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CleAnweb Gamified Energy Disaggregation

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D3.4 1st Integrated ChArGED system

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Abbreviations

API	Application Programming Interface
BLE	Bluetooth Low Energy
IoT	Internet of Things
JSON	JavaScript Object Notation
kWh	Kilowatt hours
MVP	Minimum Viable Product
mPRM	mPower Remote Manager
MQTT	MQ Telemetry Transport
NFC	Near Field Communication
SSL	Secure Sockets Layer
SQS	Simple Queue Service
TCP	Transport Communication Protocol
TLS	Transport Layer Security
REST	Representational state transfer
UI	User Interface

Executive Summary

This deliverable presents the 1st integrated system of ChArGED and is related to the integration, validation and testing task of WP3. The emphasis is on achieving efficient and low-overhead integration of all sub components (backend systems, gateways and Mobile App). This will be an on-going process, following agile methodology approaches and providing three prototypes to be tested with end-users in order to ensure their acceptance. Technical testing/validation mechanisms will take place prior to providing the deliverables to end-users for validation, to make sure that, as subsystem development is progressing, there are no unforeseen integration issues and technical problems.

The deliverable complements the work done in Deliverables 3.3 "System Components", that provided the specifications of the separate ChArGED system components, and D3.7 "Incentive mechanisms final report", that designed appropriate incentive mechanisms of the gamified approach of ChArGED. The contributions of these two deliverables are combined in D3.4 in order to achieve the integration of the software components and the developed game mechanics and to demonstrate initial end-end operation of the system addressing the first game challenges.

The deliverable presents a review of the ChArGED approach, the game concepts, the related use cases and challenges that will be addressed with the integrated system. It further describes the system architecture and software implementation details for the Data/Core Backend components that are included in the 1st integrated system. The document also provides a description of the integrated system demonstrator and indicative screenshots of an end-end challenge implementation that involves all integrated modules. Finally, the deliverable describes the procedure for performing the testing of the ChArGED platform to demonstrate that the ChArGED system implementation meets requirements established in the technical deliverables.

1 Introduction

Purpose and scope

Deliverable D3.4 has been preceded by Deliverable D3.3, entitled "System Components", that was delivered at M18 and has provided the final ChArGED platform architecture and the specifications of all the system components, functionalities and interfaces implemented.

The goal of D3.4 is to present the first demonstration of the integration between the ChArGED backend system, gateways and Mobile App. It will also include a description of the revised Mobile App and of the related Game challenges that have already been implemented, based on the game design principles that have been detailed in deliverable D3.7 "Incentive mechanisms final report" (submitted at M18).

Intended Audience

The purpose of this deliverable is to document and demonstrate the first ChArGED integrated system.

The intended audience includes the project partners, especially the pilot users and the general interested public. Members of the development team can use this report as guideline for future work.

This report also provides clarity on the ChArGED integrated system that will be deployed at public buildings through various installation stages and also shows the working modules that can be used for hands-on system demonstration and evaluation by the intended public buildings.

Relation to other activities

Emphasis will be given to achieve efficient with low-overhead integration of all sub components. The integration between the backend system, the gateways and the Mobile App will be an on-going process, following agile methodology approaches and providing three prototypes to be tested with end-users in order to ensure their acceptance (within the tasks of WP4).

Technical testing/validation mechanisms will take place prior to providing the deliverables to end-users for validation, to make sure that as subsystem development is progressing and there are no unforeseen integration issues and technical problems.

Table 1: D3.4 dependencies and handovers

ID	Title	Comments
D3.7	Incentive mechanisms final report	It provides the design principles to be integrated within the game mechanics component and affects the chosen game challenges.

D3.2	Architecture and system components specification	It describes the initial system architecture and design of system components and interfaces that will also be followed for the 1st integrated system.
D3.3	System Components	This document provides an accompanying guide on the developed software components that are considered for the 1st integrated system.
D4.2	Trials specifications	It provides the specifications of the system components that will be tested at various stage of the piloting exercise, affecting the choices for the 1st integrated system..

Document Overview

The key deliverable is the demonstration of the 1st integration of the ChArGED system components. This document provides an accompanying guide on the end-end system operation for specific game challenges and is organised as follows:

Chapter 2 presents a review of the ChArGED approach, the game concepts, the related use cases and challenges that will be addressed with the integrated system.

Chapter 3 describes the system architecture and software implementation details for the Data/Core Backend components that are included in the 1st integrated system.

Chapter 4 provides a description of the integrated system demonstrator and indicative screenshots of an end-end challenge implementation involving all integrated modules.

Chapter 5 describes the methodology for performing the testing of the ChArGED platform to demonstrate that the ChArGED system implementation meets requirements established in the technical deliverables.

Finally, Chapter 6 concludes the document.

2 Review of the ChArGED concepts, use cases and game challenges

ChArGED approach

ChArGED (CleAnweb Gamified Energy Disaggregation) develops a gamified framework that aims to change occupants' energy-consumption behaviors and reduce energy wastage in public buildings. By leveraging low-cost IoT devices (NFC/BLE), ChArGED improves energy disaggregation mechanisms and identify energy wastages at the device, area and end user level. At the same time, it engages and motivates users with serious game approach accessible through a mobile app. The gamified approach in ChArGED advances the state of the art, since it will be employed in public buildings, where multiple appliances are shared among multiple users. Energy disaggregation in this context is particularly challenging due to the vast area that needs to be monitored and the difficulty of associating particular actions to specific users. In addition, other related applications, e.g., Kill-Ur-Watts, Energy Tracker, Watts Plus, etc., mainly focus on increasing energy-consumption awareness, assuming that the users are already interested in their energy consumption and motivated to reduce it. In a public building, employees are primarily busy with their job activities and moreover they do not pay the energy bill. Therefore, their engagement to such a game app cannot be taken for granted and thus a carefully-designed gamified approach has to be followed. There have been some prior efforts to employ serious games for demand side management [1], [2] in public/office buildings. "Energy Chickens" [1] evaluated the effectiveness of a virtual pet game in reducing plug-loads in a mid-size commercial office. Changes in device-specific energy consumption were reflected in the relative "health" of chickens in a virtual farm. ChArGED app has far more ambitious goals than [1] in the sense that it aims to change a vast range energy-wasting behaviors at work. Also, most efforts in [2] focus on boosting user awareness towards energy efficiency, as opposed to incentive building in ChArGED. The ChArGED app employs both direct incentives and peer pressure to achieve the desired behavior change towards energy-consumption reduction.

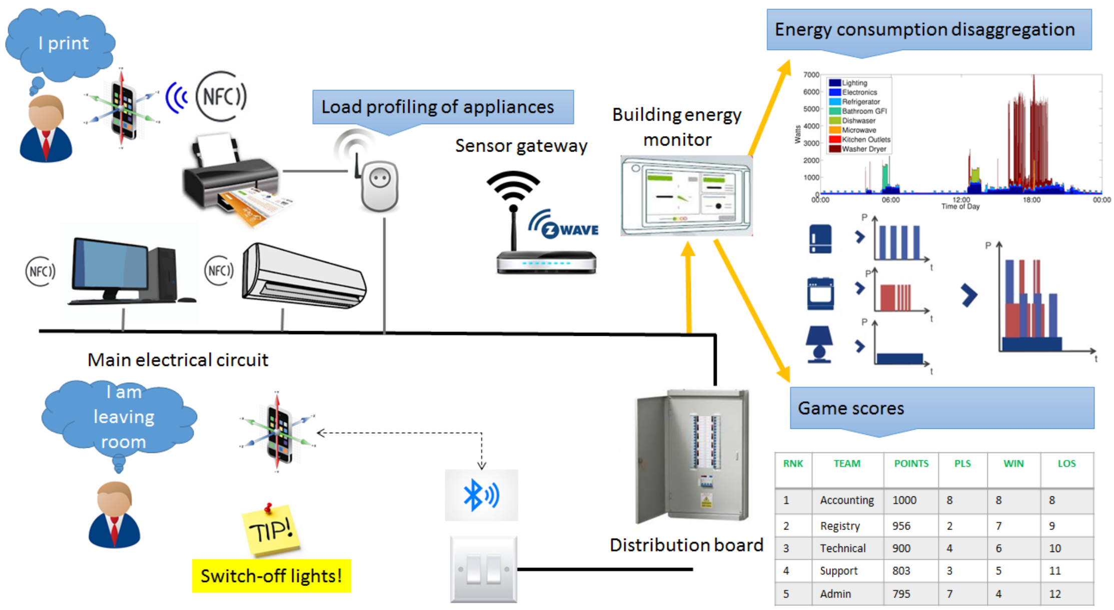


Figure 1 ChArGED approach

The game concept

The Charged Mobile app revolves around a main theme (persona) of a Tree. It shows both the persona as well as the informative parts (current score, team information, current challenge etc.) in a separate but thematically merged user interface The Mobile App includes an onboarding process, revolves around teams and is based on specific challenges that can be either pursued individually by each user or in teams. The user actions performed and validated by the ChArGED system will be rewarded. Rewards can be towards individuals and/or teams; they can also be inside (e.g. badges) or outside (e.g. real awards) the gamespace. The Mobile App also includes leaderboards showing the progression of individual members of the same team or the aggregate progression among different teams.

The core ChArGED concept revolves around a virtual living and evolving main "Persona", in the form of a Tree, that represents the effects of the energy consumption behaviour of the cumulative users in terms of each (and groups) individual effect on all the energy consuming devices in their vicinity of operation".

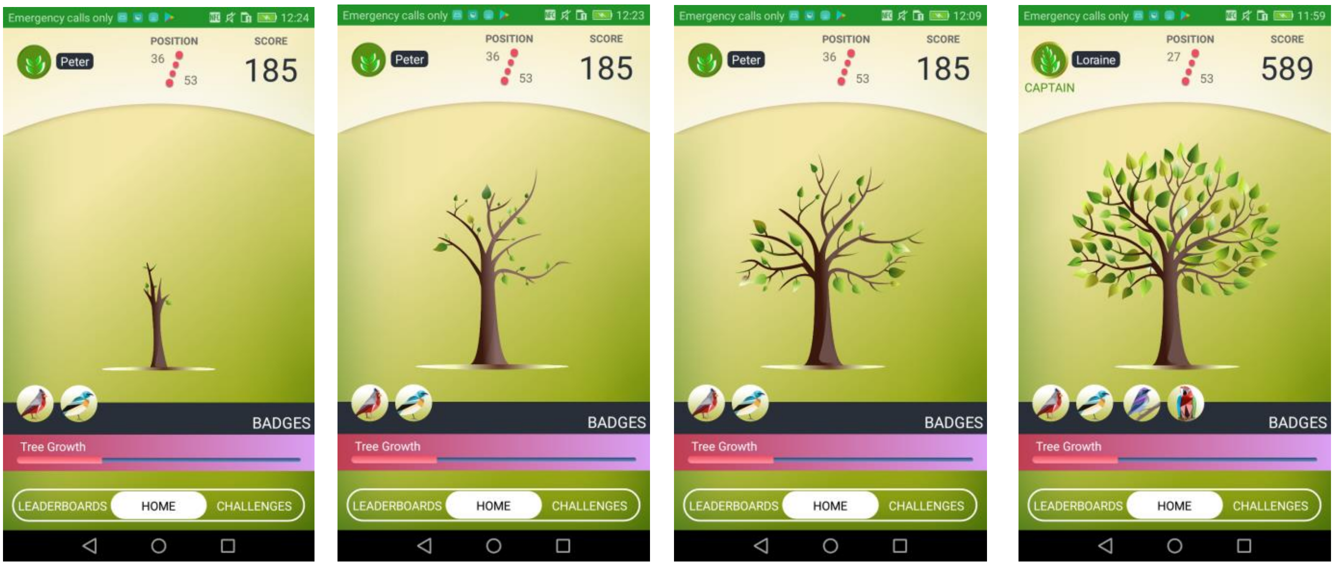


Figure 2 ChArGED UI including the Tree "Persona"

In order to achieve that feedback on energy consumption, the gamification outcomes of users' actions are directly shown to the end user and in parallel the virtual evolving persona accommodates in a graphical form the current state of the game/position or player/state of consumption etc. to create an emotional connection with the end user.

The ChArGED gamified app utilizes a two way on-boarding mechanism to ensure a smooth introduction of the end pilot users to the Mobile app. Initially users will be invited (by the person designated as Pilot Game Admin, at pilots' premises) to download the Mobile app and on first open, users are invited to "Create an Account" or "Login" to their account. Following registration, the game onboarding process begins.

Teams within the ChArGED game are formed with the following criteria:

- **Geographical:** Employees working in the same shared office space belong to the same team. In cases where a number of individual offices/rooms exist next to each-other, the employees may belong to a team competing vs other workplaces/buildings.
- **Role-oriented:** Employees of the same department / with similar, or the same, work description may be grouped in a team.
- **Device-oriented:** In cases where energy-consuming devices (such as printers / air-conditioners, lights, windows) are shared by employees, these users may be teamed together.

Employees will be assigned to teams by the administrator in the beginning of the game and as needed afterwards.

The comparison between teams will be made by their position in the team leaderboard, as well as relative notifications within gameplay. Such messages could read: "Congratulations to the TECHNICAL team for completing the morning challenge first today". "Congratulations to the TECHNICAL team for reaching the 10.000 points threshold" [3].

Types of challenges

Two types of challenges are being designed in order to be included in the Mobile App:

- **Personal challenges**: They are taken-up by individual participants and their outcome is mirrored on the participant's progress in the game, as well as incentives.
- **Team challenges**: They are taken-up by individual participants, but their outcome is mirrored both on the personal and team progress in the game, as well as incentives.

There is set of main challenges that runs over the course of the game and around which the game revolves. Several challenges can run in parallel. Each challenge is graded, according to the level of adherence. Indicative challenges are the following:

- **"Elevator up" challenge**: Upon entering the building, the employees opt for using the stairs, instead of the elevator, to reach their office. (this behaviour is corroborated by swiping on NFC tags existing on the bottom and top of the stairs, while another tag exists inside the elevator cabin, to ensure that no cheating occurs).
- **"Lights on" challenge**: The minimum lights that are needed in their workspace are lit by each team in the morning. As team members switch on the lights, they swipe the corresponding NFC tags.
- **"Equipment on" challenge**: Upon arriving at their desk, the employees turn on any office equipment they need for the day (PCs, printers, etc), at the same time swiping their tags.
- **"Windows" challenge**: The users are prompted to close the windows when the air conditioners are on, or to close the air conditioners when the windows are open.
- **"Away" challenge**: Whenever employees are away from their office, they are prompted to switch off any unnecessary devices that are forgotten on.
- **"Lights off" challenge**: The lights are switched off in the workspace by each team, by the last team member leaving their office. As team members switch off the lights, they swipe the corresponding NFC tags.
- **"Equipment off" challenge**: Before leaving their desk, the employees turn off any equipment that isn't needed after hours (PCs, printers, etc), at the same time swiping their tags.

- **"Museum Visitors" challenge:** This challenge will aim at involving the visitors at the MNHA museum. Since they will not play the same game as the employees, the objective will be to provide them an NFC sticker as they enter the museum (at the reception) and challenge them to use the stairs instead of the elevator. Every time they use the stairs they will swipe their NFC sticker over a fixed device (a customized mobile handset fixed on a booth or on the wall in the middle of the stairs and will be scored accordingly. As they leave the museum they will be able to see their score and possible get a small gift (e.g. a museum poster) or they may also visualize their contribution to the 'Visitor's team' on a screen or video wall.
- **"Solar"** challenge**:** This applies to the DAEM site that has a solar microgeneration system. The objective will be to motivate the employees to shift their energy consuming activities to the periods of high expected solar energy production (that will be provided with the solar power microgeneration forecast component.

In each case the ChArgED platform validates the user actions (kWh decrease on energy measurements) and platform calculate the kWh savings to determine whether the user has completed the challenge and to provide a respective score to user.

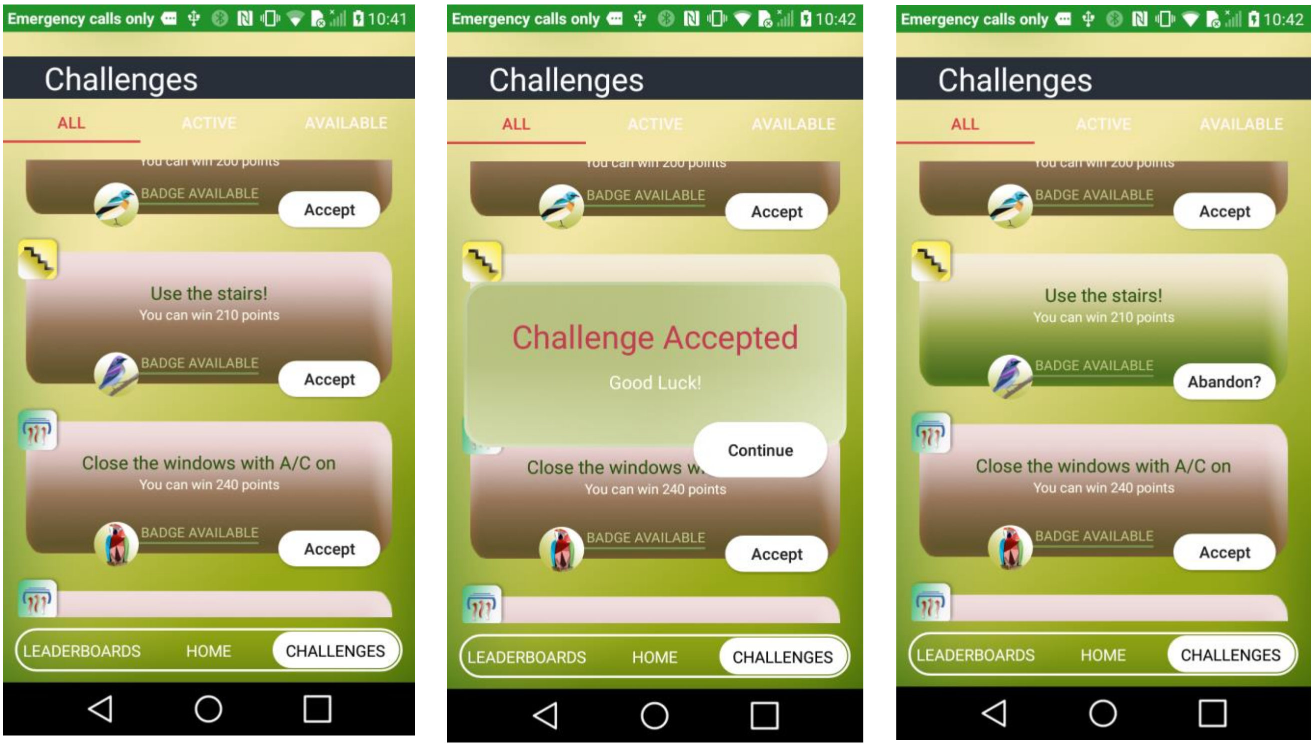


Figure 3 ChArGED UI including the list of challenges

Based on the aforementioned complete list of challenges, the ones that have been selected to be included in the 1st integrated system are:

1. **Personal challenges**

a. Challenge users to switch PC off when going home. The steps towards the realisation of this challenge are:
    i. platform engages a user to switch his/her equipment off when going home
    ii. users swipe NFC sticker with mobile phone to say they're leaving
    iii. platform validates actions (kWh decrease on energy measurements)
    iv. platform calculates kWh savings and provides score to user
b. Challenge users to switch PC off when going away for more than 30 minutes. Steps:
    i. platform engages a user to switch his/her PC off when going away for long periods
    ii. platform monitors with BLE when user leaves and returns to the room
    iii. platform checks if PC has been left on during that period
    iv. platform provides score to user (bonus points if PC was off or if user returned within 30mn, malus points if PC was on and user left for more than 30mn)
c. C3. Challenge users to use the stairs instead of the elevators. Steps:
    i. platform engages a user to use the stairs for a given period (e.g. one week)
    ii. users swipe mobile phone to say they're taking the stairs
    iii. users swipe mobile phone to say they're up the stairs (we can also consider the possibility to use only one NFC sticker in the middle of the stairs)
    iv. platform validates actions (nobody in the elevator using BLE beacons and NFC stickers swiped)
    v. platform calculates savings and provides score to user

2. **Team challenges**
    a. Challenge team to close (do not open) all windows if A/C is on. Steps:
        i. platform engages a team to close all windows (keep windows closed) when the A/C is on.
        ii. platform monitors if windows are open using switch sensors
        iii. platform assigns points to team if windows are closed and A/C energy measurements show A/C is on
        iv. platform requests team to close windows if A/C is found to be on
        v. platform validates action (kWh on A/C energy measurements to check A/C on and sensors on window to check if open), but if no action taken after timeout period the team loses points (or gets no points)
    b. C5. Challenge team to switch lighting and A/C off in room after hours. Steps:
        i. platform engages a team to switch off lighting and A/C when there is no one left in the office
        ii. Last user swipes mobile phone to say the room is now empty
        iii. platform validates actions (kWh decrease on lighting and A/C energy measurements and nobody in the room using BLE beacons)
        iv. platform calculates savings and provides score to team

3 Approach of the implementation of the system architecture and system components in the 1st integrated system

3.1 Integrated system architecture

The system architecture (depicted on Figure 4) has been developed, consisting of four main groups of functional blocks:

- The Data/Core Back-end group is responsible for providing an environment in which data, assets and users are stored and managed. The Back-end components provide the software infrastructure on which the ChArGED application is developed. That group of components is application agnostic, however it is tuned towards the needs of ChArGED project.
- The Gateway group is responsible for integration of energy use and environmental data to the Back-end system, to determine variations over the energy context within the building.
- The Analytics Back-end component is responsible for delivering insights that will enable the ChArGED application to deliver custom and targeted feedback and incentives to the end-users.
- The Gamification group is responsible for processing field data and insights created from such data and make decisions as to the evolution of the game for each user, i.e. what the next step is towards more energy savings. That group also delivers the mobile app the end-users interact with which acts as an interface between the user and the charged system updating the user with the current game state and also provides information to the system about the users' behaviour towards the energy saving goals set.

The architecture also includes an external system that is utilized to provide a solar power microgeneration forecast based on weather predictions for the specific location. It serves to maximize the building energy savings, increase end user awareness as well as to enable the use of the mobile app to maximize the solar-based electricity consumption during production, avoiding the need for energy storage.

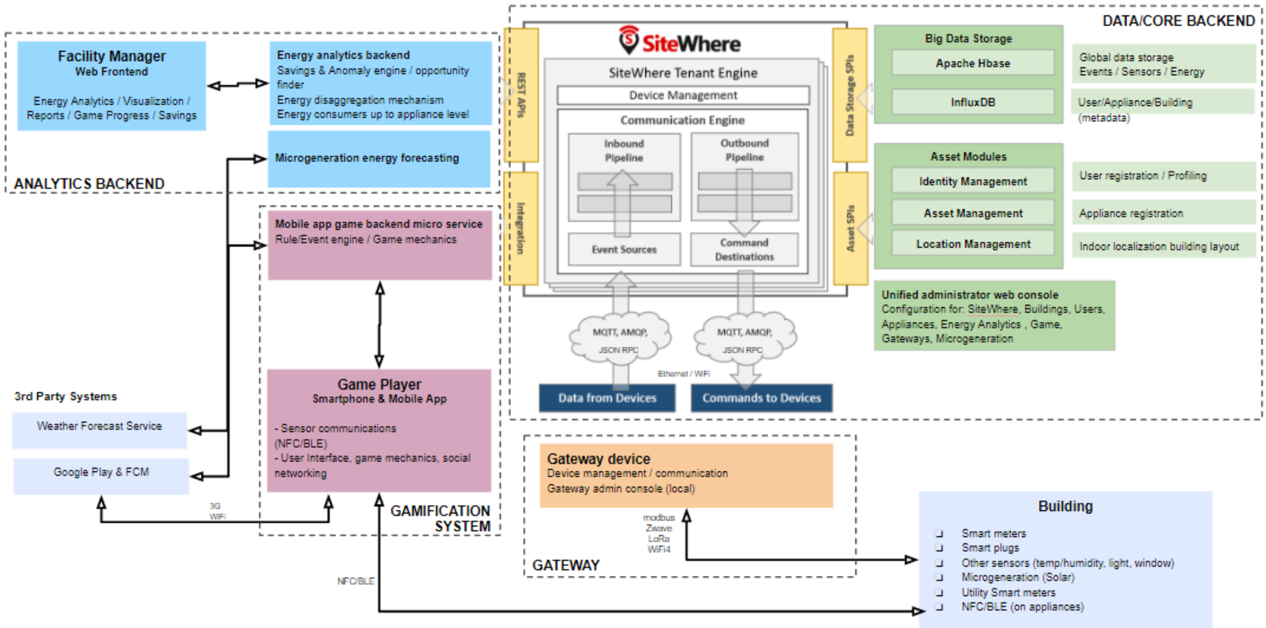


Figure 4 ChArGED system architecture

3.1.1 Data/Core Backend System

The Data/Core Back-end system components and infrastructure were implemented in SiteWhere [4]. This was chosen as the Data/Core Back-end system, as it provides an open-source platform with a number of rules and mechanisms for data exchange and operations. SiteWhere's main functionality is to supply a server based JAVA SPRING middleware between the sensing infrastructure and the different system components and acts as a controller for the processing of device data. It connects with NoSQL & Timeseries databases in order to provide persistence of the sensor data and scales effectively with a large number of devices so that the whole sensor data history is maintained and can be accessed at any point. It also provides the entities management mechanism in order to structure the devices and categorize them according to their type, location and ownership and offers full control on a device's lifecycle (providing the functionalities of creating, deleting, updating, grouping, sending data). Moreover, it provides a web based administrative console application that allows all of the system data to be viewed and manipulated in a structured way which makes their overview and administration easier and more accessible. The available functionalities are the following:

- Each new asset or entity (i.e. a sensing device, an appliance, a specific location area, a person) is assigned a unique id and can be autonomously monitored via external software. Specifically, a model for standard types of generated event data is provided for each device (which includes measurements, alerts issued and location updated by the device). The logged events are stored in massively scalable time series datastores (InfluxDB).
- Devices (appliances such as printers, air conditioners, a PCs etc) can be assigned to / associated with other entities. A can be associated with a person, a location or another sensor device of our infrastructure thus giving us the ability to establish ownership room/location metadata and establish relationships with device.
- Devices can be grouped together according to a common role they fulfil, something that enhances efficiency by simplifying the way the devices can be retrieved by other backend processing services.
- Every top level entity is modelled as a tenant and can have a completely different configuration and structure without affecting other tenants. This can be used for modelling infrastructures that are unrelated to each other such as different locations, different buildings, pilot users etc on the same server.

SiteWhere provides an extensive list of third party frameworks and software tools that can be interconnected in order to extend its capabilities. The options include different databases, identity management frameworks, event streamers, event processors, enterprise service buses and others. Moreover, being an open source software solution, new interfaces with other software tools and services can be created as needed. External communication with SiteWhere was achieved via a built in extensive REST APIs. A communication interface utilizing the MQTT protocol was also implemented to be used by devices and other embedded systems to send or get notified about new events and sensor data (e.g. NFC/BLE alerts and energy measurements).

The integration and connection of major system components as implemented is illustrated on Figure 5. The WSO2 Identity Server handles the identity management and user authentication, the Game Backend implements the logic to update the game progress of the users (i.e. score, completed challenges etc) by processing the users' actions, the Energy Analytics Backend performs estimations on user savings and is responsible for the energy monitoring of the building, and the mobile app acts as a frontend for the whole system and is the main point of interaction with the users.

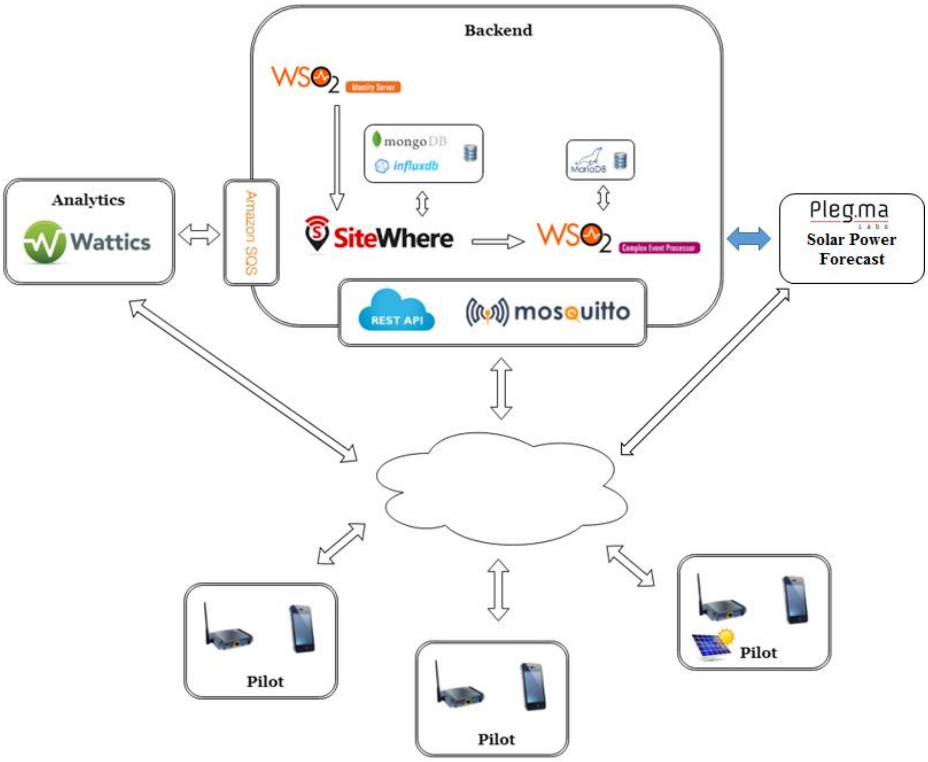


Figure 5 Organisation of SiteWhere System Components in ChArGED

WSO2 Identity Server is used for the creation, management, deletion and accessing of the user accounts. Its main functionalities include the following:

- *A sign in solution for the mobile app*

Users will need to sign in to the server through the app that will run in their smartphones. This allows their participation in the game challenges and offer personalized data to them (progress in a challenge, team information for group challenges, leaderboards etc). There is also the need to offer persistent login functionality to the users, i.e. users should log in and then for a certain period of time they should be remembered by the system so they don't have to frequently enter their credentials, which can become tedious. WSO2 Identity Server offers an implementation of many state of the art open standards, used today by the industry, that provide user authorization/authentication (oauth2/openid connect, SAML2).

- *A user account provisioning tool*

WSO2 also handles the storage of the user credentials and user info on the server in a secure way. These data are imported by SiteWhere on the background to be used for creating the user entities.

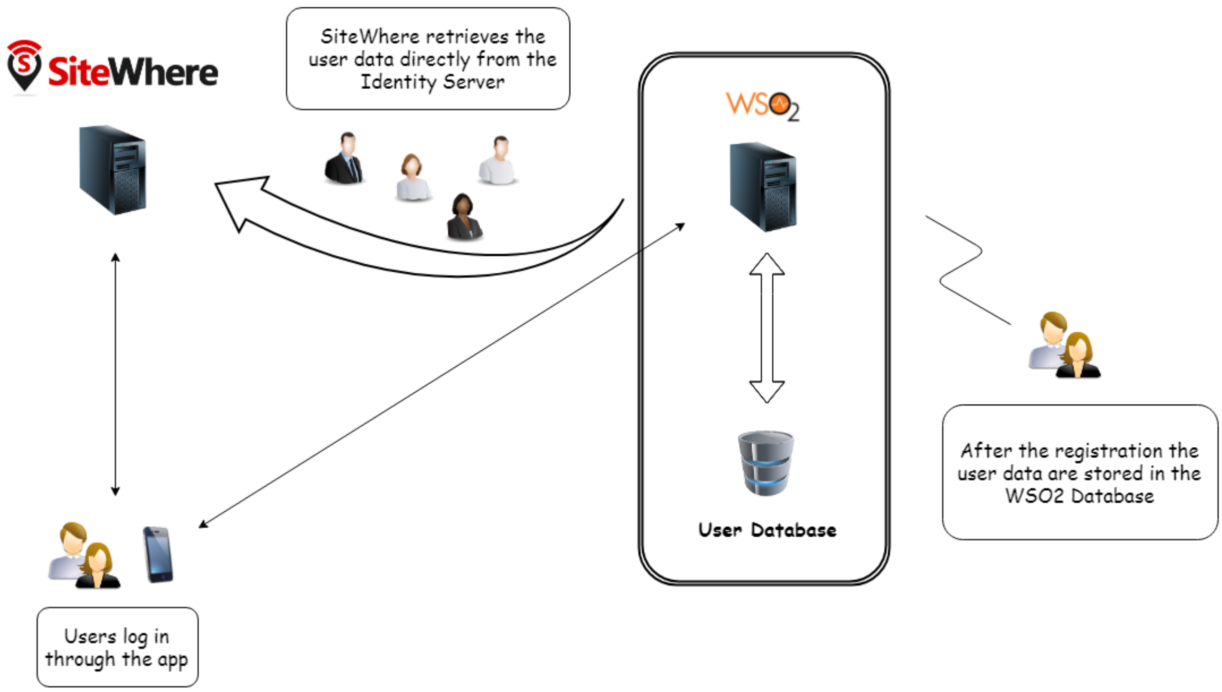


Figure 6 Capabilities provided by ChArGED Back-end

Devices and locations of our infrastructure are modelled as assets inside SiteWhere. In the case of the devices the asset provides a general description of the device (for example Printer). This asset was used to create a specification. Specifications also provide a general description of a device but are more specific that an asset (for example Printer Model). This specification then was used to create all the devices that exist in the infrastructure. An example can be, as described above, Asset -> Printer is used to produce a Specification -> Printer Model and then this specification can be used in order to create all the printers of the specific model in the building.

The devices can be inserted manually in the system by the site administrator through the graphical interface or created remotely through the SiteWhere API. This enables easily addition of a new device without access to SiteWhere's user interface as well as enable the possibility for devices to self-register when they are first integrated in the system. Locations can also be modelled as assets. The administrator can then associate the assets with devices to denote the room each device is in.

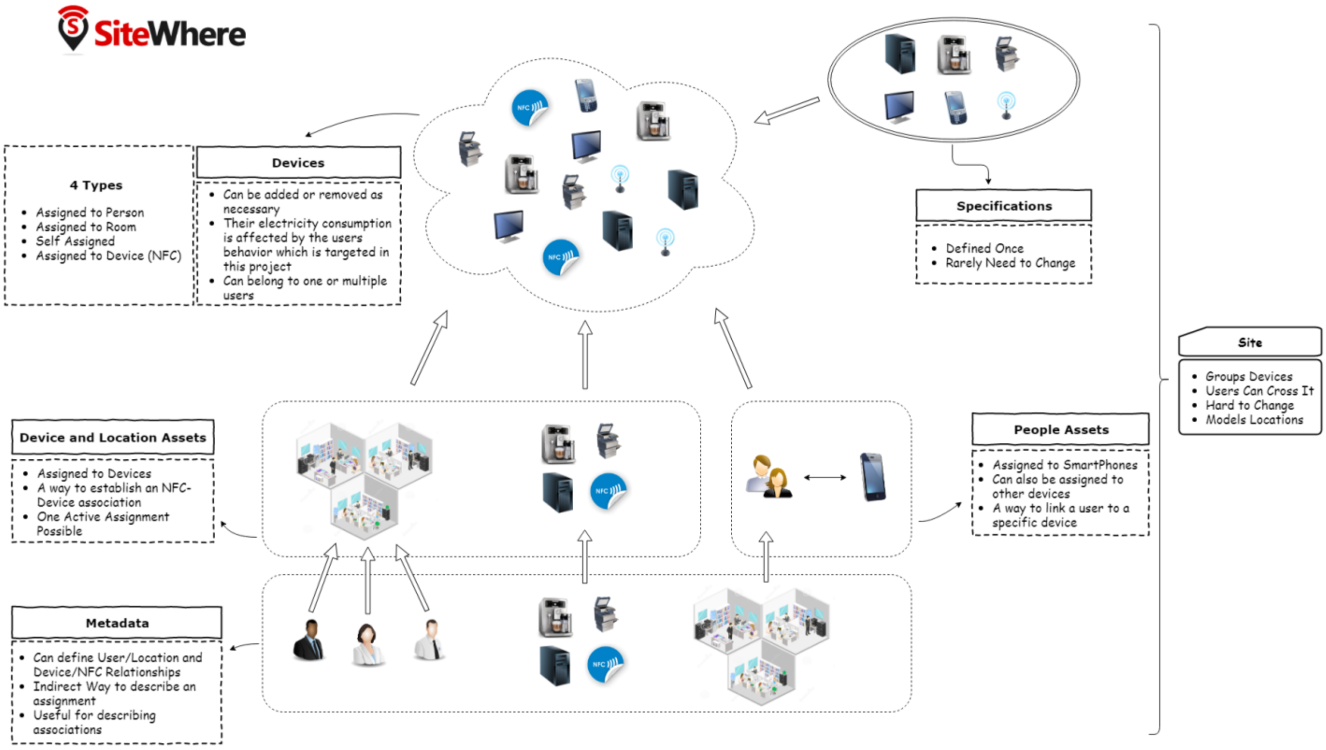


Figure 7 Asset management in the ChArGED Back-end

3.1.2 Gateway

To achieve the data acquisition process the Sensor Gateway has two connection interfaces within the global architecture, one with the building sensors (e.g. Smart plugs and Smart Meters) and another with the SiteWhere Data/Core backend. Various hardware and software requirements have to be fulfilled to support the needs of the platform. The Sensor Gateway software/middleware by Bosch Software Innovations is used as the basis of the Sensor Gateway. For the remote software management and provisioning of the product, the ProSyst Remote Manager (PRM) [5] is also used.

The Raspberry Pi (version 3 Model B) was chosen as the hardware basis for the Sensor Gateway. The Raspberry Pi is installed with a standard Raspbian OS, including the Oracle Java SE Runtime Environment (Java8), the Communications Device Class Abstract Control Model (CDC_ACM) USB to serial driver and, as mentioned before, the ProSyst mBS SH Runtime for ChArGED.

The data collection process required development of sensor drivers to retrieve data from third party sensors using industry leading communication protocols. For the connection of Z-Wave (Plus) devices, various controller options have been investigated, and two units have been selected: (1) "Razberry" GPIO Module for Raspberry Pi, (2) USB Z-Wave Controller.

Various Z-Wave devices were connected to the Sensor Gateway such as: (1) Fibaro Smart Plugs, (2) Fibaro 4in1 Sensor (Temperature, Humidity, Luminosity, Motion/Presence), (3) Fibaro Contact sensors.

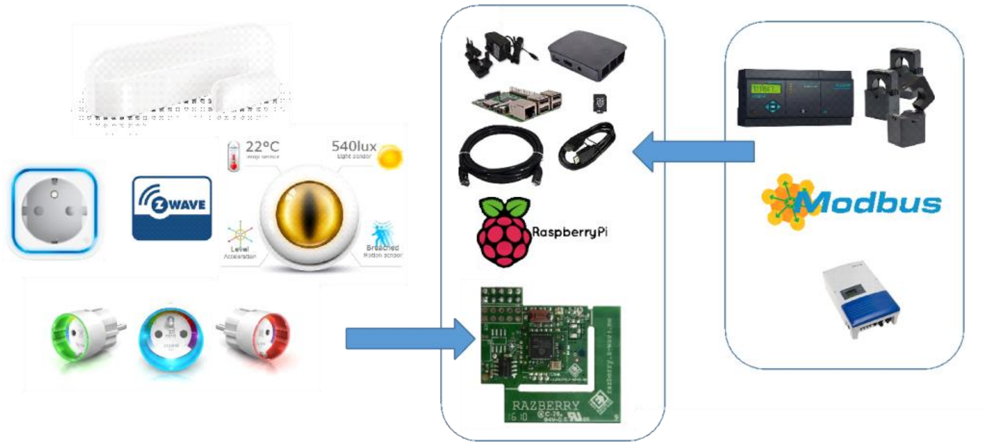


Figure 8 Illustration of the Sensor Gateway and interconnected devices and modules

Various Z-Wave devices were connected to the Sensor Gateway such as: (1) Fibaro Smart Plugs, (2) Fibaro 4in1 Sensor (Temperature, Humidity, Luminosity, Motion/Presence), (3) Fibaro Contact sensors.

These devices are managed by the mBS SH Runtime and included into the product portfolio, which allowed data to be immediately collected from the devices. The AcuRev 2000 multichannel Modbus meter by Accuenergy and the Solar Inverter by Kaco was also connected to the Sensor Gateway via the Modbus protocol, to collect detailed energy measurements at the three pilot sites and the solar energy measurements at the DAEM pilot side. All connected devices communicate their data to the Sensor Gateway, which pre-processes and forwards it to the SiteWhere backend via MQTT.

For the management of the mBS Runtime the ProSyst Remote Manager (mPRM) backend is used. mPRM is a software and device management system developed by Bosch Software Innovations. mPRM enables lifecycle management of software bundles running in the mBS Runtime. Existing bundles can be updated, new bundles installed and deprecated bundles uninstalled. All of these actions are done during runtime, this means that all not affected bundles are actively running, while the specific bundles are processed. Therefore, a 24/7 runtime of the sensor gateway is achieved.

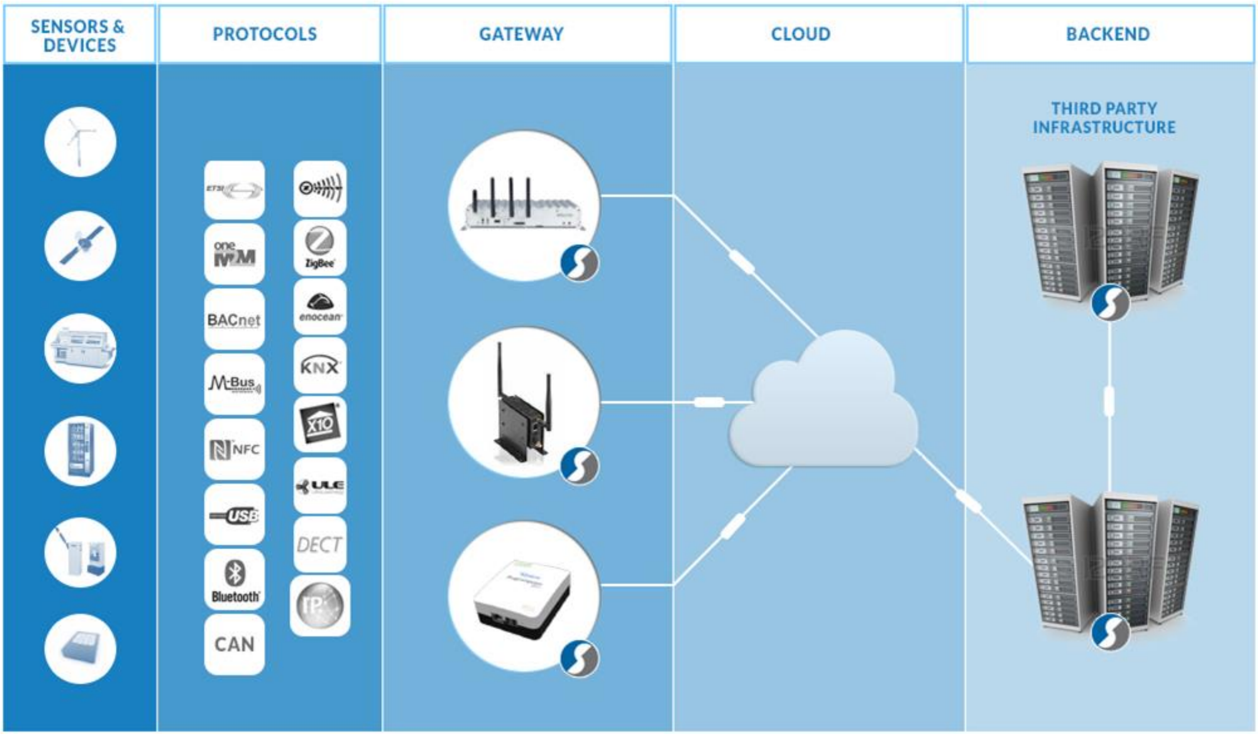


Figure 9 Typical IoT Architecture with mBS and mPRM

3.1.3 Analytics Backend

The Wattics Analytics backend is interfaced with the Sitewhere backend via RESTful web services, which allow energy measurements, NFC swipe alerts and BLE location events to be received as input, and measurements of load demand reduction and energy savings as well as energy saving opportunities to be returned. Authenticated data streams are processed in real-time through parallel analytics engines to produce valuable insights for the application.

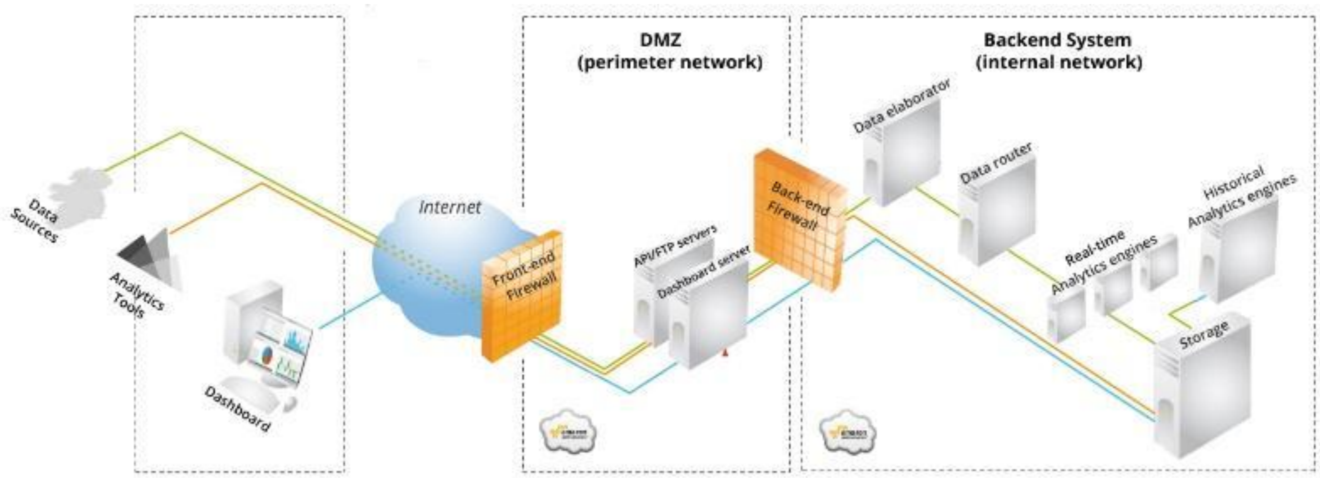
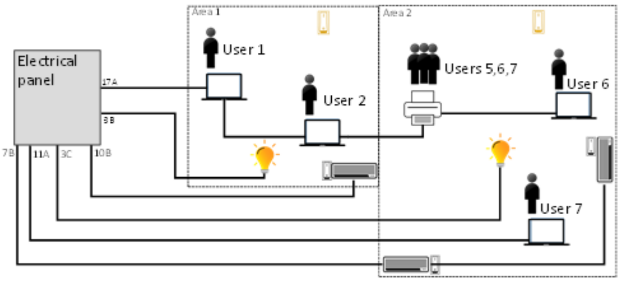


Figure 10 The Wattics Cloud Backend System Architecture

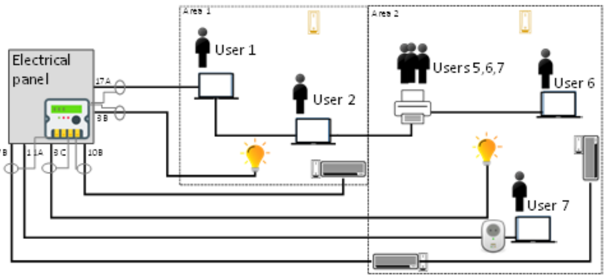
The Wattics backend infrastructure is brought to the project as background IP, and has been adapted to the needs of the project with the following additions:

- API endpoints to process NFC and BLE data packets.
- Analytics engine to validate control actions have been taken by users (e.g. device switched off when going home or when away for more than N minutes), and to estimate the energy savings achieved by such actions. In addition, the new Analytics engine is able to diagnose inefficient operation of electrical devices based on concurrent power activity (e.g. A/C left on when window is open), and to estimate the energy wasted due to such actions.
- Notification mechanism to export insights generated to Sitewhere. In addition to these extensions to the Wattics backend, a micro service was developed to reside in between SiteWhere and the Wattics Analytics backend to enable seamless integration of both backend systems via Amazon SQS.

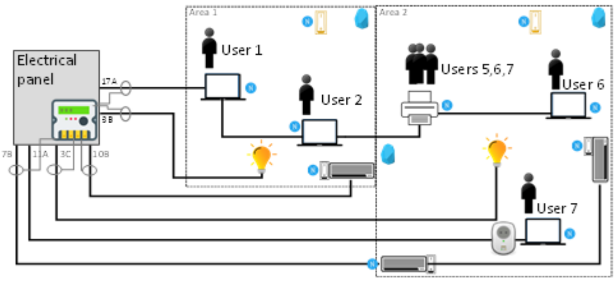
The analytics component in charge of validating the control actions and estimating the savings generated. The following set of figures shows the intermediate steps for monitoring a building, gathering events and performing the necessary analytics actions to identify energy savings.



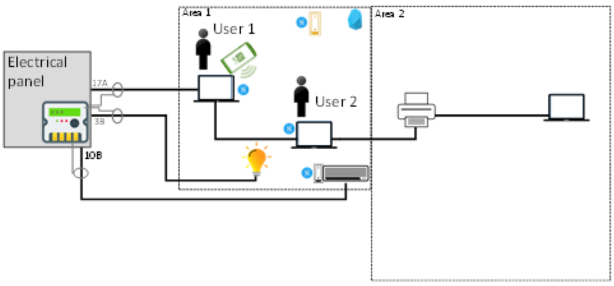
STEP 1: Mapping between electrical circuits, devices and users



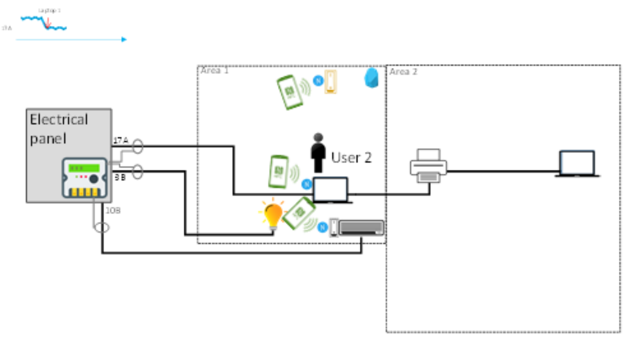
STEP 2: Capture of power measurements at the electrical panel



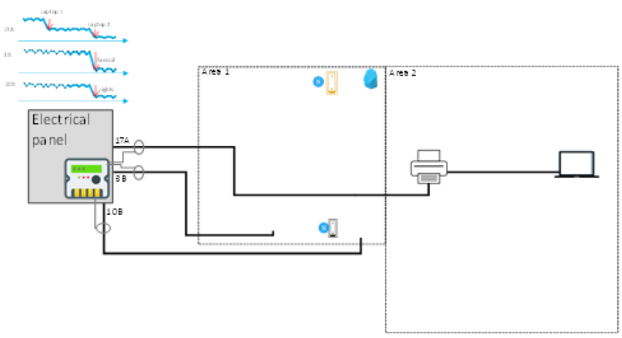
STEP 3: Capture of users' location and interaction with equipment



STEP 4: Game runtime operation



STEP 4: Game runtime operation



STEP 4: Game runtime operation

Figure 11 Intermediate steps for energy monitoring and performing analytics

The Pre/Post Event Analysis is where the algorithms for control validation and energy savings estimation happen. The disaggregation and energy allocation engine works as follows: (1) The core/backend platform informs the analytics engine that an appliance has been operated by the user after it received an NFC swipe alert from the user's mobile app, (2) the analytics software runs the NFC swipe alert against the power measurements of the circuit feeding the appliance operated by the user to detect significant power variations, (3) the analytics software analyses the power variations and informs the core/backend platform of the drop in energy use measured in relation to the user's operation of the appliance, as well as a quantification of the savings achieved by doing so and (4) the game backend calculates the points to be given to the user and the savings are stored within the platform database.

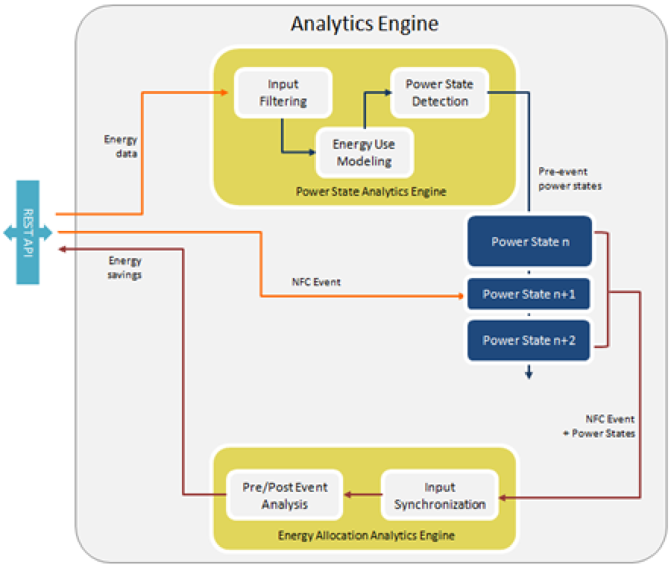


Figure 12 Architecture of the analytics engine in charge of validating user control actions and estimating energy saving generated

3.1.4 Gamification Group

The Game Backend implements the game rules logic that is going to be used in order to decide the progress of a user or a team in the game, update the scores and leaderboards, and keep track of the currently accepted/available challenges. It has been implemented in Java and interfaces with SiteWhere via MQTT and REST. All the communication between the software components happens through SiteWhere.

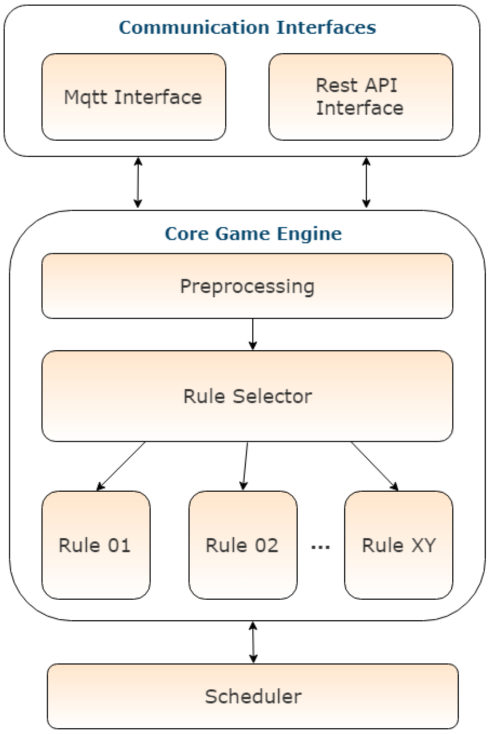


Figure 13 Game Backend Internal Architecture

Whenever an event is sent to SiteWhere from a device (i.e. a measurement or an alert), the event is stored and forwarded to a predefined MQTT topic which is listened by the other software components. The Game Backend listens to events sent to SiteWhere that describe the users' behavior and its results (such as NFC swipes, user location updates and energy updates), processes the data and determines the user progress with respect to the challenges that have been accepted or schedules delayed or recurrent processing. The processing performed by the game backend is not necessarily tied with the specific time an alert has arrived. Separate logic can also be triggered or executed at a different time to check/update the game progress and provide updates to the other system components. Internally the Game Backend consists of three different subcomponents. The first one is responsible for interfacing with the rest of the system through MQTT and REST. This interface is used to receive/request and update data according to the results of the rules. The second sub component is the core engine that implements the game logic. It consists of a pre-processing component which handles the incoming messages and accordingly selects the relevant rule out of a list of rules. These are the main part of the game logic and game challenges or actions that should be performed. One such rule determines that at the end of the week the challenges which have not been completed should be identified released if they have been assigned to any user. The third subcomponent is the scheduler. Its main use is to schedule delayed rules that should be scheduled for the future or executed at specific time intervals (i.e. every day, every week etc). New rules can be added as needed to incorporate new challenges. A separate submodule allows to easily add rules thus, ensuring the scalability and continuous enrichment of the game challenges. It organises rules in a specific structure by inheriting from an abstract class Rule, which defines a common interface as well as implements common functionality.

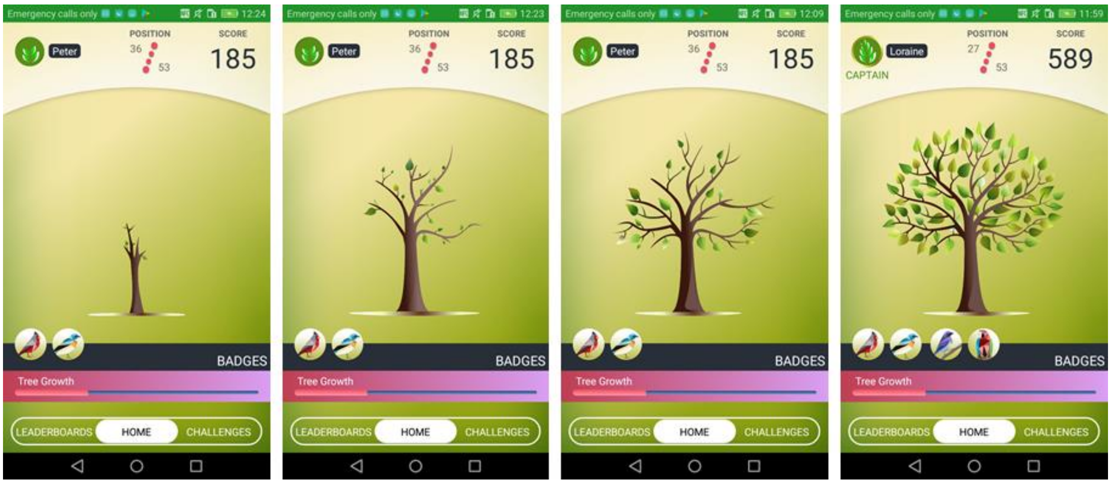


Figure 14 Screenshots of the Mobile App

The ChArGED Mobile App is the end-user front-end and visualizes data and game challenges in a user friendly, appealing, modern and motivating interface to ensure continuous engagement. The app is designed for Android smartphones supporting API Layer 21 (Lollipop) and above, equipped with NFC and BLE capabilities. The gamified app visualizes information about energy behaviour both at user level and team level. Users are informed about their progress while their actions directly contributing to the energy impact can be traced. Achieving energy savings and accomplishing challenges results in accumulating scores. A visual emotional inceptive in the form of a living tree grows and prospers according to the user score, thus rendering the game also visually attractive and engaging. When a challenge is completed, the scores and the game progress for each user and their team are updated in real time between the backend and the mobile app. The game backend has been installed on the project server and connected with the other software components through MQTT and REST. The design goal of the backend is to implement the game mechanics, manage user/team scores and leaderboards and send notifications whenever there is a new update.

Besides the design and engagement concept, the following subsections present the functionalities that are provided to the user in order to use the first prototype:

User authentication

Users authenticate at the backend using their username and a password. The Implementation will follow the functionalities described in "Identity Management" and also support automatic re-login using a provided token mechanism.

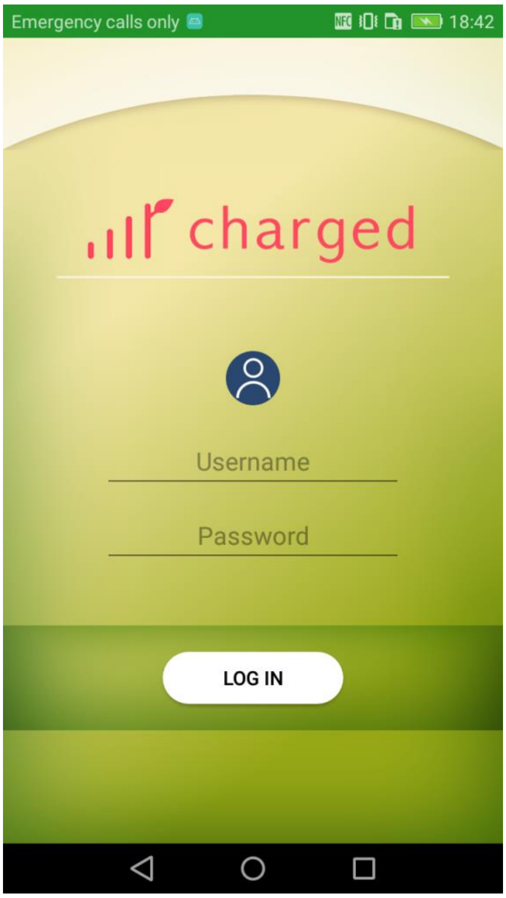


Figure 15 Login screen

Home Screen

The home screen is the first screen that the user is forwarded to after a successful login. This screen displays the user's information and progress.

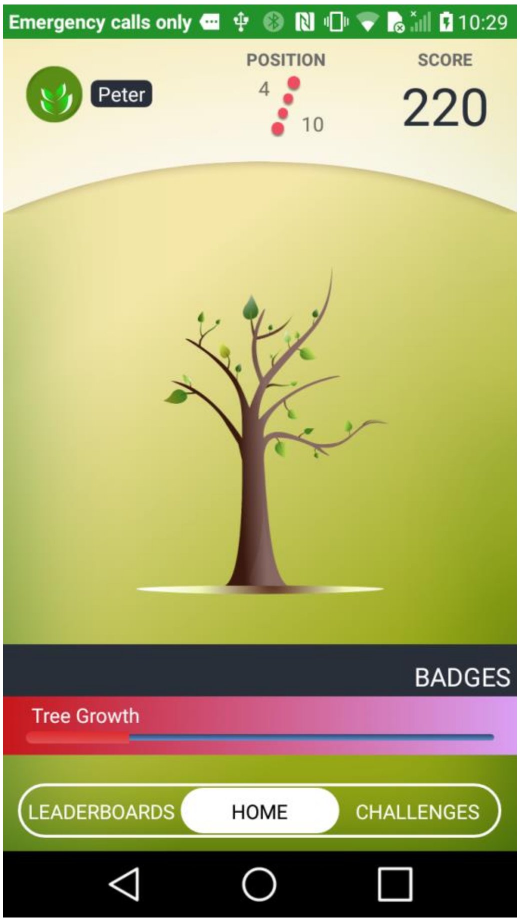


Figure 16 Home screen (Small Tree)

Figure 17 Home screen (Fully grown tree)

As the user completes different challenges he is awarded points and challenge badges. If the score is high enough (according to predefined threshold) the tree will also bloom and grow bigger. The longer the game is played the player gains experience and is assigned a corresponding user avatar (top left). Special borders of CAPTAIN and DEPUTY are also available for the two first players in each team.

Challenge Selection

The challenges screen contains all currently available and active challenges. A user can start playing by selecting one or more challenges. A challenge can also be abandoned at any time.

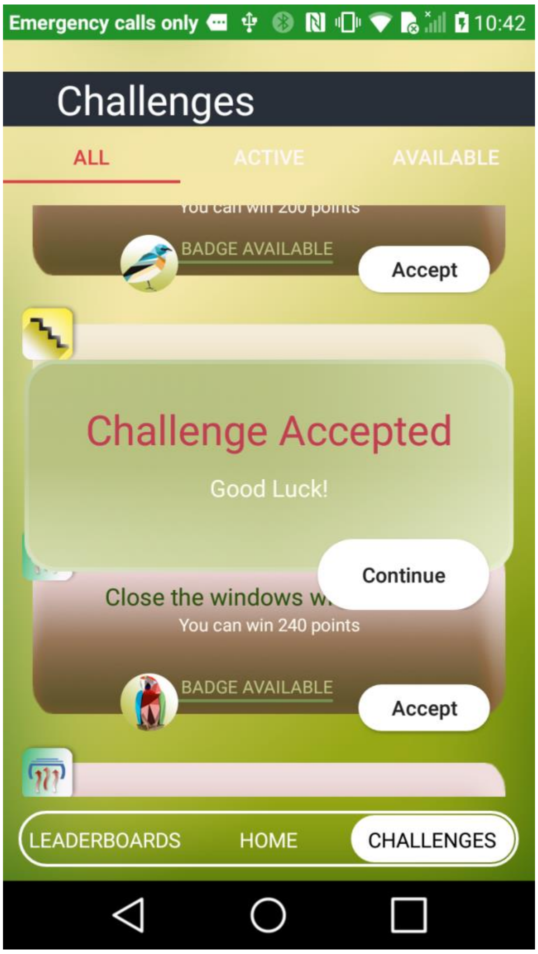


Figure 18 Accepting a new challenge

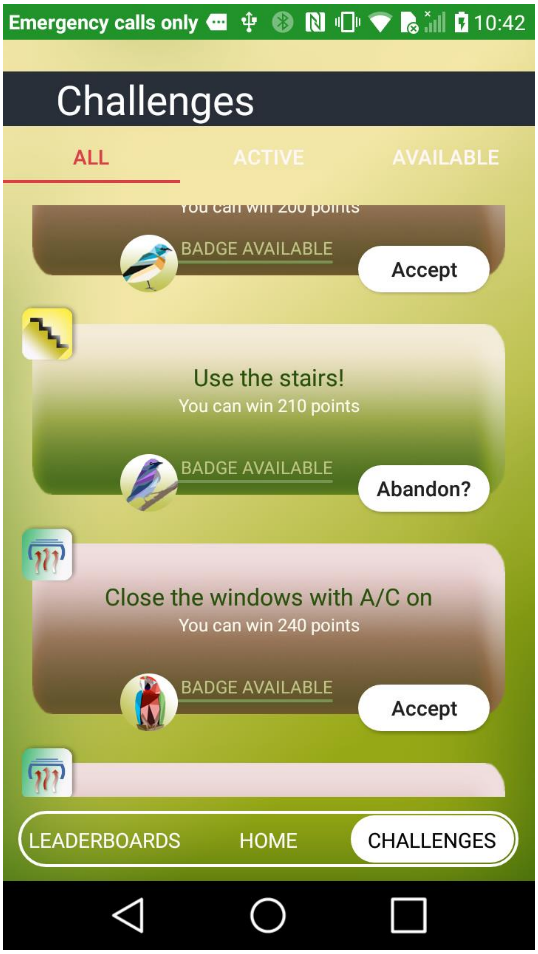


Figure 19 Challenges Overview

Leaderboards

The leaderboards screen enable the users to track their progress with respect to the other players of the same team as well as the progress of the different teams. The app communicates with the server to get and display the most recent game data.

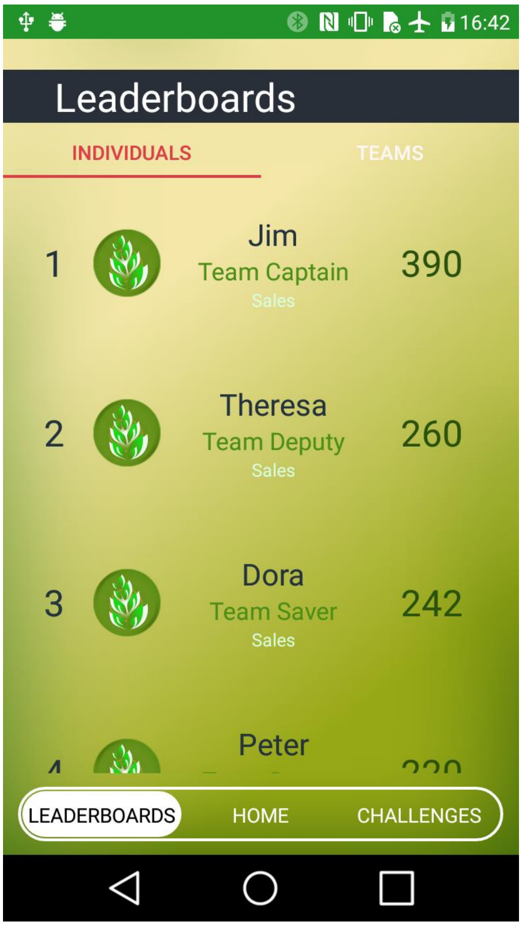


Figure 20 Individuals Leaderboard

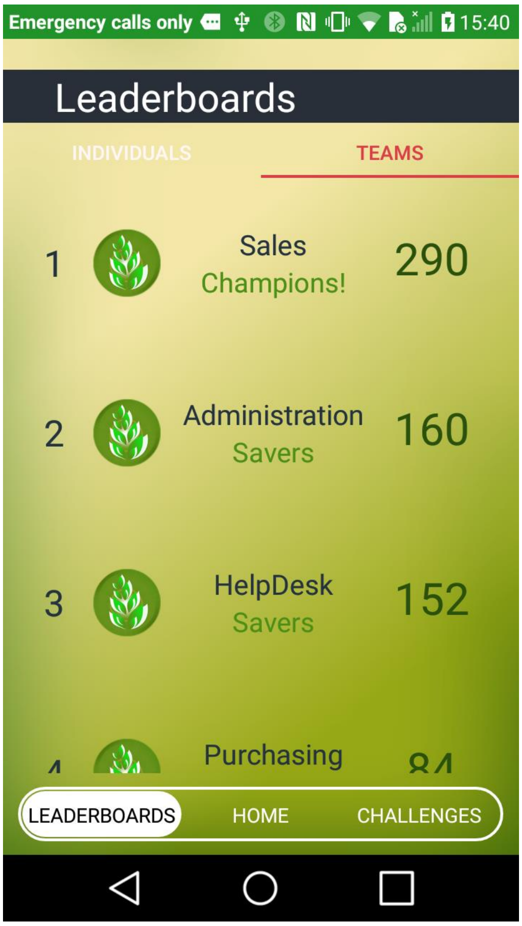


Figure 21 Teams Leaderboard

NFC integration

Smartphones NFC functionality is exploited to inform the system about specific user actions that correspond to challenges, for example switching off appliances such as desk equipment or monitoring a shared device usage such as a printer. NFCs associated with devices are used by each player by swiping their phones on the especially for this purpose installed NFC stickers on the CHARGED involved devices. By doing this, the energy saving that is identified by disaggregation /analytics engine is assigned to a specific player.

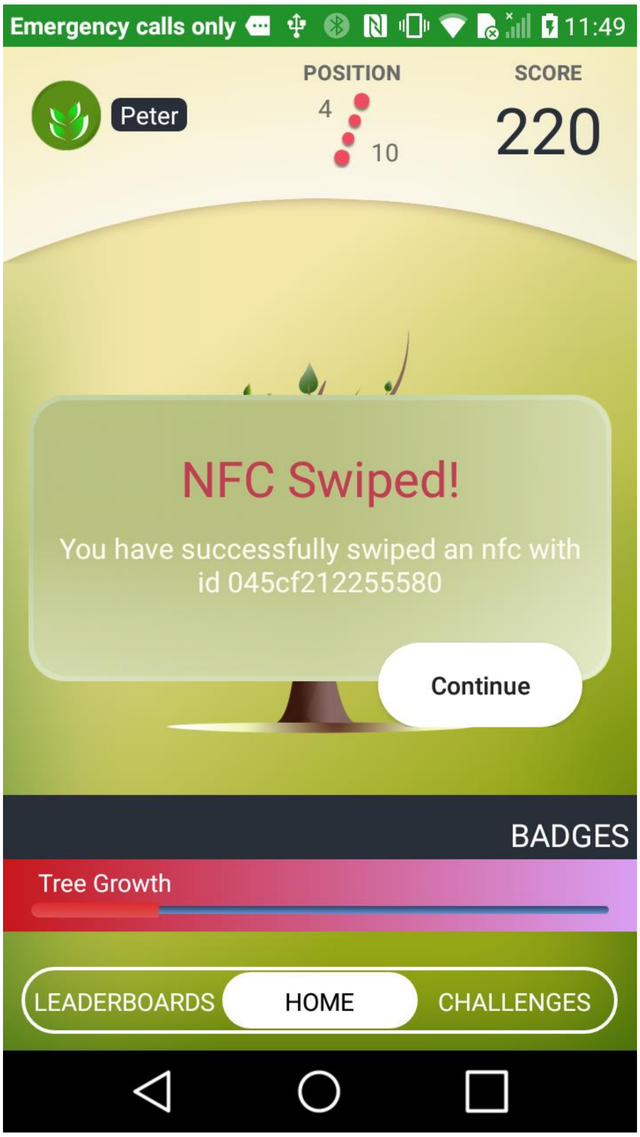


Figure 22 NFC Swiped Message

BLE integration

BLE is used to track the presence of users within a specific part of a building and can be used to distribute energy consumption from appliances which are shared between different users (ceiling lights, air conditions etc). The smartphone detects the closest BLE and informs SITEWHERE about its ID. This information is processed by the Game Backend. All the BLEs are modelled in the system and each incoming ID is matched to a specific location inside the building. Like the NFC this is a separate mechanism used to assign energy disaggregation to a user or a team.

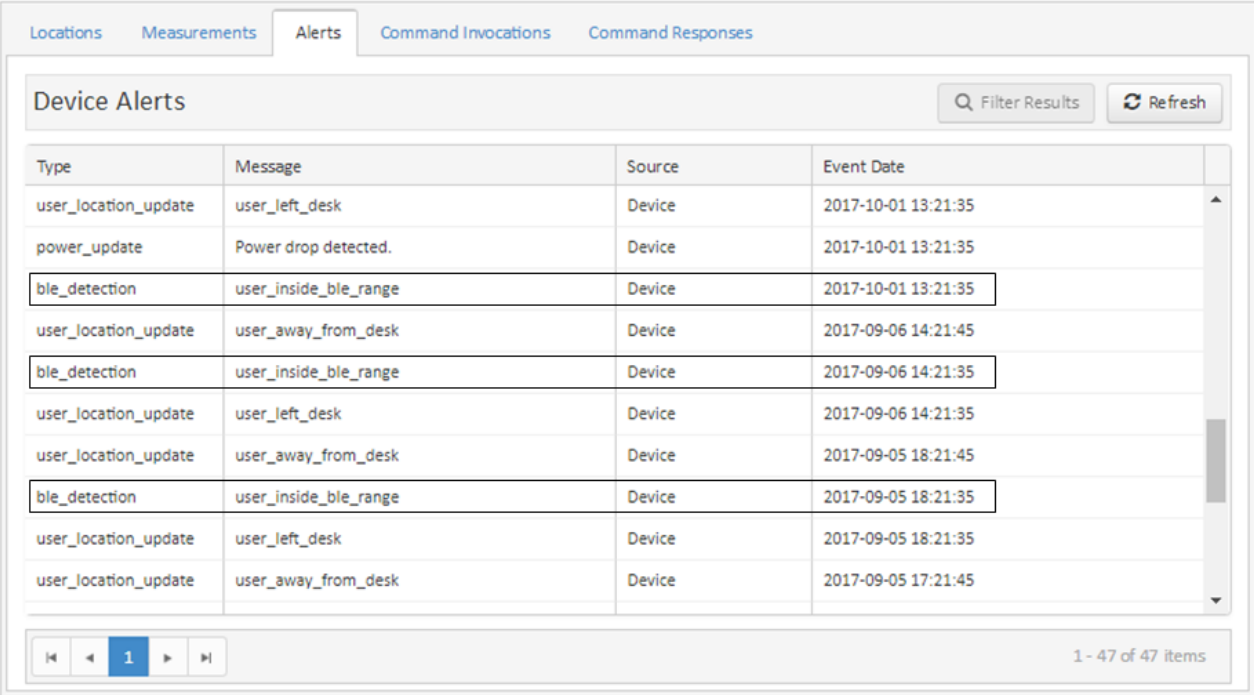


Figure 23 BLE messages sent by the user's smartphone inside SiteWhere

3.1.5 Component for microgeneration Energy Forecasting

The opportunity when utilizing a solar micro-generation in the ChArGED solution, is the ability to take maximum advantage of free/clean energy, without storing it, by shifting loads during peak generation time at most beneficial times. The most benefitial identified so far are when solar power production is more than consumed power or when price of electricity is higher than normal - in future dynamic pricing scenario. Load shifting can be achieved again by altering user behaving via gamification, however, an accurate solar power generation forecast is required to optimize the results and thus a dedicated component was introduced in to the system architecture.

This component utilizes a solar inverter (Kaco) with rich data communication capabilities (over Modbus TCP protocol) in order to monitor the generated electricity and assist the energy production forecasting mechanism which is based on daily weather forecasts. This forecasting is used for directing the game challenges towards optimizing energy use. The solar inverter is connected to the Sensor Gateway with the middleware / IoT integration software mBS SH. Through the device abstraction of the mBS SH the data are sent via MQTT to the ChArGED core platform and from there they are made accessible to all other system components. The Component for Microgeneration Energy Forecasting gets periodically (every day for five days ahead) updated on the specific location weather forecast and provides the hourly forecast of the expected energy. The solar forecast software is connected to 3rd party weather forecast provider APIs for obtaining the weather forecast data (yr.no, wunderground.com, weatherxm.com etc).

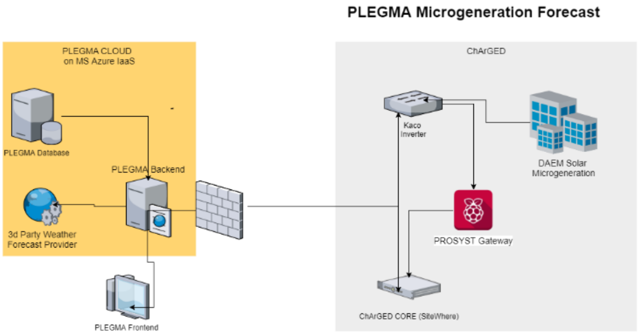


Figure 24 Solar PV Prediction Architecture

During the initial staged of development, various approaches where explored:

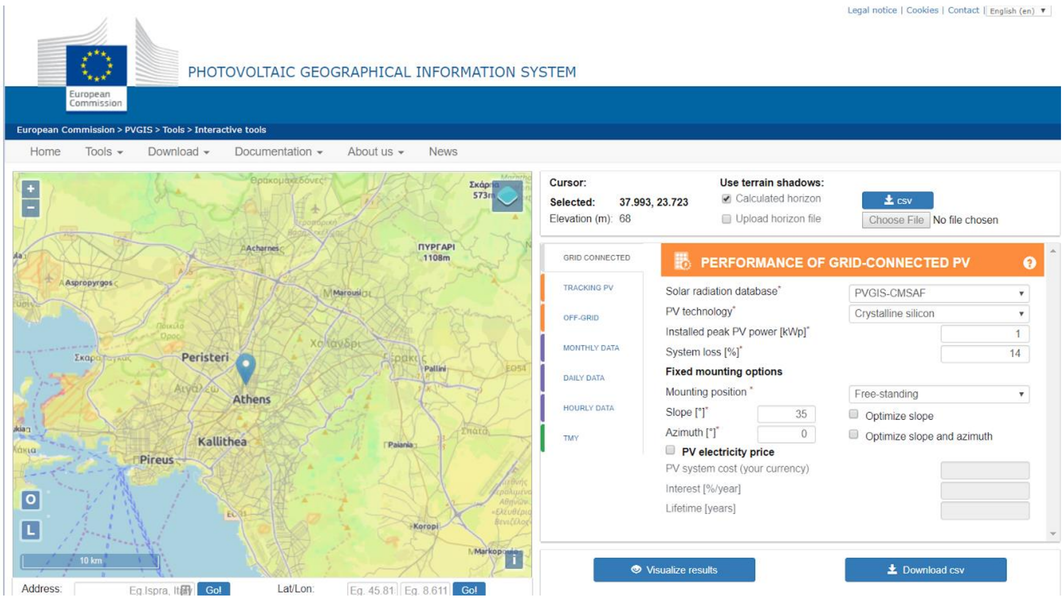
a) Forward calculator
Enriched by weather forecast PV & inverter specs X theoretical solar radiation based on lat/lon & cloud coverage and historical area performance. Apply cloud coverage forecast and temp cell efficiency correction
b) Butler FP7 solar forecast server

http://open-platforms.eu/library/renewables-energies-forecasting-smartserver/

c) Machine Learning

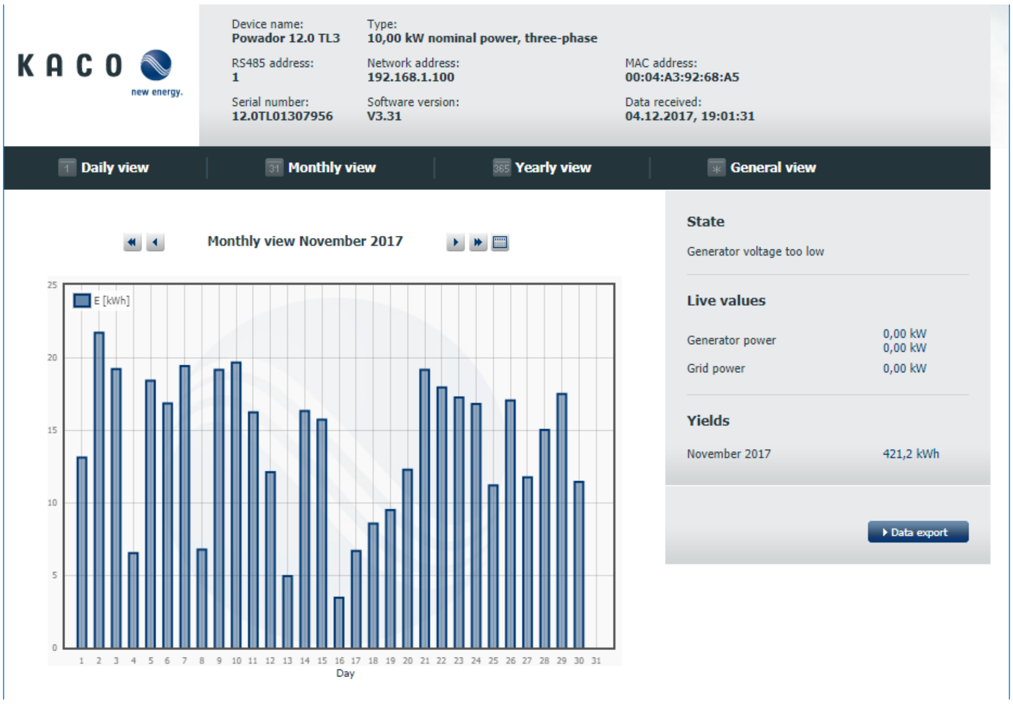
Finding correlations between all weather conditions and actual production on the pilot site.

The first approach (a) was initially consider adequate for the requirements of the project, by all technical partners. The solution was built by utilizing / validating results with data from EUs Photovoltaic Geographical Information System



Photovoltaic Geographical Information System

A theoretical yearly forecast was produced for the specific PV system deployed in DAEM, and was later corrected utilizing real data from the Kaco inverter and weather data / forecast from YR.NO.



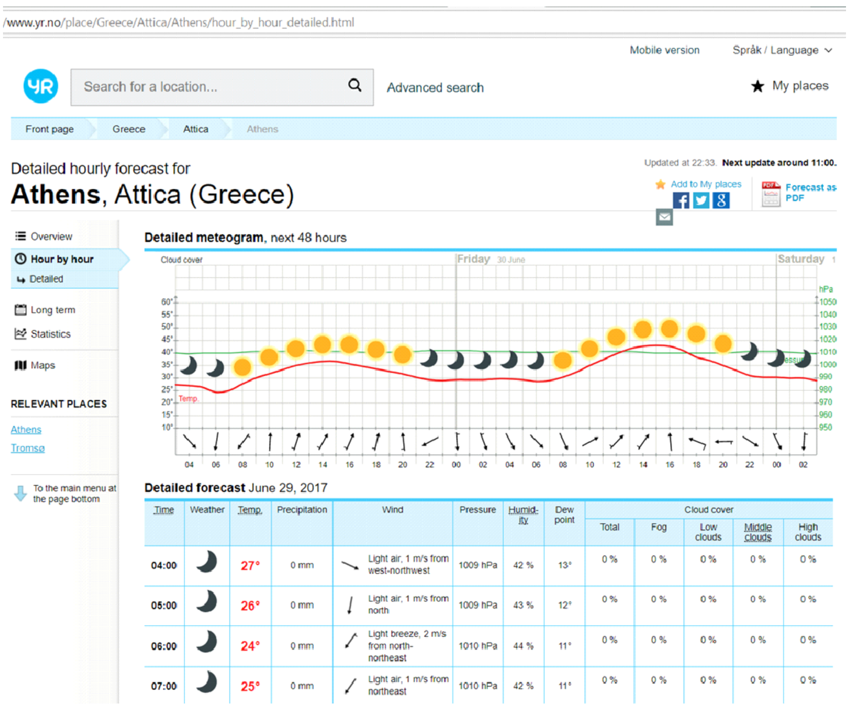


Figure 25 Weather Forecast inputs to the module

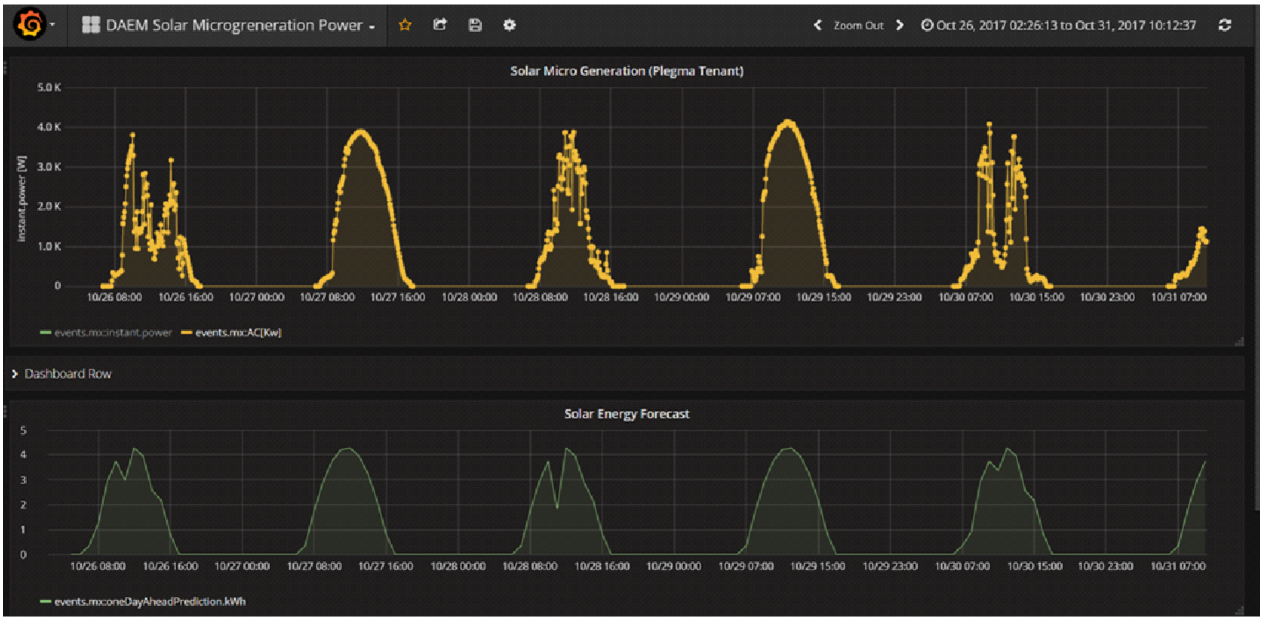


Figure 26 Solar PV Prediction Results

The results of the forecast are submitted on a daily basis to SiteWhere and include the weather data and energy forecast data for the next 48 hours, in hourly intervals, so that any component from SitheWhere can utilize it. Actual energy produced vs forecasted the day before, is plotted in the above figure, using the Grafana quick dashboard capabilities. The accuracy of the model is sufficient for ChArGED solar related challenges as they have been discussed so far, however it is expected that the model can and will be improved as more actual data are collected.

4 Demonstration of the 1st Integrated ChArGED system

4.1 High Level Description of the 1st Integrated Prototype

The 1st integrated system builds on top of the initial ChArGED integration setup of the separate components with default features that was created to test the minimum set of ChArGED specific requirements and prove the ChArGED concept feasibility and added value. The 1st integrated system demonstrates the ability to communicate core energy data and user action data between all subsystems together with a first version of "energy disaggregation" implemented within the CEP engine as proof of concept. This demonstration has been presented to the project reviewers and EC, at the review meeting at M20 in Brussels.

The goal of the 1st integrated system is to perform the following demonstration scenario:

- User's smartphone / ChArGED Mobile app scans an NFC tag while user interacts with the corresponding appliance (or enters the proximity area of a BLE beacon), thus the user action is identified by the system in the specific area.
- The user action events are transmitted via the Mobile App to the Cloud Backend, and then to the Analytics Backend.
- The Analytics Backend analyzes the energy measurements of the electrical circuit/smartplug that corresponds to the appliance that the user manipulated (e.g. PC, lights, etc.) and calculates the energy drop related to the reported user action (e.g. energy of last minute for this appliance).
- This calculation is then sent to the Cloud Backend that notifies accordingly the user via the Mobile App regarding the achievement of the related challenge.

Software and Hardware Configuration for the 1st integrated system demo

1. Sensing equipment integrated:

- Fibaro Smartplugs
- Mobile Handsets with NFC/BLE capabilities (LG-K8-Dual-2017-16GB)
- Estimote BLE beacons
- NFC stickers

2. Core backend:

1. Receives, stores and makes available energy consumption data at the level of appliances and/or electrical circuits, according to the availability of smartplugs and Accuenergy smart meters.
2. Receives, stores and forwards to other system components alerts that describe the user actions inside the buildings that are used to play the game such as NFC swipes and BLE detections.
3. Provides an interface where the different system components can connect to.

3. Energy analytics backend:

1. Receives energy data and user interaction events from SiteWhere (via Amazon SQS connection):
    - Energy data originated from zwave plugs, Accuenergy Modbus powermeters and the DAEM solar microgeneration system (via a Modbus connection to the Inverter)

- User interaction events originated from smartphones swipes on NFC stickers

2. Analyses power measurements variations around user interaction events
3. Pushes measurements of power variations and generated energy savings back to SiteWhere
4. Provides historical power measurements within a graphical user interface for advanced analysis

4. Game Backend

1. Receives the alerts generated from the mobile app (NFC and BLE events) process them and uses these events to initiate/complete specific challenges.
2. Communicates with the Energy Analytics Backend to retrieve energy information necessary to decide the outcome of a challenge (such as the power drop of the consumption in a circuit used to deduce if the user has closed a device).
3. Assigns the necessary points and challenge badges to users on successful challenge completions, updates the game data and manages the game leaderboards.

5. Gateway

1. Connect via Modbus to Accuenergy smartmeters installed at all pilots for monitoring consumption at electrical circuit level. Modbus integration ensures higher speed of polling (e.g. every 10 sec) as opposed to the traditional polling of 15 min.
2. Improve data update/push-to-sitewhere mechanism to make system more responsive
    - Taking into account zwave plugs have internal push thresholds (Fibaro) which might be useful to take advantage
    - Taking into account Accuenergy smartmeters (interfaced via Modbus) will be polled at high-speed but if there is no major value change, data should not be pushed to save resources

6.. Gamified mobile app

1. Listens for NFC/BLE events and forwards them to SiteWhere
2. Is used as a frontend through which the users can interact with the system and play the game. Through it the players can
    - Track their overall progress, points and finished challenges
    - Receive notifications and updates from the backend
    - Accept new challenges
    - Check their position in the leaderboards

Once the above minimum set of features for each component and their successful integration has been achieved, a minimum set of challenges will be further developed and integrated in to the system, the so called NOV(ember) version of the system.

4.2 Measurements

The measurements from the meters and the sensors are sent to the gateway and from there forwarded to SiteWhere which allows us to continuously monitor the energy consumption of the buildings. We use these data in the game challenges the users undertake as well as to monitor the total energy usage and energy savings achieved.

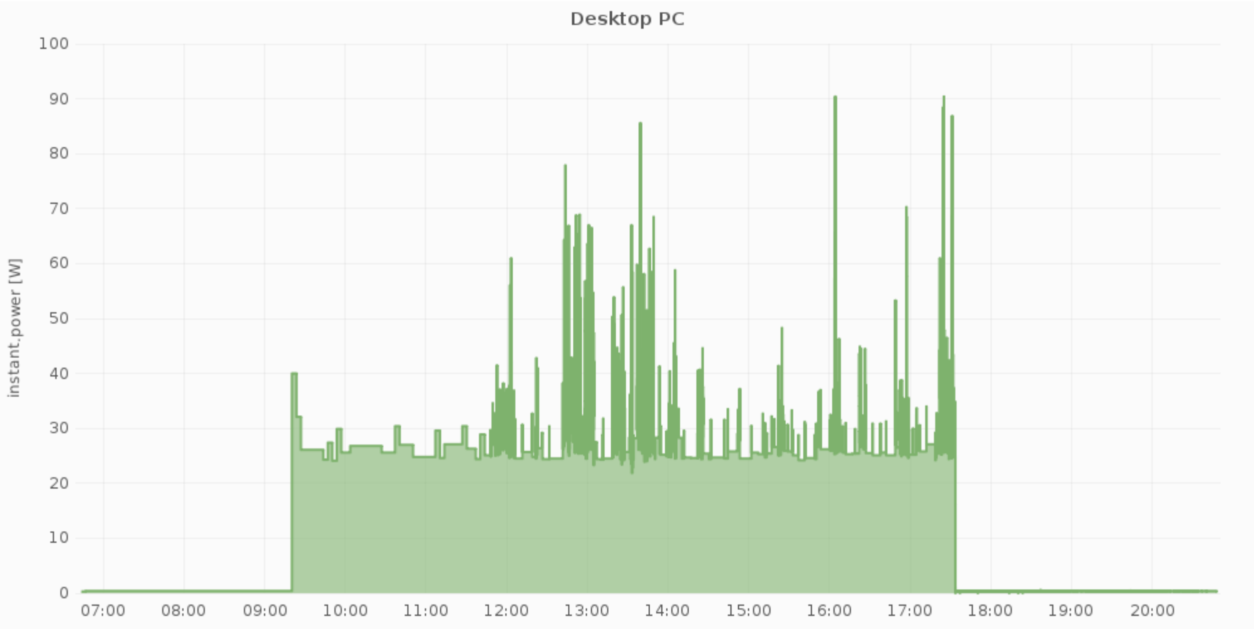


Figure 27 Indicative measurements of the electric consumption measured for different devices (I)

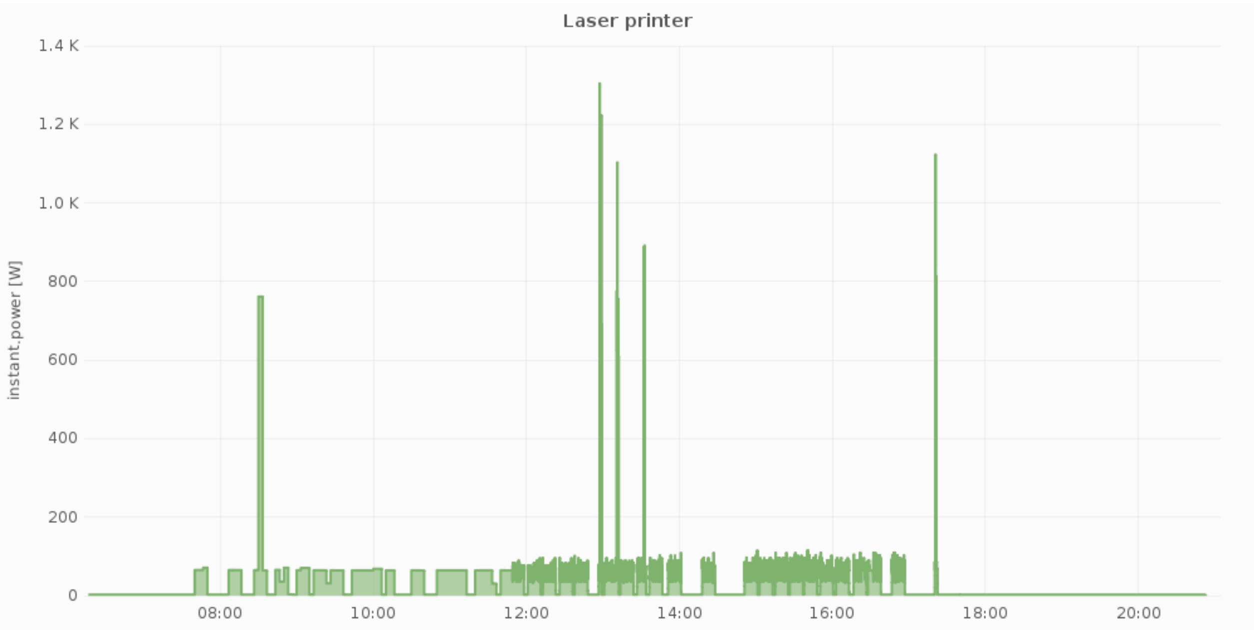


Figure 28 Indicative measurements of the electric consumption measured for different devices (II)

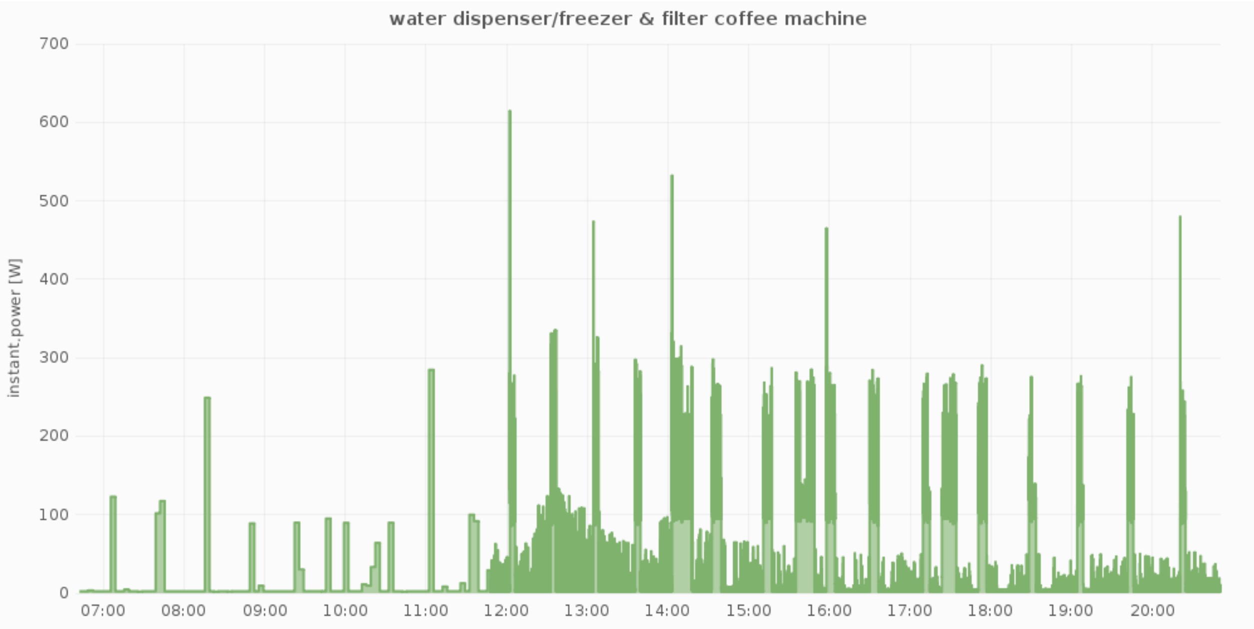


Figure 29 Indicative measurements of the electric consumption measured for different devices (III)

4.3 Integrated (End-End) Challenge demonstration

4.3.1 Challenge Overview

One of the challenges was demonstrated end-to-end as if played by a player, demonstrating the data flow and the communication of the subsystems. In this challenge, the players are required to close their pc before leaving the office in the afternoon after swiping the NFC on their desks. The ChArGED system is informed by the players' actions and awards them with points and a badge if the challenge is completed successfully.

4.3.2 User Selects the appropriate challenge from the mobile app

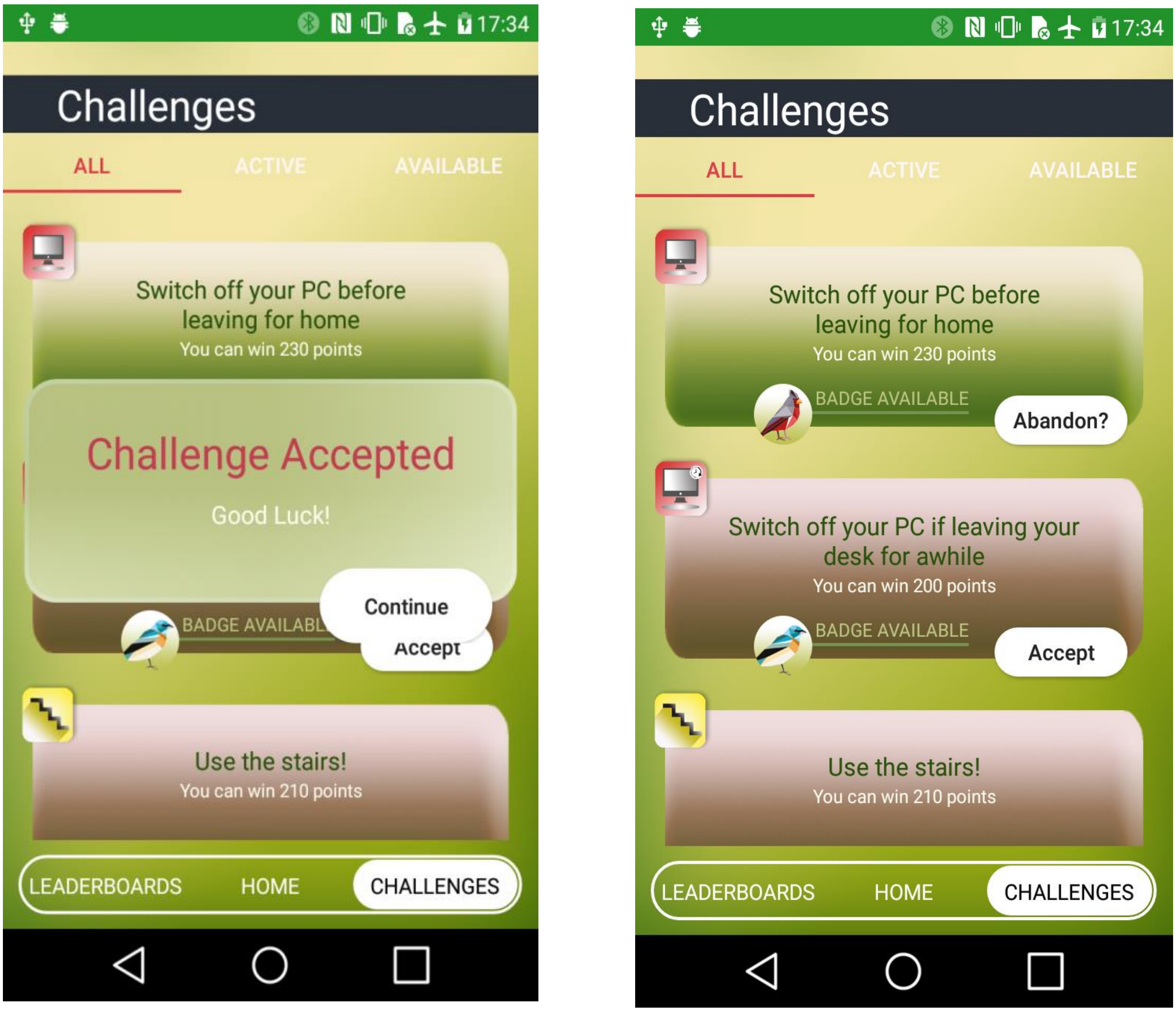


Figure 30 User Selects a Challenge

4.3.3 User Swipes the NFC

The user swipes the NFC on the desk. This NFC event is picked up by the app and forwards it to SiteWhere with the other relevant information (i.e. date and time the event happened, username, and identifier for the smartphone that produced the alert etc.). The PC on the desk is paired in the system with the corresponding NFC which lets us match the action being performed to the appropriate device.

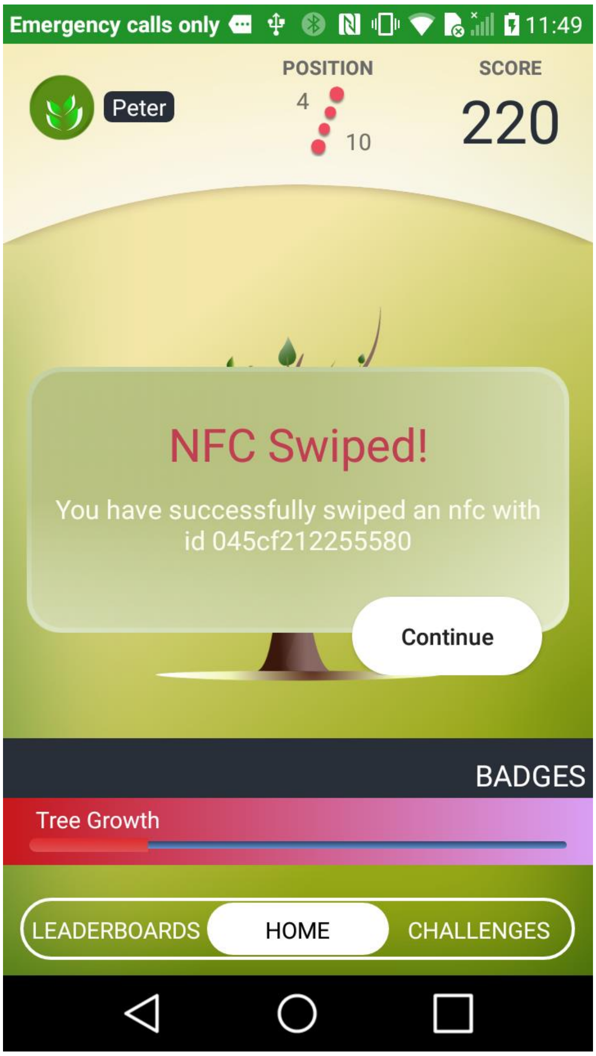


Figure 31 User Swipes The NFC Tag

4.1.1 Alert Received by the System

Inside SiteWhere a relationship has been declared which allocates players to smartphones. This is how when an event is received for an NFC alert the Game Backend queries the relationships identifies the players who did the NFC swapping. The following screenshot presents the pairs of players and phones (example).

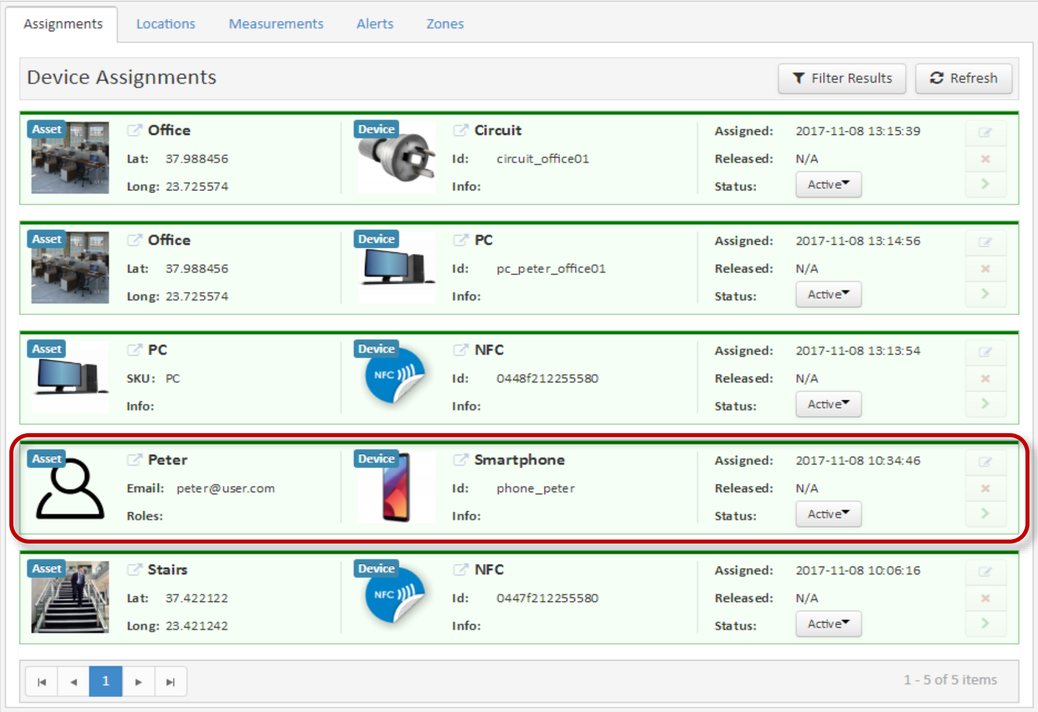


Figure 32 User Model Inside SiteWhere

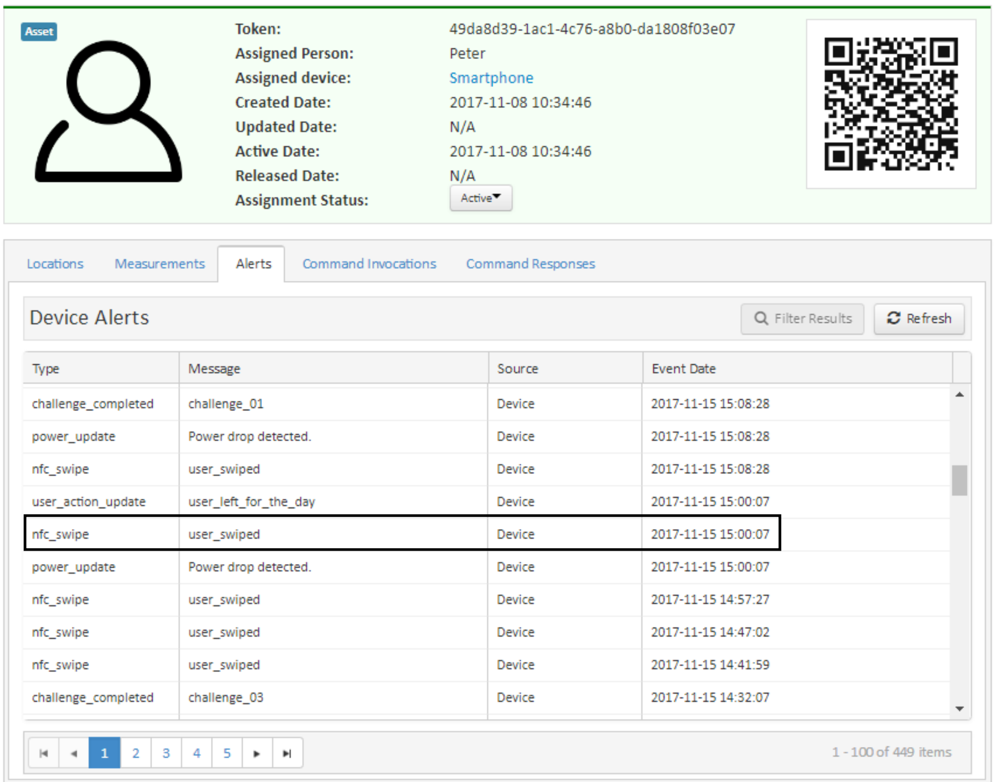


Figure 33 NFC Swipe Event In SiteWhere

4.1.2 Alert Processing

When the alert is received by the Game Backend it is processed and matched to the specific challenge (using data from the system and the time of the alert). When the challenge is identified the game backend communicates with the energy analytics to confirm that the event i.e of shutting down the PC has been identified. For this the measurements for the specific PC are retrieved by the energy analytics which then confirms the power drop in the electricity consumption. If the energy analytics confirm the power drop matching to the event of PC shut down (Fig. 33), the challenge is considered completed. The entire communication is stored in SiteWhere (see Fig. 34).

Figure 34 PC Electric Consumption

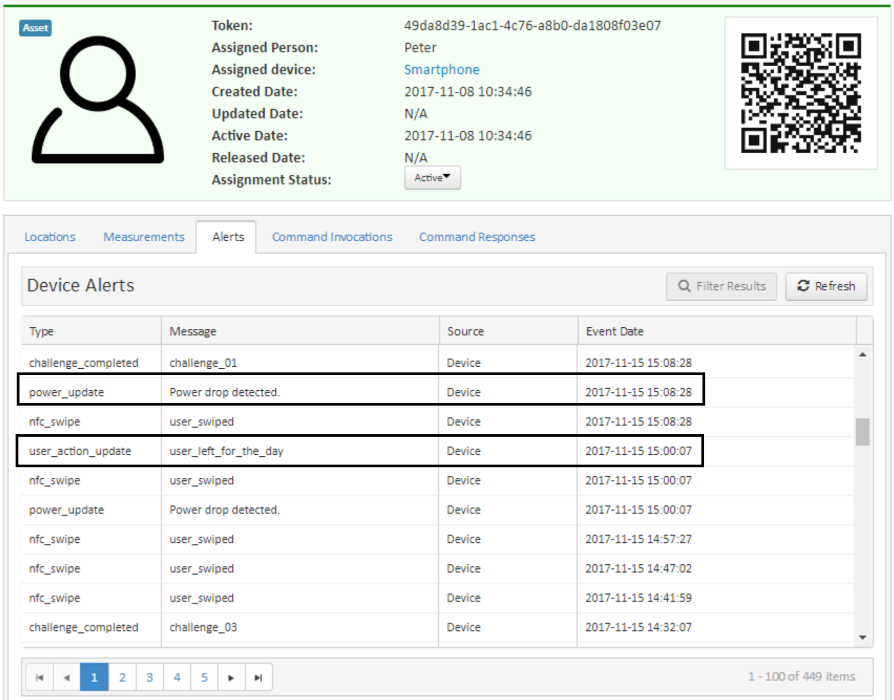


Figure 35 Messages Exchanged by The System Components

4.1.3 Challenge Completion

When the event “PC has been shutted down” has been recognised, then the game backend sends a “challenge completed” message to the app and assigns points to the user and a challenge badge. It also stores the results on the database and updates the game data in the system. If the user achieves enough points the tree will also grow to the next stage.

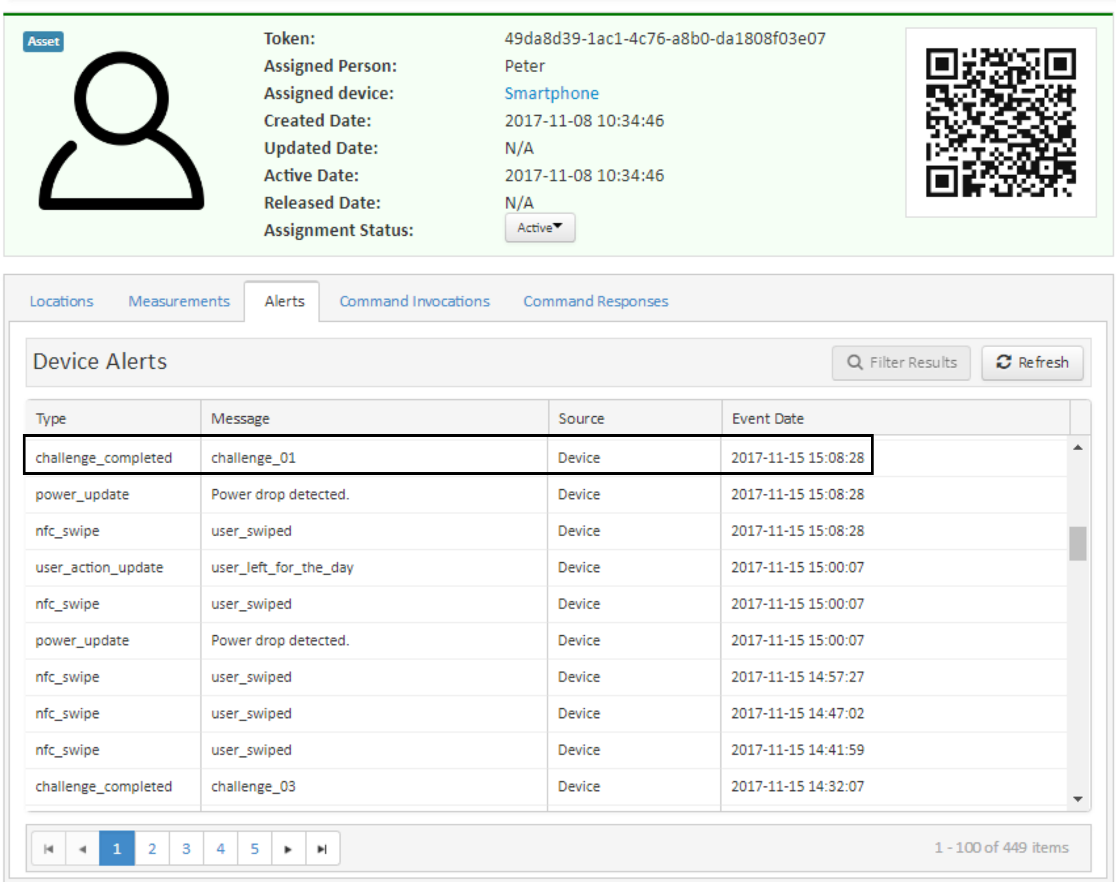


Figure 36 Challenge Complete Message

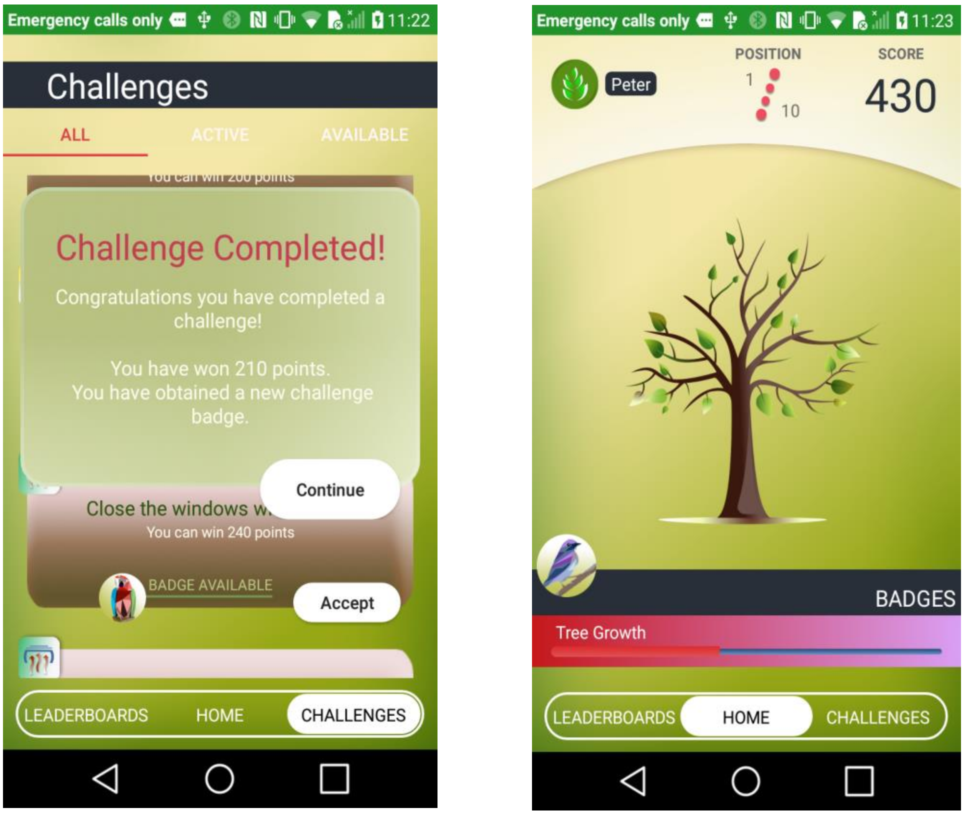


Figure 37 User Receives the Update inside the App

5 Technical Testing Plan and Results

The Validation Plan presented therein describes the general methodology that will be followed for performing the testing of the ChArGED integrated software before any release of the platform for trial at the pilot sites, inline with the multiple validation phases. This methodology aims to capture all aspects of the system operation which, when executed successfully, will demonstrate that the ChArGED system implementation meets requirements established in the technical deliverables. In particular, this validation plan must be documented so as to cover the information below:

1. Software components and interfaces included in the software release
2. Application scenarios to be supported by the platform
3. Description of the pilot test environment
4. Step-by-step description of the test cases, i.e. the validation protocol
5. Acceptance criteria and evaluation results to confirm that the system meets pre-defined requirements

Versions of software components, application scenarios and test environment will be dictated by the validation phase requirements and the current state of the software platform. They must all be documented first. In particular, the test environment is the starting point of the validation process, where the metering equipment and data collection processes are described and commissioned before the operation of the ChArGED platform is tested. For example, Figure 38 illustrates the test environment for our first end-to-end integration, where individual software components run on various servers.

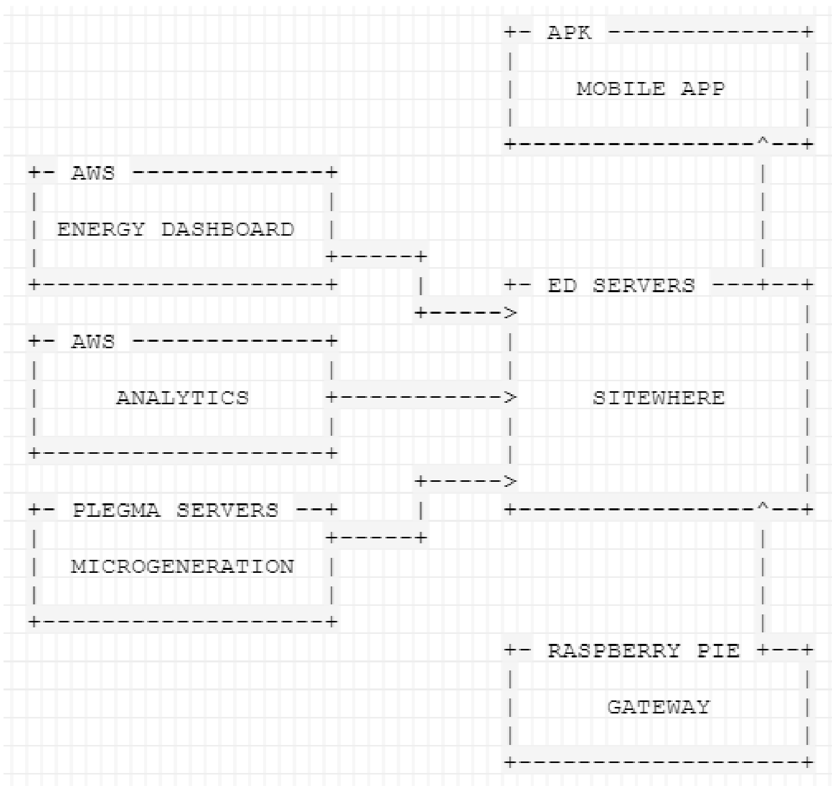


Figure 38 Illustration of a test environment for the Validation Protocol

The test cases aim to address all the mechanisms involved in the ChArGED system operation to support the supported scenarios, including the components' inner processes and interfaces between components. The Validation Protocol must therefore be constructed to recreate the major application data flows.

The scenarios supported at this stage of the project revolve around four main data flows. The following describes them in greater details, as they will shape the validation activities. A number of test case examples are provided for illustration of what is expected during each validation phase.

1. **Collection of data from the field via meters and environmental sensors**

After an organisation signs up to use ChArGED within its premises, the ChArGED system database must be configured to reflect the topology and inventory of electrical equipment that will be targeted by the gamified application. The data sources that already exist within the building, as well as new meters, smart plugs and environmental sensors are also registered within the platform backend and integrated to the platform via the ChArGED data gateway using industry standard protocols.

Once the platform is configured, the gateway initiates transmission of data to the core backend component of the ChArGED platform, and runs functionality to manage and maintain reliable connection to the various measurement devices.

A number of test cases must be defined to reflect the current compliance with those specific requirements. We provide here a number of test cases to illustrate the structure and type of tests that we expect to run for the four user scenarios. This list is not exhaustive, and every new release will include new test cases on top of previous tests.

CASE 1: Configuration of the ChArGED backend for the new building	
Instruction	The game admin creates within the platform database the new building and the various assets that will be part of the game
Expected Results:	• The game admin accesses the SiteWhere's backend admin user interface. • The game admin registers a new tenant (building). • The game admin registers a number of sites within the building corresponding to floors, departments,rooms and offices. • The game admin creates location assets to further describe the rooms if needed. The game admin creates a set of device assets with a general description of the device type to reflect a type of devices that can be found in the building. • The game admin creates devices based on the device asset specifications. The devices are the electrical equipment that we want to include into the game. • The game admin assigns each device to a person. If the device is used by many users at the same time, the game admin assigns each device to a location/room. • The game admin creates a set of IoT device assets with a general description of the device type to reflect a type of IoT devices that will be used within the building.

	● The game admin creates IoT devices based on the IoT device asset specifications, which are the monitoring equipment used for the purpose of the application. ● The game admin associates the IoT devices to devices via their metadata to indicate how the energy use of devices is measured. ● The game admin adds properties to the various assets to indicate information useful for the application, e.g. users belonging to a location.
Results	***The validation tests have been successfully executed in the controlled environment (at partners labs), which were already demonstrated at the review meeting.*** ***The next step is the validation of the pilots users (first validation phase).***

STEP 2: The Gateway is configured to collect measurements from the field sensor devices	
Instruction	The Gateway is configured to read measurements from all the sensing devices deployed within the building.
Expected Results:	● The game admin accesses the gateway admin user interface ● The game admin registers new data points by specifying their name, protocol and configuration settings ● The game admin tests the connection to the various sensing devices ● The game admin initiates data collection from the sensing devices to the Gateway
Results	***The validation tests have been successfully executed in the controlled environment (at partners labs), which were already demonstrated at the review meeting.*** ***The next step is the validation of the pilots users (first validation phase).***

STEP 3: The Gateway maintains reliable connection with the sensor devices and the SiteWhere platform	
Instruction	The Gateway
Expected Results:	● The backend is configured to listen to messages published to the MQTT Broker ● The backend receives data payload messages sent by the Gateway and parses the data point identifier to accept the data ● The backend processes the event via the inbound processing engines ● The backend stores the data to the correct IoT Device assignment

	• The backend forwards the event to outbound processing engines for use by other system components
Results	***The validation tests have been successfully executed in the controlled environment (at partners labs), which were already demonstrated at the review meeting.*** ***The next step is the validation of the pilots users (first validation phase).***

STEP 4: The Gateway is configured to initiate data upload to the platform backend	
Instruction	The Gateway is configured to initiate data upload to the platform backend, by associating the data collected to the identifiers of the IoT device assignments, and by specifying the output communication protocol.
Expected Results:	• The game admin accesses the gateway admin user interface • The game admin selects a data point monitored and registers its ChArGED backend identifier • The game admin registers the MQTT Broker as output protocol destination to forward the data to • The game admin initiates the upload of data from the Gateway to the MQTT Broker for all data points monitored
Results	***The validation tests have been successfully executed in the controlled environment (at partners labs), which were already demonstrated at the review meeting.*** ***The next step is the validation of the pilots users (first validation phase).***

STEP 5: The ChArGED backend processes incoming data payload	
Instruction	The backend system receives data published by the Gateway, and processes it to store it and generate events for other system components
Expected Results:	• The backend is configured to listen to messages published to the MQTT Broker • The backend receives data payload messages sent by the Gateway and parses the data point identifier to accept the data • The backend processes the event via the inbound processing engines • The backend stores the data to the correct Device – IoT Device assignment • The backend forwards the event to outbound processing engines for use by other system components

Results	***The validation tests have been successfully executed in the controlled environment (at partners labs), which were already demonstrated at the review meeting.*** ***The next step is the validation of the pilots users (first validation phase).***

2. **Supply of instructions to assist the end users in saving energy**

Data collected from measurements devices and the mobile app are forwarded from the ChArGED platform backend to the analytics engine for construction of predictive models and detection of abnormal patterns of energy use. The analytics engine continuously diagnoses the data collected to identify signs of waste energy. When detected, the analytics engine notifies the platform back-end of such events, upon which actions are taken by the game mechanics engine to notify the end-user via his/her mobile app that opportunities for saving energy exist. In parallel, the mobile app runs a number of pre-set challenges to engage the users in running through a number of best practice actions, and incentivises them via gamified reward mechanisms. A number of challenges are implemented to give various options to the end-user.

3. **Claim of energy savings from the end-users via the mobile app**

Whether triggered by the platform notifications or from their own initiative, end-users will swipe their mobile phone over an NFC sticker to register an energy saving action of their own. They may also move within the floor plan and trigger significant events for the game. These events are communicated to the core component of the platform for immediate feedback to the end-user via the mobile app, and forwarded to the analytics engine for in-depth analysis where the savings achieved are calculated. The output is returned to the end-user for score calculation and feedback to the end-user.

4. **Forecast of weather conditions to optimise the use of renewable energy**

The microgeneration analytics engine forecasts the time periods when the solar irradiance will be at its highest. This insight is fed to the game mechanics engine to incentivise the use of energy during such periods, and reduction of energy use outside of said hours. Notifications are passed to the end-users via the mobile app, and the microgeneration analytics engine monitors the readings for the PV installation to assess the overall response to the insights provided.

Validation Protocol

The integrated system components supporting the game scenarios implemented at each stage of the project must be evaluated, and evidence of testing and the process for handling testing failures must be documented.

The Validation Protocol is constructed to test the four use case scenarios under the test environment, current software component specs and according to the list of test cases relevant at that stage of the project. Test cases will differ depending on which version of the software platform is released, as some use cases will not initially implement all functionality.

The Validation Protocol is central to the Validation Plan, as it defines the execution of test cases, each aiming to verify a specific element of the ChArGED system at each phase of the operation. Collaboration between partners is a requisite for such a fine-grained testing procedure at subcomponent level, and the protocol allows all parties to be aligned on what functionality is being tested. Each test case includes the purpose of the test, any pre-requisites that need to be done before testing, and the acceptance criteria for the test. Test validation includes an instruction, an expected result, and the actual result, as well as operational limitations.

The process of following the instructions and recording the results is called “executing” the protocol. Any discrepancy between the expected result and the actual result should be tracked as a deviation. Deviations should be resolved before validation is complete and the application is trialled further in the three pilot sites.

The actual validation is concluded when all the steps of the Validation Protocol are executed to demonstrate the flow of information and processes common to the four scenarios supported by the current version of the ChArGED platform. The results are finally analysed and the new release of the platform can be trialed once all pending issues are resolved.

6 Next Steps and Conclusions

The deliverable presented the description of the 1st ChArGED integrated system, along with an overview of the ChArGED approach, the game concepts, the related use cases and challenges that are addressed with the integrated system. It further described the system architecture and software implementation details for the Data/Core Backend components that are included in the 1st integrated system. The description was accompanied with multiple indicative screenshots of the Mobile App and of an end-end challenge implementation that involved all integrated modules but the integrated system scenario has been demonstrated in real time at the project review meeting in M20.. Finally, the deliverable described the procedure for performing the testing of the ChArGED platform at each validation phase of the project to demonstrate that the ChArGED system implementation meets the requirements established in the technical deliverables.

7 References

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