FLEXCoop

Democratizing energy markets through the introduction of innovative flexibility-based demand response tools and novel business and market models for energy cooperatives

WP2 – Stakeholder Requirements, Business Models and Architecture Design

D2.3 – Analysis of EU-wide Interoperability Standards and Data Models and Harmonization Requirements

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EXECUTIVE SUMMARY

The compliance and use of open standards is a key success factor for the FLEXCoop project and its further replication and commercialization. FLEXCoop Task 2.5 on “Smart Grids Interoperability Standards Analysis and overall system architecture design” will provide the required guidance and input to ensure the achievement of this key objective. It will review the standardization landscape and evaluate the latest evolutions in DR, interoperability between energy market stakeholders and communication between devices and systems. This initial analysis, along with the results of FLEXCoop T2.1 on “Stakeholders Requirements, Business Models and Architecture Design”, will result in the overall architecture of the FLEXCoop framework and the specifications of the key components and their functionalities.

This deliverable examines the landscape of relevant standards, i.e. the current and expected standardization environment, in the light of the timeline of FLEXCoop developments. This environment is very broad and ranges from the market data exchange standards to in-home communication with on-premises equipment. In order to simplify the navigation in the standards environment, the deliverable divides the standards roughly in two groups: the upstream standards relevant for the environment from FLEXCoop to the grid, market operator and aggregators, and downstream standards, targeting communication and control of the FLEXCoop-related in-house equipment. As the implementation details are still pending in the parallel with T2.1, this document is not stating the architectural decisions taken for the FLEXCoop framework. The final selection of standards to be supported will be finalized along with the technical specification of the architecture. This document examines and documents the standardization environment in which the FLEXCoop framework is expected to function. Among general standards and upstream standards the key relevant ones are presented. Among the downstream standards, the market situation is elaborated as support for the final selection of protocols. The final selection of standards to be supported will be completed after a deeper analysis of the FLEXCoop pilot sites. The upstream and downstream characteristics of a particular standard only reflect the scope of application of these standards as for the FLEXCoop to function, compliance with all of these standards is equally relevant as all of the steps from upstream to downstream need to be functional.
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ABBREVIATIONS

BRP Balance Responsible Party
CIM Common Information Model
CO Confidential, only for members of the Consortium (including the Commission Services)
CSS Customer Support System
D Deliverable
DER Distributed Energy Resource
DMS Distribution Management System
DoW Description of Work
DR Demand Response
DSO Distribution System Operator
EAI Enterprise Application Integration
EMS Energy Management System
ENTSO-E European Network of Transmission System Operators for Electricity
ERP Enterprise Resource Planning
ESB Enterprise Service Bus
ETSI European Telecommunications Standards Institute
ESI Energy Services Interface
EV Electric Vehicle
FLOSS Free/Libre Open Source Software
GDEM Global Demand Manager for Aggregators
GIS Geographical Information System
GUI Graphical User Interface
H2020 Horizon 2020 Programme
ICT Information and Communication Technology
IEC International Electrotechnical Commission
IED Intelligent Electronic Device
IETF Internet Engineering Task Force
IoT Internet of Things
IPR Intellectual Property Rights
IT Information Technology
M2M Smart Machine-to-Machine
MGT Management
MS Milestone
<table>
<thead>
<tr>
<th>Abbr.</th>
<th>Definition</th>
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<tr>
<td>O</td>
<td>Other</td>
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<tr>
<td>OS</td>
<td>Open Source</td>
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<td>OSB</td>
<td>Open Smart Box</td>
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<tr>
<td>OWL</td>
<td>Ontology Web Language (within the context of CIM OWL)</td>
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<td>P</td>
<td>Prototype</td>
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<tr>
<td>PAN</td>
<td>Personal Area Network</td>
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<td>P2H</td>
<td>Power-to-Heat</td>
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<td>PM</td>
<td>Person Month</td>
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<td>PU</td>
<td>Public</td>
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<tr>
<td>PV</td>
<td>Photovoltaic</td>
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<td>R</td>
<td>Report</td>
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<td>RDF</td>
<td>Resource Description Framework</td>
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<td>RES</td>
<td>Renewable Energy System</td>
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<tr>
<td>RTD</td>
<td>Research and Development</td>
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<tr>
<td>SEAC</td>
<td>Security Access Control</td>
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<td>SGUI</td>
<td>Smart Grid User Interface</td>
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<td>SOA</td>
<td>Service Oriented Architecture</td>
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<tr>
<td>UML</td>
<td>Unified Modelling Language</td>
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<tr>
<td>USEF</td>
<td>Universal Smart Energy Framework</td>
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<tr>
<td>VEN</td>
<td>Virtual End Node</td>
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<td>VTES</td>
<td>Virtual Thermal Energy Storage</td>
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<td>VTN</td>
<td>Virtual Top Node</td>
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<td>Web Services Calendar</td>
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<td>WP</td>
<td>Work Package</td>
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<td>Wireless Sensor Network</td>
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<tr>
<td>XML</td>
<td>eXtensible Markup Language</td>
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1. INTRODUCTION

The compliance and use of open standards is a key success factor for the project and its further replication and commercialization. Task 2.5 will provide the required guidance and input to ensure the achievement of this key objective. It will review the standardization landscape and evaluate the latest evolutions in DR, interoperability between energy market stakeholders and communication between devices and systems. Based on this initial analysis, along with the results of Task 2.1, Task 2.5 will deliver the overall architecture of the FLEXCoop framework and the specifications of the key components and their functionalities. Specifically, the following aspects will be defined:

(i) Conceptual Architecture Design: an overview of the system architecture describing the components and introducing the various sub-components, their interfaces and the connections with external systems (i.e. interoperability with existing smart home systems, multi-sensorial infrastructure or DERs at building and district level, interoperability interfaces for Machine to Machine communication, interfaces for the communication between the different actors in the DR value chain);

(ii) Modules’ Functional and Technical Specifications: the purpose of this part of the architecture is twofold: i) to provide a high-level sketch of dependencies among different parts of the framework (e.g. individual components interfaces, etc.) and ii) to describe in detail the constraints of the system elements in terms of hardware and/or software resources, compatibility with standards, etc.;

(iii) Detailed Design of Individual Components of the Framework: refers to the detailed description of the functionalities, non-functional specifications as well as communicational requirements for the high-level building blocks of the FLEXCoop framework. To deliver the aforementioned architectural definitions and to materialise the conceptual architecture design, state of the art software engineering tools will be used (e.g. UML activity and sequence diagrams, actors, etc.)

Considering interoperability, scalability and flexibility of the FLEXCoop framework, the Internet of Things paradigm will be followed while analysing and evaluating the suitability of main standard-based communication protocols, smart home communication protocols (Zigbee, Bluetooth, 6LowPan, Z-Wave), open standards and data models (OpenADR, oneM2M/ SAREF, USEF, IEC-61850) and data modelling approaches (JSON, XML)

In this document, the landscape of relevant standards is examined and the most relevant ones are described and referenced. At this stage of the project, the complete implementation details of the architecture have not yet been compiled, therefore this document is not an implicit definition of architectural decisions to be taken. Instead, this document examines the standardization environment in the light of FLEXCoop project developments and its expected timeline.
2. Deliverable Concept and Objective(s)

This deliverable covers the standardization landscape regarding the latest evolutions in demand response, interoperability between market stakeholders, and communication between devices and systems.

The first draft of the FLEXCoop coarse architecture scheme is summarized as follows:

![Diagram of FLEXCoop Coarse Architectural Overview](image)

Figure 1: FLEXCoop Coarse Architectural Overview (Draft version)

It is immediately notable, even from a high level overview, that there is a significant number of standards that the FLEXCoop architecture has to keep in mind and build upon. The standards certainly differ in scope and the stakes involved, however they cannot easily be divided in the classes of importance and relevance for the FLEXCoop project. A number of standards presented here may have only a relatively limited application scope, e.g. communication within a particular home, but incompatibilities at that level can have an adverse effect on the system functionality overall and conversely on the system viability. For the FLEXCoop system promise to be delivered, all steps have to operate correctly, from the lowest level regarding the field area equipment and smart devices, all the way up to the highest level where the global demand manager communicates to the network and market operators. For this reason, this document does not aim to rank the standards by their order of importance, but instead to deliver an overview of the relevant standards for the operational practice of FLEXCoop.
The FLEXCoop system belongs to a larger context of the smart grid, a highly integrated and distributed system of interfaced subsystems covering generation, transmission, distribution, distributed energy resources and resources on customer premises. Commonly, the underlying information is standardized based on the Common Information Model (CIM) [1]. Along with the CIM standard, probably the most important protocols appearing in the architecture at the grid level are stemming from the IEC 61850 series of protocols [2]. The IEC 61850 started as an international standard defining communication protocols for intelligent electronic devices at electrical substations. It has been developed as part of the IEC TC 57’s reference architecture for electric power systems, and at the moment goes beyond the scope of electrical substations, and it is practically a specification for the automation architecture. In practice, there is a number of other used communication standards, and among them, the IEC 60870-5-104 standard [3] is the most prominent one. However, when compared to the IEC 61850, the scope of such standards is much narrower and is restricted to communication protocols. One can state that currently, in today’s electric power networks, the IEC 61850 standard covers the process, field and station, and the CIM standards are relevant in the scope of business operations, enterprise and market, with common coverage, as can be seen in subsequent sections of this document. Nowadays, both CIM and IEC 61850 standards are applied in almost all domains of electrical power engineering (generation, transmission and distribution), and will also be relevant for the scope of the FLEXCoop project.

While the aforementioned standards are of crucial importance for the electric power network, once inside the premises of the smart grid customer, there is a number of different information models and communication protocols used for direct facilities and equipment management and control (as an example, the carrier can be ZigBee or Bluetooth). Notably, the technologies used with different purposes may be incompatible with each other, and many of the existing systems involved utilize legacy and outdated protocols in which the end user has no motivation on replacing due to capital costs and time involved.

As stated previously, many of the standards have their place in different layers of the proposed system, and for the FLEXCoop promise of flexibility-based DR tools to function, all the communication steps in the chain from the tools run by the aggregator down to the actual smart devices responding to the demand flexibility requirements need to be functional.
3. Standards Overview

Figure 2: IEC Smart Grid standards map (Source: IEC)

The figure above illustrates the vast landscape of IEC standards related to smart grid. This document focuses on those relevant ones for the FLEXCoop project. This document firstly introduces the IEC 62939 standard: the Smart Grid User Interface standard [4]. In this standard name, the user is not the end user, the person using the electrical equipment. Instead, this standard defines how the components (i.e. the equipment) are interfacing with the smart grid infrastructure. These components are users of the SG infrastructure, and as the FLEXCoop system will be one of such users utilizing the smart grid, this standard is highly relevant for the FLEXCoop project as well.

Afterwards, the CIM model is described, in particular its applications to electric network modelling and the exchange of wholesale market data. Then the IEC 62746 series of standards is introduced, and particularly the IEC 62746-10 as an IEC adaptation of the Open Automated Demand Response standard (OpenADR). Along with OpenADR, two industry-driven standardization efforts have been presented – the VHPready and USEF.

Subsequently, the document presents the relevant standards divided into two groups: upstream and downstream standards. As aforementioned described in the introduction, this division only serves for the ease of understanding on where a particular standard fits within FLEXCoop. The upstream standards are relevant within the scope of the grid, thus “upstream” from the proposed FLEXCoop architecture in terms of network level. The downstream standards are mostly the ones confined to the end-user premises (e.g. within a building).
The IEC 62939, CIM, IEC 62746 (OpenADR), VHPready and USEF have been excluded from the upstream-downstream definition as they are, in a certain way, relevant for both scopes. These standards may influence the FLEXCoop architecture overall, including the internal communication of the FLEXCoop modules. The IEC 62939 standard defines the models of interfacing towards the smart grid, the CIM standard is ubiquitous in the power sector. The OpenADR, VHPready and USEF standards and relevant concepts influence the architectural decisions within the proposed FLEXCoop architecture as well, not just at its boundaries. However, this document does not aim to prejudice the definition of the FLEXCoop components in any way, as these will be defined in the implementation phase. Specifically, the deliverable that will determine the implementation details is the WP2 deliverable D2.6 - FLEXCoop Framework Architecture including functional, technical and communication specifications, due 4 months after this deliverable. Instead, only the general landscape of relevant standards that FLEXCoop needs to adapt to is defined in this document, highlighting the most important and generally relevant characteristics of each standard.

3.1. IEC 62939 Smart Grid User Interface standard

This standard aims to define the Smart Grid User Interface (SGUI) reference architecture, on how to build interfaces for information exchange between the CIM model and diverse customer facility standards. Several ecosystems (energy, telecommunication, home automation) have been growing in coexistence separately sharing the location at the customer premise. Smart homes and smart buildings, distributed energy resources, and electric vehicles point into the direction to empower consumers, not only passively consuming energy from the grid, but also feeding power back (a.k.a. “prosumer”). This poses a number of technical and organizational challenges for the grid management.

In line with this perspective, a new standard has been deemed necessary, in order to ensure effective, economical and secure operation of the power grid, as well as to increase efficiency of demand-side systems and equipment, while at the same time keeping open the paths for new business models. This is particularly relevant to information exchange between different actors, as it now begins to play an increasingly important role. The IEC 62939 standard is directed towards standardization of the interfacing methods and solutions that exchange information with the smart grid, and is closely tied to the OASIS Energy Interoperation [5]. The FLEXCoop strategy is certainly within in alignment with the objectives and requirements of IEC 62939.

The IEC 62939 specifies services for symmetric interoperation between energy suppliers and energy consumers across the SGUI, connecting customer systems to the power system. The services enable the coordination of operative systems that supply or consume energy over time across the SGUI, including:

- an information model and a communication model,
- services for demand response, including dispatch of load resources and price,
- services for measurement and confirmation of response and delivery,
- services to enable collaborative and transactive use of energy across the SGUI
- service definitions consistent with the concept of a Service-Oriented Architecture,
- XML vocabularies for the interoperable and standard exchange of Transactive Energy and
- XML vocabularies for the interoperable and standard exchange of Demand Response, including the exchange of measurement and confirmation of response and delivery.
In IEC 62939, the Energy Interoperation Services describes an information and communication model to coordinate energy supply, transmission, distribution, and use, including power and ancillary services, between any two parties, such as energy suppliers and customers, markets and service providers, in any of the domains indicated in Figure 3 above. The Energy Interoperation Services, as posted by the IEC 62939 standard, makes no assumptions about which entities will enter those markets, or as to what those market roles will be called in the future, and is not limited solely to the interfaces indicated in the figure, i.e. there may be new actors and new scopes of communication appearing and the 62939 architecture is expected to be applicable there as well.

3.1.1. DR implications of the IEC 62939 (include the similar structure in the next standards’ sections)

The IEC 62939 defines an Energy Services Interface (ESI). This is an abstraction of the SGUI for both energy consumers and producers. The ESI is the surface where Energy Interoperation Services are exchanged. The ESI is the external face of the energy-consuming or supplying node. The ESI may be directly on an energy management system in the end node, or it may be mediated by other business systems. The ESI is the point of communication whereby the entities (e.g. utilities, ISOs) that produce and distribute electricity interact with the entities (e.g. facilities and aggregators) that manage the consumption of electricity. An ESI may be in front of one system or several, one building or several, or even in front of a microgrid.

In terms of IEC 62939, a Resource (as used in Energy Interoperation) is any logical entity that is dispatchable. The Resource is solely responsible for its own response. A resource description specifies the performance envelope for a Resource. If a Resource can participate in multiple markets, it may have multiple descriptions (referring to the same technical unit, i.e. the
Resource here does not have a 1:1 mapping to the physical world). A Resource is something that can describe its capabilities in a Tender into a market. A Sequence is a set of temporally related intervals with sharing information that changes over time.

A tender is an offering for a Transaction: a binding commitment between parties entered into under an agreement. The Transactive Energy describes the established process of parties buying and selling energy based on tenders (buy or sell offers) that may lead to transactions among parties. In open wholesale forward energy markets, a generator may tender a quantity of energy at a price over a future delivery interval of time to a customer. Acceptance of a tender results in a binding transaction. In some cases, the transaction requires physical delivery of energy. In other cases, the transaction is settled for cash at a price determined by a prescribed price index. The use of Energy Interoperation Services enables present and future wholesale and retail energy markets and retail tariffs, including dynamic and multi-part tariffs.

This standard is particularly interesting in utilizing the Virtual End Node (VEN) and Virtual Top Node (VTN) concepts, similarly to OpenADR. The VEN has operational control of a set of resources and/or processes and is able to control the output or demand of these resources to affect their generation or utilization of electrical energy intelligently in response to an understood set of smart grid messages. The VEN may be either a producer or consumer of energy. The VEN is able to communicate (2-way) with a VTN receiving and transmitting smart grid messages that relay grid situations, conditions, or events. A VEN may take the role of a VTN in other interactions. VTNs and VENs may be structured in a tree-like hierarchy; however any communication between nodes at the same hierarchy levels is not supported.

Within the framework of IEC 62939, the VTN is a party which role is the aggregation of information and capabilities of distributed energy resources. The VTN is able to communicate with both the Grid and the VEN devices or systems in its domain. A VTN may take the role of a VEN interacting with another VTN.

Furthermore, the OASIS WS-Calendar (Web Services Calendar) specification is used as a standardized form to communicate schedules and intervals. WS-Calendar extends the Internet Engineering Task Force (IETF) iCalendar, a recognized basis standard for all personal scheduling, to support machine-based negotiation of human-centric schedules. WS-Calendar schedules energy production and its usage, as well as Demand Response and transactions involving specific delivery schedules. The WS-Calendar is a de-facto standard for all schedule transactions in the domain of smart grids.

Based on the above concepts, the IEC 62939 standard defines a service-oriented approach to energy interactions. The standard focuses on the desired results, instead of the requested processes and proposes a loose integration of the services provided. As the architectural decisions and locational specifics of the FLEXCoop pilot sites would directly define which parts of IEC 62939 will be implemented, for more details on the IEC 62939 standard a reader is advised to consult the standard directly [4].
3.2. CIM – Common Information Model

The Common Information Model (CIM) is an open standard that defines how managed elements in an IT environment are represented as a common set of objects and relationships between them. The CIM model, in the context of electric power engineering, is an ontology model allowing the exchange of information of the electric grid among different software applications. CIM model was developed by the electric power industry, and afterward officially adopted by the International Electrotechnical Commission (IEC), as the IEC 61968/61970 series of standards [1]. The initial development of CIM was planned with the objective of developing a common power system network model, to have a common basis to exchange information.

The CIM standard has been adopted by the main part of vendors, in order to allow the exchange of information among different devices, and it has been extended to cover tasks related to electric power industry, such customer billing, work scheduling and asset tracking.

The core of the CIM model is mainly composed by the series of standards IEC 61970 and IEC 61968.

The principal objective of the IEC 61970 series of standards is to produce standards which facilitate the integration of energy management systems (EMS) applications developed independently by different vendors, between entire EMS systems developed independently, or between an EMS system and other systems concerned with different aspects of power system operations, such as generation or distribution management systems (DMS). In particular, the IEC 61970-301 [6] standard describes the components of a power system at an electrical level and relationships among them. The IEC 61968-11 [7] standard defines semantics of other aspects of power system software data exchange such as work scheduling or customer billing. In fact, the IEC 61968-11 standard defines information exchange between electrical distribution systems on a utility enterprise level, in particular for the DMS functionalities. As the DMS is designed to monitor and control the entire distribution network, this means that the standard provides support for utilities such as outage management, by linking together the SCADA system with e.g. geographic information systems, customer information and support systems etc. This provides support for utilizing the joint benefits of having all the relevant information from these systems available and combined. Generally, the IEC 61968-11 is supposed to be implemented with middleware services brokering messages among applications, which means than it can also be applied in the FLEXCoop architecture/project.

Because the CIM model is an ontology model, it must deal with exchanges of information with all types of systems such as GIS (Geographical Information Systems), CSS (Customer Support System) or ERP (Enterprise-Resource Planning). With this purpose CIM covers 53 UML packages (Unified Modelling Language), containing approximately 820 classes with more than 8500 attributes. In addition, different serializations exist, such as XML and XML schema for building its own EAI (Enterprise Application Integration) messages based on the CIM and to use pre-defined messages built by IEC. In the case of modelling graphs of power grids, the CIM model is provided with RDF (Resource Description Framework) serializations and RDF schemas, as well as by CIM OWL (Ontology Web Language) serializations.
The extensive applicability of the CIM model makes it one of the biggest standardized domain ontologies, especially in conjunction with the IEC 61850 series of standards. Currently efforts to harmonize the two main ontologies have been applied in the field of Smart Grids.

The CIM model is in wide adoption and it has been used by the ENTSO-E, European Network of Transmission System Operators for Electricity. It is an organization of 43 electricity transmission system operators in 36 countries across Europe, thus extending beyond the EU. The initial mission of CIM is currently widely applied across Europe through the use of CGMES: Common Information Model for Grid Models Exchange standard [8], however the CIM is embedded into numerous processes of transmission and distribution system operators across Europe, which makes the CIM relevant for all levels of the FLEXCoop project. Furthermore, almost all market operators in Europe use CIM-derived XML-based protocols for communications related to energy markets, which is being established as the IEC 62325 series of standards [9]. The IEC 62325 series of standards are very wide in scope and consist in the following parts (detailed in separate IEC 62325 standard documents):

- IEC 62325-301: Common information model (CIM) extensions for markets
- IEC 62325-351: CIM European market model exchange profile
- IEC 62325-450: Profile and context modelling rules
- IEC 62325-451-1: Acknowledgement business process and contextual model for CIM European market
- IEC 62325-451-2: Scheduling business process and contextual model for CIM European market
- IEC 62325-451-3: Transmission capacity allocation business process and contextual models for European market
- IEC 62325-451-4: Settlement and reconciliation business process, contextual and assembly models for European market
- IEC 62325-451-5: Problem statement and status request business processes, contextual and assembly models for European market
- IEC 62325-451-6: Publication of information on market, contextual and assembly models for European style market
- IEC 62325-452: North American style market profiles
- IEC 62325-502: Profile of ebXML (and its conversion)
- IEC 62325-503: Market data exchanges guidelines for the IEC 62325-351 profile
- IEC 62325-504: Utilization of web services for electronic data interchanges on the European energy market for electricity
- IEC 62325-552-1: Dynamic data structures for day ahead markets (DAM)

Without any doubt, the CIM and the relevant CIM-derived XML market data exchange protocols are crucial for the FLEXCoop framework to ensure compatibility with the energy market stakeholders.
3.3. IEC 62746 Systems interface between customer energy management system and the power management system

The IEC 62746 standard is fully named “Systems interface between customer energy management system and the power management system”. This standard defines the system interfaces and communication protocols covering the whole chain between a smart grid and smart home/building/industrial area. Therefore, the IEC 62746 standard is of highest relevance for the FLEXCoop project.

The IEC 62746 standard provides application-level service communication that can be used to incentivize responses from the customer-owned and customer-located distributed energy resources. Price and demand response signals enable provision of indirect control of customer-owned devices. The IEC 62746 standard does not specify the transport mechanisms. The transport mechanisms and their interaction patterns are defined, as well as cyber security mechanisms necessary to provide non-repudiation and mitigation of cyber-security risks, but the actual “on the wire” transport mechanism is out of scope of this standard. IEC 62746 standard is agnostic in relation to the DR load control strategies, as well as to the market-specific contractual or business agreements – these are also out of scope of the definition of this standard.

In IEC 62746, the following services are specified:

- Register: identification of entities in advance of interactions with other parties
- Event: core demand response event, providing event functions and information models for price-responsive DR
- Report: this service enables feedback to provide either periodic or one-time information on the actual state of a resource and
- Opt: addressing the short-term changes in availability, providing the facility to communicate opt-in and opt-out schedules from virtual end nodes to virtual top nodes.

For the FLEXCoop project, the most relevant standard among the 62746 group of standards is probably the IEC 62746-10 [10]: Open Automated Demand Response (OpenADR 2.0b Profile Specification), which represents the adoption of the OpenADR Alliance standard as the IEC standard. This standard is a flexible data model to facilitate common information exchange between electricity service providers, aggregators, and end users. The concept of an open specification is intended to allow anyone to implement the two-way signalling systems, providing the servers that publish information to the automated clients subscribing to the information. This standard covers the signalling data models and includes information related to specific DR electric reduction or shifting strategies, which are taken at the facility. This standard can be leveraged to manage customer energy resources, including load, generation and storage, via signals provided by grid and/or market operators. These resources may be identified and managed as individual resources with specific capabilities, or as virtual resources with an aggregated set of capabilities.

The OpenADR specifications provide:

- A minimal data model and services for DR, pricing, and distributed energy resource (DER) communications.
- How to implement a two-way signalling system to facilitate information exchange between electricity service providers, aggregators and end users.
- A description of demand response signalling in terms of servers (virtual top nodes) that are publishing information to automated clients (virtual end nodes) being the subscribers of the information.

3.3.1. DR implications of the Open ADR standard

The OpenADR standard started as an open-source smart grid communications standard used for demand response applications. Typically, it is used in explicit demand response scenarios when specific signals are sent to cause devices to be turned off during periods of higher demand. For explicit DR the automation of decisions is crucial: a standard that facilitates quick, fail-safe, consistent and secure bi-directional communication between a large variety of stakeholders is an absolute necessity.

The main features of OpenADR communication profiles (and by extension of the IEC 62746-10 compliant profiles) are as follows:

- Continuous, secure, and reliable two-way communications infrastructures where the end points at the end-use site receive and acknowledge the receipt of DR signals from the energy service providers.
- Translation of DR event information to continuous Internet signals.
- Automation through the use of pre-programmed demand response strategies determined and controlled by the end-use participant (without a need for interaction for each of the transactions).
- Opt-Out enabled: override function to any participants for any DR event if the event comes at a time when changes in end-use services are not desirable.

OpenADR uses a Service-Oriented Architecture (SOA) in which all interactions occur between entities called Virtual Top Nodes (VTNs) and Virtual End Nodes (VENs).

There are two OpenADR profiles: Profile A, targeted towards low end devices and limited to a simple implementation of OpenADR: while Profile B is targeted toward fully functional control systems and devices and enable feedback and additional services. An additional profile is currently being developed to implement an even more complete version of OpenADR and is specifically aimed at aggregators.

The adoption of OpenADR 2.0b profile is by the IEC as the IEC 62746-10 is ongoing, within the wider IEC 62746 standard series. This series describes a set of use cases related to energy flexibility and demand side management, as well as an outline of potential upcoming Smart Building and Smart Home scenarios. Thus the FLEXCoop developments may influence the final IEC standard series. The IEC 62746 series provides a technical specification and architecture for the management of customer and distributed energy resources that leverages other existing IEC standards and links the standard to those. Of these, the most relevant is the IEC 61850 standard (as indicated by the mention of VTN and VENs).

The OpenADR 2.0b profile supports the following:

- EiEvent – to notify the VENs of upcoming DR events and sending DR signals from VTN to VEN
- EiOpt – opt-in and opt-out capability by the VEN
- EiReport – specifies the report by the VEN to the VTN; typically supports the VTN’s prediction and monitoring capabilities
- EiRegisterParty – establishment of communication between a VEN and a VTN.

In the OpenADR 2.0a profile, only a simplified EiEvent is possible.

The implementation of the services relies on standard-based IP communications such as HTTP and XML Messaging and Presence Protocol (XMPP). The demand-response signals make the VTN interact with a VEN in order to influence or change the load profiles of the demand-side loads, associated with the VEN in question. Two types of signals can be used: prices and load dispatches. The prices might be used if the objective is to incentivize the demand-side resource to change the load profile with a price incentive, thus implicitly. In a load dispatch signal there is an explicit instruction on what the load profile should be.

The specification of the OpenADR supports a wide range of different types of signals including direct load control interactions. The OpenADR standard only provides the DR message exchange and none of the actual underlying application logic. In other words, for the automated DR to function, VENs have to implement the actual application logic.

As a conclusion of the IEC 62746 standard, it states a set of mandatory and optional attributes within each of the services to meet broader interoperability, testing and certification. The FLEXCoop solution will have to be, in one form or another, compliant with the IEC 62746 standard. In fact, the developments of FLEXCoop may even influence the parts of the standard that are currently in the acceptance process.
3.4. VHPready – Virtual Heat and Power Ready

VHPready – Virtual Heat and Power Ready [11] is an open specification for networking and control decentralized power plants, originally developed and published by Vattenfall. Vattenfall’s latest version 3.0 is freely accessible. In the current version 4.0, the VHPready standard supports the connection of combined heat and power plants, battery storage, heat pumps and wind turbines. The communication-technological basis is made up of Internet protocols as well as the IEC 60870-5-104 (signal-oriented) or IEC 61850-7-420 (object-oriented).

An essential feature of VHPready is the support of the transmission of timetables or of timetable changes as well as the implementation and monitoring of the timetable operation of power plants. Timetables or timetable changes can be specified to the minute and consist of service blocks defined by start time, duration and a percentage value according to a default power value. VHPready basically offers the possibility of flexibilities – e.g. for the provision of balancing power, while otherwise ensuring that these timetables are feasible, i.e. represent a permissible flexibility option. With the establishment of the industrial forum VHPready e.V. in February 2014 fifteen well-known companies laid out the foundation for cross-industry and multi-vendor development of virtual power plants. In the industrial forum VHPready e.V. they work together with others (currently approx. 50 member companies) continuously on a specification for a standardized integration of decentralized energy systems.

The VHPready standard defines the communication path between a control center and a distributed energy resource. The standard includes coverage on the security and the interoperability of the connection. Regarding communications and security VHPready is based on secured internet protocol technologies with TLS 1.2 encryption and the well-established IEC protocols 60870 and 61850. VHPready is defining operating conditions, systems behavior and performance as well as interfaces and data points in an exact and explicit way. By doing so, distributed energy systems can be integrated into a VHPready network without any additional engineering effort. Security in data communications as well as in systems operation is a significant part of the currently developed standard. VHPready is providing the basis for existing and future market models in the energy sector and contributes to a stable and reliable energy supply in Germany, Europe and worldwide. Recently, a position statement on the relation of VHPReady and OpenADR has been published on the VHPReady web site [11], indicating there have been talks between the VHPReady industry alliance and the OpenADR alliance about cooperation and mutual support for open, industry driven standard for the smart grid. This is exactly the environment where FLEXCoop developments will operate, thus these two protocols along with USEF have been singled out in this document, as these standards may influence the FLEXCoop architectural decisions overall.
3.5. USEF – Universal Smart Energy Framework

The USEF – Universal Smart Energy Framework [12] is an international standard, with an aim to ensure smart energy technologies and projects are interconnectable and at lowest cost. USEF is an industry initiative, driven by USEF Foundation, a non-profit industry alliance of seven organisations and companies, active in the smart energy industry (ABB, Alliander, DNV GL, Essent, IBM, ICT Automation and Stedin).

The USEF has a quite large envisioned coverage (Figure 5): it includes market-based control mechanisms and the underlying ICT architecture, with the interfaces towards the actual downstream devices (products) and upstream services and propositions. The USEF describes the market for flexibility, offering the Framework description, with specifications, designs and implementation guidelines. There is a reference implementation of USEF and the knowledge from USEF pilots is available from the USEF foundation, we support users with insights, structure and sample coding. The reference implementation is a fully functional implementation of the USEF specification that has passed conformance testing, it is publicly available in the form of downloadable source code under Apache 2.0 license, and it is a definitive interpretation of the specification [13]. It is not, however, an operational platform nor is it tailored for specific needs of a pilot project.

The idea of USEF is to enable the commoditisation and market trading of flexible energy use and specify all stakeholder roles (new and existing), how they interact and how they can benefit by doing so. One of key mechanisms USEF is supposed to enable is to democratize the energy market. USEF recognizes the notion of “prosumers” – customers not only passively consuming but also producing electric energy, as well as aggregators. USEF is based on a roles model, instead of a business model. The idea behind the roles model is to describe the roles, their tasks and responsibilities, which can be implemented in various ways in the local market. USEF tries to follow the commonly defined business roles as defined in Europe, e.g. by the ENTSO-E.
The key roles recognized by USEF reference implementation framework are:

- Balance responsible party (BRP) – an entity responsible for balancing the supply and demand and finding the most economical solution for covering the imbalances
- Distribution system operator (DSO)
- Aggregator – common manager of flexibility from prosumers selling this to BRP and/or the DSO, depending on the local market organization
- Common Reference Operator – relating the congestion points and congestions to other relevant participants
- Meter Data Company – an entity acquiring and validating the meter data
- Active Demand and Supply – systems that demand or supply energy and that can be actively controlled with appropriate signals
- Prosumer – an end user, consumer of energy also able to produce energy.

With regards to standardization, the USEF tries to align with other developments in smart grid standardization and tries to be a technology and implementation agnostic framework. Considering that the FLEXCoop project is directly within the USEF scope of interest, and that the USEF efforts are recognized in Europe, this standardization effort might be relevant for the FLEXCoop project as well. As with OpenADR and VHPready, the final FLEXCoop project architecture may be influenced by the USEF concepts.
3.6. Upstream standard: Towards the grid and within grid operation

This section will cover the standards defining the communication directed towards grid and market operation, thus “upstream” – interacting with e.g. network operator.

3.6.1. IEC 61850 Power Utility Automation Standard

The IEC 61850 is an international standard that defines communication protocols for intelligent electronic devices at electrical substations. In fact, the IEC 61850 series of protocols go beyond the electrical substations and currently represent a specification for the automation architecture.

![IEC 61850 ed1.0 communication framework architecture](image)

Figure 5: IEC 61850 edition 1.0 communication framework architecture

The IEC 61850 series of standards determines the description of the devices in an electrical substation and the exchanged information between these devices, both at runtime and at configuration time. The initial motivation of IEC 61850 was to design a way to convert numerous incompatible standards for communication between the devices within a substation towards a common standard, where the physical implementation of the communication would be over the Ethernet, using the Internet Protocol (IP).

IEC TC 57 WG 10 was established in 1995, and the IEC 61850 ed. 1.0 [2] was developed in 2004. This version of the standard is focused on electrical substations equipment but actually covers a wider area with additions that cover distributed energy resources, electric vehicle supply equipment, battery systems wind power plants etc. From 2005 onwards, the IEC 61850 ed. 2.0 is being under development. This new version of the standard turns the IEC 61850, in fact, into an integration interface standard, covering real-time data acquisition and automated remote control with a unified integration approach. It is designed to be technology and platform independent and to support equipment of multiple vendors. It supports building of additional service applications on top of the actual data, including new control architectures as well as providing data for electricity markets.

In comparison with the previous automation standard, such as the IEC 60870 series of communication protocols (described later in this document), this protocol differs conceptually and in scope. The key conceptual difference that IEC 61850 introduces is the semantic
interpretation within the protocol, while the previous standards are limited to describing the communication only – the payload carried through the communication channel was out of scope of previous standards.

Figure 6: The coverage of IEC 61850 edition 2.0 series of standards
The IEC 61850 data model is a hierarchical, function object oriented model, described primarily in the IEC 61850-7-2, 7-3 and 7-4xx documents.

Each physical Intelligent Electronic Device (IED) can perform several functions previously performed by different devices; IEC 61850 ed. 2.0 provides provision for logical devices within a single physical device (a server). IEC 61850 describes each function in the substation equipment by a logical node, and the IEC 61850-7-4 standard standardizes 91 logical nodes,
divided into 13 logical groups (e.g. switchgear, power transformer, protection, control, generic, automatic and control, metering and measurement, etc.).

Within each of the logical nodes, there is a number of data, some of which is deemed mandatory. This data can be subdivided into:

- **Common data** relevant to the logical node (which is independent from the actual dedicated function represented by the logical node).
- **Status information** – either the status of the process or the status of the function allocated to this particular logical node.
- **Settings** – information relevant for the functioning of this logical node.
- **Measured values** – analogue data either measured from the process or calculated from the actual values in the functions. and
- **Controls** – data changed by commands.

For instance, for a circuit breaker, the basic (common) logical node data includes mode, behaviour, health, and operational counter. Within the controls, a circuit breaker has its switch position, block opening and block closing controls. The breaker data also includes its status (operational capability). As shown in Figure 87, all of these data are actually containers for a number of data attributes.

On a data exchange level, the IEC 61850 allows both client/server interfacing as well as peer-to-peer interfacing, i.e. it allows vertical and horizontal communication, as well as additional services such as time synchronization and file transfer. IEC 61850 relies on abstract communication service interfaces, defined in the IEC 61850-7-2 document.

Received data can either be spontaneous, by request or by subscription. Sending can also be by request or by subscription. The vertical ACSI (Abstract Common Service Interface) maps to client/server communication. Horizontal ACSI conforms to the publish/subscribe model.

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**Figure 9:** A map of IEC 61850 information model and ACSI services
Within the IEC 61850, the actual configuration of data exchange depends on the use case for particular data. For example, event data related to primary equipment fault are not going to be retrieved in a same manner as the measurement data.

Regarding the implementation, the IEC 61850 standard conforms to the ISO/OSI layered network model, as defined in the IEC 61850-8-1 document. In most of the applications, the data link layer is typically Ethernet, the network layer relies on the IP protocol, the transport layer is TCP, and the application layer uses the MMS (Manufacturing Message Specification) protocol, defined by the ISO 9506 standard [14]. The IEC 61850-7-x series of documents define the common data classes, information models and their mapping to MMS objects.

The IEC 61850 is definitely reaching and covering a much wider area than just a communication protocol: the IEC 61850-80-x series of documents define a series of mappings / communication extensions of the IEC 61850 protocol. For example, there are gateways to IEC 60870-5-10x series of protocols so that existing equipment, primarily communicating using these protocols, can reasonably seamlessly be integrated into the new 61850-based equipment.

The IEC 61850 standard is rapidly becoming a “lingua franca” standard in electrical power engineering. Therefore, to integrate the distributed energy resources the IEC 61850 compliant communication interfaces will be an absolute necessity for the FLEXCoop project. There is a Python-based open source implementation of the 61850 stack over XMPP, a result of the previous OS4ES H2020 project where KONČAR experts have participated. The implementation plan for FLEXCoop is that CIMNE, as the responsible party for developing the Message-oriented Middleware, will work with KONČAR experts and reuse the implementation for the FLEXCoop project, in accordance with all licensing requirements and the FLEXCoop requirements. The decision on using the upstream standard will be made after a detailed evaluation of the pilot sites and without reducing the general applicability of the FLEXCoop project solution.

### 3.6.2. IEC 60870-5 series of standard protocols

The IEC 60870 is designed to provide a communication profile to communicate between a central station and its substations. This includes a mechanism to relay the datagrams which enabled the system to handle high network load. The principal goal of IEC 60870 was to provide interoperability between different vendors, based on an open standard. Earlier approaches to achieve interoperability have mostly failed because they have not enforced the definition of the formats with enough accuracy. The IEC 60870 standards also define the message formats and the application messages itself.

The IEC 60870 series are divided into different parts. Its goal is to provide a modern approach on telecontrol equipment. The first issue/part of the standard was released in 1988 by the IEC Technical Committee 57. Over time, it was extended to different use cases and also was used over different communication networks. In practice, the IEC 60870 series represent a first international standard with enough applicability and reach, so that it is very widely used in practice, especially the IEC 60870-5-104 communication profile.
Within the standard, the IEC 60870-5 part is particularly important as it describes the communication related aspects of the standard and it is a collection of substandards and companion standards. Currently, it can be used for SCADA applications in many areas but is still mainly used in the electrical utility industry. The IEC 60870-5 defines the system topology which refers to the link layer. The companion standards IEC 60870-5-101 [15] and IEC 60870-5-104 [3] are of highest importance today and will be briefly covered below.

The IEC 60870-5-101 was the first companion standard added to define point-to-point link as well as multi drop communication. This standard was designed to be used over low bandwidth bit serial links. For communication over TCP/IP based links the standard is extended by the IEC 60870-5-104. These standards are so common that in common control engineering practice, they are often referred to as “the 101” and “the 104”.

In the IEC 60870-5-101 communication can either be initiated by the master (unbalanced mode only point-to-point) or by both, master and slave, in multi drop mode. Communicating entities are described as controlling or controlled station depending on the direction of the commands. A device can switch these roles or also operate in dual mode. Addressing happens at two layers. There are a link layer address and also an application layer address. This allows to have more than one endpoint behind a link layer address. Besides this low layer in the standard, there is a definition of ASDUs (Application Service Data Units) which are complete application information and control blocks.

The IEC 60870-5-104 uses TCP/IP as transport network protocol. This allows the usage of IEC 60870 over any kind of modern computer network. It, coupled with wide availability, ensured the popularity of this protocol until today. With regards to the Smart Grids in general, this means that TCP/IP can be considered as a “lingua franca” compatibility layer for the message transport. One should however have in mind that IEC 60870-5-101 and 104 have no security profiles defined so the communication needs to be protected on the transport link e.g. by a secured tunnel.

For the FLEXCoop project, the IEC 60870-5-104 may not be directly relevant – however a certain implementation of communication with the TSO or the DSO may require the FLEXCoop components to communicate using these two protocols. Within the consortium, KONČAR experts can provide direct knowledge and relevant implementation of these protocols.

3.6.3. Coverage of other upstream protocols

In practice, most of today’s communication with the operators can be either defined through a set of CIM-related standards, or at a lower level by using the 61850 or 60870 series of communication protocols. For other protocols that may be required by the grid operators, this can be resolved by the use of protocol converters, readily available on the market, i.e. it would not add much value to the FLEXCoop proposition to cover a number of legacy telecontrol protocols. Within the consortium KONČAR experts can provide direct input and experience on these issues.
3.7. Downstream standards: Towards customer facilities management and control

This section provides an overview of the protocols and standards targeting communication and control of the FLEXCoop-related in-house equipment. From this point onward, these will be referred to as “Downstream Protocols and Standards”.

The FLEXCoop in-house equipment includes the multi-sensorial infrastructure (i.e. sensors for measuring in-house temperature, humidity, air quality, luminance, occupancy) and the following DER devices: Heating Ventilation Air Conditioning (HVAC), Lighting Devices Domestic Heat Water (DHW), photovoltaic (PV) systems and batteries, along with the dedicated devices (smart metering units) for tracking their energy consumption.

3.7.1. Introduction

One of the critical aspects of the FLEXCoop project towards the implementation of an innovative and feasible (technologically and economically) solution is the selection of sensor and gateway equipment for the FLEXCoop Wireless Sensor Network (WSN) topology.

The selection of the final solution is complicated, as different limitations and requirements should be taken into account. Therefore, a detailed evaluation of alternative solutions must be considered for the final deployment. The current analysis starts with the selection of the most appropriate criteria for the evaluation process (mainly based on user requirements and specifications analysis that has already taken place). Then, a review of the alternative solutions is performed based on the defined criteria towards the selection of the optimal FLEXCoop WSN topology. The goal of this section is not a complete protocol evaluation, which is out of the scope of this deliverable, but the selection of a solution that will serve project needs and fulfil the requirements of the relevant stakeholders (pilot users).

Considering that we are in an early stage of the project and that the pilot users have not yet been chosen, the analysis focuses on evaluating the main downstream communication protocols based on more generic criteria. Although this initial analysis will be used as a basis for the FLEXCoop solution implementation later on in the project, the final decision will be taken after having selected and analysed the available appliances of the pilot users to ensure that a fully operational solution will be delivered to the pilot users.

3.7.2. The FLEXCoop Approach

The FLEXCoop solution at the building level should provide:

- a modular communication system;
- an easy to install in a plug and play manner and user-friendly solution;
- a sensing/control smart system utilising (in the extent possible) off-the-self low-cost components.

As mentioned above, the scope of this section is not to evaluate and compare the different communication protocols per se but to estimate how these can be applicable and feasible in the frame of the FLEXCoop proposed solution. To this end, the key elements that will be examined are the existing available commercial equipment (meters, sensors, actuators, gateway, etc.) and how these can be integrated and applied in the FLEXCoop solution through the different
downstream protocols. Towards this direction, there is a following description regarding the functional and technical requirements that the FLEXCoop WSN should comply with.

The FLEXCoop solution will interface with:

- device controllers to monitor and control the operational statuses of each device mentioned above (i.e. HVAC, DHW, lights, PV systems);
- smart metering units to measure the consumption and generation of specific devices;
- sensors for measuring temperature, humidity, luminance, air quality, occupancy).

The FLEXCoop major WSN functional requirements defined so far are summarised in the following table.

**Table 1: List of FLEXCoop WSN functional requirements**

<table>
<thead>
<tr>
<th>FLEXCOOP WSN - FUNCTIONAL REQUIREMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Access on occupancy presence/absence data, through occupancy sensors installed in premises</td>
</tr>
<tr>
<td>2. Access on building environmental conditions data (luminance, humidity, temperature) through environmental sensors installed in premises</td>
</tr>
<tr>
<td>3. Access on device operational data (status, operational model, settings) through device management sensors installed in premises. Both reporting and control functionalities will be supported</td>
</tr>
<tr>
<td>4. Access on energy consumption and generation data (per device) through metering sensors installed in premises</td>
</tr>
<tr>
<td>5. Real time health related data through health sensors installed in premises</td>
</tr>
<tr>
<td>6. The topology of sensors installed (number of sensors/ placement of sensors) should take into account the pilot specific requirements</td>
</tr>
<tr>
<td>7. The solution will provide interfaces with the commercial (off-the-shelf) sensors/actuators solutions selected in the project</td>
</tr>
</tbody>
</table>

The relevant technical requirements of the network topology stemming from the aforementioned functionalities along with their priority level are summarised in the table below.

**Table 2: Technical Requirements of the FLEXCoop Network Topology**

<table>
<thead>
<tr>
<th>FLEXCOOP NETWORK TOPOLOGY - TECHNICAL REQUIREMENT</th>
<th>PRIORITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The network of devices should adopt a standardized wireless mesh topology, architecture and information flow (To overcome deployment site obstacles, such as walls in indoor environments, and maximize communication reliability)</td>
<td>High</td>
</tr>
<tr>
<td>2. The selection of the network topology will take into account the building types and installations and the maximum distance from the gateway etc</td>
<td>High</td>
</tr>
<tr>
<td>3. The network of OSB should be able to interface with the FLEXCoop system over the internet through a gateway module.</td>
<td>High</td>
</tr>
<tr>
<td>4. The application software of the gateway should be able to offer network monitoring and management services (acquire and manage information about the status and health of the network, joining and disjoining of new devices etc.)</td>
<td>Medium</td>
</tr>
<tr>
<td>5. The solution should comprise of an appropriate composition of already existing / mature technological sub-components where possible</td>
<td>Medium</td>
</tr>
</tbody>
</table>
6. The solution should (where possible) utilize commodity, off-the-shelf components as much as possible to drive down the bill of materials and integration costs and enable small/mid-scale procurement with small lead times

3.7.3. Criteria for Evaluation for the FLEXCoop WSN Approach

Having presenting the FLEXCoop project needs regarding the WSN topology, this section tackles the relevant and critical criteria developed in this document to achieve the successful implementation of the FLEXCoop solution.

As there is a vast development of WSN topologies with special focus on building automation, this task is of significant importance for the evaluation of the best fitted solution(s). The selection of these criteria enables the consortium to first set a subgroup of potential topologies for the final deployment. The selected criteria are further presented below:

Well-known, well-established and Mature Solution. The project is a demonstration project and thus a maturity on the adopted technologies with a supporting active community is expected. Although there are emerging technologies (e.g. 6LoWPAN) that seem very promising, the maturity of their implementation is a remaining issue [16]. In the FLEXCoop project, we need to consider mature technologies, thus only a simple reference in 6LoWPAN is made for completeness in Section 4.5, without incorporating it in the competitive analysis that follows in Section 45.4.9. In addition, we need to select a standardized approach for the WSN topology of the project. For example, there are some RF-based efforts (e.g. OpenEnergyMonitor [17]) that focus mainly on energy efficiency, though these are customized approaches with minimum support and deployment scale and thus are not examined in our analysis.

Plug and play Solution. There are building automation solutions (e.g. BACnet [18]) that are promoted by large hardware vendors and are considered as mature solutions for building automation. However, these solutions are hard to configure and thus are not examined in the project. Within the FLEXCoop project, we need to promote an “off-the-shelf” plug and play solution that does not require special installation and configuration skills from building facility managers and additionally can support the development of a custom software stack on top of the network layer.

Hardware Available Solution. We need to select a WSN topology that covers all the sensor devices needed in the project. There are some vendor specific WSN solutions (e.g. plugwise [19]) that could stand as a potential topology, though the range of available solutions doesn’t cover project needs. Therefore, we need to adopt a solution that is dynamic enough and hardware vendor independent to cover project needs.

Inexpensive Solution. The cost of WSN topology is considered as a critical parameter to be considered during the evaluation phase. This is one of the main boundaries that hinder the mass deployment of WSN in buildings. Therefore, we need to take into account also the cost of equipment as a main parameter for the selection of project topology.

Low-power Wireless Solution. Another requirement, which is considered optional at this phase of the project, is to provide a wireless sensor topology. The installation of equipment is
considered as a retrofitting activity and thus minor modifications on existing building infrastructures is expected.

**Secure Solution.** An additional criterion that have to be taken into account, is the security provided from the selected solution. Given the fact that the selected WSN topology will provide control functionality (automated / ad hoc), only technologies that implement sophisticated security mechanisms should be selected.

**Reliable Solution.** Reliability can be defined as a high probability that a network functions continuously and properly in a time period interval. A reliable network is a network that is capable to unceasingly deliver an accurate service. [20]

**Interoperable Solution.** We need to select a WSN topology that will allow us to choose the best device of a kind given the described criteria. Hence, our choice should allow us to interact with different devices without facing either hardware or software compatibility issues.

Taking into account the pre-selection phase and the definition of main evaluation criteria for WSN topology, we have considered the following sensor networks for further evaluation:

- ZigBee Protocol
- Bluetooth Low Energy (BLE)
- Z-wave Protocol
- EnOcean Protocol
- INSTEON Protocol

The next section provides a detailed analysis of the respective WSN protocols along with a comparative analysis among them towards the selection of the most appropriate topology for project needs (as they have been defined until this initial stage of the project).

### 3.7.4. Zigbee

ZigBee [21] is a low-cost, low-power, wireless mesh network standard targeted at wide development of long battery life devices in wireless control and monitoring applications[21]. ZigBee devices have low latency, which further reduces average current. ZigBee chips are typically integrated with radios and with microcontrollers that have between 60-256 KB flash memories. ZigBee operates in the industrial, scientific and medical (ISM) radio bands: 2.4 GHz in most jurisdictions worldwide; 784 MHz in China, 868 MHz in Europe and 915 MHz in the USA and Australia. Data rates vary from 20 kbit/s (868 MHz band) to 250 kbit/s (2.4 GHz band).

![ZigBee Protocol and Applications](image-url)

**Figure 10: ZigBee Protocol and Applications**
The ZigBee network layer natively supports both star and tree networks, and generic mesh networking. Every network must have one **coordinator** device, tasked with its creation, the control of its parameters and basic maintenance. Within star networks, the coordinator must be the central node. Both trees and meshes allow the use of ZigBee routers to extend communication at the network level. The following figure depicts an indicative topology for a ZigBee network.

**Figure 11: ZigBee network topology**

ZigBee builds on the physical layer and media access control defined in the IEEE standard 802.15.4 for low-rate WPANs. The specification includes four additional key components: network layer, application layer, ZigBee device objects (ZDOs) and manufacturer-defined application objects which allow for customization and favour total integration. ZDOs are responsible for a number of tasks, including keeping track of device roles, managing requests to join a network, as well as device discovery and security. Figure 12 depicts the network stack for the ZigBee WSN protocol.

**Figure 12: ZigBee network stack**
The ZigBee Alliance is a group of companies that maintain and publish the ZigBee standard. The Alliance publishes application profiles that allow multiple Original Equipment Manufacturer (OEM) vendors to create interoperable products. Currently, there are different types of application profiles available [22] (indicatively):

- ZigBee Home Automation 1.2
- Smart Energy 1.2b
- Telecommunication Services 1.0
- Health Care 1.0
- RF4CE – Remote Control 1.0
- Remote Control 2.0
- Light Link 1.0
- Gateway 1.0
- Commercial Building Automation 1.0

Additionally, at the time this study is made, future versions of ZigBee are under development (e.g. ZigBee Smart Energy 2.0, Home Automation 1.3) but not publicly available yet. Thus, they are not considered here.

ZigBee Home Automation and ZigBee Light Link are considered as the most mature application profiles related to building automation. Following the trend on the market for an inseparable solution, the ZigBee Alliance plans to put all forms of its low-power wireless technology under one standard, ZigBee 3.0, in a move that could make it easier to connect many wireless devices in homes. ZigBee 3.0 is one of several wireless communications standards in the works to link up appliances, light bulbs, security systems, thermostats and other equipment in homes and enterprises. If all those devices could talk to one another, the thinking goes, developers could come up with many new applications to make life easier and homes and buildings more efficient.

Summing up, ZigBee [23] is a mature, well-tested and proven (over 2,500 products certified and 300 million products deployed) technology. It is a low-cost, low-power, wireless mesh network standard. The final and most critical advantage of this protocol is the fact that it supports a number of readily available commercial off-the-shelf hardware solutions falling in the scope of the FLEXCoop project (e.g. smart plugs, lighting, gateways, sensors, smart metering devices, etc.). A more detailed analysis of the available FLEXCoop-related hardware solutions is presented in Section 4.9.

3.7.5. Bluetooth Low Energy (BLE)

The Bluetooth Low Energy (BLE) [24] standard was introduced in 2011 as the hallmark feature of Bluetooth v4.0 designed and marketed by the Bluetooth Special Interest Group (Bluetooth SIG). BLE is ideal for applications requiring episodic or periodic transfer of small amounts of data. Therefore, BLE is especially well suited for sensors, actuators and other small devices that require extremely low power consumption.

BLE incorporates the following features:

- It works well with high numbers of communication nodes with limited latency requirements;
- It has very low power consumption;
- It is as robust as the classic Bluetooth;
- It provides short wake-up and connection times;
- It provides good smartphone and tablet support.

Many features of classic Bluetooth are inherited in BLE, including Adaptive Frequency Hopping (AFH). These inherited features make BLE easy to setup, robust and reliable in tough environments. To support simpler and cheaper radio chipsets, BLE uses 402 MHz wide channels while classic Bluetooth uses 791MHz channels.

The BLE software stack consists of the following components (Figure 13):

- L2CAP (Logical Link Control and Adaptation Protocol) is the stack layer responsible for multiplexing data between various higher layer protocols as well as segmentation and reassembly of data packets.
- GAP (Generic Access Protocol) defines the generic procedures related to device discovery and link management when connecting to Bluetooth devices.
- GATT (Generic Attribute Protocol) provides profile and service discovery for BLE. The described procedures show how to use the ATT (Attribute Protocol) for service discovery as well as how to read and write attributes (data). Services and profiles are developed on top of GATT.
- 6LoWPAN (IPv6 over Low power Wireless Personal Area Networks). An alternative to GATT is to use TCP/IP based communication with 6LoWPAN. 6LoWPAN technology can be used to compress the IP messages sent over BLE to save on size requirements and power consumption.

![Figure 13: The Bluetooth low energy software stack](image-url)
When using BLE for IoT applications, the range can become a limitation as BLE implements a star topology. Competing technologies using the 2.4 GHz ISM band (e.g. 802.15.4 based technologies) often support meshing and routers to extend the coverage; however, such solutions are currently not possible in BLE.

Figure 14 and 14 show a possible solution to extend the wireless range by using interconnected gateways. The upstream link can be a cable (Ethernet) or a wireless link (Wi-Fi or classic Bluetooth) and the downstream can be a BLE link. In these examples, Wi-Fi upstream links are used. Since the upstream connection in the provided examples is based on Internet protocols, the IP protocol contains all the necessary mechanisms to support traffic routing to cloud services and in some cases also between the local BLE devices (e.g. when IPv6 over Bluetooth low energy is used).

Figure 14: Example of how to extend the Bluetooth low energy range via gateways [24]
Bluetooth SIG has defined several profiles – specifications describing how a device works in a particular application for low energy devices. For example, there are many profiles for BLE devices in healthcare applications, profiles for sporting and fitness accessories, generic sensors, etc.

To sum up, BLE is a wireless networking technology designed as an ultra-low power PAN. BLE does not support a mesh topology that is included in the FLEXCoop technical requirements provided in Table 2. The requirement for mesh networking is a key enabler for the IoT paradigm and Bluetooth SIG has already solved this “BLE issue” with the Bluetooth mesh networking officially launched in July 2017 [26]. Even though this technology seems promising to be used for smart home applications, it does not meet our requirement on maturity and thus, it is not further analysed.

An addition pitfall of BLE for being adopted in the FLEXCoop solution is the fact that to our knowledge there are only few BLE-compatible hardware solutions (that can be used in the scope of the FLEXCoop project i.e. lighting, thermostats, etc.) readily available in the EU market. From the above analysis, it is deduced that BLE is considered an unfavourable solution to be used for the deployment of the FLEXCoop solution.

3.7.6. Z-Wave

The Z-Wave protocol [27] is a wireless RF-based communications technology designed specifically for control, monitoring and status reading applications in residential and light commercial environments. The protocol is specified by the Z-Wave Alliance and the specifications are not publicly available. It is a low- powered RF communications technology that supports full mesh networks without the need for a coordinator node. It operates in the sub-1GHz band, is designed specifically for control and status apps, and supports data rates of up
to 100kbps. The application layer specification defines what and why two Z-Wave nodes communicate with each other and contains the relevant semantics.

Description of the semantic coverage

A Z-Wave network consists of various devices interconnected by a wireless communication protocol. Thanks to the Z-Wave standard, products from different vendors can work together seamlessly. Another advantage of Z-Wave is their ability to act as repeaters and forward data packets between nodes not able to communicate directly over the air. This extends the range of a Z-Wave network and improves stability. In order to perform this packet routing and forwarding the particular node needs to be mains powered. Battery operated nodes cannot act as repeaters.

Each device in a home can either control other devices or being controlled by other devices. Controlling devices are called Controllers, reporting devices are called Sensors, and controlled devices are called Actuators. Z-Wave differentiates between portable and static controllers to control other devices. Portable controllers change their location and they are battery powered. To allow long battery life-time they are inactive most of the time and will only communicate with other devices during manual interaction (pressing a button). Static controllers are installed on a fixed location. They are mains powered and therefore able to stay alive all the time to communicate with other devices. It is also possible to combine a logical sensor controller or actor function within one physical device. Actors switch either digital (on / off for an electrical switch) or analogue signals (0% - 100% for a dimmer or blind control). Sensors deliver either a digital signal (door, glass breaking, motion detector, window button on the wall) or an analogue signal (temperature, humidity, power). The following figure depicts the Z-Wave network topology.

![Z-Wave mesh topology](image)

**Figure 16: Z-Wave mesh topology**

Z-Wave devices on the market can be categorized into one of the following function groups:

- Electrical switches are designed either as plug in modules for wall outlets or as replacement for traditional wall switches (digital actors). It is also possible to have these actors already built into certain electrical appliances such as electrical stoves or heaters.
- Electrical dimmers, either as plug-in modules for wall outlets or as replacement for traditional wall switches (analogue actors).
- Motor control, usually to open or close a door, a window, a window sun blind or a venetian blind (analogue or digital actors).
- Electrical Display or other kind of signal emission such as siren, LED panel, etc. (digital actors).
- Sensors of different kind to measure parameters like temperature, humidity, gas concentration (e.g. carbon dioxide or carbon monoxide), analogue or digital sensors.
- Thermostat controls: either as a one knob control or using a temperature display (analogue sensors).
- Thermostats controls such as TRVs (Thermostat Radiator Valves) or floor heating controls (analogue or digital actors).
- Remote Controls either as universal remote control with IR support or as dedicated Z-Wave.
- USB sticks and IP gateways to allow PC software to access Z-Wave networks. Using IP communication these interfaces also allow remote access over the internet.

All communication within the Z-Wave network is organized in Command Classes, which are a group of commands and responses related to a certain function of a device. The Basic command class is the smallest common denominator of all Z-Wave devices. Every Z-Wave device must support the Basic command class. Device classes are organized as a hierarchy with three layers:

1) Every device must belong to a Basic device class;

2) Devices can be further specified by assigning them to a Generic device class;

3) Further functionality can be defined as assigning the device to a Specific device class.

In case the Z-Wave device is assigned to a specific device class, it is required to support a set of command classes as functions of this specific device class. These required command classes are called Mandatory command classes and they are individual of certain generic and specific device classes. Besides the mandatory device classes, Z-Wave devices can support further Optional command classes. They may be very useful but the standard does not enforce the implementation of these classes.
Figure 17: Z-Wave protocol stack

Figure 17 shows the Z-Wave protocol stack [28]. The Z-Wave Alliance was founded in 2005. It is a consortium of over 250 independent manufacturers (data of 2013), who have agreed to build wireless home control products based on the Z-Wave standard. Principal members include ADT, GE/Jasco, Evolve, Ingersoll-Rand, Linear, FAKRO and Sigma Designs. Z-Wave was developed by a Danish start-up called Zen-Sys that was acquired by Sigma Designs in 2008.

Therefore, the Z-wave is a candidate protocol that can adequately serve to the scope and requirements of the FLEXCoop project. It uses a source-routed mesh network architecture and it is a well-established, well-tested (more than 50 million products worldwide) and mature technology. According to the Z-wave official website [29], currently there are more than 2100 available smart home automation products (including sensor, smart meters, thermostats, etc.) on the market. As explained before, this criterion is ranked first in our analysis towards the selection of the most appropriate downstream protocols to be used for FLEXCoop deployment purposes.

Another feature of Z-wave that makes it favourable for a FLEXCoop implementation is the fact that Z-wave technology uses the same encryption as online banking, thus, being a “safe” choice for the FLEXCoop pilot users.

3.7.7. EnOcean protocol

EnOcean [30] is a company that develops energy harvesting wireless sensors which are claimed to be maintenance free and flexible allowing cost reduction in buildings and industrial facilities. The EnOcean Alliance was founded in 2008 by the EnOcean company and includes over 250 members and aims to create interoperability between the OEM partners of the EnOcean technology. The Alliance has 9 so-called promotor members which besides EnOcean include BSC Computer GmbH, Honeywell, OPUS greenNet, Pressac Communications, ROHM, Texas Instruments, Thermokon Sensortechnik, and Verve Living Systems. The EnOcean Alliance develops and promotes self-powered wireless monitoring and control systems for sustainable buildings by formalizing an interoperable wireless communication technology. In 2012, this technology has subsequently been standardized as ISO/IEC 14543-3-10.
The standard covers the OSI (Open Systems Interconnection) layers 1-3 which are the physical, data link and networking layers, and is geared to wireless sensors and wireless sensor networks with ultralow power consumption. It also includes sensor networks that utilize energy harvesting technology to draw energy from their surroundings – for example from motion, light or temperature differences. The EnOcean protocol stack is shown below.

![EnOcean Protocol Stack](image)

Figure 18: EnOcean Protocol Stack

This principle enables electronic control systems to be used that work independently of an external power supply. Full interoperability is guaranteed together with the EnOcean Equipment Profiles (EEPs) drawn up by the EnOcean Alliance.

Description of the semantic coverage

The EEP contains information about devices “enabled by EnOcean”, including RORG (identifies the EnOcean Radio Protocol (ERP) radio telegram type), FUNC (identifies the basic functionality of the data content), and TYPE (identifies the type of device in its individual characteristics).

There are 4 types of Telegrams (RPS, 1BS, 4BS, VLD) and for each of them there are several corresponding devices functions and types.

- The RPS telegram contains the following device functions: Rocker Switch, which has several channels and states, and can be further classified in 2 Rocker or 4 Rocker, Position Switch Home and Office Application, Detectors, and Mechanical Handle. Each of these functions is further divided in device types, for example, the Rocker Switch – 2 rockers function has types “01 Light and Blind Control – Application Style 1”, “02 Light and Blind Control – Application Style 2”, “03 Light and Blind Control – Application Style 3” and “04 Light and Blind Control ERP 2”.
- The 1BS telegram contains only one function and type, namely the Contacts and Switches device function with type “01 Single Input contact”.
- The 4BS telegram contains the following device functions: Temperature Sensors, which is further classified in types depending on the range of temperature handled, Temperature and

- The VLD telegram contains the following device functions: Electronic switches and dimmers with energy measurement and local control, Sensors for temperature-illumination-occupancy and smoke, Light Switching + Blind Control, CO2-Humidity-Temperature-Day/Night and Autonomy, Fan Control, Floor heating controls and automated meter reading, Automated reading meter gateway, Standard valve.

EnOcean could also be a potential candidate protocol for the FLEXCoop project. It is a well-established, mature, wireless solution that supports mesh networking. Its current weakness is that although it supports a number of different commercial hardware products relevant to the project worldwide (Europe, Japan, USA/Canada), only a limited number of them are dedicated to the European market.

3.7.8. INSTEON

INSTEON [31] is a low-power dual-band network technology optimized for home management and control, enabling all compatible devices to communicate using the powerline, radio frequency (RF) or both together. INSTEON devices respond to commands with no perceptible delay. INSTEON’s signalling speed is optimized for home control—fast enough for quick response, while still allowing reliable networking using low-cost components.

Installation in existing homes does not require any new wiring, because INSTEON products communicate over powerline wires or they use the airwaves. Users never have to deal with network enrolment issues because all INSTEON devices have an ID number pre-loaded at the factory—INSTEON devices join the network as soon as they’re powered up.

An INSTEON network becomes more robust and reliable as it is expanded because every INSTEON device repeats messages received from other INSTEON devices. Dual-band communications using both the powerline and the airwaves ensures that there are multiple pathways for messages to travel.

INSTEON software is simple and compact, because all INSTEON devices send and receive messages in exactly the same way, without requiring a special network controller or complex routing algorithms. The cost of networking products with INSTEON is held to an absolute minimum because INSTEON is designed specifically for home control applications, and not for transporting large amounts of data.

Figure 19 shows how devices can communicate with each other using the INSTEON protocol over the air via RF signals and over the powerline.
Figure 19: INSTEON device communication [31]
Every INSTEON device is capable of repeating INSTEON messages (Figure 20). They will do this automatically as soon as they are powered up—they do not need to be specially installed using some network setup procedure. Adding more devices increases the number of available pathways for messages to travel. This path diversity results in a higher probability that a message will arrive at its intended destination, so the more devices in an INSTEON network, the better. As an example, suppose RF device RF1 desires to send a message to RF3, but RF3 is out of range. The message will still get through, however, because devices within range of RF1, assuming DB1 and RF2, will receive the message and retransmit it to other devices within range of themselves. In the drawing, DB1 might reach RF2, DB2, and RF4, and devices DB2 and RF1 might be within range of the intended recipient, RF3. Therefore, there are many ways
for a message to travel. RF1 to RF2 to RF3 (1 retransmission), RF1 to DB1 to DB2 to RF3 (2 retransmissions), and RF1 to DB1 to RF2 to DB2 to RF3 (3 retransmissions) are some indicative examples.

On the powerline, path diversity has a similar beneficial effect. For example, Figure 20, shows powerline device PL1B without a direct communication path to device PL4B. In the real world, this might occur because of signal attenuation problems or because a direct path through the electric wiring does not exist. But a message from PL1B will still reach PL4B by taking a path through DB2 (1 retransmission), through PL2B to DB2 (2 retransmissions), or through PL2B to DB2 to PL3B (3 retransmissions). Figure 20 also shows how messages can travel among powerline devices that are installed on different phases of a home’s wiring. To accomplish phase bridging, at least one INSTEON hybrid RF/powerline device must be installed on each powerline phase. In the figure, hybrid device DB1 is installed on phase A and DB2 is installed on phase B. Direct RF paths between DB1 to DB2, or indirect paths using RF2 or RF4 (1 retransmission) allow messages to propagate between the powerline phases, even though there is no direct electrical connection.

Amongst a list of advantages, INSTEON is considered to be highly secure solution because the network security is maintained at two levels. Linking Control ensures that users cannot create links that would allow them to control their neighbours’ INSTEON devices, even though those devices may be repeating each other’s messages. Encryption within Extended Messages permits completely secure communications for applications that require it.

- **Linking Control.** INSTEON enforces Linking Control by requiring that users have Physical Possession of Devices in order to create links, and by Masking Non-linked Network Traffic when messages are relayed outside the INSTEON network itself.

- **Encryption within Extended Messages.** For applications such as door locks and security systems, INSTEON Extended messages can contain encrypted payloads. Possible encryption methods include rolling-code, managed-key, and public-key algorithms. In keeping with INSTEON’s hallmark of simplicity, rolling-code encryption, as used by garage door openers and radio key fobs for cars, is the method preferred by INSTEON.

From the above analysis, it is clearly deduced that INSTEON concentrates a number of advantages as a downstream communication protocol. However, our market research revealed that the majority of hardware devices that are required for the project are limited or even unavailable in the European market (see table below). From our consideration, this fact on its own led us to exclude INSTEON from the FLEXCoop solution implementation.

### 3.8. Downstream protocols evaluation based on the FLEXCoop-related selection criteria

A comparative analysis among the different protocols presented above will further lead us to the selection of the most appropriate ones that can potentially fulfil the FLEXCoop project needs. As commented previously, the final selection will be made later on during the project lifecycle after having selected, analysed and evaluated the pilot sites where the FLEXCoop solution will actually be deployed.
## Analysis of EU-wide Interoperability Standards and Data Models and Harmonization Requirements

### Figure 21: Overview of FLEXCoop evaluation criteria for downstream protocols

<table>
<thead>
<tr>
<th>FLEXCoop Criteria</th>
<th>zigbee</th>
<th>Bluetooth</th>
<th>EnOcean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maturity of Solution</td>
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<td>🚧 x</td>
<td>✔️ ✔️</td>
</tr>
<tr>
<td>Plug and play Solution</td>
<td>✔️ ✔️</td>
<td>✔️ x</td>
<td>✔️ ✔️</td>
</tr>
</tbody>
</table>

**Available Hardware (Available in EU)**

<table>
<thead>
<tr>
<th>Device Type</th>
<th>zigbee</th>
<th>Bluetooth</th>
<th>EnOcean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smart Metering Devices</td>
<td>Limited Availability in EU</td>
<td>Limited Availability in EU</td>
<td>Not available in EU</td>
</tr>
<tr>
<td>Smart Plugs</td>
<td>Limited Availability in EU</td>
<td>Limited Availability in EU</td>
<td>One product available (Insteon ON-OFF Plug)</td>
</tr>
<tr>
<td>Thermostats</td>
<td>Limited Availability in EU</td>
<td>Limited Availability in EU</td>
<td>Limited Availability in EU</td>
</tr>
<tr>
<td>Lighting</td>
<td>Limited Availability in EU</td>
<td>Limited Availability in EU</td>
<td>Limited products available (Only two)</td>
</tr>
<tr>
<td>Relays (Switches)</td>
<td>Limited Availability in EU</td>
<td>Limited Availability in EU</td>
<td>One product available (Insteon Micro Switch)</td>
</tr>
<tr>
<td>Gateways (Open API)</td>
<td>Limited Availability in EU</td>
<td>Limited Availability in EU</td>
<td>Not available in EU</td>
</tr>
<tr>
<td>Sensors</td>
<td>Limited Availability in EU</td>
<td>Limited Availability in EU</td>
<td>Not available in EU</td>
</tr>
</tbody>
</table>

### Network Properties

<table>
<thead>
<tr>
<th>Network Properties</th>
<th>zigbee</th>
<th>Bluetooth</th>
<th>EnOcean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Means of communication</td>
<td>Air</td>
<td>Air</td>
<td>Air</td>
</tr>
<tr>
<td>Network Configuration</td>
<td>Star + Mesh</td>
<td>Star Mesh</td>
<td>Mesh / Point to Point</td>
</tr>
<tr>
<td>Security</td>
<td>🚧 x</td>
<td>✔️ ✔️</td>
<td>✔️ x</td>
</tr>
<tr>
<td>Reliability</td>
<td>✔️ ✔️</td>
<td>✔️ ✔️</td>
<td>✔️ ✔️</td>
</tr>
<tr>
<td>Interoperability</td>
<td>✔️ ✔️</td>
<td>✔️ ✔️</td>
<td>✔️ ✔️</td>
</tr>
</tbody>
</table>

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We have highlighted the parameters that set critical bottlenecks for the FLEXCoop project implementation. Of course, the ultimate selection criterion will be what is readily available and fully supported by an active community at the time the project is running. Moreover, different hardware vendors provide sensor equipment that fits to project needs, while the cost of equipment should also be taken into account ensuring that will be in line with project limitations. However, this final criterion will be evaluated later on in the project.

The modern household appliances can hardly be seen as passive loads – commonly, these are highly intelligent and networked devices. To be able to reduce the energy usage of such smart-enabled devices, one has to be able to manage and optimize the energy utilization at a system scale.

3.9.1. SAREF – Smart Appliance Reference Ontology

The home systems are technically very heterogeneous, and standardized interfaces on a sensor and device level are required. There is a large number of required standards, and to enable semantic interoperability for smart appliances TNO developed SAREF, the Smart Appliance REReference ontology [32]. A part of what is needed is a unified data model for appliance is a reference ontology.

The creation of device and technology abstraction layers and corresponding common Application Programming Interfaces (APIs) are enabled by such an ontology and can be addressed, without the need to know specifics of the various standards, by developers of energy-saving application developers for generic types of appliances. By explicitly specifying recurring core concepts in the smart appliances domain, the relationships between these concepts, and mappings to other concepts used by different assets/standards/models a reference ontology offers this. To propose this high-level model, the European Commission (EC) launched a standardization initiative, to be conducted by European Telecommunications Standards Institute’s (ETSI) Smart Machine-to-Machine (M2M) Technical Committee. The SAREF Technical Specification has been already published by ETSI [33].

3.9.2. oneM2M

The oneM2M [34] organization is a consortium developing technical specifications that address the need for a common M2M Service Layer, readily embeddable within various hardware and software, and relied upon to connect the myriad of devices in the field with M2M application servers worldwide. A critical objective of oneM2M is to attract and actively involve organizations from M2M-related business domains such as: telematics and intelligent transportation, healthcare, utilities, industrial automation, smart homes, etc.

The area of smart appliance ontologies is still in preliminary phase and, as described in the above sections, the situation in “downstream” protocols is far from being clear and even further from having a single dominating protocol. The FLEXCoop consortium will closely follow the developments in this regard, but the decisions that will be taken will be influenced by the timeline of the project as well. The developments of FLEXCoop will be ready for such situation – but won’t be limited to it, i.e. the project should not be limited by non-existence of a dominating standard in this regard.
### 4. Overview of Examined Standards

A summary of the examined standards, along with their relevance to the FLEXCoop project is presented in the tables below.

**Table 3: Overview of examined standards: General and upstream-related standards**

<table>
<thead>
<tr>
<th>Standard name</th>
<th>Brief description</th>
<th>Relevance to FLEXCoop</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 62939</td>
<td>IEC Smart Grid User Interface standard defines the smart grid reference architecture</td>
<td>FLEXCoop interfaces to Smart Grid and communicates with other entities that are part of it.</td>
</tr>
<tr>
<td>CIM – Common Information Model and related standards</td>
<td>XML-based standard and semantic model used throughout the power sector.</td>
<td>CIM is the basis for many information exchange protocols with market and grid bodies.</td>
</tr>
<tr>
<td>IEC 62746, OpenADR</td>
<td>The IEC 62746 family of defines the systems interfaces and communication protocols from smart grid to smart home. The OpenADR defines an open model for DR-related activities.</td>
<td>As DR-related protocols, these are highly relevant for FLEXCoop. Some of the concepts may be used also for internal communication between the modules of FLEXCoop and the FLEXCoop final architecture may be influenced by this standard.</td>
</tr>
<tr>
<td>VHPready</td>
<td>A standard formed by an industry alliance in Germany, currently being deployed in the German grid, designed to ease the integration of renewables into the energy supply system.</td>
<td>The VHPready standard covers activation of flexibility. It is an open specification for networking and control decentralized power plants.</td>
</tr>
<tr>
<td>USEF</td>
<td>A standard formed by an industry non-profit alliance, directly covering the area of flexibility in the electricity system.</td>
<td>This standard covers the area where the FLEXCoop should operate in. The final FLEXCoop project architecture may be influenced by the USEF concepts.</td>
</tr>
<tr>
<td>IEC 61850</td>
<td>The IEC 61850 family of standards is de facto power utility automation standard.</td>
<td>FLEXCoop infrastructure will almost surely require communicating by using this protocol to provide data e.g. to the grid operator.</td>
</tr>
<tr>
<td>IEC 60870-5 series</td>
<td>A commonly used set of communication protocols for SCADA applications.</td>
<td>The 101 and 104 protocols from this series are very commonly used in practice, so FLEXCoop may be required to support these protocols as well.</td>
</tr>
</tbody>
</table>
### Table 4: Overview of examined standards: Downstream-related standards

<table>
<thead>
<tr>
<th>Standard name</th>
<th>Brief description</th>
<th>Relevance to FLEXCoop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zigbee</td>
<td>Low power wireless mesh network standard for long battery life devices.</td>
<td>One of downstream standards within FLEXCoop evaluation. Commonly used to link appliances, lighting and other equipment in buildings.</td>
</tr>
<tr>
<td>Bluetooth Low Energy</td>
<td>Low power variant of Bluetooth tailored for episodic or periodic transfers of small amounts of data.</td>
<td>A downstream standard with a good support in smart devices, however with less compatibility in the appliances and lighting.</td>
</tr>
<tr>
<td>Z-Wave</td>
<td>Low power, wireless RF-based mesh communication protocol for control, monitoring and status reading in residential and light commercial environments.</td>
<td>A downstream standard with reasonably good characteristics and availability in Europe.</td>
</tr>
<tr>
<td>EnOcean</td>
<td>An interoperable wireless protocol supporting self-powered wireless monitoring and control systems, designed for sustainable buildings.</td>
<td>A downstream protocol, well-established, mature with however a limited coverage in European market at the moment.</td>
</tr>
<tr>
<td>INSTEON</td>
<td>Low-power dual-band network technology designed for home management and control, supporting powerline communication and wireless.</td>
<td>A well-designed and advantageous downstream protocol, however with very limited scope of device support.</td>
</tr>
<tr>
<td>SAREF</td>
<td>Smart Appliance Reference ontology – designed to enable semantic interoperability of various smart appliances.</td>
<td>The key promises of FLEXCoop require communication with a number of end-user devices, thus these ontologies that enable semantic interoperability are highly interesting for the FLEXCoop project.</td>
</tr>
<tr>
<td>OneM2M</td>
<td>The oneM2M organization is a consortium developing technical specifications of a common M2M Service Layer. It should be readily embeddable within various hardware and software.</td>
<td></td>
</tr>
</tbody>
</table>
5. CONCLUSION

For the FLEXCoop services and products to be functional and replicable, a key success factor is interoperability through compliance and use of open standards. This deliverable is a part of the task T2.5 and delivers the overview of the current European standardization landscape. It describes the standardization environment where the FLEXCoop framework is expected to function.

Numerous established standards and ongoing standardization efforts are relevant for the FLEXCoop project. In this document, the standards have been tentatively divided in two main groups: the “upstream” standards where the FLEXCoop framework communicates with other entities in the energy market (e.g. the network operator or the market operator); and the “downstream” group of standards where the FLEXCoop framework communicates with the devices within the house as the actuators. These two areas also differ very significantly in the proliferation of standards and the existence of a dominant key standard. Besides the upstream and downstream standards, there are also several standards that influence the FLEXCoop project overall. Of those, the IEC 62939, CIM, IEC 62746, VHPready and USEF are presented.

The upstream and downstream characteristics of a particular standard only reflect the general scope of application of the particular standard. This does not classify the standards by their relative importance to the FLEXCoop project. In other words, the FLEXCoop framework needs to be fully operational both in the upstream and in the downstream environment.

Within the upstream standards, the standardization situation is relatively clear: on the technical side, most of the necessary communication requires the support of the IEC 61850 protocol, and eventually the IEC 60870-5-104 protocol. These are the established standards in the industry and other older legacy protocols can be utilized by means of protocol converters if necessary. On the business side, most of the needs are covered by implementing the CIM-derived standardized messaging with market entities.

In the downstream standards, the situation is much more difficult to assess as the market is more fragmented and there is a number of competing protocols without a clear winner. A comparative analysis among the different protocols is presented in this document. This, along with a more detailed evaluation of pilot sites, will support the final selection of the most appropriate ones that fulfill the FLEXCoop project needs. The efforts to drive a harmonization in this space have been identified, and the FLEXCoop solution will closely follow the developments in this area.

This document will serve as one of the inputs to the overall FLEXCoop system architecture, as it delivers the overview of the standardization landscape, primarily to the D2.6 FLEXCoop Framework Architecture including functional, technical and communication specifications. This deliverable will deliver the final architectural decisions on the standards and protocols to support in the FLEXCoop implementation. These decisions will be made after selection, analysis and evaluation of the pilot sites where the FLEXCoop solution will be deployed.
APPENDIX A: LITERATURE


[23] “Zigbee 3.0 | Zigbee Alliance.”


