Ref. Ares(2023)8182693 - 30/11/2023

H2020-LC-SC3-EE-2019

EUROPEAN COMMISSION

European Climate, Infrastructure and Environment Executive Agency

Grant agreement no. 893857

frESCO

New business models for innovative energy services bundles for residential consumers

Deliverable D7.3

"Standardisation analysis for the next generation of energy services"

Project acronym	**frESCO**
Full title	New business models for innovative energy service bundles for residential consumers
Grant agreement number	893857
Programme	H2020-EU.3.3.1. - Reducing energy consumption and carbon footprint by smart and sustainable use
Topic identifier	LC-SC3-EE-13-2018-2019-2020 - Enabling next-generation of smart energy services valorising energy efficiency and flexibility at demand-side as energy resource
Call	H2020-LC-SC3-EE-2019
Funding scheme	IA – Innovation Action
Project duration	42 months (1 June 2020 – 30 November 2023)

Project adviser	Rebecca Kanellea - CINEA
Coordinator	CIRCE – Fundacion Circe Centro de Investigacion de Recursos y Consumos Energeticos
Consortium partners	CIRCE, S5, EI-JKU, CARTIF, UBITECH, UBE, KONCAR KET, KRK, COSMA, LCTE, VOLT, VERD, IOSA, RINA-C
Website	http://fresco-project.eu
Cordis	https://cordis.europa.eu/project/id/893857

DISCLAIMER OF WARRANTIES

This document has been prepared by frESCO project partners as an account of work carried out within the framework of the EC-GA contract no. 893857.

Neither Project Coordinator, nor any signatory party of frESCO Project Consortium Agreement, nor any person acting on behalf of any of them:

(a) makes any warranty or representation whatsoever, expressed or implied,

   (i). with respect to the use of any information, apparatus, method, process, or similar item disclosed in this document, including merchantability and fitness for a particular purpose, or
   (ii). that such use does not infringe on or interfere with privately owned rights, including any party's intellectual property, or
   (iii). that this document is suitable to any particular user's circumstance; or

(b) assumes responsibility for any damages or other liability whatsoever (including any consequential damages, even if the Project Coordinator or any representative of a signatory party of the frESCO Project Consortium Agreement has been informed of the possibility of such damages) resulting from your selection or use of this document or any information, apparatus, method, process, or similar item disclosed in this document.

ACKNOWLEDGMENT

This project has received funding from the European Union's 'Horizon 2020' research and innovation programme under grant agreement n. 893857

Disclaimer: *The European Commission is not responsible for any use made of the information contained herein. The content does not necessarily reflect the opinion of the European Commission.*

Deliverable D7.3
Standardisation analysis for the next generation of energy services

Deliverable number	D7.3
Deliverable name	Standardisation analysis for the next generation of energy services
Lead beneficiary	KONCAR
Description	This task investigates the possibility of initiating standardisation or label creation actions for the next generation of smart energy services and incorporates conclusions and recommendations taken from the demonstration of the business models.
WP	7
Related task(s)	T.3 Standardization recommendations
Type	Report
Dissemination level	Public
Delivery date	30.11.2023
Main author	Leila Luttenberger Marić, Hrvoje Keko KONCAR
Contributors	Alessio Pacchiana RINA-C

Document history

Version	Date	Changes	Author
V0.5	27.06.2023.	ToC and content backbone	KONCAR
V0.8	28.09.2023.	Contribution to sections	KONCAR
V1.0	10.11.2023.	Final draft version	KONCAR
V1.1	16.11.2023.	Contribution to sections	RINA-C
V1.2	18.11.2023.	Consolidated full version ready to review	KONCAR
V2.0	21.11.2023.	Reviewed version	MOH
V2.1	25.11.2023.	Proofreading and final version	KONCAR
V3.0	30.11.2023	Submission to EC	CIRCE

ABBREVIATIONS

Abbreviation	Name
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CIM	Common Information Model
CWA	CEN Workshop Agreement
DER	Distributed Energy Resources
DR	Demand Response
EC	European Commission
EN	European Standard
ESCO	Energy Services Companies
EU	European Union
EV	Electric Vehicles
HVAC	Heating, ventilation, and air conditioning
IoT	Internet of Things
KER	Key Exploitable Result
NAESB	North American Energy Standards Board
PLC	Programmable Logic Controllers
P4P	Pay-for-Performance
SGAM	Smart Grids Architecture Model

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This work analyses the current state of the art of technical and modelling standards in smart energy services and introduces the mapping of frESCO solution architecture to these standards. A revision of the standardization barriers derived from the experiences in the frESCO demo sites has been performed. Additionally, the policy and standardization synchronization efforts along with the upgrade paths to the frESCO solution towards the adaptation of new standards have been discussed.

1 SCOPE AND OBJECTIVES

The scope of this work is to analyse the technical and modelling standards, identify relevant standardization bodies along with the stakeholders and entities involved in the creation of energy services in the EU. The barriers currently compromising the full deployment of such services identified mainly during the pilot implementation phase were discussed.

The analysis presented hereby builds upon the results of task T3.6 "Contractual relations between all stakeholders involved" and WP6 "Testing and validation of the new services" with the aim to create targeted, actionable, and realistic standardization recommendations at the EU level as well as for specific countries involved in the frESCO pilot activities.

This Deliverable along Deliverables 7.2, 7.4, 7.5 and 7.6 successfully satisfies Milestone 9 of the project: "Identified final description of KERs and exploitation strategies".

2 STANDARDIZATION IN SMART ENERGY SERVICES

Standards are at the core of the EU single market [1] as stated in the communication document published by the European Commission (EC). The standardization is of particular importance for enabling the green and digital transformation of the European market, as well as for increasing its resilience and interoperability. The EU ambitions towards achieving a low-carbon, resilient and circular economy cannot be delivered without a strong support for delivering European standards on interoperability solutions, testing methods and management systems. As also noted by the EC, current standards do not only have to deal with technical components but also have the urgency to incorporate social and sustainable principles such as cybersecurity and critical infrastructure resilience. The introduction of novel smart energy services and technologies in the European market could not coexist without regulatory and standardization frameworks.

Traditional procedures for standardization do not follow the pace of the technological developments. Specifically, for the introduction of novel smart energy services in the EU both technical and data modelling related standards should be covered, thus an existing standard could not typically cover all the requirements for such a specific business model.

This chapter studies the current state of the art in technical and modelling standards for smart energy services, with a particular focus on the solutions adopted in the frESCO architecture.

2.1 State of the art analysis

2.1.1 Relevant technical standards and protocols

Smart energy services toolkits introduced in the frESCO business models cover several stakeholders, from energy services companies (ESCO), building and facility managers, aggregators to ICT companies. Each stakeholder in the day-to-day business uses different technical standards and procedures for data sharing and processing. Since the frESCO toolkit considers both energy market and the energy savings market, different technical standards could be applicable. The categories covered by the frESCO novel smart energy services are smart equipment, energy efficiency, flexibility, and non-energy services. Considering different smart energy service providers and categories in the frESCO framework, several technological and process standards could be tackled.

2.1.1.1 Smart home equipment and non-energy services

For smart energy services data accessibility and interoperability in smart home equipment is an absolute precondition. Standardisation and compatibility between sensors, meter gateways or energy boxes should be established in such a service. Different communication protocols are being used in practice and the most representatives are described.

2.1.1.1.1 ZigBee CEN EN 16836

The ZigBee standard enables machine-to-machine communication and interoperability enhancement at smart building level. It specifies the requirements for access control between the physical layer and networking layer of a communication protocol for the exchange of data from metering devices to other devices within a mesh network [2, pp. 16836–2]. In a smart home equipment environment, the Zigbee CEN EN 16836 intents to define devices and interfaces for smart energy applications. It can be used for communication between devices in a smart home environment or for sub-metering purposes. The Zigbee describes real time recordings, historical information, status indicators and metering types. Besides type of devices PCT (Programmable Communicating Thermostat), ESI (Energy Services Interface) and In-Premises Display are also incorporated in the standard. Energy management functions such as demand response (DR), messaging, load control, pricings and billing are also available. Both tree star and generic mesh networks are supported in Zigbee. 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.

ZigBee builds on the physical layer and media access control as this is defined in the IEEE standard 802.15.4 for low-rate WPANs. The specification includes: a network layer, application layer, ZigBee device objects (ZDOs) and a manufacturer-defined application objects which allow for customization and integration. ZDOs are responsible for keeping track of device roles, managing requests to join a network, as well as device discovery and security.

2.1.1.1.2 KNX CENELEC EN 50090

The KNX standards is approved as European Standard through CENELEC EN 50090 and CEN EN 13321-1 [3] which is designed for numerous smart home applications such as heating, ventilation and air conditioning (HVAC) and water control, energy management, lighting and security systems control and lots more. It can be applied to new and existing homes. The KNX system is a bus system for building control which means that all devices in a KNX system use the same transmission method and can exchange data via a common bus network. The KNX structure is decentralized, which means that there is no need for a central control unit, even though centralized units are possible.

2.1.1.1.3 SPINE CENELEC EN 50631-1

The SPINE standard adopted in the EU as CENELEC EN 50631-1 [4] also focuses on interoperability on information exchange among various appliances in the home environment. Apart from defining a set of functions for smart home appliances, it describes the monitoring and control of various devices. SPINE outlines a neutral layer with the purpose to connect different technologies in the smart home environment, covering also electric vehicles (EV), HVAC and smart appliances.

2.1.1.1.4 Z-Wave

The Z-Wave protocol is also spread among home automation devices. The protocol specifications are not publicly available but through public documents [5] it is shown that it relies on a wireless RF-based communication technology which is designed for controling, monitoring and status reading of applications in residential and commercial environments. Z-Wave supports full mesh networks, thus enabling the communication between various devices. There exist numerous devices on the market that work on a Z-Wave protocol such as electrical switches, dimmers, monitoring devices, electrical displays, sensors, thermostat control, USB sticks and IP gateways. The communication Z-Wave network is organized in command classes, enabling group command and responses related to certain functions.

2.1.1.1.5 Modbus

Modbus is an application-layer messaging protocol which provides client or/and server communication between devices connected on different types of buses or network [6] which was originally developed for programmable logic controllers (PLCs). The Modbus protocol supports communication between multiple devices connected to the same cable or Ethernet network. As an example, one device could measure humidity and another temperature both connected to the same cable. Modbus has originally been developed in late 1970s by a company called Modicon that is now a part of Schneider Electric. As it has been designed to run in quite low capability devices it is simple to implement and has relatively low overhead. It has proliferated quite widely and became a standard for many types of devices across numerous industries. These, in the context of frESCO, range from solar panel inverters, heat pumps, battery management systems and other systems. Modbus supports running over TCP/IP in Ethernet networks, and also a wide range of asynchronous serial communication carrier standards such as RS-485 (two-wire serial). The principal challenge of the Modbus protocol is that the user must know the exact addresses and the exact data types of the data to retrieve, as well as know how to interpret the underlying data as due to its simplicity, Modbus does not offer any kind of interrogation functionality.

2.1.1.1.6 Smart metering CENELEC EN 50491-11

The CENELEC EN 50491-11 Smart Metering European standard specifies a data model to abstract the metering world towards external consumers displays [7]. It describes a data model which lays down a format of metering data accessible through a simple display. The EN 50491-11 standard does not specify the communication protocol used between the meters and the meter communication functions but considers the EN 62056 COSEM series for the definition of the data model [5].

As described in [5] the main concepts addressed in EN 50491-11 are those of Meter (i.e., instrument for measuring, memorizing and displaying data related to the consumption of a commodity) and Data Point (i.e., container element, in which information is located related to a function of a product). Meters are characterized by metering functions. Each metering function is represented by a corresponding Functional Block, typically part of the metering communication function which is accessed by a simple user display. Some meters may also provide metering data history values (e.g., monthly data). A functional block is specified for each typical metering function, grouping several in- and output data points. Most functional blocks of the data interface specified in the EN 50491-11 standard contain data that are intended as output to a connected display.

2.1.1.1.7 IEC 62056 COSEM

The COSEM [8] stand for Companion Specification for Energy Metering is a world-wide standard that specifies smart meter functionality and it is maintained by the DLMS (Device Language Message Specification) User Association. The DLMS is a generalized concept for abstract modelling of communication entities [5]. The middleware protocol can be applied to various physical layer technologies such as Zigbee or Internet. It is designed to support messaging between devices and the computer integrated environment.

COSEM sets the rules for data exchange with energy meters, and it is designed for use with DLMS but can be also applied to other protocols. In the COSEM server model the physical meter is defined as a composition of several logical devices, thus this logical device concept permits the same meter to be utilized for energy, gas and water. For semantic interpretation it is limited to the context of smart meters. The OBIS (Object Identification System) standardized as IEC 62056-6-1 is an essential part of COSEM and it specifies the overall structure and the mapping of commonly used data items in metering to their identification codes.

2.1.1.2 Flexibility services and demand response activations

Besides smart home equipment interoperability, for demand response (DR) activation, the interfaces between a smart grid flexibility user and smart home should be defined. The DR activations signals should be properly delivered and registered. The ‘Open Automated Demand Response (OpenADR 2.0b Profile Specification)’ [9] is the most representative standard of the IEC 62746 family of standards, is IEC 62746-10. It represents the adoption of the OpenADR Alliance standard as an IEC standard.

2.1.1.2.1 OpenADR IEC 62746

The IEC 62746, which represents the European adoption of the ‘OpenADR’ standard established by the ‘OpenADR’ Alliance, defines the system interfaces and communication protocols, essentially covering the demand response value chain between a smart grid flexibility user and smart home or building. The ‘IEC 62746’ enables common information exchange between electricity service providers, aggregators, and end users. The open specification facilitates anyone to implement the two-way signalling systems by providing the servers that publish information to the automated clients subscribing to the information. This standard covers the demand response value chain; a smart grid flexibility activator (i.e., aggregator or ESCO) and a smart home flexibility for resources. Additionally, the standard provides an application-level service communication, which can be used to incentivize responses from the customer-owned and customer-located distributed energy resources.

In the framework of ‘IEC 62746’, the following services are specified:

- *Register*: identification of entities (prior to the interaction with other parties).
- *Event*: providing event functions and information models for price-responsive demand response.
- *Report*: provides feedback either periodic or one-time information.

The ‘IEC 62746’ is capable of addressing short-term changes in availability, therefore opt-in and opt-out schedules from virtual end nodes to virtual top nodes [10]. The opt-in and opt-out options are a key difference to classic telecontrol protocols where only technical unavailability is implemented [11].

In terms of data semantics, these are specified solely to a limited extend as the message payload interpretation does not go beyond the generic types of events. It provides minimal extent of a data model for the cases of the demand response, pricing, distributed energy resources (DER) and communication. It also facilitates information exchange between electricity service providers, aggregators, and end users [11].

This standard supports explicit demand response – direct load control by providing a DR message exchange without the underlying application logic. However, the ‘IEC 62746’ has definite importance for any kind of demand-response solution.

2.1.2 Relevant data modelling standards

The development of proper data modelling standards in smart home automation, especially for residential buildings, are a work in progress task. As in the electrical utility enterprises, there is no such core common information model (CIM) as the 'IEC 61970-301', which is an abstract model that represents all the major objects in an electric utility enterprise typically involved in utility operations.

2.1.2.1.1 Energy@home

One of the ZigBee semantic extensions is given by the 'Energy@home' protocol [12]. Its data model specifies the home area networkincluding smart appliances, smart meters, smart user interfaces and renewable energy generation. Its main advantage is that is based on the 'OpenADR' shema, with a 'Common Information Model (CIM)' approach.

2.1.2.1.2 SAREF family of standards

The 'Smart Applications REFerence (SAREF)' ontology enables the matching of existing assets in the smart applications domain [13]. SAREF was created with the intention to interconnect data from different protocols and platforms (i.e. ZigBee, Z-Wave), thus enabling communication between in-home devices that use different protocols and standards [5]. It could be described as an "umbrella" that enables better integration of semantic data from and across various vertical domains in the IoT. As pointed out in [5], although the physical connection with smart appliances can differ depending on what specific protocol is implemented, SAREF can be used to provide a shared language at the semantic level for common concepts that are exchanged between different devices from various manufactures and systems/platforms from multiple vendors that co-exist in the same home/building environment.

SAREF is based on four principles:

- reuse and alignment of (existing) concepts and relationships that are defined in existing assets,

- modularity to allow separation and recombination of different parts of the ontology depending on specific needs,
- extensibility to allow further growth of the ontology and
- maintainability to facilitate the process of identifying and correcting defects, accommodate new requirements, and cope with changes in (parts of) SAREF [13].

The SAREF requires one set of mappings to each asset, instead of a dedicated set of mappings for each pair of assets. As an example, different assets share some recurring core concepts, but they often use different terminologies and adopt different data models to represent these concepts. With SAREF different assets can keep using their own terminology and data models, but still can relate to each other through their common semantics.

The main concepts of SAREF are listed in alphabetical order:

- Building Object (Door, Window)
- Building Space
- Command (e.g., OnCommand, OffCommand, PauseCommand, GetCommand, NotifyCommand, SetLEvelCommand)
- Commodity (e.g., Electricity, Gas, Water)
- Device (e.g., Switch, Meter, Sensor, Washing Machine)
- Device Category
- Duration Description
- Function (Actuating Function, EventFunction, Metering Function, Sensing Function)
- Function Category
- Profile
- Property (Energy, Humidity, Light, Motion, Occupancy, Power, Pressure, Price, Smoke, Temperature, Time)
- Service
- State
- Task (e.g., Cleaning, Safety, Entertainment)
- Temporal Entity

- UnitOfMeasure (e.g., Currency, EnergyUnit, Power Unit, Temperature Unit).

The listed concepts are applicable for DR purposes, especially for monitoring and verification purposes, as they provide a qualitative description and insights about relationship of smart home appliances [11].

Within the SAREF, a dedicated extension for buildings was developed by 'buildingSMART' as 'SAREF4BLDG' [14], which was published as the ISO 16739 standard. The idea behind 'SAREF4BLDG' is to enable the interoperability between these actors: architects, engineers, consultants, contractors, product component manufacturers, etc. and applications managing building information involved in the different phases of the building life cycle. The relationship between building spaces and devices and building objects has also been transferred and generalized from the 'SAREF' ontology which could be theoretically useful for energy efficiency impacts evaluation, as an example could be useful for making proper classification of buildings involved in a flexibility program. However, such an ontology extension might be excessive while targeting residential buildings and users.

2.1.2.1.3 EEBUS

'EEBUS' describes the communication interface (application, transportation, communication) in order to allow for the interconnection between energy management relevant devices as well as corresponding control systems [15]. It has been developed by the 'EEBUS' initiative, which is a non-profit organization for interoperability in the area of the IoT with a strong focus on standardisation. The 'EEBUS' architecture is based on a 'Smart Grids Architecture Model (SGAM)', and it specifies the language of energy using the 'SHIP', 'SPINE' and use case specifications.

'SHIP' describes the standardized transport of data over IP and provides mechanisms for setting up a secure network. A 'SHIP' device can communicate with any other 'SHIP' device within the same network. The 'SPINE' is a modular toolbox which contains a collection of data classes which can be exchanged on different technological platforms, communications, or transmission channels. 'SPINE' can be mapped in various technologies such as KNX, Modbus, and others. Furthermore, ‘EEBUS’ and ‘Energy@home’ are cooperating with the goal to embed ‘SPINE’ into ‘SAREF’.

2.1.2.2 Energy efficiency services and demand response

To calculate the impact of energy efficiency, it is essential to implement appropriate measurement and verification procedures. The measurement and verification of energy efficiency encompass the assessment of any renovation, enhancement, or energy-saving initiative, whose aim is to provide energy and/or economic savings. The same holds true when evaluating the effectiveness of demand response strategies. Energy savings triggered by demand response events are calculated by computing the difference between actual energy consumption and the expected baseline consumption during the event. The frESCO business model framework encompasses both energy efficiency and demand response, which is why standardized procedures for measuring and verification were carefully examined during the development of the frESCO Performance Measurement and Verification (PMV) methodology.

The frESCO’s ‘Performance Measurement and Verification (PMV)’ methodology was developed by incorporating elements from established methodologies, such as ‘IPMVP’ and ‘eeMeasure’ methodology as outlined in detail in D3.4, the definition of the frESCO PMV methodology.

2.1.2.2.1 IPMVP

The ‘International Performance Measurement and Verification Protocol (IPMVP)’ [16] provides a structured framework for implementing ‘Performance Measurement and Verification (PMV)’ procedures and establishes the fundamental concepts required to determine savings. Moreover, this protocol serves as a safeguard for both the client and the supplier of’ Energy Efficiency Measures (EEMs)’ since it is crucial to have a universally accepted ‘PMV’ methodology that all parties can rely on. The ‘IPMVP’ is a guidance document designed to facilitate investments in efficiency. It achieves this by measuring, calculating, and reporting the savings generated through energy or water efficiency projects in commercial and industrial facilities. These savings are determined by comparing energy consumption or demand before and after the project, considering any necessary adjustments. It is important to note that energy, water, or demand savings are defined as a reduction in consumption and cannot be directly measured.

The 'IPMVP' provides guidance on several critical aspects, including the assessment period, reporting period, and the methodology for calibrating or rectifying calculations. It emphasizes the importance of continuously calibrating and adjusting baseline consumption values to account for changing conditions such as climatic variations or fluctuations in household (or other facility) occupancy. This is done to ensure that baseline values remain comparable to the measured consumption values. Additionally, special consideration should be given to the requirements for input measurement data, such as the total consumption of the entire facility or specific sections of it, and the level of detail in the data needed to determine savings.

2.1.2.2.2 Demand response standardized measurement and verification guidelines

If demand response flexibility is to be recognized as energy savings, it is essential to choose appropriate measurement and verification procedures. The parameters employed for monitoring and verifying short-term flexibility play a critical role in assessing the impact of the flexibility program and quantifying the realized savings. The techniques employed to measure the estimated consumption should consider factors such as the user's or consumer's characteristics, the influence of various variables (such as weather and seasonal conditions) on observed load. These techniques should be regularly adjusted to accommodate changing circumstances.

The challenge lies in achieving a straightforward yet precise assessment of reductions in a customer's energy usage compared to a baseline during a specific time interval (i.e., the DR deployment period) and ensuring that this calculation is equitable for all stakeholders. Since these are estimates, it's important to acknowledge that baselines may be imperfect.

However, in line with the recommendations of the 'North American Energy Standards Board (NAESB)' [17], effective baselines should strike a balance across four key aspects: accuracy, integrity, simplicity, and alignment. Adhering to these principles is essential in creating fair and effective baseline measurements for demand response programs. While there isn't a universally applicable standardized procedural protocol for all cases, it is advisable to follow general guidelines, such as the ‘National Assessment and Action Plan on Demand Response (NAPDR)’ [18] as they can provide valuable direction in the absence of specific protocols.

2.2 Mapping of frESCO solution architecture to the standards

Relevant data standards such as ‘SAREF’ and ‘OpenADR’ were identified and chosen as the foundation for shaping the frESCO CIM (as described in D4.1 frESCO Common Information Model). The Common Information Model of frESCO was developed under some very specific foundations, starting with the need to be as resilient as possible. The different data relationships were introduced, so that stakeholders (both within and outside the frESCO consortium) may manage and leverage them using the project's integrated Platform.

The frESCO CIM includes entities that are related to the:

- different Actors involved (encompassing: Aggregator, EnergyServiceCompany, Prosumer, BuildingManager)
- Building Framework (encompassing: Building, BuildingArea, BuildingLevel, Comfort, Tenancy, Tenant)
- Appliances (encompassing: SmartMetering, Gateway, Sensor, LightSource, AirConditioning, WaterHeater, Battery, ElectricVehicle, ElectricVehicleChargingPoint)
- Measurements (encompassing: EnergyMeasurements, SensingMeasurements, WeatherMeasurements)
- Flexibility (encompassing: Flexibility, DemandResponseEvent, DemandResponseReport)
- Energy Market (encompassing: TariffProfile, Settlement, ContractualAgreement, ContractualAgreementStructure)
- Power Plants (encompassing: VirtualPowerPlant, WeatherStation, PhotovoltaicPlant)
- General Information entities (encompassing: Address, ContactSpecifics, Location, Period, Status)

It should be emphasised that enabling demand side flexibility entails more than just collaboration among energy market participants like traditional ‘Distribution System Operators (DSOs)’ and ‘Energy Service Companies (ESCOs)’. It also necessitates the integration of their technical infrastructures responsible for managing and coordinating demand [5], and in that sense interoperability is imperative, particularly when different infrastructure share essential information, such as smart metering data, required by demand-side flexibility applications.

3 REVISION OF THE FRESCO STANDARDIZATION BARRIERS IN THE DEMO SITES

3.1 Experiences from the demo sites

The demo sites, in the context of standardization, have provided a valuable and direct insight into weak points, i.e., where the current standards are not really providing enough coverage. It is expected that the innovation projects stretch the established standards. Even though these standards may work well in the original setting, the pilot deployment has required additional efforts and additional solutions not envisioned previously, in all of frESCO pilot sites.

Some of the challenges of utilizing the Modbus protocol have been exhibited in the Greek pilot site. The Modbus protocol, while quite well established, easy to integrate, develop and utilized in millions of devices, does not support any type of “general interrogation” mechanism common in more complex protocols such as ‘IEC 60870-5-104’ protocol [19]. This means there is no possibility for the device to list the registers and data types required – which is not surprising given the simplicity and the protocol age, as it originated in Modicon (now Schneider Electric) PLC controllers in 1979. In effect, while the protocol does solve the interoperability mechanics at the communication layer, the actual data that is carried by the protocol is not standardized and thus is left to the implementer. This situation allows for flexibility, but consequently, in order to communicate via Modbus, the user needs to have knowledge of the addresses of the protocol data units and the data types in order to correctly read out the data.Furthermore to utilize the data the semantics of the data have to be aligned separately. Attempts were made to standardize the information model set up in Modbus, such as in the SunSpec standard [20] which specifies common parameters and settings for monitoring and controlling distributed energy systems. Effectively, Modbus simplicity, low overhead and flexibility is kept, but the SunSpec standard is used to specify the addresses and data types to increase interoperability. This standard is gaining traction in the United States in recent years, and many newer solar panel inverters conform to this standard – however, in many cases the simpler and older devices will still have custom addresses that have to be specified correctly by the manufacturer. Even worse, in some cases the hardware and software revisions by the manufacturer affect these registers which makes finding the correct

Modbus register set difficult. Finally, due to security and in some cases even contractual terms, Modbus/TCP support is often turned off by default on the inverters. Contractual terms have been the obstacle to standardized Modbus usage in the Netherlands, where a specific company providing PV hardware would make the warranty void if the Modbus control were used at all, aiming to shift the users to their own custom solution.

In the development of the Greek pilot, this has been solved with the work by CIRCE team and their flexible support for Modbus in the Energy Box, so the Energy box has been able to read out the measurement registers and package these in MQTT message payloads. However, this required custom development and iterative deployment, which significantly increases the costs and barriers for wide-range adoption.

Creating and diligently applying a common information model that keeps track of the data semantics is challenging and this has influenced all pilots in their technical implementation. Namely, similar to Modbus, the MQTT protocol that was extensively used in the project also does not define the payload semantics, i.e., the definition of the MQTT protocol does not include how the payload is formed and interpreted – this is left to the implementer. MQTT is a lightweight, publish-subscribe, machine to machine network protocol for message queue/message queuing service. It has been designed for connections and devices with resource constraints. The brokerage supports organizing the messages into topics and the subscriber can choose to subscribe only to certain topics. The filtering and organization of topics is left to the implementer. This, in turn, means that a part of the information might be contained in the topic, and the rest within each of the message payload. Precisely this has been the case with the Develco devices – the default data model of the devices carries a part of the data in the topic. The identifier on which device sent the message is contained in the topic, and the actual measurements in the message payload. This required an installation of repackaging service for Greek and Croatian pilots where a single MQTT job is utilized to collect all the messages from these pilot sites – in effect, the repackaging moved the information on the devices into the MQTT payload.

There are two takeaways in this case: the common information model should be thoroughly enforced and as close to the data harvesting as possible, and care should be taken with regards to the carrier protocols and their handling of data. This has been the topic of investigation in several ‘Horizon 2020’ projects such as the ‘InterConnect’ project (funded in the DT-ICT10 call). Regarding the device connectivity, frESCO is no exception to connectivity issues and challenges that exhibited themselves in all pilots we have exhibited challenges in connectivity, with Zigbee devices and to an extent with WiFi connectivity as well. In Croatian pilots, we had problems of detecting whether there has been a hardware failure in the device or a connectivity issue to the devices as some devices have been dropping out intermittently. It turned out to be a hardware problem in one case, and a connectivity issue solved by relocating the gateway in other two cases. Both the Spanish and the Greek pilot sites have exhibited connectivity issues and these also have been intermittent.

The overall conclusion of frESCO resembles several other projects working with end-user premises technologies. The most challenges, both in technical terms and in terms of business models, are in the “last meter” connectivity within the end user premises. Reliable, simple to implement and deploy, robust end user premises data acquisition is a particularly hard problem. This is even more the case when legacy devices are involved.

It is not surprising that the development of in-house standardized protocol currently called Matter is ongoing. The Matter standard is expected to supersede Zigbee and other similar in-house protocols and is currently maintained by the ‘Connectivity Standards Alliance (CSA)’, formerly known as the ‘Zigbee Alliance’ with numerous large technological partners as members (e.g., Google, Apple and Amazon). The Matter protocol has officially launched in November 2022, and is accompanied by the Thread wireless protocol, a low-powered mesh-based wireless protocol. In theory the combination of these two protocols would solve many of the “last meter” issues faced in the pilots – but this requires first the adoption of the standards by the manufacturers and then the upgrade of the existing devices or development of gateway devices that would convert older communication protocols into Matter operating over Thread. Finally, the mesh character of Thread would most probably require users to upgrade their network equipment such as routers which represents an additional barrier to the adoption.

Finally, an issue being faced in pilots, considers the trade-off between the complexity at the edges and the complexity of the central platform which is an effect of a conceptual challenge regarding the idempotence of the data upload process. If the upload process is idempotent and thus allows multiple reuploads of the same data without creating duplicates, taking care that the duplicates are not created at all, then the upload gateway does not need to be stateful and does not need to take care on which data has been uploaded and which has not. This however increases the requirements for bandwidth and the capabilities of the central data collection platform. Conversely, if the upload process is not idempotent and retries in uploads will result in duplicate entries, then the data uploading gateways must keep track on what records have been published into the platform.

3.2 Conclusions and identified barriers from demo sites

The findings from the pilot site can be summarised as follows:

1) **Connection to legacy devices**, especially those equipped with simple protocols with no features on interrogation such as **Modbus**, may be a challenging barrier as detailed and up-to-date vendor documentation is necessary. There have been efforts to standardize the semantics of the data shared over protocols such as SunSpec, but with limited traction. As the lifecycle of these devices is quite long and the capital and labour expenditures for an upgrade is high, a strategy of covering legacy devices in the field is necessary. Here, the trade-off focuses between development and device costs and coverage of the devices in the field.
2) Keeping the **consistent data model and data message payload format**, such as the payload of MQTT messages sent to the platform, is a challenging issue. Carrier protocols such as Modbus and MQTT do not specify the data semantics. The interaction with numerous devices, even if these support MQTT, may not be trivial and data repackaging may be needed.The takeaway is that it is better to enforce the common information model as soon as possible, closer to the platform edges.
3) **Connectivity and compatibility** issues of in-house devices remain a notable barrier for the scalability and replication of projects such as frESCO, especially when cost is considered. The adoption of the solutions will be challenging if the barrier to entry is not lowered, both in terms of additional price and impact to the existing (implemented) devices.
4) There is a need to hit the correct amount of **trade-off between the end-user device compatibility range and the platform complexity.** Installing and configuring the

devices at the end user sites can be a barrier to entry and equally prohibitive as the technical incompatibility, since this requires qualified teams whose field visits are both expensive and difficult to schedule. A better tailored approach would be to choose a subset of end-user devices and make the configuration automatic for these devices, for example by automatic polling of known Modbus addresses or by using a similar detection approach. In effect the frESCO solution becomes simpler to install and the barrier to entry is lower for the end users.

5) **Uneven development of upstream services** across Europe also represents a challenge for frESCO business models as the services to be offered require adaptation to local situation – at least until these are standardized across Europe.

4 IDENTIFICATION OF RELEVANT STANDARDIZATION ENTITIES, INITIATIVES AND STAKEHOLDERS FOR SMART ENERGY SERVICES IN THE EU

The EU aspirations for achieving a climate neutral as well as a resilient and circular economy cannot be realized without European standards on testing methods, management systems or interoperability solutions. As stated in the 'European Standardization Strategy' [1], Europe's competitiveness, technological sovereignty, ability to reduce dependencies and protection of EU values, including our social and environmental ambitions, will depend on how successful European actors are in standardisation at international level. This mission not only involves strong standardisation skills across industry and academia, but also requires European standardisation to become more agile, flexible, and focused to anticipate the standardisation needs.

Classical standardization processes tend to be notably slow, even with meticulously prepared standardization materials. In numerous cases, several years can elapse between the initial drafting and the eventual delivery of the final standard. As described in Chapter 2, several standards can target the same implementation area such as home automation protocols. This challenge of applying a classical standardization process is particularly relevant in the context of data modelling standards.

At EU level, there are multiple initiatives aimed at accelerating standardization processes and facilitating the development of European standards. These efforts are intended to promote harmonization and consistency across various sectors and domains within the EU.

4.1 CEN and CENELEC standardization initiatives

The 'European Committee for Standardization (CEN)' and the 'European Committee for Electrotechnical Standardization (CENELEC)' aim to support the new 'European Standardization Strategy'. The CEN and CENELEC's National Members work in a decentralized way, via national committees, hence standardization processes are usually channelled by the national members but in some cases, the request comes from the European Commission or from other stakeholders. After the evaluation and approval of a standard proposal, it proceeds to the drafting phase, which involves consensus-building. Upon finalizing the draft standard, it enters a public inquiry open to all interested parties. Following the conclusion of the inquiry, votes and feedback on the standard are assessed, and depending on the outcome, the draft standard is either published or further refined before being formally voted on.

The CEN-CENELEC Innovation Plan identifies specific actions, addressing which are addressing 3 strategic goals:

- Strategic Goal 1: Recognizing contributions from the Research.
- Strategic Goal 2: Fast-track Approach.
- Strategic Goal 3: Recognition and support from Institutions.

Specifically, the Strategic Goal 2 – Fast-track approach enables the development best practice on how to involve research consortia (Horizon 2020, Horizon Europe and national or similarly financed consortia) in standardization. This is particularly important for developing the so-called 'CWAs - CEN Workshop Agreements'. The Fast Track processes aims to transform the CWAs into consensus standards (EN). Essentially, the Fast Track program acknowledges the existing gap between the outcomes of research and innovation initiatives and their impact on standardization. This gap arises from the complexity involved in formulating standardization proposals and the comparatively lengthy standardization processes. The program's role, among other functions, is to enable project contributors to serve as intermediaries with the standardization body, thereby shortening the timeline for developing a globally accessible agreement, known as a CWA (CENELEC Workshop Agreement), to just six to twelve months. The Fast Track to Standardization workshops are accessible to research participants, and the opportunity for providing feedback on the proposed CWAs is available. During the production of a CWA, the interested party initiates contact with the CEN-CENELEC Management Centre. The entity proposing the workshop then formulates the proposal and subsequently submits the workshop proposal form to the relevant CEN-CENELEC technical committees. CWAs represent expedited documents that can be created within a short timeframe, and they can serve as an initial phase towards the eventual development of a European or International Standard.

4.2 Horizon Standardization Booster

The Open Calls on HSbooster.eu [21] offer a chance for active or completed projects under H2020, Horizon Europe, and Digital Europe to seek practical assistance in evaluating the readiness of their project outcomes for standardization. It is also possible to connect with standardization experts who will offer guidance on how those outcomes can be integrated into standardization working groups or technical committees. This represents the Commission's initiative to extend expert assistance to European projects, by assisting consortium members to enhance and capitalize the developed outcomes. The HSbooster.eu is in practice an open (opened until June 2024), and after completing the application it provides a three-month consultation period with experts. The applicants can access tailored expert services, with the expert's role being to offer guidance and steer the project's results toward the most appropriate standardization pathway. During the application process, the projects results are emphasized, whilst the application is conducted by a project partner. This approach is designed to sustain standardization efforts even after the project's conclusion.

The eligibility, that is related to a company and not to the project consortium, has some main challenges that standardization could solve and unlock possible barriers. These are primarily focused in two categories: data modelling including semantic interoperability and cost-effective and easy to install technological solutions capable of integration with legacy solutions in the field.

4.3 Smart Built 4 EU Initiative

As an example of a stakeholder engagement, the ‘Smart Building Innovation Community’ or the ‘SmartBuilt4EU’, funded by ‘Horizon 2020’ program, with the aim to support smart buildings and facilitate exchange of information, launched four task forces aimed in promoting innovation in smart building technology:

- Task Force 1: User Engagement, focusing on aspects such as end-user awareness, acceptance, and feedback.
- Task Force 2: Optimal Building Operation, addressing issues related to interoperability, cost efficiency, and resource optimization.

- Task Force 3: External Environment Interaction, outlining the prerequisites for smart buildings to engage with the external environment.
- Task Force 4: Cross-Cutting Concerns, encompassing topics like data management, security, business development, financial implications, education, and more.

The ‘SmartBuilt4EU’ develops communicational material to promote and disseminate material (project brochures, success stories), and to investigate the key issues and trends related to smart buildings by identify barriers, challenges and opportunities to support their take up. KONČAR experts have actively participated in ‘SmartBuilt4EU’ workshops and contributed to the development of ‘SmartBuilt4EU’ deliverables with lessons learned from frESCO.

5 MAPPING THE BENEFITS OF FRESCO OUTCOMES

5.1 Policy and Standardization – Synchronization of Efforts

The forthcoming discussion is strictly related to the comprehensive analysis laid out in Deliverable D7.4 "Roadmap for the replication of frESCO developments". The central focus of this section is on strategically aligning policymaking and standardization efforts to dismantle barriers and foster the seamless expansion of frESCO solutions across the EU.

Firstly, it's worth mentioning some of the main enablers from a regulatory point of view by means of some examples:

- Spain's regulatory landscape, as exemplified by RD 244/2019, stands out as a beacon, promoting self-consumption and creating a conducive environment.
- The progressive legalization of local energy communities in Portugal paves the way for flexibility aggregation.
- Belgium's subsidies actively encourage the aggregation of renewable energy sources.
- Croatian legislative framework changes in 2021 and 2022 have opened the way for the citizen energy communities and renewable energy communities that target local energy sharing and self-consumption, with the first ones being in the process of fully establishment. It is also expected that net metering scheme that accounts for the monthly consumption will end during 2024, which will further incentivize the establishment of these types of local communities.

However, the efforts for alignment of regulations must focus on the need to dismantle the obstacles to the replication of these innovative technologies. Therefore, the suggested actions to dismantle the main barriers for frESCO replication are described below.

Equalization of flexibility market markets

Closed flexibility markets in several EU countries have posed a substantial challenge for demand response. Current EU directives emphasize the role of having independent demand response aggregators. Proposed amendments to existing directives aim to ensure equal conditions for demand-side resources, mitigating challenges posed by closed flexibility markets and fostering a level playing field.

Streamlining Real-time Metering Access

Despite the widespread smart metering implementation rollout, persistent obstacles hinder accessing real-time metering data. Existing EU directives stress the importance of real-time data sharing. Metering service operators are obliged to provide the users access to the raw metering data. A proposed standardized protocol for real-time metering data accessibility aims to streamline data access, enhancing energy service efficiency and facilitating more accurate demand response mechanisms.

Filling the PMV standardization gap and addressing interoperability issues

The absence of clear European or national standards for PMV commercialization complicates the regulatory landscape. Moreover, the lack of standardization and interoperability among data-driven smart devices hinders the deployment of PMV. Advocating for the adoption of the frESCO protocol as a benchmark for a hybrid PMV methodology, introducing consistency and clarity. Proposing ongoing updates to frESCO solutions to adapt to emerging standards, ensures flexibility and adaptability to the market.

Harmonizing Regulatory Frameworks

Discrepancies in regulatory frameworks across EU nations result in varying levels of competition. Lobbying for regulatory changes within Europe for a common market environment creation, fosters fair competition and innovation. The advocate for a comprehensive harmonization strategy includes regulatory amendments to create a cohesive market environment, ensuring a level regulatory playing field for frESCO solutions.

5.2 Upgrade paths to frESCO solutions – Adaptation to new standards

Over the course of frESCO development some of standards and standard proposals, especially at higher levels of abstraction, have started to appear and changed the general standards landscape quite significantly. Within the project, as described in pilot experiences, one of key takeaways is that the data information model should be enforced diligently and as close to the system edges as possible. Both the experiences of the project itself and the developments that have happened in parallel, suggest the directions of the adaptation of the frESCO platform as well as indicate the solutions to the challenges being faced.

Several frESCO project partners participated also in the SYNERGY project [22], which is a 'Horizon 2020' project in the 'DT-ICT Digital Transformation' family of calls. The SYNERGY project delivers an end-to-end reference big data platform to coordinate the electricity stakeholders both in terms of business interactions and data exchange. Effectively, the SYNERGY project aims towards providing an architectural backbone that leverages data to unleash collaboration between currently fragmented electricity actors. This project, primarily oriented in the ICT vertical, is more focused on the data backbone itself. It has been extensively involved in the 'BRIDGE' and 'Big Data Value Association' initiatives, and one of key advantages of the project approach has been the extensive and diligent use of internal data model, as well as its maintenance procedures. Not only has the model been established, but also the provisioning for model maintenance and updates have been specified in the project. Another finding of the SYNERGY project highly relevant to frESCO is that the proper management of meta data (information about the data) is also vitally important for a big data exchange platform. In that regard, frESCO requires further development to be scaled upwards.

The 'InterConnect' project [23], a large 'Horizon 2020' project, funded within the DT sequence of 'Horizon 2020' calls as well, has had several large-scale test sites and has developed the Semantic Interoperability Framework (SIF), utilized across all the pilots. The SIF aims toward cross-domain semantic interoperability without a centrally hosted facilitator. This project has pioneered cross-domain semantic interoperability, primarily leveraging the work previously developed within the SAREF context. In a way, the 'InterConnect' project findings reinforce our findings from the pilot sites: ensuring and managing the last meter in the connectivity, right to the user devices, is probably the most challenging part of any flexibility infrastructure.

The importance of semantic interoperability is also one of key deliveries of the 'OneNet' project [24]. Although this project primarily targets the system operators and not the end-users, it acts as a complement and counterpart to the services that have been developed and demonstrated in frESCO. This project aims to develop a customer-centric approach to grid operation and once again, one of key takeaways of that project is the architecture and data interfacing that allows the whole European electrical system to operate as a single market, opening the participation to stakeholders regardless of their location.

These and several other projects have been extensively involved in working with the ‘BRIDGE’ initiative. In July 2023, the ‘BRIDGE’ has released the ‘European Energy Data Exchange Reference Architecture (DERA)’ version 3.0 [25]. This document summarizes very well the state of the art of data interoperability and synthesizes the concrete steps to be taken, as of 2023. The ‘DERA’ raises the issues raised by numerous projects to a level above and aims at contributing to the discussion and to the practical implementation of business process agnostic data exchange arrangements, at European scale. The proposed implementation should leverage years of effort in ‘Smart Grid Architecture Modelling (SGAM)’ complementing it with data governance requirements, and especially from the end-user perspective. For its implementation, it calls for continued harmonization of national regulations across Europe and coordination and cooperation between the different initiatives, as well as leveraging the ‘BRIDGE’ use case repository. Harmonisation should move beyond the simple data collection into functional data processes, calling for common vocabulary and federated catalogues be established.

In line with the developments of the projects mentioned above, the critical finding is that a common reference semantic data model and a data format agnostic approach to cross-sector data exchange is needed. This will be implemented in business process agnostic data platforms – similar to uncoupling of data format (e.g., CSV, JSON, or similar), of the data semantics (e.g. energy, power, ambient measurements), so that the data platform be capable of uncoupling itself from the business processes. In a longer-term perspective, a data exchange platform for whole Europe is envisioned as well.

The findings above outline quite well what the conclusions and recommendations for the frESCO project deliveries should be after the project ends: it should closely follow the developments both in upstream and downstream as well as by aligning and taking advantage of these as quickly as possible.

6 CONCLUSIONS AND RECOMMENDATIONS

As indicated in the previous chapter and by revisiting the lessons learned from all the pilot sites, for frESCO solutions to remain sustainable and following the development of data exchange reference, architectures formation is crucial. This is true in upstream terms, i.e., from the frESCO developments towards system and market operators, and in downstream terms, from the frESCO solutions towards the equipment and end users. As the operators establish customer-facing standards-compliant semantically consistent interfaces, there will be no alternative to being compatible with these standards and semantics. Otherwise, the frESCO solutions won't be able to provision any services facing these institutions.

Analogously, as the downstream facing standards evolve, frESCO solutions should be able to collect the data by being compliant with these newly established and proliferated standards. This might also result in delegating a share of challenging data collection to the processes established elsewhere and thus making the frESCO solutions much more attractive with significantly lowered onboarding costs.

The data collection process can then become a shared, commonly utilized part of the energy infrastructure, exactly as the European Commission initiatives call for. Then not every project has to carry the burden of rolling out its own infrastructure – it can reuse the common infrastructure. Once that happens, the frESCO solutions would profit directly by reducing or even removing the onboarding cost for the end users.

As the DSOs and metering service operators are obliged to expose the raw collected data, this will certainly be the case in the medium term. In shorter term, the challenge of data collection affecting all frESCO solutions and visible in all the frESCO pilots should be tackled directly. To reach viability on a larger scale, the end-user's onboarding total cost, in terms of equipment, required qualifications, and regulatory compatibility should be as low as possible. Otherwise, the barrier to entry is too high; the most indicative example is the case when qualified technicians are needed to install the metering equipment which is hardly scalable, both in terms of cost and time. Reducing the onboarding cost can be achieved by partnering with a technology provider that solves the data collection layer problems with cost-effective solutions. These solutions should be established in a particular market, and targeted selection and development of the easy to deploy and cost-effective devices for a particular market is also an option.

To conclude, the standardization-related contributions from frESCO, especially the ones coming from the pilot site experiences, reinforce quite directly the findings of the projects mentioned in the previous chapter as well as the findings of the ‘BRIDGE’ initiative from in the ‘DERA’ document. The principal implementation challenges relate to the legacy devices in the field. These devices mostly use very simple protocols so the devices can’t be interrogated to provide response which data is available. The protocol users must rely on vendor documentation, which may not be easily available. In many cases, standard protocol compliant interfaces are not enabled in default configurations or require the purchase of additional hardware devices. This requires additional on-site work and site-specific engineering to successfully connect. This is not scalable.

A challenge further upstream is to maintain a consistent data format and data semantic. This is required to hit a correct trade-off between the end-user device compatibility and overall setup complexity. Given the above situation, a pragmatic approach to ensure viability in short term would require targeted efforts for national or even regional markets. An alternative approach is partnering with local technological partners that could alleviate the onboarding costs and embed the end user onboarding into their user-facing business models.

In upstream direction, the efforts to unify the customer-facing interfaces to market and system operators would be of great value to frESCO. Conversely, the recommendations retrieved from the standardization environment to be implemented in frESCO are a direct counterpart of the above. The frESCO solutions can only maintain their viability by keeping their compatibility with the established and emerging standards, both in upstream and downstream directions. To ensure viability, the development should focus on removing the barriers to entry, in the short term initially with a stratified approach that will work around the current implementation obstacles, and in the medium term, making the solutions compatible with the emerging standards and syndicated data infrastructure is a prerequisite for the solution longevity.

7 REFERENCES

[1] European Comission, ‘An EU Strategy on Standardisation: Setting global standards in support of a resilient, green and digital EU single market’. European Comission, Feb. 2022. Accessed: Oct. 08, 2023. [Online]. Available: https://ec.europa.eu/docsroom/documents/48598

[2] ‘CEN - EN 16836-2 - Communication systems for meters - Wireless mesh networking for meter data exchange - Part 2: Networking layer and stack specification | GlobalSpec’. Accessed: Oct. 09, 2023. [Online]. Available: https://standards.globalspec.com/std/10058688/en-16836-2

[3] ‘KNX - MyKNX’. Accessed: Oct. 09, 2023. [Online]. Available: https://my.knx.org/en/shop/knx-specifications

[4] ‘CENELEC - EN 50631-1 - Household appliances network and grid connectivity - Part 1: General Requirements, Generic Data Modelling and Neutral Messages | GlobalSpec’. Accessed: Oct. 09, 2023. [Online]. Available: https://standards.globalspec.com/std/10263408/EN%2050631-1

[5] European Commission. Directorate General for Communications Networks, Content and Technology., Toegepast natuurwetenschappelijk onderzoek., DNV GL., and ESMIG., *Study on ensuring interoperability for enabling Demand Side Flexibility.* LU: Publications Office, 2018. Accessed: Oct. 10, 2023. [Online]. Available: https://data.europa.eu/doi/10.2759/26799

[6] ‘Modbus Specifications and Implementation Guides’. Accessed: Oct. 10, 2023. [Online]. Available: https://www.modbus.org/specs.php

[7] ‘About EN 50491-11:2015 - General requirements for home and building electronic systems (HBES) and building automation and control systems (BACS) - Part 11: Smart Metering - Application Specifications - Simple external consumer display- | Joinup’. Accessed: Oct. 10, 2023. [Online]. Available: https://joinup.ec.europa.eu/collection/ict-standards-procurement/solution/en-50491-112015-general-requirements-home-and-building-electronic-systems-hbes-and-building/about

[8] ‘IEC TR 62746-2:2015 | IEC Webstore’. Accessed: Oct. 10, 2023. [Online]. Available: https://webstore.iec.ch/publication/22279

[9] ‘OpenADR Alliance Releases 2.0b Profile Specification’. Accessed: Jun. 13, 2022. [Online]. Available: https://www.openadr.org/index.php?option=com_content&view=article&id=84

[10] H. Keko, K. Tzanidakis, C. Malavazos, P. Hasse, and A. Wolf, ‘Analysis of EU-wide Interoperability Standards and Data Models and Harmonization Requirements’. FLEXCOOP - Grant Agreement No. 773909, 2017. [Online]. Available: http://www.flexcoop.eu/deliverables-and-resources

[11] L. Luttenberger Marić, H. Keko, and S. Sučić, ‘Semantic alignment in monitoring and verification of energy savings achieved by demand response flexibility programs’, *45th Jubil. Int. Conv. Inf. Commun. Electron. Technol. MIPRO*, pp. 55–59, 2022, doi: 10.23919/MIPRO55190.2022.9803329.

[12] ‘Energy@home - Home’. Accessed: Jul. 31, 2022. [Online]. Available: http://www.energy-home.it/SitePages/Home.aspx

[13] ‘SAREF Portal’. Accessed: Jun. 15, 2022. [Online]. Available: https://saref.etsi.org/

[14] ‘SAREF extension for building’. Accessed: May 17, 2022. [Online]. Available: https://saref.etsi.org/saref4bldg/v1.1.2/

[15] ‘EEBUS | Make the world speak energy - EEBus Initiative e.V.’ Accessed: Jul. 31, 2022. [Online]. Available: https://www.eebus.org/

[16] D. Tanguay, ‘International Performance Measurement and Verification Protocol (IPMVP)’, Efficiency Valuation Organization (EVO). Accessed: Jun. 12, 2022. [Online]. Available: https://evo-world.org/en/products-services-mainmenu-en/protocols/ipmvp

[17] M. Agenis-Nevers, Y. Wang, M. Dugachard, R. Salvazet, G. Becker, and D. Chenu, ‘Measurement and Verification for multiple buildings: An innovative baseline model selection framework applied to real energy performance contracts’, *Energy Build.*, vol. 249, p. 111183, Oct. 2021, doi: 10.1016/j.enbuild.2021.111183.

[18] M. L. Goldberg and C. Goldman, ‘Measurement and Verification for Demand Response’, Electricity Markets and Policy Group, Energy Analysis and Environmental Impacts Division, 2013. [Online]. Available: https://eta-publications.lbl.gov/sites/default/files/napdr-measurement-and-verification.pdf

[19] ‘IEC 60870-5-104:2006 | IEC Webstore’. Accessed: Nov. 10, 2023. [Online]. Available: https://webstore.iec.ch/publication/3746&preview=1

[20] ‘SunSpec Modbus Specifications - SunSpec Alliance’. Accessed: Oct. 20, 2023. [Online]. Available: https://sunspec.org/sunspec-modbus-specifications/

[21] ‘HSBooster.eu’. Accessed: Nov. 10, 2023. [Online]. Available: https://hsbooster.eu/

[22] ‘About’, Synergyh2020. Accessed: Nov. 20, 2023. [Online]. Available: https://synergyh2020.eu/about/

[23] ‘About - Interconnect Project’, Interconnect. Accessed: Nov. 20, 2023. [Online]. Available: https://interconnectproject.eu/about/

[24] ‘The Project’, OneNet Project. Accessed: Nov. 20, 2023. [Online]. Available: https://onenet-project.eu/the-project/

[25] Directorate-General for Energy (European Commission), M. J. Couto, K. Kotsalos, and K. Kukk, *European (energy) data exchange reference architecture 3.0*. LU: Publications Office of the European Union, 2023. Accessed: Oct. 20, 2023. [Online]. Available: https://data.europa.eu/doi/10.2833/815043