D1.2 System Architecture

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1. INTRODUCTION

1.1 Project objectives and D1.2 aims

D1.2 describes the overall architecture of the SportE² system focusing on its main features: modularity, scalability and openness to a wide array of technology providers. In this document, the description of each module specifies the structure, sub-components and communication mechanisms necessary to make the intent of the SportE2 approach feasible from a technical point of view. With this background, the scope of the deliverable is:

- To provide high level specifications for the development of project's modules (SportE² *How*, *Why*, *When* and *Where*).
- To identify an appropriate interoperability architecture for the future implementations in the Test Pilots and Kubik facility and to ensure that the appropriate high-level requirements from communication protocols and interfaces are clearly identified in order to guarantee a full independence from manufacturers and tech-component vendors.
- To identify a common data structure that will be used throughout the different modules and that can be taken as a reference for future replication scenarios.

For completeness and to make this a stand-alone document, a general introduction to SportE² modules and the references to other project Work Packages and related deliverables is provided in the following section.

1.2 Definition of the 4 modules

The project is structured to develop 4 scalable modules that provide different products and services adaptable to client needs. For each module, a short description of scope and objectives is defined as follows:

- <u>SportE² How</u>: This module is a Smart Metering System able to exploit the installation of commercial meters by offering to the user two applications with different purposes:
    - A meter network optimization tool able to indentify, from the overall facility design, the best meters positioning in the different areas of the sport center, taking into account the actual costs of the meters on one hand and the potential benefits of the installed system.
    - A data analysis tool able to digest the data generated by meters, offering different views and graphs allowing the facility managers to identify sub-optimal behaviours.

  The *How* module will be designed, developed and tested in Work Package 2 (Smart Metering Network). Performed activities will be:
    - Analysis and definition of energy quantities and variables to be monitored
    - Identification of Smart metering technologies
    - Dedicated algorithms for sensor network optimization
    - Data representation and analysis
    - Development of *How* module prototype.

- SportE^2 Why: This module offers an integrated control system able to manage and control the different facility sub-systems, making the facility manager able to control energy generation, consumption and energy exchange with the grid. This module comprises an automation control platform together with SportE^2 *How* visualization tool in a unique application, allowing a complete understanding and control of the facilities.

  The *Why* module will be designed, developed and tested in Work Package 3 (Integrated Control System). Performed activities will be:

  - Design and development of control system
  - Design and Development of Machine to Machine Interface
  - Design and Development of Human User Interface
  - Development of *Why* module prototype.

- SportE^2 When: This module offers an Energy Optimization Tool able to collect the real-time information from Smart Meters as well external information like wheatear forecasts or electric energy time-based bills. These data are used to identify the best management scenario for the specific facility and then close to loop by putting the suitable set points in the SportE^2 *Why* modules.

  The *When* module will be designed, developed and tested in Work Package 4 (Energy Optimization System). Performed activities will be:

  - Definition of an Energy Model for simulation purposes
  - Definition of the objective function
  - Comparative study of different Evolutionary Algorithms
  - Deployment of an integrated central decision system
  - Development of *When* module prototype.

- SportE^2 Where: This module offers benchmarking capabilities by the comparison of energy situations and measures from different facilities. This module offers a web interface allowing managers of different facilities to monitor the actual situation of energy demands, consumptions, production, and grid exchange across multiple facilities (e.g. [kWh/m2] or [TEP/m2], [€/m2], [kg of CO2/m2]) from a remote web browser.

  The *Where* module (Multi-Facility Energy Indicator System) will be designed, developed and tested in Work Package 5 (Integration and Testing). Development will be based on the experimental data collected (during WP2 and WP3) and benchmarks, according to the requirements delivered in (WP1).

2. System Components

The modular approach presented in the previous chapter is justified through the perspective of exploitation, where the different modules can be adapted using different module combinations specific to the needs of the facility or manager. Using ROI as a benchmark and total energy consumption, it may be the case that a small facility may only warrant the *How* module, larger facilities a *Why* or *When* module and municipalities, ESCOs or Energy Managers the *Where* module to benchmark performances across facilities. To support the intent of multiple and scalable possible configurations, these possible configurations of the SportE^2 system are presented and analysed in the next chapter where the aggregation and communication constraints among the components have also been considered.

From an architectural perspective, the different modules are complex and independent entities that must rely on different components, but share a seamless integration when combined. Therefore in the rest of the chapter we identify the component/s that forms/form the different modules and the way these components interact among them.

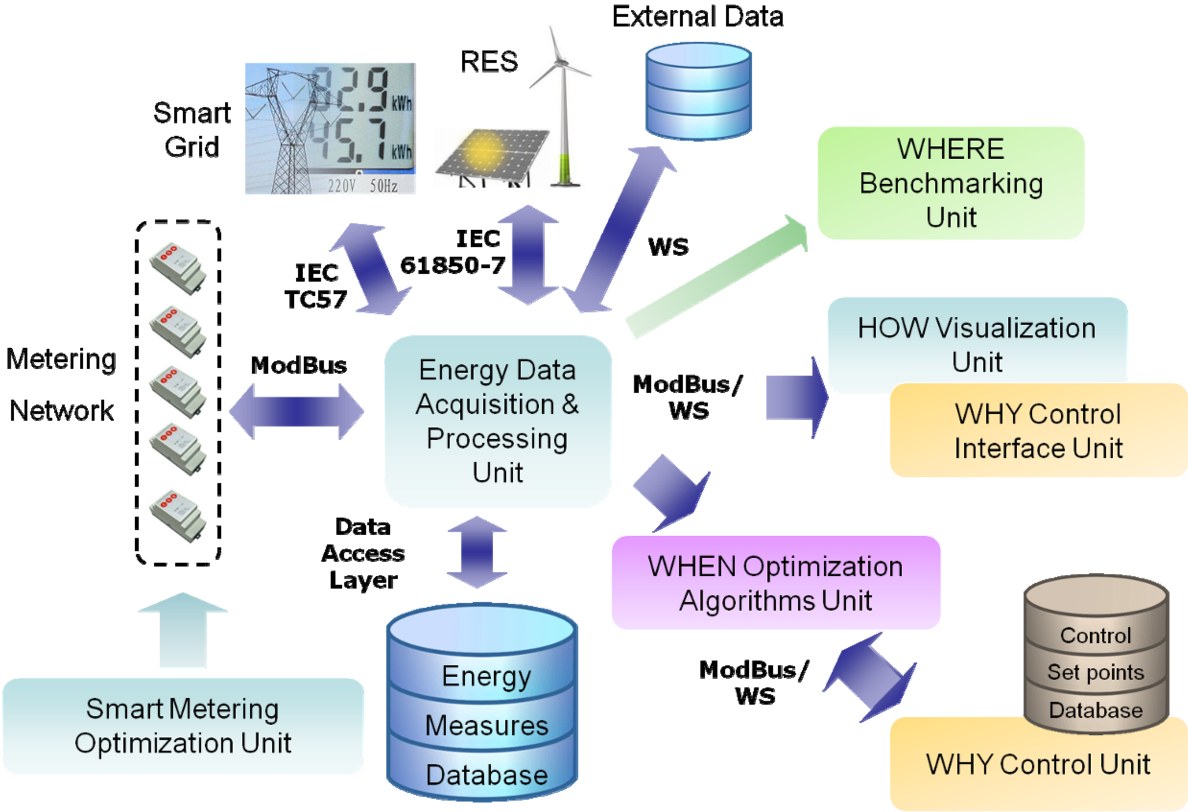

Figure 1: SportE^2 Architecture Overview

2.1 SportE^2 How

The *How* module acts as the baseline for the SportE^2 system architecture. In fact, the *How* component allows the retrieval of all the necessary real-time data for all available system functionalities.

The *How* module comprises 5 different components:

- Metering Network – This subsystem is represented by a network of meters communicating via standard communication protocol (Ethernet, ModBus, M-bus, Radio Frequency, ZigBee). These meters are commercial units already available on the market. Sensors and sensor networks are used for typical applications including:

- HVAC (Heating Ventilation and Air Conditioning System)
- Lighting/Shading
- Air quality and windows control
- Metering
- Systems switching off devices
- Safety and security
- Typical sport facility applications (e.g. swimming pool water temperature, specific gym tools, etc.).

- Energy Data Acquisition and Processing Unit – This unit is a software tool comprising:
    - Modbus gateway able to retrieve data from the different meters.
    - Web Service interface able to retrieve data from the different meters.
    - IEC TC57 Gateway allowing communication with Smart Grid operators.
    - Processing algorithms able to digest the measured data providing High Quality Data Sets (HQDS). By HQDS we intend that some amount of pre-processing has taken place to disregard errant data and to take averages where necessary.
    - Validation algorithms for data inputs acquired from the sensors' network.
    - Acquisition of data from facility energy subsystems, RES (Renewable Energy Sources) generation, smart grids, indoor and outdoor spaces in order to evaluate the load factor of the system and the related energy demand.
    - Acquisition of energy demand data from internal meters to provide this information to the Optimization Unit (*When* module) in order to contribute to the grid level optimization i.e.:
        - shaping energy load profiles over time,
        - if RES are deployed in the facility, shaping the generation profiles on the basis of an optimization strategy (high-level decision).
    - Acquisition of weather data from internal (meters) or external (Internet-based Web Services) sources in order to provide this information to the Optimization Unit (*When* module) when this software module is deployed in the system.
    - Data Access Layer able to store and retrieve data on the *Energy Measures Database.*
    - HQDS Modbus Interface, an interface for requests of HQDS on Modbus protocol.
    - HQDS Web Service Interface, an interface for requests of HQDS on HTTP protocol through a Web Service (e.g. SOAP Web Service).
- Energy Measures Database – This unit is a relational database (managed by a SQL RDBMS or Relational DataBase Management System) allowing to store all the most relevant data, both raw and processed (HQDS, High Quality Data Set) for historical and post-processing purposes.
- How Visualization Unit – This unit visualizes HQDS for auditing and continuous assessment purposes. This software application (hosted on a machine inside the facility):
    - interacts with the Energy Data Acquisition and Processing Unit by the Web Service Interface.

- visualizes the status of the metering network and load factor (power demand) of the system/facility of interest.
- provides the relevant performance indicators in a series of screens and summary dashboard
- provides low level analysis of the data (e.g. a comparison to a previous time period).

During the smart metering system design phase the Smart Metering Optimization Unit is used. This module is a preset/design issue of *How* module (independent software application) and it does not need of data from *Energy Data Acquisition Unit* but of geometric data of facilities and network's data (sensors, communication protocols, existing network, etc.). This software application works (before the network installation and real-time acquisition phases) with "static" data above the *How* Module and allows the optimization of the meter network design, leading to minimization of installation costs and improvement of retrieved information quality. For these reasons, this optimization unit has been considered an element of the *How* module and accordingly represented in the architecture of the system.

2.2 SportE2 Why

The *Why* module can act as a standalone module or together with other SportE^2 modules according to the planned configurations, in order to allow the real-time control of devices deployed within each facility.

Why module comprises 3 different components:

- Control Unit – This unit is responsible to manage the set points of the controllers used in the facility network. The control can be automatic or supervised by human operator by means of the interface unit. Depending on the complexity of the facility and the desired redundancy of the system, it is possible to combine more than one control unit in the *Why* module. Control Units can utilize various communication protocols, such as Modbus, LonWorks or BACnet, to exchange information and control system components. The unit(s) will process the HQDS information from the Energy Data Acquisition and Processing Unit of the *How* module based on the selected strategy. Considering the configuration of the SportE^2 system, when the Optimization Algorithms Unit is deployed remotely, the *Control Unit* will need to interact with this unit in order to manage the set points according to the optimization functions. The selected hardware for this task is a controller-gateway device, an IP controller which can be connected to the Ethernet network of the facility and perform the requested operations. Equipment that does not have a communication interface will be controlled with the use of dry contacts, provided by I/O modules installed along with the controller.
- Control Set points Database – This module is a relational database (managed by a SQL RDBMS or Relational DataBase Management System) allowing to store set points values of the control devices.
- Control Interface Unit – This unit will allow visualizing the status of the set points of each deployed SCADA system and remote controller. It will interact with the Control Unit(s) by means of Ethernet network. *Control Interface Unit* could be deployed on the same machine of the How Visualization Unit: as standalone software application or as software module of more complete *Visualization* and *Control Interface Unit*. The selected software for this task also allows the integration of access and security control. The remote real-time monitoring and control is realized through a web interface that provides full overview of the system status.

2.3 SportE^2 When

The *When* module is a software application that can be deployed only when a *How* and a *Why* module have been considered within the SportE^2 system configuration. The aim of the SportE^2 *When* module is to make the overall system "Intelligent" which includes the optimisation of control actions performed by the *Control Unit* (*Why* Module) in order to achieve planned efficiency targets (single or multi-objective optimization) and the identification/conduct of any energy savings strategy.

The *When* module comprises 2 different components (each of them could be locally or remotely deployed):

- Optimization Algorithm Unit – This unit collects the real-time information from Smart Meters in the shape of HQDS (by using the HQDS Web Service Interface, when remote, or Modbus interface, when local, of the Energy Data Acquisition and Processing Unit) as well external information like weather forecasts, energy pricing, or facility scheduling. These data are elaborated to provide suitable set points in the SportE^2 *Why* modules (closing the control loop) in order to optimize the management scenario of a specific facility. Several possibilities exist to provide optimization parameters to the Control Unit:
    - <u>Automatic Optimization</u>: the facility operator (by using the *Optimization Interface Unit*) establishes a desiderate management scenario for the facility and then the *Optimization Unit* automatically manages the *Control Unit* providing the "optimized" set points for the controlled devices.
    - <u>Manual Optimization</u>: in this scenario, the facility operator is able to modify each parameter or value provided to the *Control Unit*, trying to perform in this sense the optimization of a specific efficiency objective.
    - <u>Semi-Automatic Optimization</u>: this scenario represents a more flexible management of the *Control Unit* in order to achieve desiderate efficiency objectives. In this framework, an optimization scenario for the best management of the facility is chosen by the human operator as in the automatic optimization but, in this case, the facility operator can directly supervise the optimization process and modify output parameters according to his/her efficiency objectives.

  The *Optimization Unit* as a software module enables human operator to select and try to achieve a predefined optimization objective for the sport facility in terms of energy performance considering a limited set of optimization alternatives. For example, the facility manager could decide to minimize the energy bill or carbon emissions or he/she could decide to maximize the comfort level of the facility users. In the current document, the identification of the specific optimization functions is an open point and out-of-scope since Work Package 4 (Energy Optimization System) will perform this task. However, such an approach will enable the development an energy optimisation system that moves beyond a SCADA based logic structure to an intelligent, flexible and adaptable decision making tool specifically focused on sport facilities. WP4 will develop the system and device models, optimisation algorithms, and simulations for set points as necessary to support this system.

  The *Optimization Algorithm Unit* typically elaborates a huge amount of data from different sources: in this sense and in order to satisfy performance requirements, it could be useful to consider the deployment of this software module on a dedicated machine. The deployment of this elaboration unit can be local to the sport facility or remote to the service provider data centre providing the possibility for a software-as-a-service business model.

- Optimization Interface Unit – This unit represents the interface (GUI, Graphical User Interface) by means of the facility operator is able to supervise and control the *Optimization Algorithms Unit*. The communication between the components of the *When* SportE^2 module is based on Web Service interfaces since these software modules reside on different machines. There are two different deployment scenarios concerning the *Optimization Interface Unit*:

- Local Deployment: the interface unit is located within the sport facility, typically on the same machine where *How Visualization Unit* and *Control Interface Unit* are deployed. The unit communicates with the *Optimization Algorithms Unit* by the WS interface on the LAN (Local Area Network) infrastructure if the *When* SportE^2 main component is located on the same network or on a WAN (Wide Area Network) or public WAN (Internet) if the unit is remotely deployed outside the facility.
- Remote Deployment: the interface unit is located outside the sport facility on a dedicated machine and communicates with the *Optimization Algorithms Unit* by the WS interface on a LAN infrastructure if the *When* main component is located on the same network (externally to the facility) or on a WAN or public WAN (Internet) if the *Optimization Algorithms Unit* is internally deployed to the facility network.

2.4 SportE^2 Where

The SportE^2 *Where* module comprises a single component called Benchmarking Unit (considering also the user interface or *Benchmarking Visualization Unit*). This software module (deployed externally to the facility) represents a web interface accessing to HQDS information of each managed facility to monitor the actual situation of energy demands, consumptions, production, and grid exchange. The developed GUI offers benchmarking capabilities by the comparison of energy situations and measures from different facilities. Software interface provides information to human operators in the remote Data Center in the form of:

- Energy Dashboards for real-time monitoring
- Charts and Tables enabling historical data evaluation
- Comparison metrics
- Energy Reports.

Input data (HQDS) are retrieved by using the HQDS Web Service Interface of the Energy Data Acquisition and Processing Unit (*How* module) and delivered to this remote visualization unit.

Considering the modularity of the system, this element can be used in a configuration of the SportE^2 system comprising only two modules: *How* module and *Where* module. The presented scenario could represent a set of sport facilities where only the *How* module has been deployed (one-to-one relationship, one *How* module for each facility) and a single *Benchmarking Unit* (*Where* module) remotely deployed monitoring energy performances across the managed facilities.

3. Building Model and Methodology for Simulation purposes

Simulation is a powerful instrument providing realistic sets of data associated with different scenarios for the development and testing of algorithms. In the case of learning algorithms, simulations can be utilised to “train” parameters by creating thousands of scenarios without the cost or time of having to develop or wait for such scenarios to occur. In SportE2, simulation is initially envisioned in two work packages to perform two different tasks. They are WP2 (Smart Metering) where simulation will be utilised with the intent of determining the optimal number and placement of measurement devices and WP4 (Optimisation) where simulations will be developed to better understand the energy modelling of the facility or its sub-systems with the intent of developing optimisation strategies and algorithms.

3.1 Simulation in WP2 (How Module - Smart Metering)

In the framework of the WP2 system development, the Matlab/Simulink environment will be used to develop simulation models as support for variable analysis (such as performance indicators sensitivity to some variables) and for optimization algorithms tests (sensors positioning): the outputs of these activities will be used in the implementation of the Smart Metering Optimization Unit (*How* module).

The use of Matlab is increasing across a large number of fields. Together with its dynamic simulation toolbox Simulink, originally developed for control and automation applications, it has become a powerful tool that is suitable for a large number of applications. This now includes the field of energy to include built in or available tools for energy consumption, control strategies, hydraulic and air flow studies, comfort, and sizing problems. More and more studies are being published using Matlab/Simulink environment for development of specific tools and for simulations of buildings and technical building services. Several examples of using Matlab/Simulink in this sector are:

- Multizone building models have been developed based either on heat and moisture or on heat, providing a graphical user-interface (GUI) for the building description. Specific work has been carried out on conduction in walls and their mathematical reduction.
- Room modelling has been described either on perfectly mixed air; UNIVPM performed one in the context of European Project IntUBE, or on air distribution in rooms. These can also be based on the zonal modelling or on CFD (Computational Fluid Dynamics) modelling also coupled the CFD approach with HVAC system models.
- Ventilation, air flow and air quality has been studied by integrating multizone air flow modelling in Simulink environment. This work includes the modelling of moisture phenomena and pollutant transport (e.g. CO_2).
- Hydronic networks have been modelled and simulated in order to study water networks and the control of variable speed pumps in heating or cooling systems.
- Heat generation by solar, CHP or heat pumps.
- Some work has also been carried out on heat storage, from water storage to thermo-chemical seasonal heat storage.
- Lighting and blinds: Models for lighting and blinds have been implemented.
- Renewable systems: PV system, solar thermal, wind generator.

In spite of a growing number of available models in MATLAB/Simulink, it will helpful to have the capability to link to other existent building simulation tools or software. This allows one to leverage the advantages of multiple analysis tools. An example could be to use the use TRNSYS for energy simulation and Simulink for multizone modelling. Another approach consists in the coupling of analysis tools by data models. Common data bases for model parameters would then be used. Data exchange, from/to simulation model, can be performed using many type of communication channel such as OPC server, SQL server, TCP/IP protocol, or intermediate file such as text, Excel tables or database tables.

The next example will clarify the intended use of simulation for SportE[2] project (WP2).

Consider an indoor swimming pool and the purpose of optimizing the sensors number and placement for temperature measuring (Figure 2). Optimization also means finding the optimal accuracy of the measurement related to the energy saving in the facility. One temperature sensor allows an accuracy of e.g. 5°C of air temperature measurements, while two installed sensors allows an accuracy of e.g. 3°C. Obviously this rate of accuracy means a certain rate of energy saved. This value can be retrieved by simulation model, so that using simulation outcomes, optimization defines the optimal number of sensors balancing energy saving and network cost.

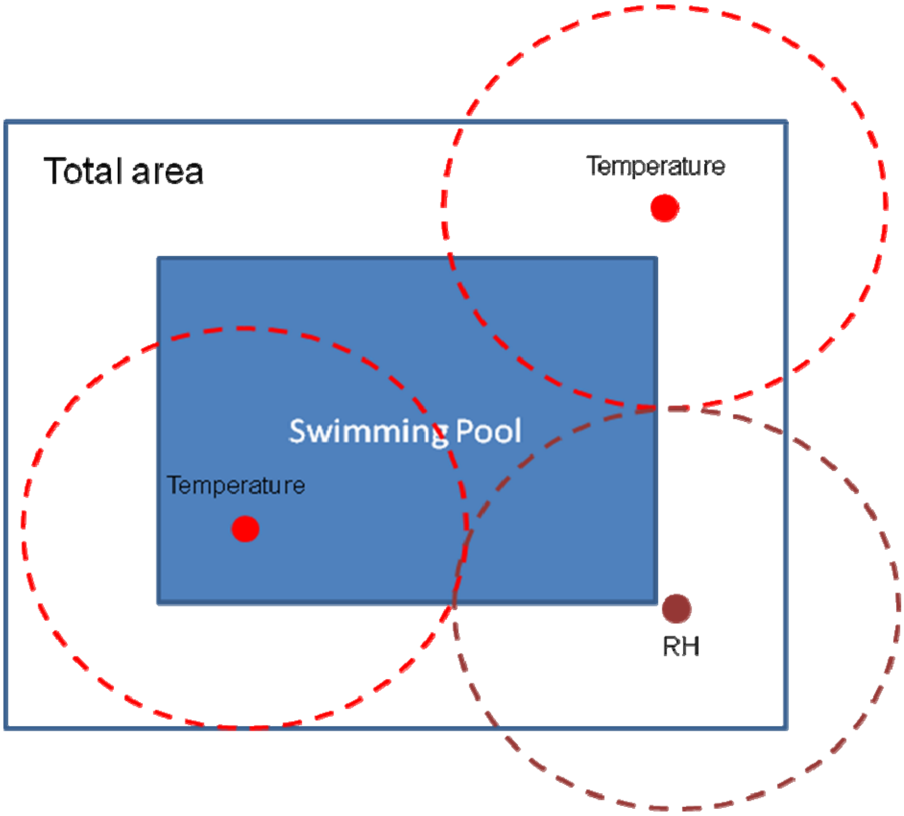

Figure 2: Example of optimization scenario of the sensors number and placement for temperature measuring in indoor swimming pool

3.2 Simulation in WP4 (When Module - Optimisation)

The initial approach for SportE[2] When, is to virtually test different operation strategies in order to identify the optimal strategy that can be implemented at different levels (device, sub system or global) in the real sport facility. The different tests on operation strategies are grouped in scenarios focusing on particular aspects of a typical sport facility such as optimal water and air temperature scheduled in the swimming pool or optimal HVAC operation schedule depending on weather and expected occupancy.

These scenarios are tested in physical energy simulation models in order to identify the energy/comfort impact of the suggested changes in the operational strategies. These models can provide a better understating of the problem and can also be used to generate high quality data sets. The data sets will be used in turn to train Artificial Neural Networks (ANN) or fuzzy logic models that will be used for optimisation purposes. Building energy simulation models require much effort to be implemented and are not suitable as part of a commercial product. However building simulation models could be used during the initial phase of the project in order to test different strategies under different weather/occupancy conditions and understand their impact on energy and comfort.

Ideally the virtual testing phase will result in the identification of the key parameters to be optimised and the development of a set of meaningful tests that will be then implemented in the real building (during the first installation phase). These tests will show the real building/system response and train the ANN models with actual measured parameters, provided by the smart meters installed as part of SportE² How. These models represent the core of SportE² When its relative commercial product expected to be developed within the project.

Similar to WP2, WP4 will make broad use of the MATLAB/Simulink environment. In addition, the WP will make use of Dymola/Modelica, and Easy Java Simulations (EJS).

In order to train the ANN models the initial planned solution is to use MATLAB for optimization and an energy modelling tool like Dymola for the physical building/HVAC modelling. With Dymola/Modelica it is possible to simulate the dynamic behaviour and complex interactions between systems of many engineering fields, such as mechanical, electrical, thermodynamic, hydraulic, pneumatic, thermal and control systems. This means that users of Dymola can build more integrated models and have simulations results that better depict reality. With Dymola/Modelica is also very easy to create the physical models and then export it as block that can in turn be incorporated in MATLAB. Another interesting solution is the use of an open source tool named "Easy Java Simulations (EJS)". With this tool it is possible to model the system roughly in Java and then communicate directly with MATLAB.

Figure 3 shows simulation in the concept of the SportE2 When module.

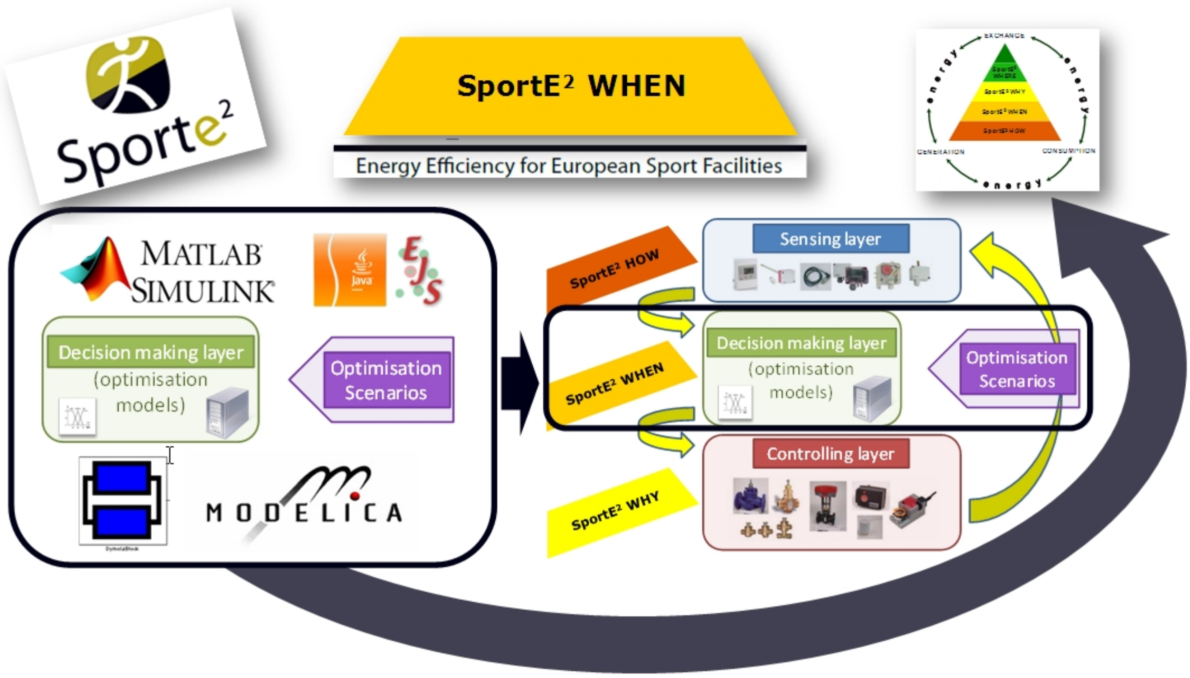

Figure 3. Simulation in the context of SportE² When

4. Common Data Structure

The aim of a common data structure in SportE² project is to unify all the communications in the project. The proposed data structure has been used with success in other EC projects, like Save Energy, and will be adapted for use in SportE². Partner ISA participates in Save Energy (http://www.ict4saveenergy.eu/) and will lead the adaptation of this general structure for use in SportE².

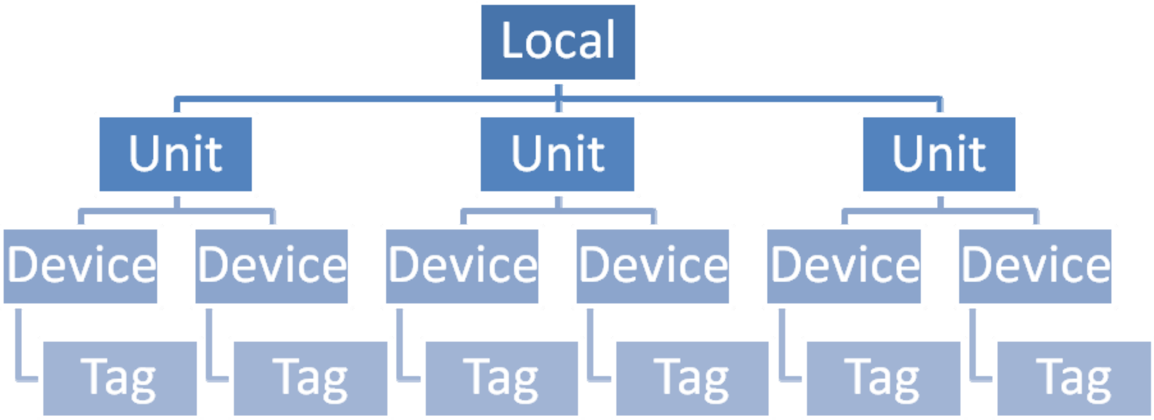

Figure 4: Common Data Structure

In the SportE² common data structure (Figure 4), there are considered 4 levels of information to be carried out among different modules:

- Local represent a specific sport facility;
- Unit represents a specific data logger, i.e. a specific SportE² module;
- Device represents a specific meter/instrument that handles the data;
- Tag represents a parameter to be exchanged.

5. Overall System Architecture

A block diagram showing SportE² system architecture is given below (Figure 5). In this diagram the four modular elements have been represented as well as their main architectural units:

- *How* module (5 components) defines the baseline for the whole SportE² system architecture since it allows the retrieval of the real-time data necessaries for all the available system functionalities.
- *Why* module (3 components) provides the integrated control system to manage and control the different facility sub-systems.
- *When* module (2 components) closes the control loop with the *Why* module optimizing the control laws in order to satisfy predefined energy efficiency objectives.
- *Where* module (1 component) enables the remote energy performances benchmarking across the managed facilities.

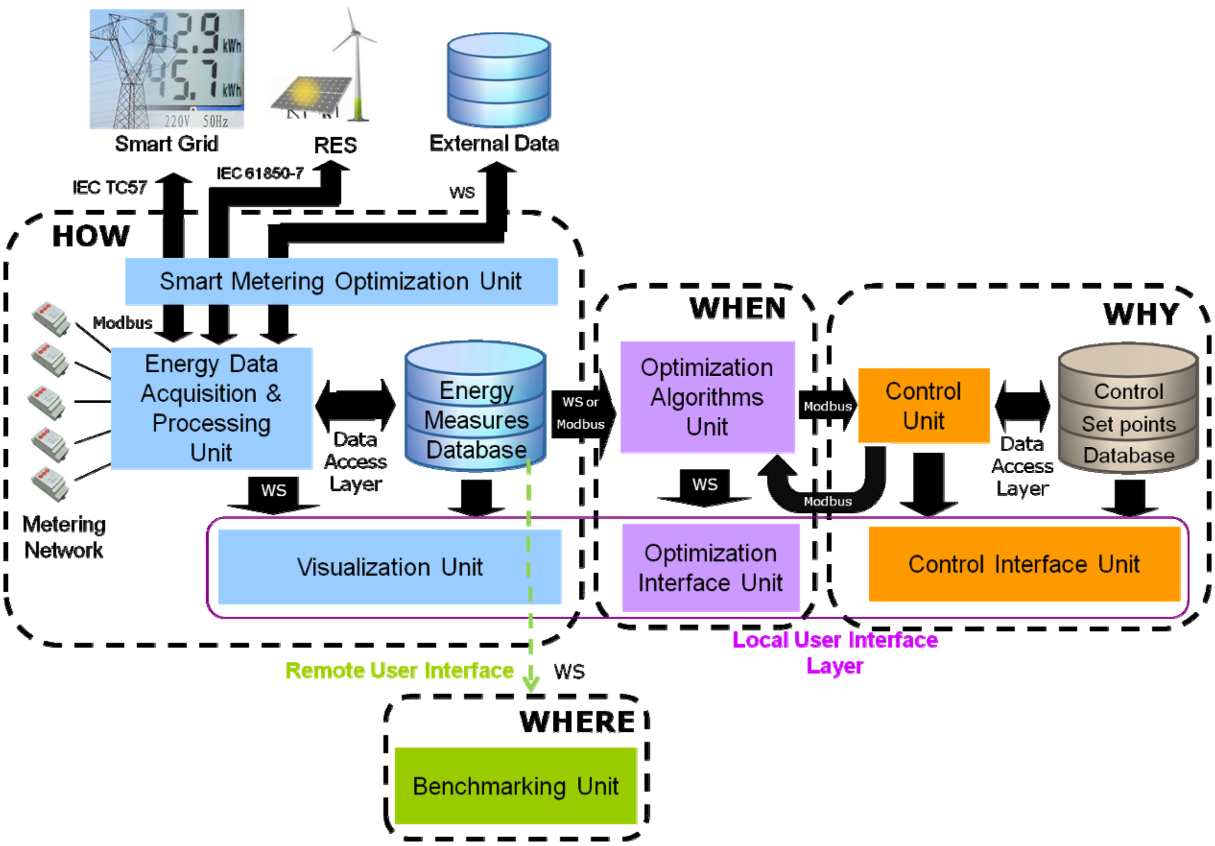

Figure 5: SportE² system architecture

5.1 System Communication

A detailed representation of SportE² system communication architecture is depicted in Figure 6.

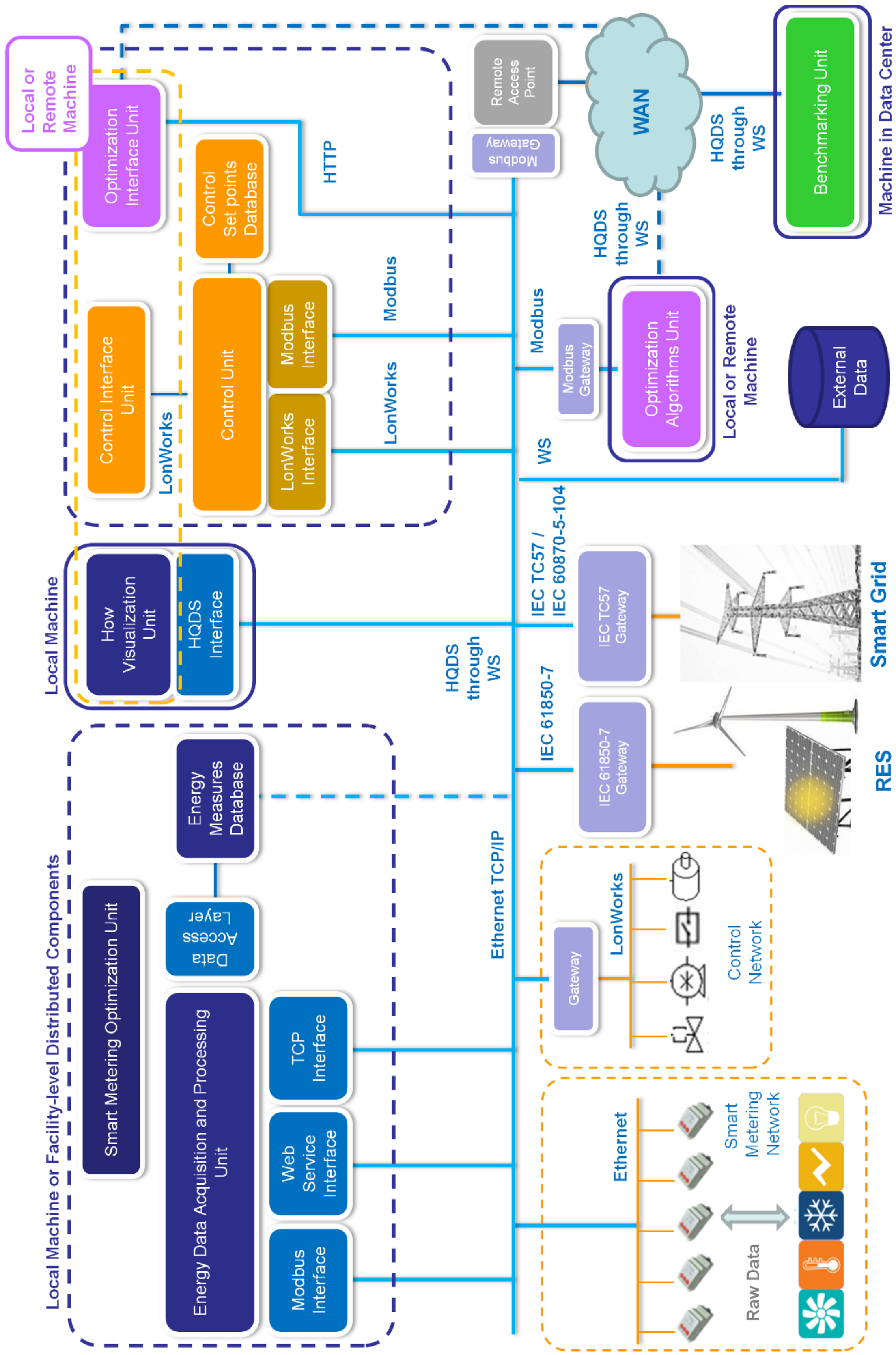

Figure 6: Detailed Architecture of SportE² System

All the components/modules (except the Benchmarking Unit) are locally represented to the facility: the Optimization Algorithms Unit and the Optimization Interface Unit can be both deployed to a remote Data Center or to the same sport facility or by using a mixed deployment configuration (in the remote deployment case data are accessed by means of Web Service interface, in the local deployment case data are accessed by means of a Modbus interface). When the *Optimization Interface Unit* is local to the facility, it is accessed by human operators as software interface module deployed on the machine hosting How Visualization Unit and Control Interface Unit (HMI, Human Machine Interface).

In the facility, the backbone element enabling the communication among subsystems is represented by a TCP/IP Ethernet (TCP over Ethernet) network infrastructure while the above application layer is based on Modbus (in particular in the smart metering network), LonWorks (for the control network) and Web Service (communication at software application level). In this network a Remote Access Point provides the access control functionalities (proxy, firewall, DMZ host) and the gateway with external world communicating over Internet or public/private WAN (Wide Area Network). Data provided by Smart Grid (if available and necessaries according to the optimization strategy) and elaborated by the Energy Data Acquisition and Processing Unit are accessed thanks to an IEC TC57 Gateway (based on the IEC 60870-5 standard). When RES generation is available in the facility, a communication infrastructure (represented as IEC 61850-7 Gateway) representing a bridge between the distributed energy resources and the internal network (and the related interface) is used. The external data needed to the *Where* module (weather forecasts, etc.) are gathered through a web service interface.

Considering the presented architecture, following elements can be highlighted:

- *Energy Data Acquisition and Processing Unit* can be deployed on a local machine together with or not the Energy Measures Database that is accessed by means of a Data Access Layer (a persistence layer between the software application and the underlying database). The development of this software component considers the evaluation of different state-of-the-art technologies (e.g. Hibernate, Oracle Toplink and OpenJPA) in order to assess the best solution according to the objectives of the software module. The database can also be deployed on a different machine (dedicated machine) in order to provide better performances avoiding computational overload of the *Energy Data Acquisition and Processing Unit* when huge bulks of data have to be retrieved and elaborated.
- Modbus and Web Service interfaces enable *Energy Data Acquisition and Processing Unit* to communicate with other modules and devices in the network (gateways, control units, visualization unit, remote machines, etc.).
- *How Visualization Unit* is deployed on a separate machine inside the facility and communicates with *Energy Data Acquisition and Processing Unit* thanks to a Web Service interface to retrieve HQDS information to display on the supervising cockpit. This machine can also host the *Control Interface Unit* and the *Optimization Interface Unit* (when this software module is locally deployed in the sport facility).
- *Control Unit* communicates over the network with metering devices using Modbus (Modbus TCP) and with PLCs and other controlled devices using LonWorks protocol storing set points in the Control Set points Database.
- Control network comprises router/gateway devices to the transfer of data point values and other information from different networks, switches, security devices and various control devices (e.g. PLC, RTU, etc.). The network is based on LonWorks standard protocol.
- *Optimization Algorithms Unit* is a software application that can be locally or remotely deployed on a separated machine (workstation or server) in order to optimize the control loop to satisfy an optimization objective (stated at high level in the facility management).

When deployed in Data Center (outside the sport facility), this software component retrieves HQDS information from the *Energy Data Acquisition and Processing Unit* by using a Web Service interface (authentication data are requested), differently, when local to the facility, by using a Modbus interface. Communication between *Control Unit* and *Optimization Algorithms Unit* is based on Modbus protocol.

- *Benchmarking Unit* is a software module, comprising also a visualization interface, deployed on a machine outside the facility (this unit is typically used when multiple facilities have to be managed). This unit retrieves HQDS information from the *Energy Data Acquisition and Processing Unit* by using a Web Service interface (authentication data are requested since the module is external to the sport facility).

5.2 System Deployment

In order to better clarify where each main software and hardware component for each SportE[2] system module is physically located, a deployment diagram (compliant to UML, Unified Modelling Language) has been provided in Figure 7.

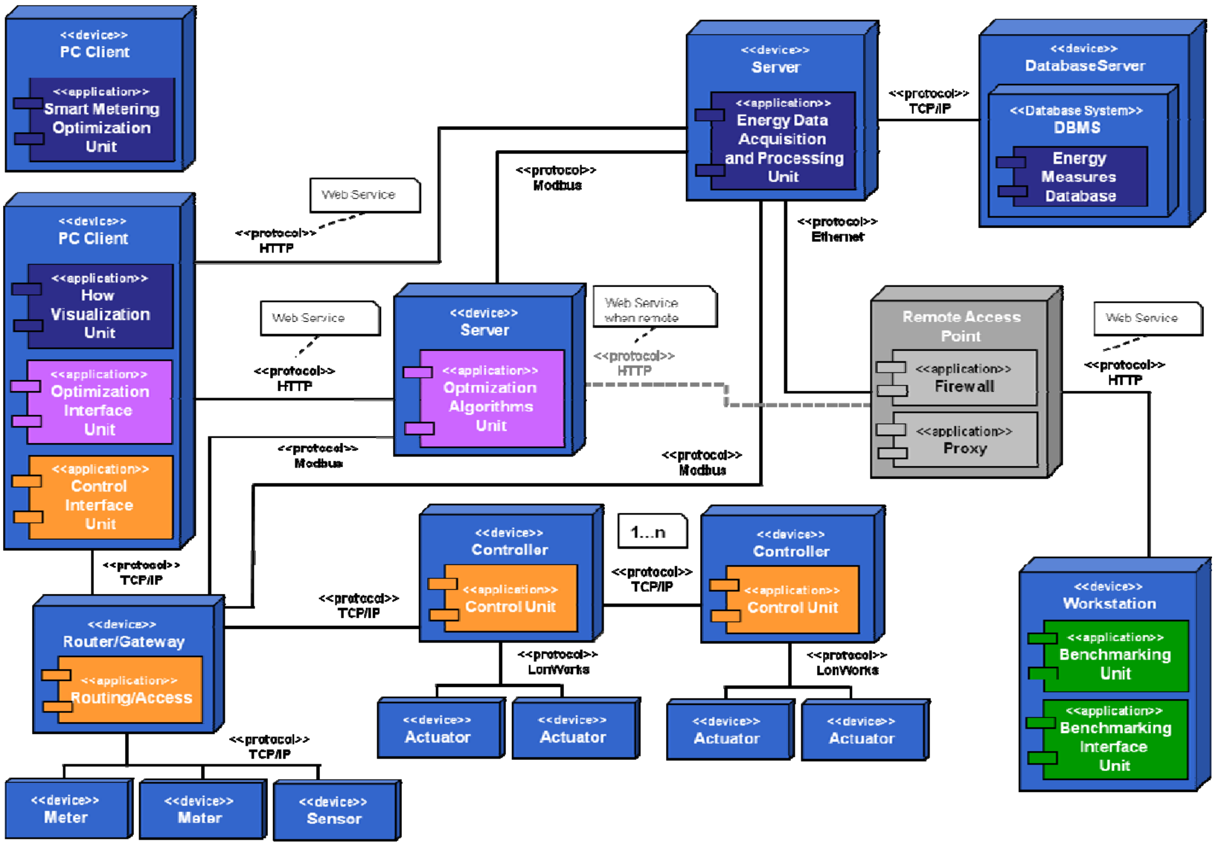

Figure 7: Deployment Diagram of SportE[2] system

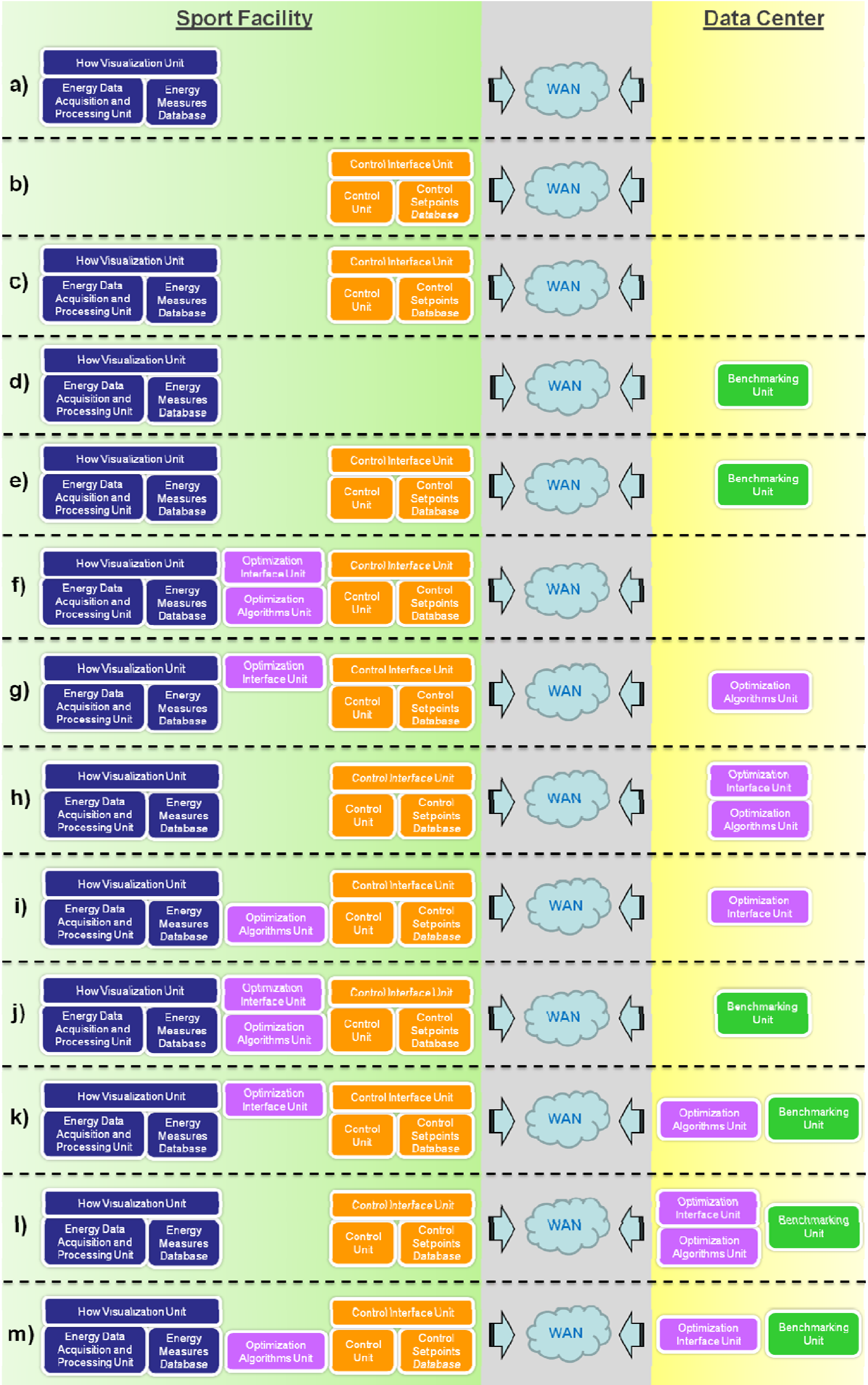

Figure 8: Local and Remote deployment of SportE^2 software and hardware modules

In order to stress the modularity of the system architecture (a better description is provided in the next chapter), Figure 8 provides an overview of four different deployment scenarios of SportE^2 software and hardware modules through a sport facility and the data or management center:

a) A single *How* module is deployed inside the sport facility.

b) A single *Why* module is deployed inside the sport facility.

c) *How* and *Why* modules are local to the sport facility.

d) *How* module is local to the sport facility instead the *Where* module is deployed inside data center (unique location when this module is used).

e) *How* and *Why* modules are local to the sport facility instead the *Where* module is deployed inside data center.

f) *How*, *Why* and *When* modules are local to the sport facility.

g) *How*, *Why* and *Optimization Interface Unit* modules are local to the sport facility, *Optimization Algorithms Unit* module is deployed inside data center.

h) *How* and *Why* modules are local to the sport facility instead the *When* modules is deployed inside data center.

i) *How*, *Why* and *Optimization Algorithms Unit* modules are local to the sport facility, *Optimization Interface Unit* is deployed inside data center.

j) *How*, *Why* and *When* modules are local to the sport facility instead the *Where* module is deployed inside data center.

k) *How*, *Why* and *Optimization Interface Unit* modules are local to the sport facility, *Where* module is deployed inside data center such as the *Optimization Algorithms Unit*.

l) *How* and *Why* modules are local to the sport facility instead the *Where* and *When* modules are deployed inside data center.

m) *How*, *Why* and *Optimization Algorithms Unit* modules are local to the sport facility, *Where* module is deployed inside data center such as the *Optimization Interface Unit*.

5.3 Communication and security systems in Local Area Network

A simplified overview of the subsystems and components deployed in the sport facility Local Area Network has been presented in Figure 9. In order to satisfy security requirements secured network switches, routers and firewalls have been considered in the SportE² network architecture.

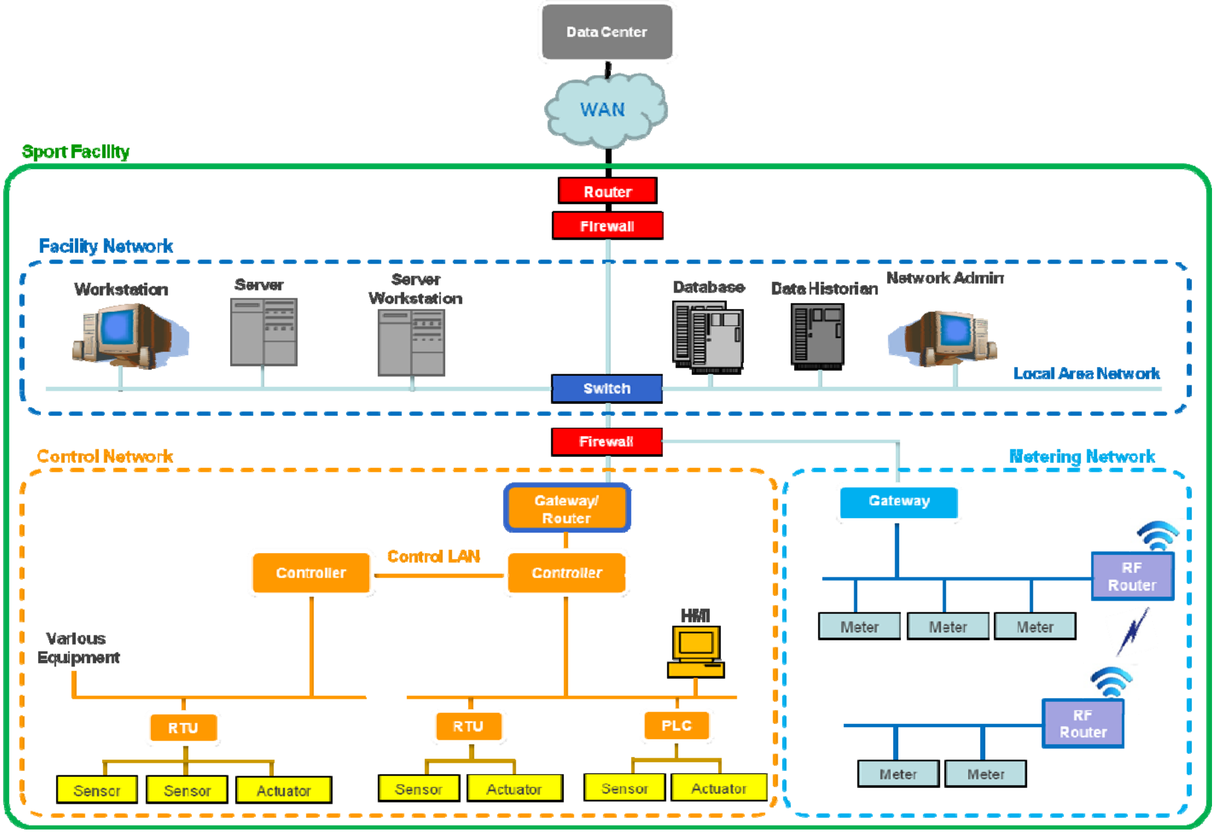

Figure 9: Communication and security systems in Local Area Network

5.4 Communication over WAN

Communication between a data center (remote location) and one or multiple facilities, as depicted in the figure above, takes place using a WAN (Wide Area Network) infrastructure that can be public (Internet) or private and implemented with different technologies (a description of strengths and weakness of each WAN technology has been reported in table below). The impact on SportE² system related to the choose of a particular WAN technology only involves the communication interfaces used in the Remote Access Point infrastructure (facility side) and in the remote management infrastructure (Data Center side).

WAN Technology	Strenghts	Weakness
ADSL	- high availability - consistent bandwidth regardless of number of users and use in time	- decreasing bandwidth with distance
Cable Modem	- high bandwidth - high availability	- inconsistent bandwidth depending on number of users and time of day
FTTH	- scalability - high bandwidth - planned security measure	- relatively high costs - no deployment in rural area
WiMAX (IEEE 802.16)	- does not require deployment of a costly wired infrastructure	- early stage of deployment, uncertain whether the technology will meet its range targets
Cellular Services	- high coverage area - potentially low cost	- fast development of new technology (danger of being tied to one provider) - some packet-switched services not very reliable - security concerns - some systems may not transmit unsolicited data
Satellite Services	- universally available, regardless of concrete location	- high costs - low effective bandwidth - additional security measures required - low reliability during bad weather condition
BPL (Broadband over Power Line)	- existing wired infrastructure (particular advantage in rural areas)	- cost of deployment - BPL not suited for particular applications as it is dependent on current on the power line - mostly proprietary

(Source: OECD adapted from EPRI, 2006)

Table 1: WAN Technologies

5.5 Compliancy to Standards

The designed architecture is compliant to international standards defined at different levels (communication, data representation and exchange, management protocols).

Considering the integration of SportE[2] system with existing Smart Grid, system architecture makes reference to IEC international standards in order to assure the desiderate level of interoperability and quality of service (QoS). IEC TC57 Seamless Integration Reference Architecture (IEC TR 62357) has been represented in Figure 10 (in grey the CENELEC adopted standards): the diagram (not complete since standards for non-electricity metering are not included) gives an overview of IEC TC57 focused and maintained communication and data model standards as well as the applications using these standards.

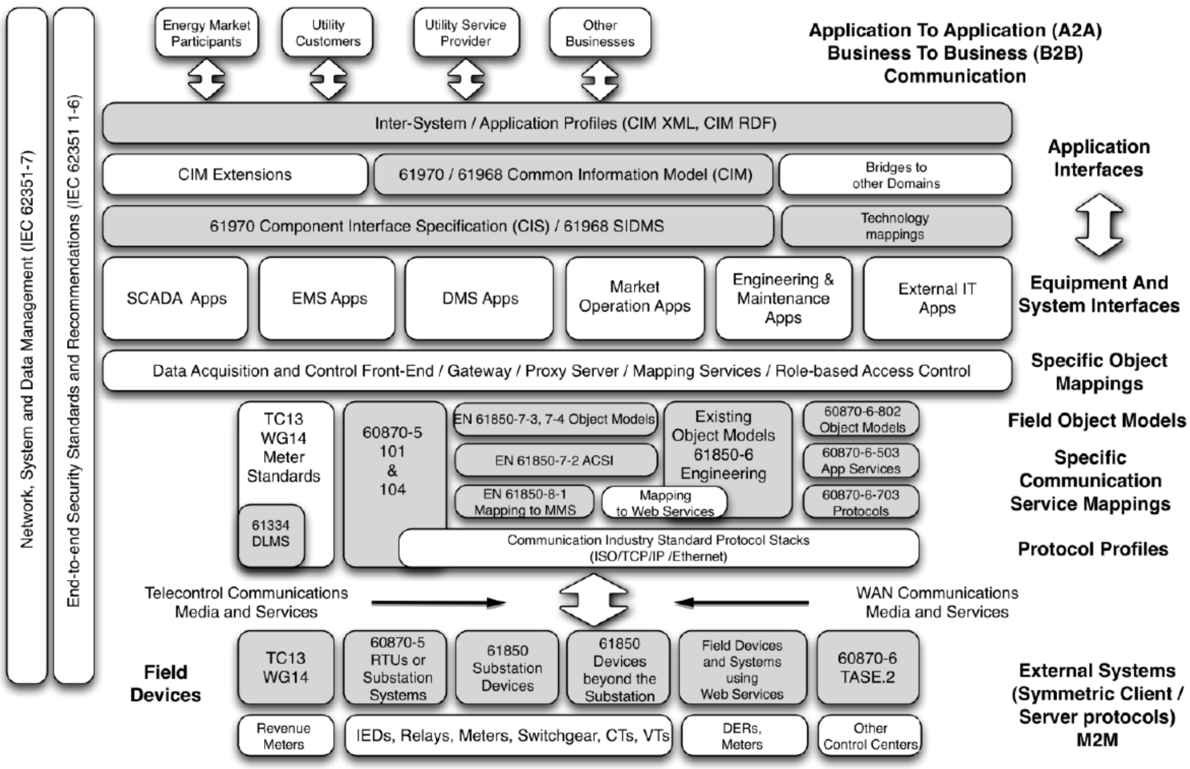

Figure 10: IEC TC57 Seamless Integration reference Architecture (IEC TR 62357)

When RES generation is active in the facility, a communication bridge between RES plants and internal control and monitoring devices is mandatory. In the SportE[2] architecture, a gateway representing a LAN/WAN interface to the Distributed Energy Resources (DERs) is deployed and compliant to international standards, in particular the IEC 61850-7-420 (*Communication networks and systems for power utility automation – Part 7-420: Basic communication structure – Distributed energy resources logical nodes*) adopted by CENELEC as EN 61850-7-420:2007.

Summarizing the compliancy with the Smart Grids standards, developed system architecture considers the following international standards (according to CEN specifications):

- IEC 62357: Seamless Integration Reference Architecture
- IEC 60870: Transport protocols (e.g. EN 60870-5-104:2001-05)

- IEC 61970/61968: Common Information Model CIM (e.g. EN 61970-405:2007-09, EN 61968-3:2004-06)
- IEC 62325: Market Communications using CIM
- IEC 61850, 61850-7-4XX: SAS, Communications, DER (EN 61850-7-420:2009-06). In particular IEC 60870-5 is commonly used to access Generation operation controllers;
    - IEC 60870-5-101 and IEC 60870-5-104 (Transmission Protocols - Network access for IEC 60870-5-101 using standard transport profiles) for EMS (Energy Management System)/SCADA
    - IEC 60870-5-103 is used to access Generation operation protection devices for the electrical process part.
- IEC 61400: Communications for monitoring and control of wind power plants (EN 61400-1:2004-02)
- IEC 62351: Security for Smart Grid.

Finally, the SportE^2 system is also compliant with other international standards used in the modules' interfaces:

- Modbus is a de facto industrial standard representing an application-layer messaging protocol (Modbus Application Protocol, level 7 of the OSI model) and a communication protocol (Modbus Serial Protocol, level 2 of the OSI model). It provides client/server communication between devices connected on different types of buses or networks. There are many variants of Modbus protocol, e.g. Modbus TCP (communication over TCP/IP networks), Modbus RTU, Modbus ASCII, etc.
- LonWorks is a standard communication protocol for building automation developed by Echelon SNVT and approved by ISO and IEC as ISO/IEC 14908-1 standard and by ANSI as ANSI/CEA-709.1-B.
- Service Oriented Architecture (SOA) following W3C (World Wide Web Consortium) standards and guidelines, for example, SOAP for the Web Service interface. SOAP (Simple Object Access Protocol) is a W3C standard for structured information interchange (based on XML standard for the message format) relying on HTTP (Hypertext Transfer Protocol) for message negotiation and transmission.
- Ethernet is a IEEE standard (IEEE 802.3 and ISO 8802) that uses Carrier Sense Multiple Access with Collision Detection (CSMA/CD) access method to physically monitor the traffic on the line at participating (transmitting/receiving) stations. Using Ethernet, there is not need to learn proprietary protocols allowing at the same time the reduction of the total cost of setting up and the maintenance of the communication network.

6. System Configurations and Constraints

The current chapter details all the available configurations of SportE² system focusing on the constraints in the combination of the different modules within the architecture presented in the previous section of the current document.

6.1 Configuration Constraints

Table 2 shows the potential configurations of the modules defining the overall architecture of SportE² system. Seven different setups have been identified and grouped by means of a level-based logic (from 0 to 3): each level is defined by the number of modules included in the considered configuration and in this sense different configuration are present in the same level.

Available Configurations	How Module	Why Module	When Module	Where Module
Base - Level 0.1	✓	-	-	-
Base - Level 0.2	-	✓	-	-
Level 1.1	✓	✓	-	-
Level 1.2	✓	-	-	✓
Level 2.1	✓	✓	✓	-
Level 2.2	✓	✓	-	✓
Level 3	✓	✓	✓	✓

Table 2: SportE² system configurations and constraints

6.2 Base Configurations

The Level 0 representing the base configuration of the SportE² system has been shown in Figure 11.

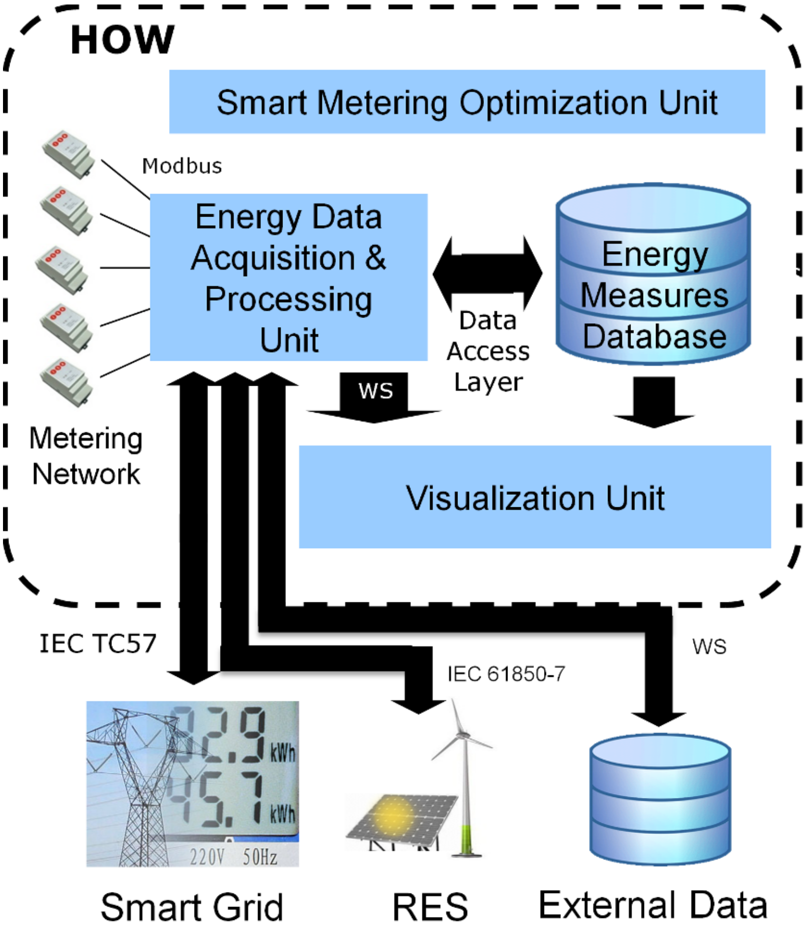

Figure 11: Base (Level 0.1) Configuration Architecture (How Module)

In this scenario the overall system is based only on the *How* module: the *Energy Data Acquisition and Processing Unit* acquires data from the *Smart Metering Network*, stores the measures in the *Energy Measures Database* and provides the High Quality Data Sets to the *How Visualization Unit* and, optionally, to the *Smart Metering Optimization Unit* by means a Web Service interface. The communication with the electric smart grid is enabled using an IEC TC57 Gateway, the communication with RES is enabled thanks to the IEC 61850-7 Gateway and finally the communication with external data (weather forecast, etc.) is achieved through web services.

Potentially it is also possible to consider a more basic configuration of the SportE^2 system (Level 0.2) where the overall system is represented by the only *Why* module (Figure 12): the *Control Unit* and the *Control Interface Unit* are the main elements of the system. Considering this configuration, the *Control Unit* directly acts over the control network (by using the LonWorks communication protocol) in order to modify the set points of the controlled devices (PLC, RTU, etc.).

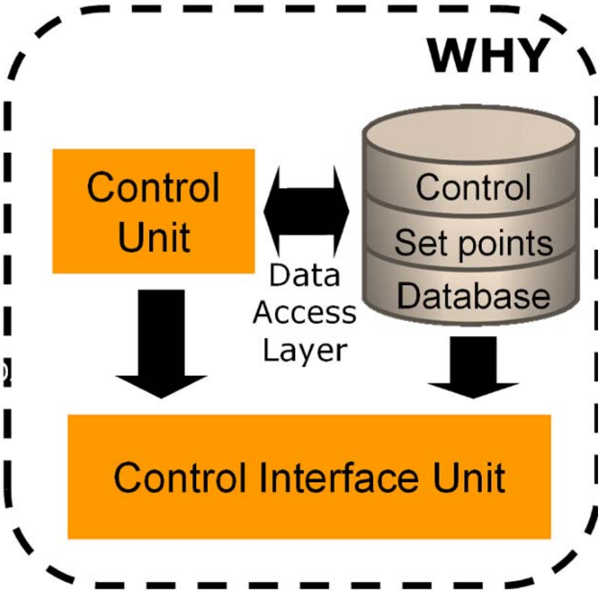

Figure 12: Base (Level 0.2) Configuration Architecture (Why Module)

6.3 Level 1 Configuration

The level 1 configuration of SportE² system considers two out of four main modules: Level 1.1 and Level 1.2 configurations. *How* module is the common element between these setups.

Level 1.1 Configuration (Figure 13): *How* module and *Why* module. In this configuration the two modules are locally deployed in the sport facility on two different machines communicating over an Ethernet TCP/IP network by means of Modbus protocol and Web Service interface (application level).

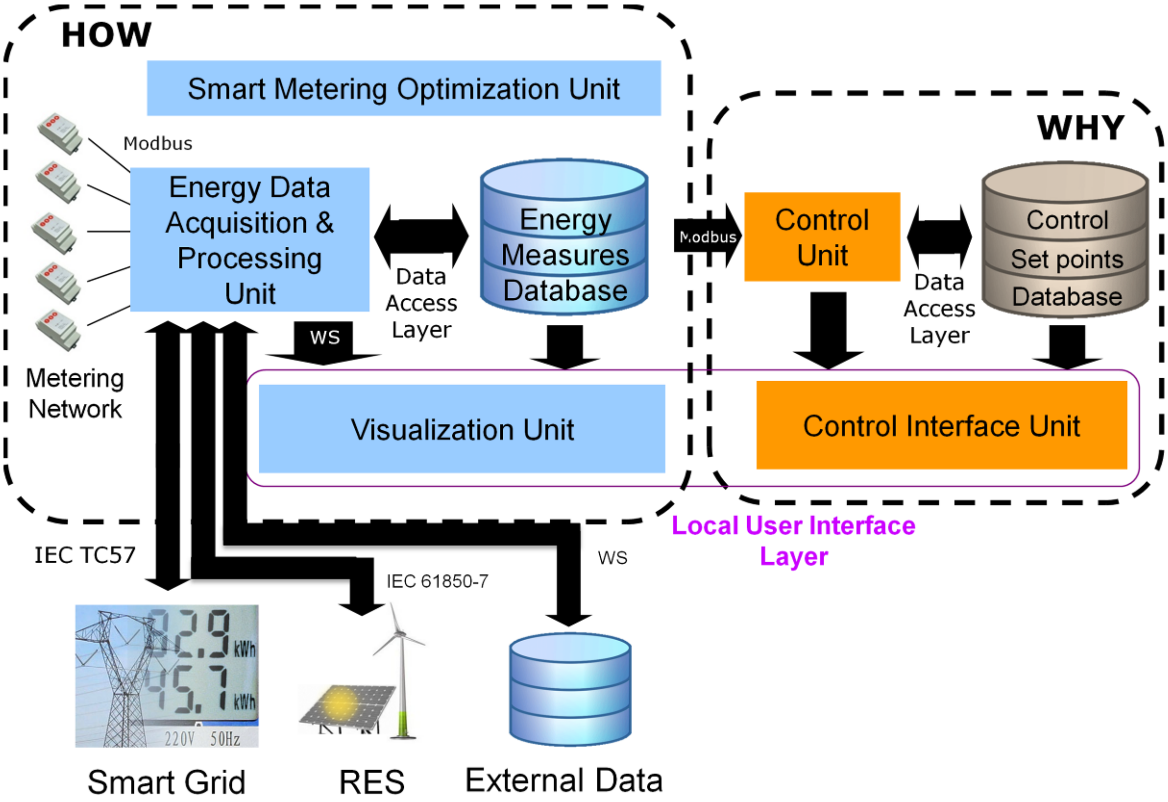

Figure 13: Level 1.1 Configuration Architecture

Level 1.2 Configuration (Figure 14): *How* module and *Where* module. This setup of SportE² system considers a local deployment (at sport facility level) of one (or more than one) *How* module(s) and a remote deployment of the *Benchmarking Unit* (*Where* module). Communication between modules takes place using a Web Service interface (over Internet or other Wide Area Networks, WANs) in order to permit to the *Benchmarking Unit* to retrieve HQDS information and performs the monitoring of the actual situation of energy demands, consumptions, production, and grid exchange across facilities.

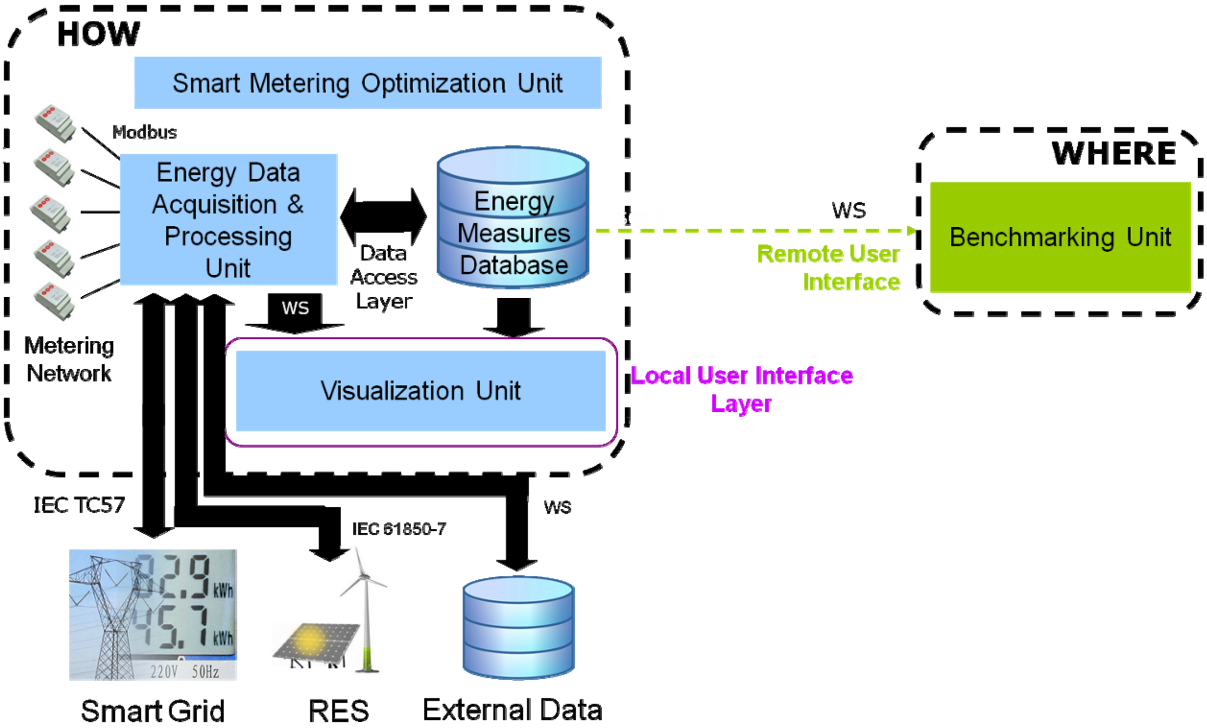

Figure 14: Level 1.2 Configuration Architecture

6.4 Level 2 Configuration

The level 2 configuration of SportE² system considers three of the main modules: Level 2.1 and Level 2.2 configurations. The common elements between these two setups are represented by the *How* and *Why* modules.

Level 2.1 Configuration (Figure 15): *How*, *Why* and *When* modules. In this configuration *How* and *Why* modules are locally deployed in the facility whereas the *When* module can be:

- completely local (*Optimization Interface Unit* and *Optimization Algorithms Unit*) or
- completely remote (*When* units are externally deployed to the facility) or
- local and remote at the same time (a single unit inside the facility and the other one outside the facility, typically in Data Center).

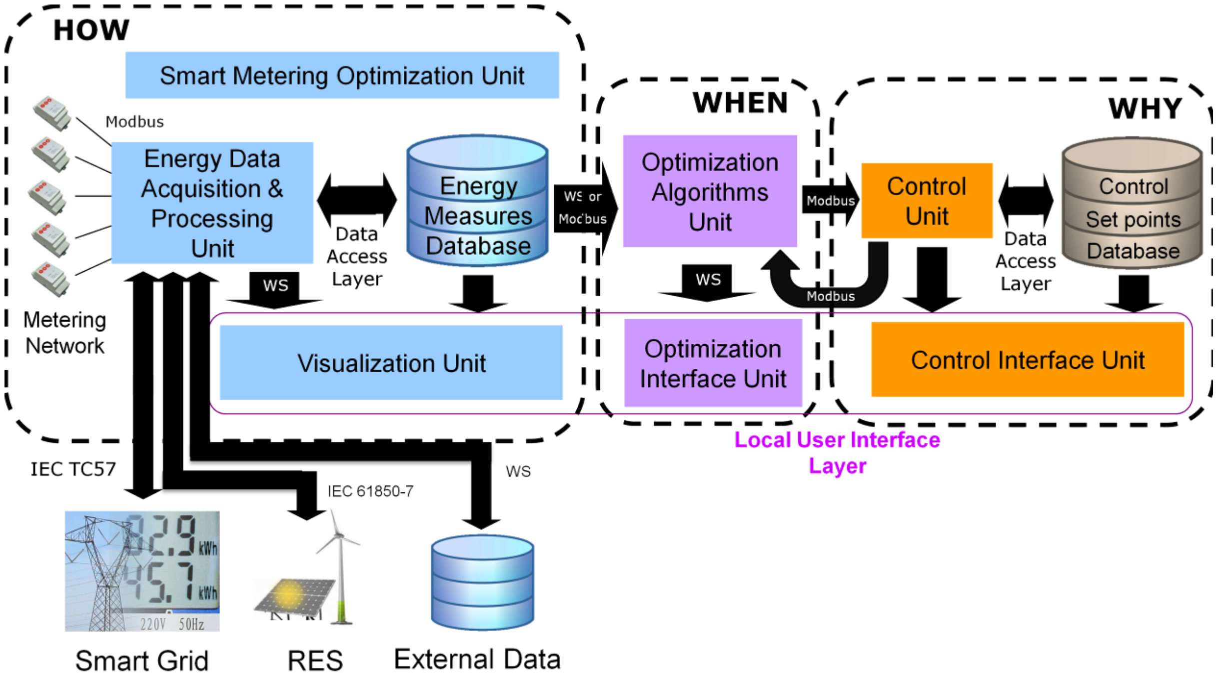

Figure 15: Level 2.1 Configuration Architecture

Level 2.2 Configuration (Figure 16): *How*, *Why* and *Where* modules. In this configuration *How* and *Why* modules are locally deployed inside the sport facility while the *Where* module (*Benchmarking Unit*) is remotely located accessing to the information provided by the *Energy Data Acquisition and Processing Unit* by a Web Service interface.

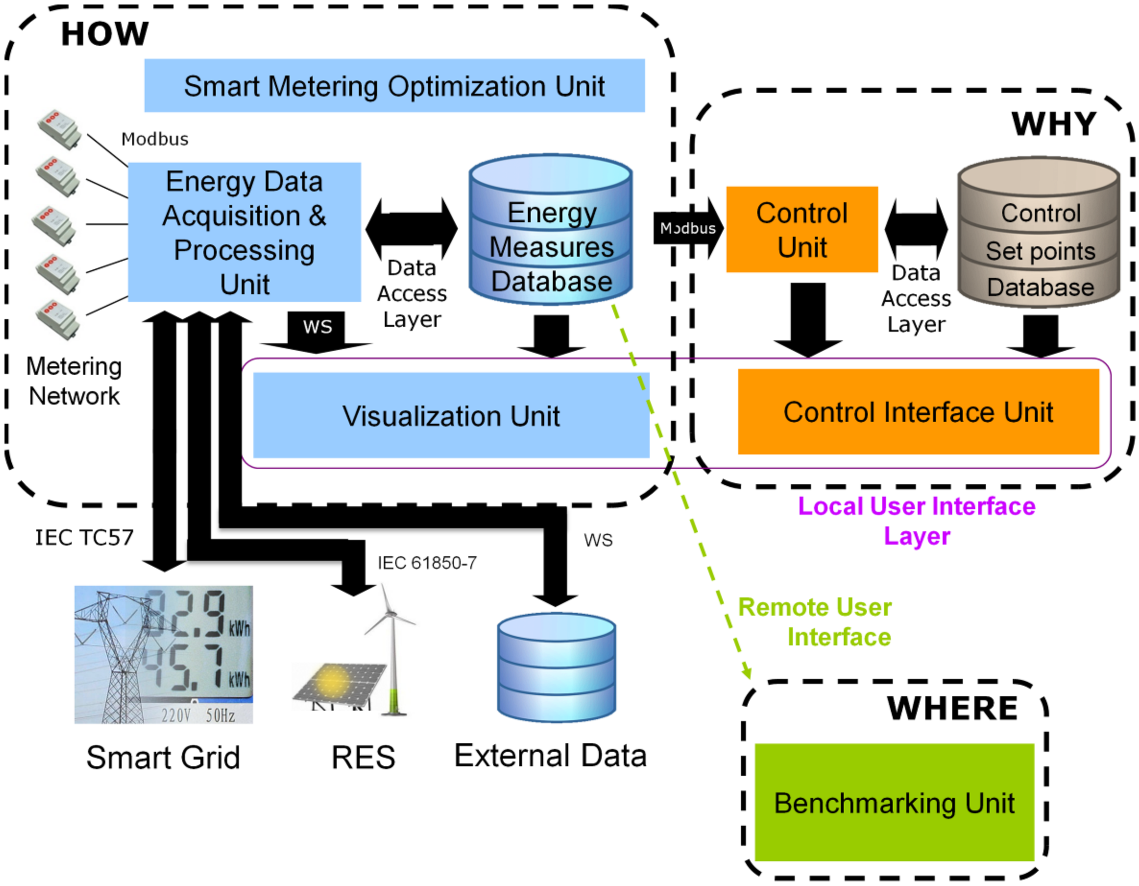

Figure 16: Level 2.2 Configuration Architecture

6.5 Level 3 Configuration

The Level 3 configuration (Figure 17) represents the complete architecture of the SportE² system when all the modules have been deployed and work together.

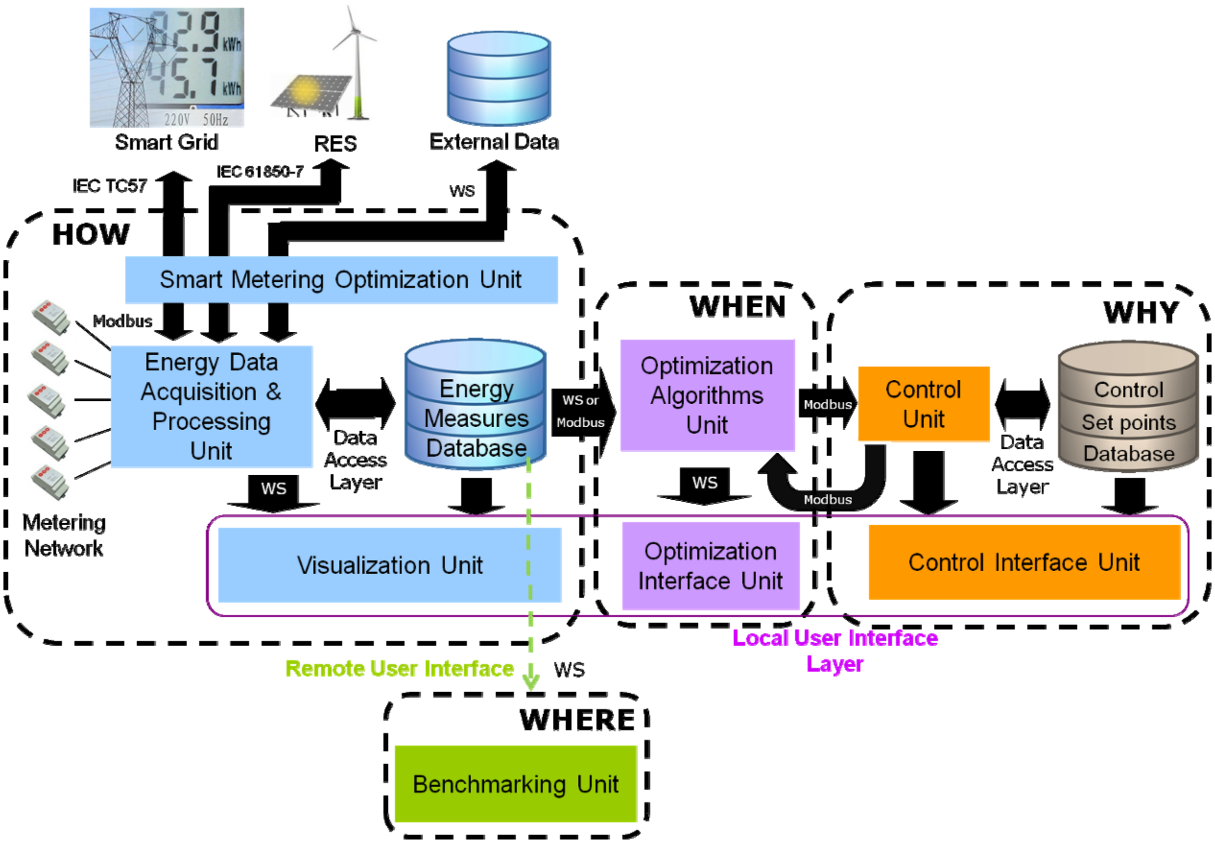

Figure 17: Level 3 Configuration Architecture

In this configuration, the SportE² *How* module retrieves the data generated by the meters network, *Why* module provides the integrated control system to manage and control the different facility sub-systems: the *How Visualization Unit* and the *Control Interface Unit* is integrated and deployed on the same machine in order to allow a complete understanding and control of the facility. *When* module (*Optimization Unit*), elaborating HQDS information gathered from the *How* module (*Energy Data Acquisition and Processing Unit*) closes the control loop by putting the suitable set points in the SportE² *Why* modules. Finally, the *Where* module, deployed outside the monitored facilities, offers the benchmarking capabilities comparing the energy measures (HQDS information) provided by the different *How* modules.

7. OPEN DISCUSSION POINT

Even if this deliverable tries to define as much as possible all the high-level aspects of the overall system, a discussion points on SportE^2 system architecture is still open, i.e. the deployment of SportE^2 When module as stand alone application or as Software as a Service (SAAS). On one hand using it as stand alone module could make easier system installation and exploitation for users, on the other hand a SAAS module would allow to access to data for benchmarking, to create a continual relationship with the client, to decrease the amount of local computation and data storage necessary and to decrease the hardware cost of module. Deliverable 1.2 has drafted the architecture that supports both options (stand alone and SAAS). Once exploitation plans will be drafted and, in particular, the complexity of the optimisation calculations will better understood, a decision on this action will be taken (or both will be made possible). In order to avoid delays in the project activities this decision must be taken before than M10 and integrated in SPortE^2 When module design.

8. Conclusions

Deliverable 1.2 has provided a description of the overall architecture of SportE² system focusing on the modularity, scalability and opening to industrial standards aspects. For each module, the description for its structure, sub-components and communication mechanisms with other system modules has been provided. The high level specifications necessary for the development of the SportE² modules (*How*, *Why*, *When* and *Where*), are detailed and the interoperability architecture to meet the modular approach and intent is provided with respect to communication protocols and interfaces in order to guarantee a full independence from manufacturers and tech-component vendors. Moreover, this document has identified a common data structure that will be used throughout the different modules.

9. Acknowledgements

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Furthermore, information on the supporting program and like projects can be found at the homepage for the ICT Group for Sustainable Growth:

ec.europa.eu/ictforsg

Lastly, it is appropriate to especially acknowledge the collaboration of Intelligent Sensing Anywhere and Schneider Electric to develop a joint system architecture appropriate to integrate the hardware and software protocols of both companies.