes several operational issues to every layer for the electricity grid, from the lowest one at prosumer level up the highest one at market level.

The integration of distributed RES production units close to the consumption highly affects the energy flows in the electricity grids. Currently, electricity grid are designed, planned and managed considering the top down approach, large generation units concentrated at cental plants procude the power for serving demand which is transfered through the transmission and distribution network. In this respect, the principal operational rule is that production follows consumption. The increasing deployment of distributed RES in electricity grids, in order to achieve the energy transition, implies significant changes to the way electricity grids are planned and operated. Due to their intermittent production, the principal operational rule in future smart grids will be modified to the following one: consumption follows production. This can be realized only if sufficient storage and flexible demand capacity exist in electricity grids.

The PV monitoring service presented in this document is the enabling tool for coupling PV production and electric vehicles considering the latter ones as small distributed battery storages. Real monitoring and forecasting data is a prerequirement for the majority of EV/RES management mechanisms. The EV/RES synergy can be realized in different electricity grids levels:

- At prosumers level in order to increase their self-consumption and improve their environmental and financial energy footprint
- At network level in order to increase its RES hosting capacity by exploiting more efficiently the local excess of RES production for EV charging
- At market level in order to achieve higher RES shares since EV aggregated battery capacity can be exploited for forecast error balancing purposes.

7. Conclusions

This document reports the development of the added value services which are exposed on the top of the SHAR-Q interoperable communication platform in order to offer e-mobility services (asset management and smart charging) to different energy stakeholders, i.e. prosumers, EV users, CPO, EmSP, system and market operators. The supported functionalities of the added value services serve the users' requirements as these were identified within the SHAR-Q project based on the face-to-face interactions with stakeholders.

The deliverable analysed the development and operation of two categories of added value services: services for RES producers and services for the e-mobility area. More specifically, the first service category refers to PV producers or prosumers with PV production aiming to offer monitoring and forecasting services. PVs are considered as non-controllable energy components with no capability of active/reactive power control. The second category refers to the CPO and EmSP enabling charging station management and advanced grid/market oriented smart charging.

The implementation of the AVS in a real environment requires the existence of specific infrastructures and the development of gateway APIs/Adapters capable of connecting smart energy components to the SHAR-Q platform. Thus, the development of the AVS is tightly coupled with the pilot requirements defined in the SHAR-Q project. However, the extendability of the AVS towards new user requirements is considered by adopting a micro-services approach. Each service comprises several modules each one of which is responsible for specific functionalities or services. The PV and charging station monitoring micro-services offer the core functionalities on top of which more advanced micro services such as forecasting and smart charging are built. In this respect, new user requirements can be served either by enhancing the respective service module or by developing a new one.

The interaction of the end-users with the added value services is realized through the service's user interface. This UI visualizes the monitoring data for each energy component and allows users to express their preferences and to request more personalized services. Indicative examples from the whole services' process chain with the respective UI screenshots are available in this document for better understanding of the service exploitation. End users are categorized in two different groups with different data access rights: *simple users* and *pilot managers*. Simple users are the infrastructure owners who wish to integrate diverse infrastructure technologies into the SHAR-Q platform and request personalized or collaborative advanced services. Pilot managers are the representatives of an organisation such as a pilot site or an energy community and they are capable of monitoring the aggregated operation of all the assets under their responsibility.

The emobility added value services can be exploited directly by the infrastructure owners as energy management solution or as enabling tools by e-mobility stakeholders which unlock new business opportunities for offering advanced e-mobility services to end users.

8.References

[SQD25] "SHAR-Q collaboration business models and business requirements"

[SQD26] *"SHAR-Q functional design document*"

[SQD27] "*Architecture of SHAR-Q technology components*"

[SQD31] "*Detailed specification of the SHAR-Q interfaces and semantic models*"

[SQD42] "Collaboration Web Component"

[SQD43] "Open Interoperability Gateway API"

[SQD51] "SHAR-Q Added value service definition"

[SQD52] *"Meteorological services for renewables & climate services"*

[SQD61] "SHAR-Q gateway adapters"

[SQD65] "Report on integration of pilot with adaptive e-vehicle charging"

[SQD74] "Report on SHAR validation in the context of RES/EV synergy"

[SQD75] "Report on overall evaluation of UX and performance of SHAR-Q framework"

9. ANNEX I

9.1 Emobility Service Description

```
{
  "name": "user defined",
  "type" : "core:Service",
  "infrastructure-id": "user defined",
  "adapter-id": "uder defined",

  requirements: {
    "properties":[
      {
          "monitors" : /{oid}/properties/reset",
          "input" : {
              "datatype" : {“oid”: “string”, “request”:jsonObject},
              "units" : ""
          },
          "output" : {
              "datatype" :”sting”,
              "units" : ""
          },
          "optional": false,
      },
      {
          "monitors" : /{oid}/properties/remoteStart",
          "input" : {
              "datatype":{“oid”: “string”, “request”:jsonObject},
              "units" : ""
          },
          "output" : {
              "datatype" :”sting”,
              "units" : ""
          },
          "optional": false,
      },
      {
          "monitors" : /{oid}/properties/remoteStop",
          "input" : {
              "datatype":{“oid”: “string”, “request”:jsonObject},
              "units" : ""
          },
          "output" : {
              "datatype" :”sting”,
              "units" : ""
          },
          "optional": false,
      },
      {
          "monitors" : /{oid}/properties/smartCharging
          "input" : {
              "datatype":{“oid”: “string”, “request”:jsonObject},
              "units" : ""
          },
```

```
        "output" : {
            "datatype" :jsonObject,
            "units" : ""
        },

        "optional": false,
    }
    ],
    "actions": [ ... ],
    "events": [ ... ]
  },

  "properties": [
    {
      "pid": "heartbeat",
      "monitors": adapters:heartbeat",
      "write_link": {
        "href": "/objects/{oid}/property/{pid}",
        "input": {
            "type": {"ObjId":"string", "request":Ocpp heartbeat.req, "timestamp":"string"},
          }
        "output": {
            "type":ocpp heartbeat.conf,
          }
        }
     },
     {
      "pid": "authorize",
      "monitors": "adapters:authorize",
      "write_link": {
        "href": "/objects/{oid}/property/{pid}",
        "input": {
            "type": {"ObjId":"string", "request":Ocpp authorize.req, "timestamp":"string"},
          }
        "output": {
            "type":ocpp authorize.conf,
          }
        },
     {
      "pid": "bootNotification",
      "monitors": "adapters:bootNotification",
      "write_link": {
        "href": "/objects/{oid}/property/{pid}",
        "input": {
            "type": {"ObjId":"string", "request":Ocpp bootNotification.req, "timestamp":"string"},
          }
        "output": {
            "type":ocpp bootNotification.conf,
          }
        },
      {
      "pid": "statusNotification",
      "monitors": " adapters:statusNotification ",
```

```
    "write_link": {
      "href": "/objects/{oid}/property/{pid}",
      "input": {
          "type": {"ObjId":"string", "request":Ocpp statusNotification.req, "timestamp":"string"},
        }
      "output": {
          "type":ocpp statusNotification.conf,
        }
      },
    {
    "pid": "StartTransaction",
    "monitors": " adapters:startTransaction",
    "write_link": {
      "href": "/objects/{oid}/property/{pid}",
      "input": {
          "type": {"ObjId":"string", "request":Ocpp StartTransaction.req, "timestamp":"string"},
        }
      "output": {
          "type":ocpp StartTransaction.conf,
        }
      },
    {
    "pid": "StopTransaction",
    "monitors": " adapters:stopTransaction",
    "write_link": {
      "href": "/objects/{oid}/property/{pid}",
      "input": {
          "type": {"ObjId":"string", "request":Ocpp StopTransaction.req, "timestamp":"string"},
        }
      "output": {
          "type":ocpp StopTransaction.conf,
        }
      },
    {
    "pid": "meterValues",
    "monitors": " adapters:meterValues",
    "write_link": {
      "href": "/objects/{oid}/property/{pid}",
      "input": {
          "type": {"ObjId":"string", "request":Ocpp meterValues.req, "timestamp":"string"},
        }
      "output": {
          "type":ocpp meterValues.conf,
        }
      }
  ],
  "actions": [ … ],
  "events": [ … ]
}
```

9.2 Charging Station Description

```
{
  "name": "user defined",
  "type" : "adapters:EVCharger",
  "infrastructure-id": "user defined",
  "adapter-id": "uder defined",

  requirements: {
    "properties":[ … ],
      "actions": [ ... ],
      "events": [ ... ]
    },

    "properties": [
      {
        "pid": "reset",
        "monitors": “adapters:reset”,
        "write_link": {
          "href": "/objects/{oid}/property/{pid}",
          "input": {
              "type":  {“oid”: “string”, “request”:{“type”:”string”} },
            }
          "output": {
              "type":”string”,
            }
          }
       },
      {
        "pid": "remoteStart",
        "monitors": “adapters:remoteStart”,
        "write_link": {
          "href": "/objects/{oid}/property/{pid}",
          "input": {"type": {“oid”: “string”, “request”: {"connetorId”: int, “card”:”string”,
“chagringProfileSessionArray”: [{“startTime”: date,  ”stopTime”:date, “currentlimit”:int}, ….]}
 },
            }
          "output": {
              "type":”string”,
            }
          }
       },
      {
        "pid": "remoteStop",
        "monitors": “adapters:remoteStop”,
        "write_link": {
          "href": "/objects/{oid}/property/{pid}",
          "input": {
              "type":  {“oid”: “string”, “request”: {"transactionId”: “string”}},
            }
          "output": {
              "type":”string”,
            }
```

```
        }
      },
      {
        "pid": "smartCharging",
        "monitors": "adapters:smartCharging",
        "write_link": {
          "href": "/objects/{oid}/property/{pid}",
          "input": {
              "type":  {"oid": "string", "request": {"connetorId": int, "chagringProfileSessionArray": [{"startTime": date, "stopTime":date, "currentlimit":int}, {….}] } },
            }
          "output": {
              "type":[{"startTime": date, "stopTime":date, "currentlimit":int, "profileId":int, "response": "string"} ,{….}],
            }
          }
      }
    ],
    "actions": [ ],
    "events": [   ]
  }
```

9.3 PV monitoring Service Description

```
{
  "name": "user defined",
  "type" : "core:Service",
  "infrastructure-id": "user defined",
  "adapter-id": "uder defined",

  requirements: {
    "properties":[
      {
        "monitors" : /{oid}/properties/PvInstalledCapacity",
        "output" : {
            "datatype" : "string",
            "units" : "Wp"
        },
        "optional": false,
      },
      {
        "monitors" : /{oid}/properties/Location",
        "output" : {
            "datatype" : "double double",
            "units" : ""
        },
        "optional": false,
      },

      {
        "monitors" : /{oid}/properties/Azimuth",
```

```
      "output" : {
         "datatype" : “string”,
         "units" : "degrees"
      },
      "optional": true,
   },
   {
      "monitors" : /{oid}/properties/Elevation",
      "output" : {
         "datatype" : “string”,
         "units" : "degrees"
      },
      "optional": true,
   },
   {
      "monitors" : /{oid}/properties/ServiceLevel",
      "output" : {
         "datatype" : “string”,
         "units" : ""
      },
      "optional": true,
   },
   {
      "monitors" : /{oid}/properties/InverterPVActualActivePower",
      "output" : {
         "datatype" : double,
         "units" : "W"
      },
      "optional": false,
   },
   {
      "monitors" : /{oid}/properties/InverterPVActualReactivePower",
      "output" : {
         "datatype" : double,
         "units" : "Var"
      },
      "optional": false,
   },
   {
      "monitors" : /{oid}/properties/InverterAccumulatedActiveEnergyProduction",
      "output" : {
         "datatype" : double,
         "units" : "Wh"
      },
      "optional": false,
   },
   {
      "monitors" : /{oid}/properties/InverterConsumerActivePowerLoad",
      "output" : {
         "datatype" : double,
         "units" : "W"
      },
      "optional": false,
```

```
    },
   {
        "monitors" : /{oid}/properties/InverterGridActivePowerLoad",
        "output" : {
           "datatype" : double,
           "units" : "W"
        },
        "optional": false,
    },
   {
        "monitors" : /{oid}/properties/Timestamp",
        "output" : {
           "datatype" : date,
           "units" : ""
        },
        "optional": false,
    },
    ],
    "actions": [ ... ],
    "events": [ ... ]
   },
 "properties": [ … ],
   "actions": [ … ],
   "events": [ … ]
 }
```

9.4 Single-phase PV thing Description

```
{
  "name": "user defined",
  "type" : "adapters:EVCharger",
  "infrastructure-id": "user defined",
  "adapter-id": "uder defined",

  requirements: {
    "properties":[ … ],
      "actions": [ ... ],
      "events": [ ... ]
    },

    "properties": [
      {
        "pid": " PvInstalledCapacity ",
        "monitors": “adapters: PvInstalledCapacity”,
        "read_link": {
          "href": "/objects/{oid}/property/{pid}",
          "output": {
             "type":double,
            }
          }
       },
      {
```

```
      "pid": " Location ",
      "monitors": "adapters: Location",
      "read_link": {
        "href": "/objects/{oid}/property/{pid}",
        "output": {
            "type":"string",
          }
        }
    },
    {
      "pid": " Azimuth ",
      "monitors": "adapters: Azimuth",
      "read_link": {
        "href": "/objects/{oid}/property/{pid}",
        "output": {
            "type":"string",
          }
        }
    },
    {
      "pid": " Elevation ",
      "monitors": "adapters: Elevation",
      "read_link": {
        "href": "/objects/{oid}/property/{pid}",
        "output": {
            "type":"string",
          }
        }
    },
  {
      "pid": " ServiceLevel ",
      "monitors": "adapters: ServiceLevel",
      "read_link": {
        "href": "/objects/{oid}/property/{pid}",
        "output": {
            "type":"string",
          }
        }
    },
  {
      "pid": " InverterPVActualActivePower ",
      "monitors": "adapters: InverterPVActualActivePower",
      "read_link": {
        "href": "/objects/{oid}/property/{pid}",
        "output": {
            "type":double,
          }
        }
    },
  {
      "pid": " InverterPVActualReactivePower ",
      "monitors": "adapters: InverterPVActualReactivePower",
      "read_link": {
```

```
        "href": "/objects/{oid}/property/{pid}",
        "output": {
            "type":double,
          }
        }
      },
   {
      "pid": " InverterAccumulatedActiveEnergyProduction ",
      "monitors": “adapters: InverterAccumulatedActiveEnergyProduction”,
      "read_link": {
        "href": "/objects/{oid}/property/{pid}",
        "output": {
            "type":double,
          }
        }
      },
   {
      "pid": " InverterConsumerActivePowerLoad ",
      "monitors": “adapters: InverterConsumerActivePowerLoad”,
      "read_link": {
        "href": "/objects/{oid}/property/{pid}",
        "output": {
            "type":double,
          }
        }
      },
   {
      "pid": " InverterGridActivePowerLoad ",
      "monitors": “adapters: InverterGridActivePowerLoad”,
      "read_link": {
        "href": "/objects/{oid}/property/{pid}",
        "output": {
            "type":double,
          }
        }
      },
   {
      "pid": " Timestamp ",
      "monitors": “adapters: Timestamp”,
      "read_link": {
        "href": "/objects/{oid}/property/{pid}",
        "output": {
            "type":date,
          }
        }
      },


   ],
   "actions": [  ],
   "events": [    ]
 }
```

9.5 Three-phase PV thing Description


```
{
 "name": "user defined",
 "type" : "adapters:EVCharger",
 "infrastructure-id": "user defined",
 "adapter-id": "uder defined",

 requirements: {
  "properties":[ … ],
   "actions": [ ... ],
   "events": [ ... ]
  },

  "properties": [
   {
    "pid": " PvInstalledCapacity ",
    "monitors": “adapters: PvInstalledCapacity”,
    "read_link": {
     "href": "/objects/{oid}/property/{pid}",
     "output": {
        "type":double,
       }
     }
    },
   {
    "pid": " Location ",
    "monitors": “adapters: Location”,
    "read_link": {
     "href": "/objects/{oid}/property/{pid}",
     "output": {
        "type":”string”,
       }
     }
    },
   {
    "pid": " Azimuth ",
    "monitors": “adapters: Azimuth”,
    "read_link": {
     "href": "/objects/{oid}/property/{pid}",
     "output": {
        "type":”string”,
       }
     }
    },
   {
    "pid": " Elevation ",
    "monitors": “adapters: Elevation”,
    "read_link": {
     "href": "/objects/{oid}/property/{pid}",
     "output": {
        "type":”string”,
       }
```

```
      }
    },
  {
      "pid": " ServiceLevel ",
      "monitors": "adapters: ServiceLevel",
      "read_link": {
        "href": "/objects/{oid}/property/{pid}",
        "output": {
            "type":"string",
          }
      }
    },
  {
      "pid": " InverterPVActualActivePower ",
      "monitors": "adapters: InverterPVActualActivePower",
      "read_link": {
        "href": "/objects/{oid}/property/{pid}",
        "output": {
            "type":double,
          }
      }
    },
  {
      "pid": " InverterPVActualReactivePower ",
      "monitors": "adapters: InverterPVActualReactivePower",
      "read_link": {
        "href": "/objects/{oid}/property/{pid}",
        "output": {
            "type":double,
          }
      }
    },
  {
      "pid": " InverterAccumulatedActiveEnergyProduction ",
      "monitors": "adapters: InverterAccumulatedActiveEnergyProduction",
      "read_link": {
        "href": "/objects/{oid}/property/{pid}",
        "output": {
            "type":double,
          }
      }
    },
  {
      "pid": " InverterConsumerActivePowerLoad ",
      "monitors": "adapters: InverterConsumerActivePowerLoad",
      "read_link": {
        "href": "/objects/{oid}/property/{pid}",
        "output": {
            "type":double,
          }
      }
    },
  {
```

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Research and Innovation Action

Storage capacity sharing over virtual neighbourhoods of energy ecosystems

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WP 5 – SHAR-Q added value services based on collaboration business models

D5.4 Part II Decentralized Services

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Executive Summary

The scope of this deliverable is to describe the development and the implementation of the decentralized added value services which enable the peer to peer management of energy components towards the objectives and use cases identified in D2.5 “SHAR-Q collaboration business models and business requirements” and D5.1 “SHAR-Q Added Value Service Definitions”.

The decentralized AVS layer, which lies on the top of the SHAR-Q platform, aims to link consumer/prosumer and grid/market operators by offering peer to peer management capabilities in a transparent way.

In this deliverable, two generic types of decentralized added value services are described: one service for providing ancillary services to the grid operators, such as congestion management, and one service for provision of ancillary services to the market operators, such as imbalances management.

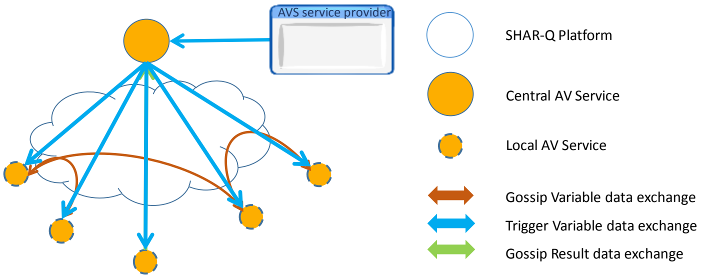

Figure I Overall architecture

The overall architecture in a high level annotation is illustrated in Figure I. Decentralized architecture consists of the Central Service (CS) and the Local Services (LS), which are interacting in asynchronous mode in a hierarchical fashion. Central Service is the representation of the AVS above the SHAR-Q platform framework. Local Services are the peers which are interacting towards the optimal management policy. Each Local Service is physically connected to an energy component of a local infrastructure.

This document presents in detail the gossip algorithm and the related weights’ update rule which are essential for the implementation of the decentralized services.
The decentralized AVS which are described in this document are:

- Ancillary services for grid operator
  - Congestion management via gossiping
- Ancillary services for market operator
  - imbalance management via gossiping

The interaction of service providers with the added value services is realized through the GUI, which facilitates also the input of preferences of end-users. Indicative examples from the services’ application are available in this document for better understanding of the service exploitation.

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List of Acronyms and Abbreviations

Term	Description
CS	Central Service
LS	Local Service
AVS	Added-value Service
EV	Electric Vehicle
DSO	Distribution System Operator
EVSE	Electric Vehicle Supply Equipment
PV	Photovoltaic
OGWAPI	Open Gateway API
SOC	State of Charge

1. Introduction

1.1 Scope of the document

This document is the part 2 of D5.4 and describes the functionality of decentralized use cases as integrated in the SHAR-Q platform. The document is organized in three major sections. In the first section the overall architecture is detailed, providing illustrations of the interconnections between modules. The second section describes the integration procedure in the SHAR-Q collaboration framework. The third section includes a short description of the scope of the decentralized services and explanatory selection of results of their implementation.

2. Decentralized (gossiping) AVS Architecture

2.1 Overall decentralized architecture design

The participants of energy market are peers which can benefit from the decentralized setup of added value services as described in this document. During the design and implementation of interaction among peers the following architecture has been emerged.

Decentralized architecture consists of the Central Service (CS) and the Local Services (LS), which are interacting in asynchronous mode in a hierarchical fashion, as further explained.

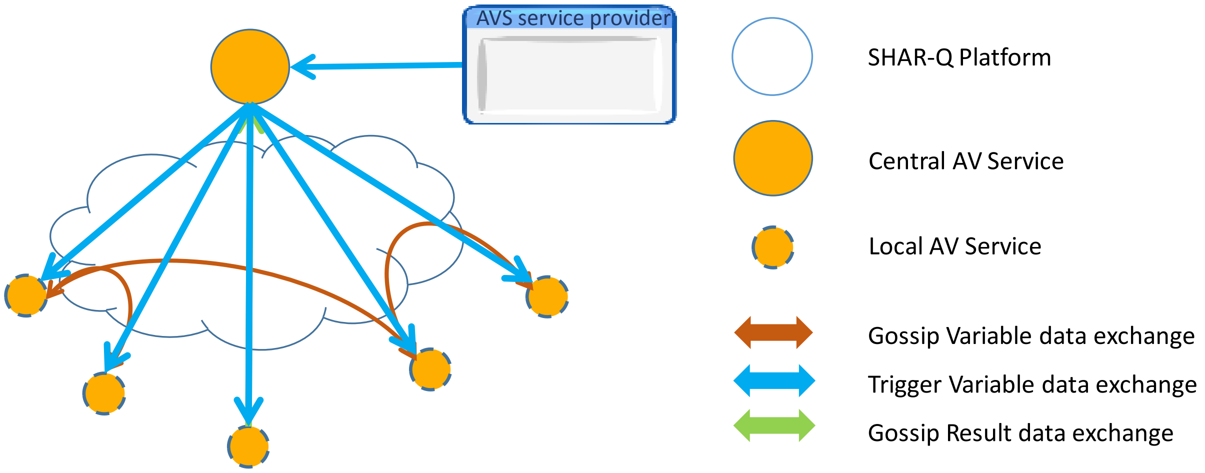

Figure 1 Overall architecture

Under the SHAR-Q framework, each energy component is represented by a Local Service for the purposes of the decentralized architecture. LS is physically linked with the object and is placed in the same level as the SHAR-Q adapter. Specifically, each EV charging station has been matched to its dedicated Local Service(s), which reside in the same private network, and thus they have inherently access to local measurements (Power, Energy, etc.) and preferences/information (SOC, Battery Capacity, time of departure, etc.) of EV Charging Stations and EV users. Taking into account the information, each Local Service calculates appropriate information in order to interact with other Local Services. Appropriate information includes the utility rate, which reflects the value of flexibility that can be exploited by the AVS.

Figure 1 shows a generic form of utility rate. The instant value of the function is calculated locally by the LS, taking as input the current values of measurements (Power, Energy) and the current preferences of users (SOC, Battery Capacity, time of departure). In any case, the values of utility rate are not associated with real costs and revenues and are just an approximation of relative comparisons among peers. In a short example, an EV which has just arrived has a very low SOC and very narrow charging window typically will show a utility rate of 0 units per kW, while an EV which is almost full and has a large charging window will show a utility rate of 100 units per kW. If we need to compare the flexibility of the two EVs, we will obviously select for curtailment the second candidate. In the decentralized architecture, we let the representatives of the two EVs (namely the two Local Services) to compare themselves by exchanging the appropriate information (namely the utility rate), in a decentralized fashion as explained further.

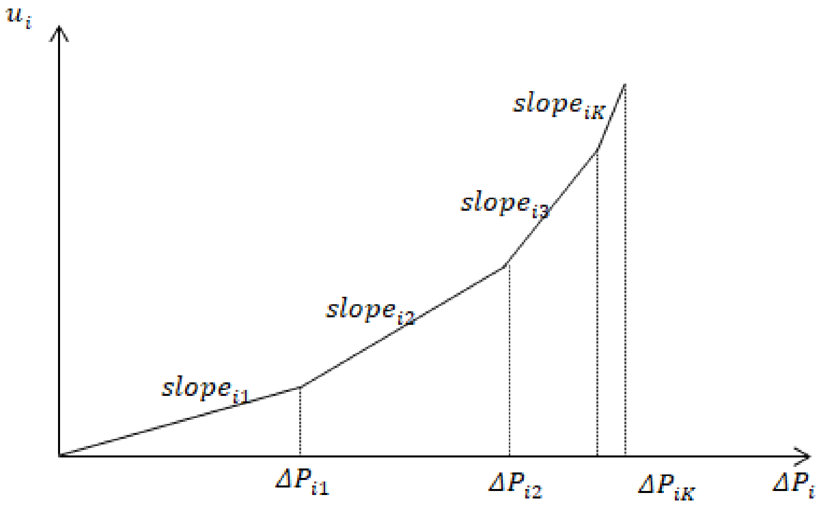

Figure 2 Utility function example

Each Local Service is an autonomous entity which interacts with other Local Services in its neighborhood towards the common target. All Local Services interact with the Central Service, which is responsible for their triggering and for the update of the neighborhood setup. During the initialization phase, the information of neighborhood is shared between each of the Local Services and the Central Service. The Central AVS queries Local Services about their neighbors and after accept the answers responds with the proper gossiping weights. Information of graph connectivity and regarding the proper weights can be retrieved by Central AVS, which stores the information in its own local DB. Graph connectivity and the selection of proper weights is essential for the convergence of decentralized algorithm, because the weights are used during the information processing.

Additionally to this role, Central Service is the shell of the AVS with the outer environment. Market and grid operators can access the AVS via the GUI. After entering their target into the GUI, Central Service is responsible for triggering the Local Services, which in their turn are starting to gossip with their neighboring Local Services.

Gossiping includes the mailing of specific values to neighbors and accepting the respective messages. After processing the information, which is contained in the aforementioned messages, a Local Service decides whether convergence has been reached or if more gossiping is needed. Technically, Local Services and Central Service communicate with each other via the SHAR-Q APIs, since they are located in remote sites.

The following image depicts the overall decentralized architecture from the perspective of Services.

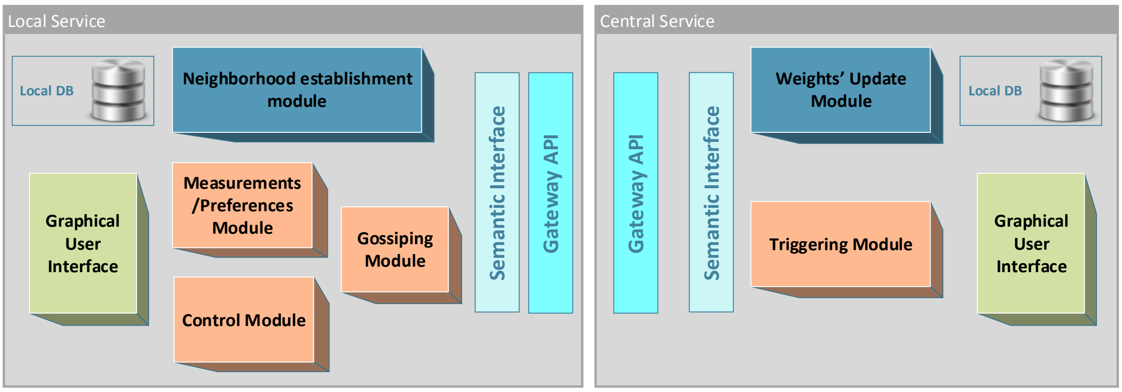

Figure 3 Architecture of Local and Central Services

End points are created in LS and CS, in order to expose local properties and facilitate the communication among independent entities.

The definition of local properties of Local Services is shown in Table1.

Table 1 Local Service properties

Property Name	Property field name	Type	Unit
Gossip	Active Power	Double	W
	Scale	Double	-
	Utility Rate	Double	-
	Epoch	Integer	-
	Gossip Type	Enumeration	e.g. AVERAGING, GOSSIP IS DONE
	Sender OID	String	-
Trigger	Gossip Type	Enumeration	e.g. AVERAGING, CONGESTION
	Target	Double	W
	Tolerance	Double	W
Neighbors	Neighbors	List of Neighbor class members (Neighbor Oid <String>, NeighborWeight <Double>)	-

Each Local Service gains access to the 'Gossip' endpoint of the neighboring Local Services via the appropriate call of the platform API. Accordingly, the Central Service gains access to the ''Neigbours'' and ''Triger'' endpoints of Local Services.

The definition of local properties of the Central Service is shown in Table 2.

Table 2 Central Service properties

Property Name	Property field name	Type	Unit
GossipResult	Active Power	Double	W
	Scale	Double	-
	Utility Rate	Double	-
	Epoch	Integer	-
	Gossip Type	Enumeration	e.g. AVERAGING, GOSSIP IS DONE
	Sender OID	String	-
TriggerGUI	Gossip Type	Enumeration	e.g. AVERAGING, CONGESTION
	Target	Double	W
	Tolerance	Double	W

A Local Service gains access to the 'GossipResult' endpoint of the Central Service, just to transfer the information that gossip has finished and that there is a viable result.
On the other hand, the 'TriggerGUI' endpoint of the Central Service is accessed by the market/grid operator via the GUI in order to initiate the AVS.
The following diagram explains the overall procedure of decentralized added-value services, showing the syntax of messages among the interacting entities (EV charging station, LS, CS, SHAR-Q Platform)

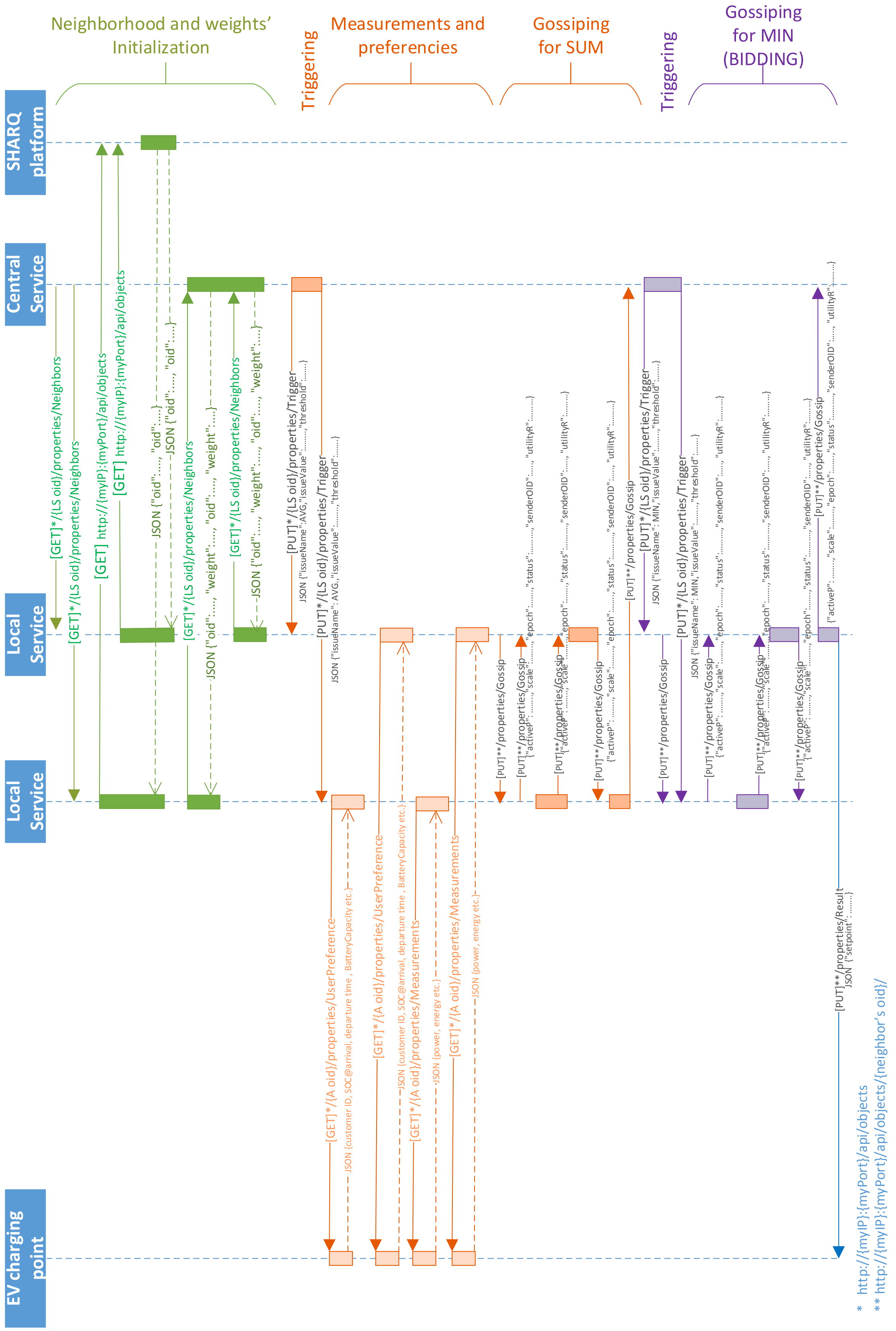

Figure 4 Overall procedure decentralized services

2.2 Communication level

Central Service communicates with Local Services via their open gateway APIs. Local Services communicate with each other also via their open gateway APIs.

Local Service communicates with energy components via the local infrastructure adaptor or via the infrastructure gateway API. Essential requirement is that the EV charging point should be capable to accept a smart profile and should have been registered to the monitoring service. End Users of EV charging station should have followed the procedure for end user registration, so as to grant access to their preferences.

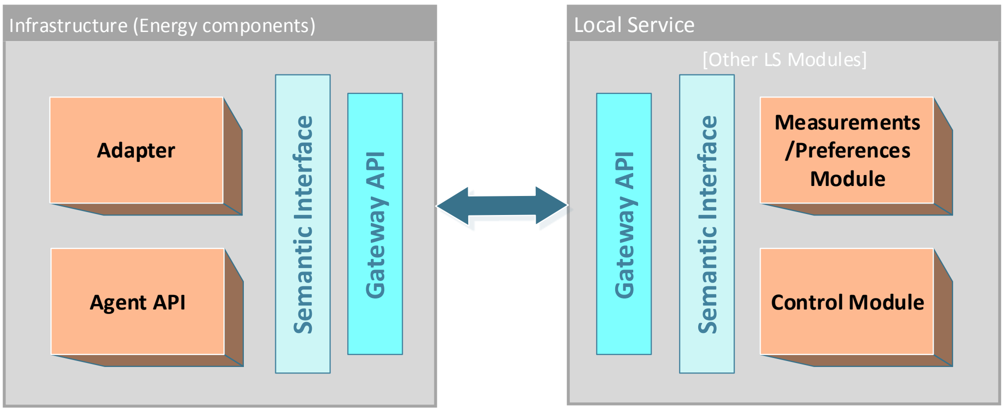

Figure 5 Communication architecture

2.3 Central AVS Service

The Central Service consists of the following structural entities:

- Weights' update Module
- Triggering Module
- Graphical User Interface
- Local Database

2.3.1 Weights' update Module

The weights' update module is a background procedure, which is active during the initialization phase. Initialization phase is scheduled at the first registration of the Central Service and whenever there is a change of status in the Local Service contracts with the Central Service.

The first step of this module includes the retrieval of OIDs of Local Services. Specifically, the Central Service sends a message to every LS that is contracted so as to ask for their neighboring OIDs.

Each Local AVS should become aware of his own OID and of his friends' OIDs via SHAR-Q platform. After conducting the contract with Central AVS, each LS should inform Central AVS about the OIDs of his own neighbors' OIDs, by answering to his message.

The second step of this module includes the Weights' calculation and the verification of graph connectivity. Upon receipt of neighborhood information, Central Service sends new messages to Local Services with the corresponding weights, one for every neighbor.

After a Local AVS leaves a contract, Central AVS recalculates and resends the proper weights so as to ensure graph connectivity and gossip convergence.

2.3.2 Triggering Module

The triggering module is a background procedure, which is always standby awaiting for a triggering input from the GUI. After accepting the triggering input, the Central AVS triggers every Local AVS in his list, by sending the issue Name and the targeted value (e.g. Congestion management- 5 kW, Production & Demand balancing – 0 kW), as well as the appropriate threshold for local calculations. After accepting triggering messages, the Local Services begin gossiping by sending messages to the Local Services in their friendship list.

2.3.3 Local Database

A local database is created onsite where the Central Service resides. The database is populated by the grid and market operators with information regarding the anticipated behavior of peers. Specifically, the database consists of list of potential combinations among Local Services and their neighborhood establishment in the form of properly calculated weights.

The Central AVS has access to the local DB where the appropriate weights are stored. Retrieval of weights is a procedure that follows the activation of the initialization module.

2.4 Local Service

The Local Service consists of the following structural entities:

- Neighborhood establishment Module
- Gossiping Module
- Control Module

2.4.1 Neighborhood establishment Module

The neighborhood establishment module operates after the query of the Central Service. Each Local Service has access to the OID of its neighboring Local Services, either via a local DB or via querying the SHAR-Q platform accordingly. The neighborhood establishment module is responsible for providing the Central Service with information about contracted OIDs and for accepting and keeping information regarding the appropriate weights.

Furthermore, neighborhood establishment module is responsible for accessing the EV charging stations' measurements and EV end-users' preferences after triggering, so as to update the information needed for the decentralized processing.

2.4.2 Gossiping Module

<u>Messaging</u>

The gossiping module is responsible for preparing, sending and accepting messages among the Local Services. Specifically, each LS is sending its internal information as contained in the Gossip Property (Active Power, Scale, Utility Rate, Epoch, Gossip Type, Sender OID) to the neighboring Local Services.

<u>Updating</u>

Each Local AVS accepts messages and updates accordingly her own internal values for the Gossip Property, before resending messages to friends. The update procedure depends on the Gossip Type. If the Gossip Type is 'AVERAGING', the update rule is the weighted summation of the Active Power values.

<u>Convergence</u>

Each Local AVS checks the deviation from her previous estimation and continues gossiping if this is under a threshold. Otherwise the "winner" announces convergence to Central AVS.

Convergence is granted by the selection of the appropriate weights for the neighborhood and by the connectivity of the graph, which are checked by the Central Service.

2.4.2.1. Gossip Algorithm for calculation of summation

The calculation of summation over the physical quantity $x_{i,0}$ associated to node i includes the exploitation of the modified push gossip algorithm, denoted as Algorithm 1. Let's assume appropriate initialization of the scaling vector $\boldsymbol{s}_0$ such that $\boldsymbol{s}_0 \in S$, where $S = \{s \in \mathcal{R}^n, s_{0,i} = 0, \forall i \in V \ and \ i \neq 1, s_{0,i} = 1 \ for \ i = 1\}$.

Let r denote the gossip round, $\boldsymbol{x_{AV}}$ the vector of n-elements corresponding to the average value of the quantity x, $x_{i,0}$, $x_{AV,r}^{est,i}$,and $x_{MIN,r}^{est,i}$ represent the value of x at node i, at round $r = 0$, the average and the minimum value of x at round r, respectively. $s_{i,0}$ and $s_r^{est,i}$ are the values of s in node i, at round $r = 0$ and at round r. $v_{Q,r+1}^{est,i}$ is any calculated value by node i over the function q at gossip round $r + 1$

Algorithm 1 Modified push gossip algorithm

1: **procedure** GOSSIP(x_i,$w_{ii}, w_{ij} \in \boldsymbol{W}: j \in N_i, threshold$)

2: **round** r=0

3: $x_{AV,r}^{est,i} \leftarrow x_{i,0}$

4: $s_r^{est,i} \leftarrow s_{i,0}$ // initialization varies according to the function

5: sends to all nodes $j \in N_i$ the pair of values $(x_{AV,r}^{est,i}, s_r^{est,i})$

6: error← 1

7: **while** error>threshold

8: **round** r=r+1

9: receives from all nodes $j \in N_i$ their pair of values $(x_{AV,r}^{est,j}, s_r^{est,j})$

10: calculates $x_{AV,r+1}^{est,i} = w_{ii} \cdot x_{AV,r}^{est,i} + \sum_{j \in N_i} w_{ij} \cdot x_{AV,r}^{est,j}$

11: $s_{AV,r+1}^{est,i} = w_{ii} \cdot s_{AV,r}^{est,i} + \sum_{j \in N_i} w_{ij} \cdot s_{AV,r}^{est,j}$

12: $v_{AV,r+1}^{est,i} = x_{AV,r+1}^{est,i}$

13: **if** $s_{AV,r+1}^{est,i} > 0$ **then**

14: $v_{Q,r+1}^{est,i} = \frac{x_{AV,r+1}^{est,i}}{s_{AV,r+1}^{est,i}}$

15: **end if**

16: error=$\left|v_{q,r+1}^{est,i} - v_{q,r}^{est,i}\right|$

17: sends to all nodes $j \in N_i$ the pair of values $(x_{AV,r+1}^{est,i}, s_{r+1}^{est,i})$

18: **end while**

19: **return** $v_{AV,r+1}^{est,i}$

20: **end procedure**

The proof that Algorithm 1 converges to the summation derives from the selection of matrix $\boldsymbol{W}$, so as to ensure that the calculation step 10 of Algorithm 1 converges to x_{Av} after a certain number of rounds. The same holds for step 11, which allows us to assume that node i possesses a good estimate of the average value of the scaling vector, which is $s_{AV} = \underline{\boldsymbol{1}}^T \cdot$

$\boldsymbol{s}_0 = \sum_{i=1}^{n} s_{i,0} = \frac{1}{n}$. Following the calculation step 14, assuming convergence of both steps 10 and 11 to x_{AV} and s_{AV} correspondingly, we have $\lim_{r\to\infty} \boldsymbol{v}_{Q,r}^{est} = \lim_{r\to\infty} \frac{x_{AV,r}^{est}}{s_{AV,r}^{est}} = \frac{\lim_{r\to\infty} x_{AV,r}^{est}}{\lim_{r\to\infty} s_{AV,r}^{est}} = \frac{x_{AV}}{s_{AV}} = \frac{1}{n} \cdot \sum_{i=1}^{n} x_{i,0} \cdot \left(\frac{1}{n}\right)^{-1} = \sum_{i=1}^{n} x_{i,0}$.

Therefore, according to the calculation step 14, every node i has its own estimate of the value of summation, which is $\boldsymbol{x}_{SUM} = \sum_{i=1}^{n} x_{i,0}$, after a certain number of rounds. In this case the notation about the function of interest q is SUM.

2.4.2.2. Gossip Algorithm for calculation of minimum

Algorithm 2 Gossip algorithm for minimum calculation

1: **round** r=0

2: $x_{MIN,r}^{est,i} \leftarrow x_{i,0}$

3: sends to all nodes $j \in N_i$ the value $x_{MIN,r}^{est,i}$

4: **while r<r$_{max}$**

5: **round** r=r+1

6: receives from all nodes $j \in N_i$ their values $x_{MIN,r}^{est,j}$

6: calculates $x_{MIN,r+1}^{est,i} = \min\{x_{MIN,r}^{est,i}, x_{MIN,r}^{est,j}\}$

7: **if** $x_{MIN,r+1}^{est,i} < x_{MIN,r}^{est,i}$ **then**

8: sends to all nodes $j \in N_i$ the value $x_{AV,r+1}^{est,i}$

9: **end if**

11: end while

The algorithm for the calculation of the minimum of the physical quantity $x_{i,0}$ converges after $O(nlogn)$ rounds. Taking into account the graph topology, we can identify the maximum number of rounds to obtain convergence to the minimum value at every node. This number is introduced in line 4 as r_{max}

2.4.3 Control Module

"Winner" Local Service(s) send the effective control policy to the facility owners via their Open Getaway API or via the Adapter by accessing the appropriate endpoint and the EV charging point operates according to the new smart profile. Results are also sent to the Central Service for information purposes.

2.4.4 Local Database

A local database is created onsite where the Local Services reside. The database is populated by the LS itself with information regarding the OIDs and weights of peers. Specifically, the database is updated whenever a new contract has been conducted and when the Central Service sends a weights update.

2.5 User Interface

2.5.1 Graphical User Interface for service activation

The Graphical User Interface facilitates the market and grid operators to interact with the Central AVS. For the purposes of triggering, the GUI provides the appropriate input box, where the operator can enter his requirement for flexibility. Afterwards, GUI connects to the dedicated end point of the Central Service and sends the input of the operator. Central AVS has been triggered via the GUI.

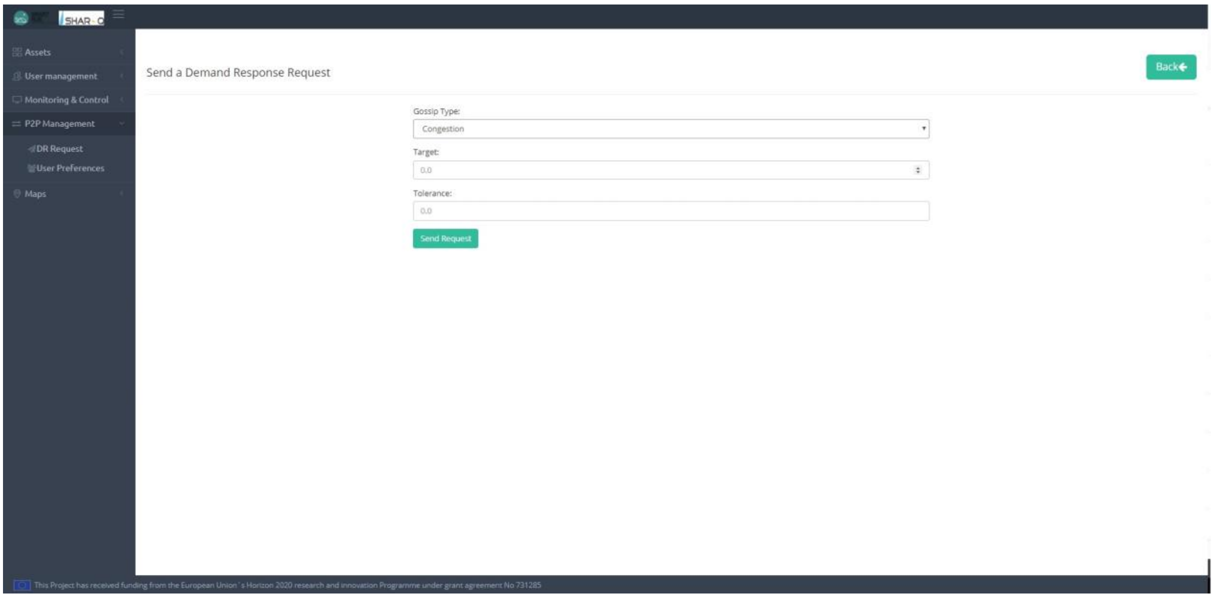

Figure 6 GUI for Decentralized Service activation

2.5.2 Graphical User Interface for End-Users' preferences

The user interface of the EV charging points facilitates also the end-users to insert their preferences, which are transferred via the GUI to the linked Local Service(s). With the introduction of user preferences, one commits to the service. In Figure 7 the relevant GUI is shown. End-User should insert information about the Nominal Battery Capacity, SOC, Expected Departure Time, Number of Phases and Maximum cable current.

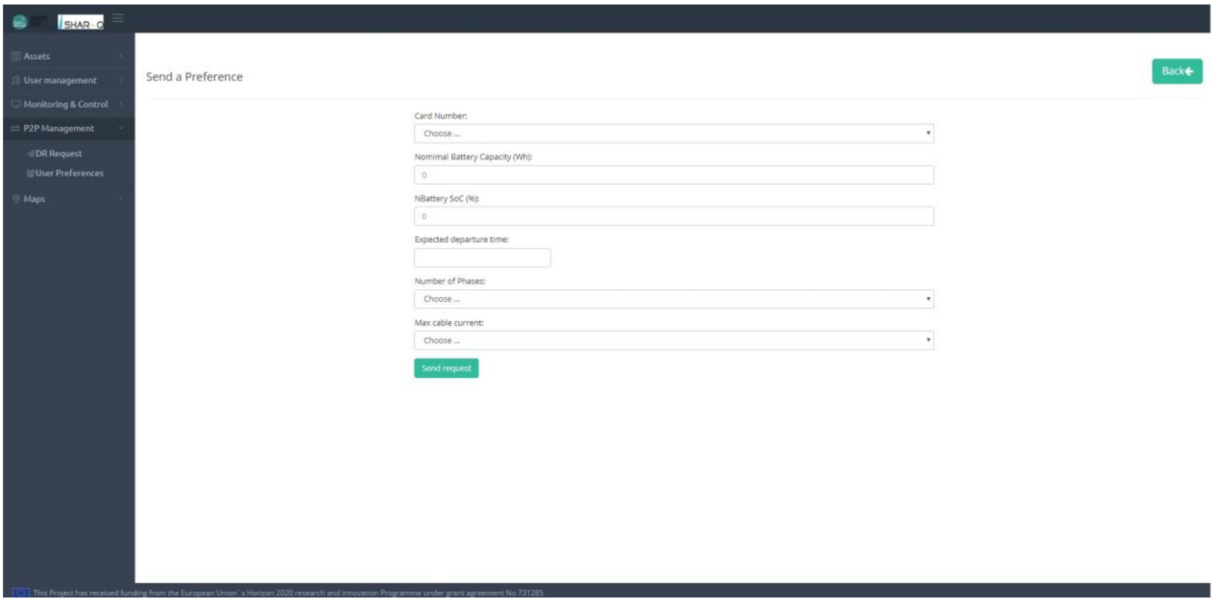

Figure 7 GUI for User Preferences

3.Decentralized AVS integration into SHAR-Q platform

3.1 Central Service registration to SHAR-Q

The Central Service is the representation of the added-value service in the SHAR-Q platform. The Service should be created and registered by the grid or market operator respectively according to their requirements. The registration procedure includes the selection of the Central Service type, if it is meant to provide ancillary services to the grid operator or to the market operator. Thing description for the registration of the Central Service is provided in the Annex.

According to the knowledge about the potential peers, the grid/market operator should create and update a supportive local database containing a catalogue with the appropriate weights to be sent to the Local Services later on. The maintenance and update of the local database is under the control of the operator and is independent of the SHAR-Q platform.

After registration to the platform, the owner of the Central Service should enable the public visibility and the data exchange under request. The owner of the Central Service should accept the incoming requests for contracts coming from Local Services. OIDs of Local Services are provided as contractual information.

3.2 Local Services registration to SHAR-Q

Energy components may be registered under different organisations in order to be able to participate in gossiping (e.g. storage associated to PVs vs storage distinct from PVs). Thing description for the registration of the Local Service is provided in the Annex.

Facility representative/owner should register a Local AVS under the same organisation with the energy components that are going to participate in the decentralized added-value services. The association of energy components and Local Services is inherent and does not require a contract, because the two entities have been registered under the same organization. However, special requirements and the final link between Local Service and a specific energy component is under the only responsibility of the facility owner. For EV charging stations one Local Service corresponds to each card slot, thus there are two local Services associated with each EV charging station. Subsequently, the owner of the EV charging station should register two Local Services under his organization, which are inherently neighbors.

After registration to the platform, the owner of a Local Service should enable the public visibility and the data exchange under request.

3.3 Local service to Local Service and Local Service to Central Service contract establishment

Each Local AVS is conducting one or several contracts with other Local Services that have been registered under different organisations. The owner of each Local Service should conduct a new contract with the Central Service after registration. OIDs of Local Services are provided as contractual information at this stage. The owner of the Local Service should handle the incoming requests for contracts coming from other Local Services and may also conduct new contracts with other Local Services by sending the appropriate requests via the SHAR-Q platform. A Local Service should have a valid contract with the Central Service and at least a valid contract with one other Local Service in order to be gossip ready.

The definition of the neighborhood is deriving from the mutual contracts.

The contract between LS and CS contains the essential information about the OID of the LS in the platform. The OIDs of neighboring LS are not included in the registration information and they are mailed to the CS in the initialization phase.

3.4 Charging infrastructure registration to SHAR-Q

The EV charging infrastructure should follow the typical procedure for the registration to the platform as described in D5.4 Part A. However, there is an inflexible requirement for the EV charging points in order to be gossip ready, that they should accept smart profiles.

3.5 Local AVS-EVSE contract establishment

As already described, the association of EV Charging infrastructure and Local Services is inherent and does not require a contract, provided that the two entities have been registered under the same organization.

Furthermore, we assume that the EV charging infrastructures' owners should have subscribed to the monitoring service, in order to facilitate the measurements requirements of the Local Services. Another prerequisite is that the communication layer of EV charging station includes the appropriate decentralized module, so as to handle properly the incoming requests by the Local Services.

3.6 Neighborhood establishment and weights' update

After conducting the mutual contracts, each Local Service is aware of the OIDs of its contracted (neighboring) Local Services. The Central Service queries every contracted Local Service about the neighboring Local Services via the gateway API. After accepting the answers, the Central Service processes the information in order to perform the graph connectivity check and determine the appropriate weights. There follows a second round of messages towards the Local Services APIs, which contain the corresponding weights for every link.

The appropriate selection of the weights' matrix ensures that the gossip algorithm converges after a finite number of r rounds to the average, thus $\lim_{r\to\infty} x_{AV,r}^{est,i} = x_{Av}$ for every Local Service i. The convergence is not only guaranteed, but also accelerated, if we construct the weights' matrix according to the assumptions of the semi-definite problem associated to the minimization of spectral radius of W.

More specifically, we assume a symmetric weights' matrix (the branches of the graph have the same weight for both connected Local Services) of the form $\boldsymbol{W} \in \mathcal{L}$, where $\mathcal{L} = \{W \in \mathcal{R}^{n\times n}, W_{ij} = 0, \forall j \notin \mathcal{E}\ and\ i \neq j, W_{ij} = W_{ji}\}$.

The construction of the optimal weights' matrix to be used within the gossip rounds, is based on the semi-definite programming problem (1) associated with the minimization of the convergence rate (7), thus the minimization of spectral radius of W .

We want to accelerate convergence of the gossiping by solving the following problem:

$$\begin{aligned} &\text{minimize } rate_{conv}(W) = \rho\left(W - \frac{\mathbf{1}^T\cdot\mathbf{1}}{n}\right) \\ &\text{subject to} \qquad W \in \mathcal{L}, \lim_{r\to\infty} \boldsymbol{W}_r = \frac{\mathbf{1}^T\cdot\mathbf{1}}{n} \end{aligned} \quad (1)$$

The convergence rate is associated with the spectral radius ρ of the weights' matrix, and the problem (1) is very close to the fastest mixing Marcov chain for graph G. However, the non-existence of the positive weights' constraints, leads to solutions containing negative weights, which in fact are accelerating even more the convergence.

The Central Service may have local access to optimization tools in order to perform the aforementioned optimal selection of weights, especially if the number of Local Services is increased.

The following example shows the procedure of Neighborhood establishment and weights' update.

We assume that nine Local Services have been registered to the SHAR-Q Platform and that they have conducted mutual contracts as shown in Table 3.

Table 3 Example contracts between 9 Local Services

Local Service Name	Contracted with
LS1	LS2
LS2	LS1, LS3, LS5
LS3	LS2, LS4, LS6, LS7
LS4	LS3
LS5	LS2
LS6	LS3
LS7	LS3, LS8, LS9
LS8	LS7
LS9	LS7

We assume that each one of the nine Local Services has a valid contract with the Central Service. Therefore, the Central Service sends nine messages, one to each Local Service, and receives nine answers containing the information that is shown in Table 3. For example, LS3 will answer to the Central Service that its list of contracted neighbours contains {LS2, LS4, LS6, LS7}. After accessing the local database, the Central Service sends one message to each Local Service containing personalized information as shown in Table 4. We should mention that the first weight refers always to the Local Service itself.

Table 4 Message content to Local Services (weight update)

	Message content				
Recipient Name	Self-weight	Weight of 1st neighbor	Weight of 2nd neighbor	Weight of 3rd neighbor	Weight of 4th neighbor
LS1	0.6059	0.3941			
LS2	-0.2250	0.3941	0.4205	0.4104	
LS3	-0.1233	0.4205	0.1216	0.1491	0.4320
LS4	0.8784	0.1216			
LS5	0.5896	0.4104			
LS6	0.8509	0.4191			
LS7	-0.1690	0.4320	0.4064	0.3305	
LS8	0.5936	0.4064			
LS9	0.6695	0.3305			

4. Ancillary services for grid operator

4.1 Scope

This service is grid oriented and supports the grid operator by providing ancillary services. The grid operator announces his total demand forecast to the Central AVS via the GUI and the gossiping procedure initiates immediately if the total PV production does not meet demand. After convergence has been achieved, decisions are taken in a decentralized manner and actions are done locally by Local Services without the need of any interaction with the grid operator.

4.2 Service integration of PVs and EVs

In order for the actions to be done locally, energy components should be linked to the corresponding Local Services. Specifically, PVs and EVs should enable the monitoring service so as the Local Service can grant access to their measurements. EV charging points should also accept smart profiles, which will be their endpoints where the LS can send their control actions after convergence has been achieved. EV end-users should also use the appropriate part of the GUI to provide their preferences and accept their participation in the decentralized services.

4.3 Congestion management via Gossiping

We denote as $N_i \subseteq V$ the set of neighboring Local Services of the Local Service i, namely set N_i contains every Local Service j of V such that $(i, j) \in E$.

Problem statement

Let P_i^t be the active power as measured by the PV/EV charging linked to the Local Service i at time t. The Local Service i is associated with a utility function $u_i(\Delta P_i)$, which expresses the flexibility to curtail or increase demand of EV charging point and production of PVs.

Let the forecast for total demand be S_{max}, as targeted by the grid operator. In case the total apparent power $S_{TOT}^{t_0}$ at time t_0 exceeds S_{max} , the mismatch $S_{TOT}^{t_0} - S_{max}$ should be resolved, so that the total power S_{TOT}^{t} at time t is $S_{TOT}^{t} = \sum_{i=1}^{n} S_i^t \le S_{max}$. The time for the solution of the overcharging $t - t_0$ depends on the thermal limits of transformers and lines and in practice, it is in the order of several minutes.

The apparent power as measured can be approximated by

$$S_{TOT}^{t_0} = \sum_{i=1}^{n} S_i^{t_0} = \sum_{i=1}^{n} \sqrt{{P_i^{t_0}}^2 + {Q_i^{t_0}}^2} \qquad (2)$$

In order to simplify calculations, we assume the same, constant power factor at each node, thus the total power P_{TOT}^{t} at time t should be:

$$P_{TOT}^{t} = \sum_{i=1}^{n} P_i^t \le P_{max} \qquad (3)$$

The difference $\Delta P^{t_0 - t} = \sum_{i=1}^{n} P_i^{t_0} - \sum_{i=1}^{n} P_i^t = \sum_{i=1}^{n} \left(P_i^{t_0} - P_i^t\right)$ should be allocated among the Local Services, as expressed by the following cost-like objective function:

$$F = \sum_{i=1}^{n} u_i(\Delta P_i) \qquad (4)$$

The formal representation of the congestion management problem is expressed as:

$$\begin{aligned} & \qquad\qquad\qquad\qquad Minimize \;\; F \\ subject\ to \qquad & \sum_{i=1}^{n} \mathrm{P_i} \leq \; P_{max} \qquad\qquad (5) \\ & 0 \leq \mathrm{P_i} \leq P_i^{t_0} \;\;, \text{for i as loads} \\ & P_{G,max} \leq \mathrm{P_i} \leq P_i^{t_0} \;, \text{for i as generators} \end{aligned}$$

This is a resource allocation problem among separable utility functions under the global restriction of the total amount of resources. It belongs to the class of monotropic optimization problems, which means optimization over a summation of linear functions of single variable.

For illustration purposes, the proposed gossip algorithm is applied to a set of two PVs and 7 EV charging end users. It is considered that each resource is associated with a Local Service and that procedure of registration has been completed. Table 5 summarizes the demand and production data, as measured at the beginning.

It is considered that the grid operator is constrained by P_{max}=75 kW. It can be easily seen that the total net load at t_0 results in violation of this limit, as $P_{TOT}^{t_0} = \sum_{i=1}^{9} P_i^{t_0} = 100\ \mathrm{kW} > P_{max}$. However, we assume that the grid operator has not direct access to this measurements and acts just as the service provider of the appropriate Central Service.

Table 5 Measurements for the ancillary services for grid operator

Energy component	End-User	Local Service	Controllable	Active Power Measurement (kW)
PV1	-	LS1	No	0
EV Charging Station 1	End-User 1	LS2	Yes	10
EV Charging Station 1	End-User 2	LS3	Yes	30
EV Charging Station 2	End-User 3	LS4	Yes	3
EV Charging Station 2	End-User 4	LS5	Yes	15
EV Charging Station 3	End-User 5	LS6	Yes	2
PV2	-	LS7	No	-10
EV Charging Station 4	End-User 6	LS8	Yes	30
EV Charging Station 4	End-User 7	LS9	Yes	20

The grid operator inserts his target into the GUI and so the Central Service is triggered with the values Target=75 kW, Tolerance=0.01 and Gossip Type=AVERAGING. The Central Service is transferring the trigger event to the Local Services, which are starting to gather the EV and PV measurements. The neighborhood establishment and the weights' update is assumed to have already been completed in a previous stage.

After triggering every Local Service participates in the AVERAGING by activating the Gossiping Module, while exchanging information only with its immediate peers. Figure 5 depicts the gossip rounds that each Local Service performs to achieve consensus on $\sum_{i=1}^{9} P_i^{t_0} = 100\ kW$. The total number of gossip rounds until convergence is about 50 with the given tolerance.

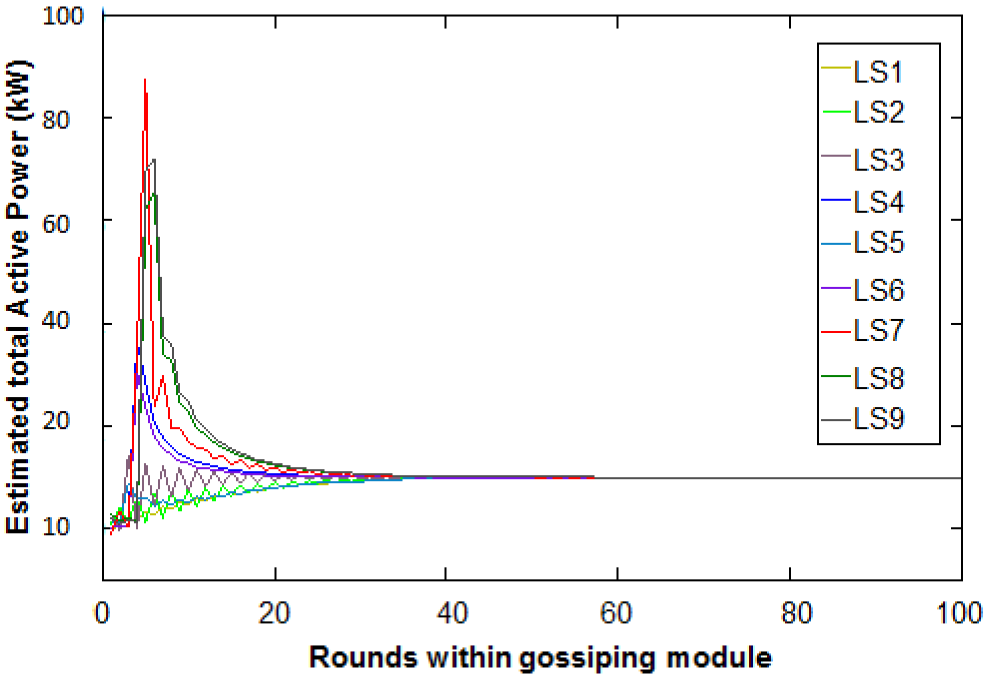

Figure 8 Convergence of gossiping to the total power

Table 5 provides a sample of the gossip rounds' calculations for Local Service 7, which shows the largest deviations during the summation calculation. In every gossip round the $Pest\ v_{7,r+1}$ is calculated as a weighted summation over the tuples of $(P_{AV,r}^{est,j}, s_r^{est,j})$, where $j \in N_7 = \{3,8,9\}$.

The largest deviation occurs at the gossip round 4, when the information about the scaling factor s is for the first time disseminated through the graph until Local Services 8 and 9, letting them update their s to non-zero values.

Table 6 Sample gossip rounds for LS7

	$v_{7,r}$ (kW)	$P_{3,r}$	$s_{3,r}$	$P_{8,r}$	$s_{8,r}$	$P_{9,r}$	$s_{9,r}$
$Pest_{7,r=0}$	-0,1000	0,3000	0.0000	0,3000	0.0000	0,2000	0.0000
$Pest_{7,r=1}$	0,3345	-0,0315	0.0000	0,1374	0.0000	0,1008	0.0000
$Pest_{7,r=2}$	0,0191	1,4165	0.1657	0,2175	0.0000	0,1780	0.0000
$Pest_{7,r=3}$	3,4285	0,0080	0.0427	0,1368	0.0000	0,1255	0.0000
$Pest_{7,r=4}$	8,7822	1,2743	0.1614	6,2204	0.0291	6,9802	0.0237
$Pest_{7,r=5}$	2,3509	0,4266	0.0575	6,5535	0.0199	7,1911	0.0179
$Pest_{7,r=6}$	2,9715	1,2187	0.1519	3,3897	0.0477	3,7622	0.0412

5. Ancillary services for market operator

5.1 Scope

This service is market oriented and supports the market operator by providing ancillary services. The market operator declares his requirements for total demand to the Central AVS via the GUI and the gossiping procedures initiates immediately if there is an imbalance. After convergence has been achieved, decisions are taken in a decentralized manner and actions are done locally by Local Services without the need of any interaction between EV charging stations and the market operator.

5.2 Service registration of charging stations

In order for the actions to be done locally, energy components should be linked to the corresponding Local Services. EV charging points should enable the monitoring service so as the Local Service can gain access to their measurements and status. EV charging points should also have the capability of accepting smart profiles, which will be their endpoints where the LS can send their control actions after convergence has been achieved. EV end-users should also use the appropriate part of the GUI to provide their preferences and accept their participation in the decentralized services.

5.3 Imbalance ancillary services via Gossiping

This service's problem statement is similar to the aforementioned problem statement. However, we assume that there are only EV charging points participating in the service, which means that the problem is formulated in the same way with the EVs to be considered either as loads either as negative loads if we are going to increase their demand.

This service facilitates the market operator to alleviate imbalances in the market, if for example there is a higher EV charging demand than the declared one. For illustration purposes, the proposed gossip algorithm is applied to a set of 8 EV charging end users. It is considered that each resource is associated with a Local Service and that procedure of registration has been completed. Table 6 summarizes the active power measurement and the utility function of the EVs, as measured and estimated at the beginning.

It is considered that the market operator has declared P_{max}=100 kW. It can be easily seen that the total net load at t_0 results in violation of this limit, as $P_{TOT}^{t_0} = \sum_{i=1}^{8} P_i^{t_0} = 110\text{ kW} > P_{max}$. However, we assume that the market operator has not direct access to this measurements and acts just as the service provider of the appropriate Central Service.

Table 7 Measurements for the ancillary services for grid operator

Energy component	End-User	Local Service	Utility Rate	Active Power Measurement (kW)
EV Charging Station 1	End-User 1	LS1	35.7	10
EV Charging Station 1	End-User 2	LS2	100	30
EV Charging Station 2	End-User 3	LS3	100	3
EV Charging Station 2	End-User 4	LS4	37.4	15
EV Charging Station 3	End-User 5	LS5	36.1	2
EV Charging Station 3	End-User 6	LS6	33.3	0
EV Charging Station 4	End-User 7	LS7	38.5	30
EV Charging Station 4	End-User 8	LS8	34.8	20

The grid operator inserts his target into the GUI and so the Central Service is triggered with the values Target=100 kW, Tolerance=0.01 and Gossip Type=IMBALANCE. The Central Service is transferring the trigger event to the Local Services, which are starting to gather the EV measurements and the EV End-User preferences. According to the preferences, each LS calculates the value of the utility rate. The neighborhood establishment and the weights' update is assumed to have already been completed in a previous stage.

After triggering every Local Service participates in the IMBALANCE Service by activating the Gossiping Module, to calculate the minimum value in order to identify the lowest bid at each stage, while exchanging information only with its immediate peers.

After six gossip rounds, every Local Service knows that the minimum bid for curtailment is 34.8 during the first stage of gossiping. Comparison with the internal bid lets the Local Service with the least bid to self-define itself as the "winner" and react by reducing its demand or increasing its production.

The "winner" of the first stage is Local Service 8, which decides to restrict its demand. Gossiping continues until the global load curtailment meats the targeted value as posed by the market operator. The final allocation of difference ΔP^{t_0-t} among the Local Services is shown in Table 7.

Table 8 Allocation of target total active power

Local Service	Active Power after control (kW)
LS1	6
LS2	30
LS3	3
LS4	15
LS5	0
LS6	0
LS7	30
LS8	16

Figure 6 shows the stage-by-stage allocation of the ΔP^{t_0-t} , until the desired consensus in P^t_{TOT} has been reached at the 4th stage.

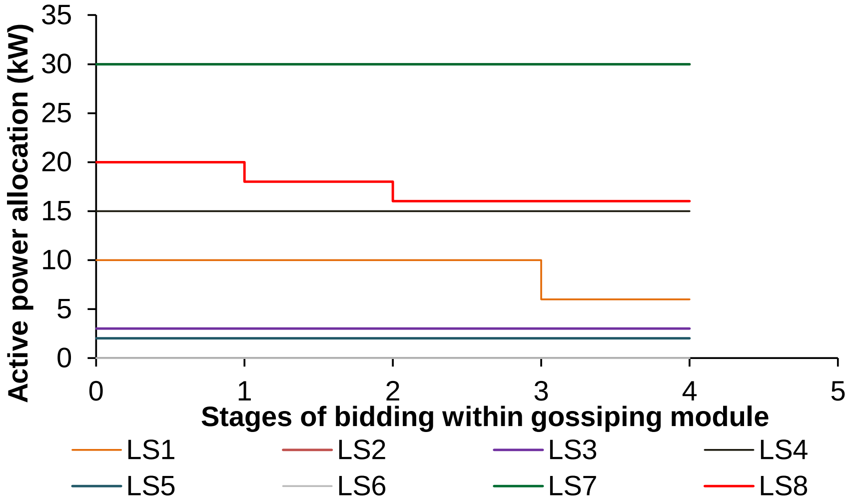

Figure 9 Allocation of target total power

6.Conclusions

This document is the part 2 of D5.4 and describes the functionality and implementation of decentralized use cases as integrated in the SHAR-Q platform. The decentralized AVS layer, which lies on the top of the SHAR-Q platform, aims to link consumer/prosumer and grid/market operators by offering peer to peer management capabilities in a transparent way.

In this deliverable, two generic types of decentralized added value services have been described: one service for providing ancillary services to the grid operators, such as congestion management, and one service for provision of ancillary services to the market operators, such as imbalances management.

The implementation of the AVS in real conditions requires the existence of specific infrastructures and the development of gateway APIs/Adapters capable of connecting smart energy components to the SHAR-Q platform. Thus, the development of the AVS is tightly coupled with the pilot requirements defined in the SHAR-Q project.

The decentralized added value services can be exploited by the grid and market operators as management solutions to unlock new ancillary service possibilities.

7.References

[KOU16] D. I. Koukoula and N. D. Hatziargyriou, "Gossip Algorithms for Decentralized Congestion Management of Distribution Grids," in IEEE Transactions on Sustainable Energy, vol. 7, no. 3, pp. 1071-1080, July 2016.

[KOU15] D. I. Koukoula and N. D. Hatziargyriou, "Convergence acceleration of gossip protocols applied for decentralized distribution grid management," 2015 IEEE Eindhoven PowerTech, Eindhoven, 2015, pp. 1-6.

8. ANNEX I

8.1 Thing description for the registration of Central Service


```
{
  "name": "user defined",
  "type" : "core:Service",
  "infrastructure-id": "user defined",
  "adapter-id": "uder defined",

  requirements: {
    "properties":[
                        {"pid": "Trigger",
                               "write_link":{
                                    "href":"objects/{oid}/properties/{pid}",
                                    "input":{
                                       "type":"object",
                                       "field":[
                                         {"name":"gossipType", "schema":{  "type":"string" }  },
                                         {"name":"target",  "schema":{   "type":"string"  }       },
                                         {"name":"tolerance",  "schema":{ "type":"double" }    }
                                        ]
                                    }
                                }
                            }
      ],
      "actions": [ ... ],
      "events": [ ... ]
    },
  "properties" : [
          {
            "pid": "GossipResult",
            "monitors":"gossipVariables",
            "write_link":{
                 "href":"objects/{oid}/properties/{pid}",
                 "input":{
                    "type":"object",
                   "field":[
                      {"name":"activePower", "schema":{ "type":"double" } },
                      {"name":"scale", "schema":{ "type":"double" } },
                      {"name":"epoch", "schema":{  "type":"integer" } },
                      {"name":"utilityRate", "schema":{  "type":"double" }  },
                      {"name":"epoch", "schema":{  "type":"integer" }  },
                      {"name":"gossipType", "schema":{  "type":"string" }  },
                      {"name":"senderOID",  "schema":{  "type":"string" }  }
                    ]
                 }
            }
          }
       ],
  "actions" : [],
```

"events" : []
}

8.2 Thing description for the registration of Local Service

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{  "name": "Local_Service_XX",
"type": "core:Service",
"infrastructure-id": " Local_Service_XX ",

"properties" : [
        {
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          "monitors":"gossipVariables",
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               "input":{
                   "type":"object",
                   "field":[
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                      {"name":"scale", "schema":{ "type":"double" } },
                      {"name":"epoch", "schema":{  "type":"integer" } },
                      {"name":"utilityRate", "schema":{  "type":"double" }  },
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                      {"name":"senderOID",  "schema":{  "type":"string" }  }
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               "input":{
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                   "field":[
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                      {"name":"target",  "schema":{   "type":"string"  }      },
                      {"name":"tolerance",  "schema":{ "type":"double" }    }
                   ]
               }
            }
        }
    ],
"actions" : [],
"events" : []
}
```