Outsourcing Electric Vehicle Smart Charging on the Web of Data

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***Abstract*—This paper describes the results of a joint work between partners in ITEA2 12004 Smart Energy Aware Systems (SEAS) project, which aims at developing an ecosystem of distributed services that target energy efficiency. This paper particularly focuses on Electric Vehicle (EV) need for smart charging, which is made possible with Internet-of-Things (IoT) capabilities and smart grid deployment. A use case is proposed by Compagnie Nationale du Rhône (CNR) to tackle the emerging need for electric mobility. In this CNR scenario, a new player, named Smart Charging Provider (SCP), exposes a charge plan optimization algorithm on the Web. This service can be used by any Charging Station Operator (CSO) over the world in order to optimize their charge plans. These optimizations are computed with respect to economical or environmental criteria, while ensuring the satisfaction of constraints expressed by EV Drivers and CSOs. Apart from describing the actual implementation and deployment of this service as a RESTful Web service, this paper also overviews three of the main contributions of SEAS project that were used together to achieve this goal: (1) SEAS Reference Architecture Model, designed to enable real-time interconnection of any energy actors; (2) SEAS ontology, used throughout SEAS ecosystem to quantify systems and their interconnections; (3) SPARQL-Generate language and protocol, implemented to ensure semantic and syntactic interoperability at low cost in SEAS ecosystem.**

Keywords–Smart Charging; Electric Vehicle; Distributed Architecture; Web of Data; Ontologies

I. INTRODUCTION

Lately, the number of Electric Vehicle (EV) has been constantly increasing and it is expected to grow even more in the coming years. However, [1] estimated that EV charging may have a significant impact on electricity peak demand, at the level of giga watts, and at specific time and location. Indeed, EVs are charged at a constant amount of power as soon as they are plugged in. Hence according to [1], 90% of the charging is going to take place in the late mornings when drivers arrive at their office, or in the evenings when drivers come back home. This constant charging will therefore occur during already existing electricity demand peaks, leading to important fluctuations in energy consumption. Such situation will cause tremendous undesired effects for the distribution grid – power peaks, voltage drops, expensive generation and grid reinforcements, finally ending up with increased electricity costs.

However, in most cases, these EVs stay parked for several hours. Therefore, it would be possible to coordinate the charging during such period. This concept is known as smart charging. [2] defines smart charging as follows:

> Smart charging of an EV is when the charging cycle can be altered by external events, allowing for adaptive charging habits, providing the EV with the ability to integrate into the whole power system in a grid and user-friendly way.

Smart charging targets the following benefits for:

- Customers: it might reduce their electricity costs;
- DSOs (i.e., Distribution System Operators): it could assist grid management with control signals;
- The society: it could avoid grid and generation investments;
- The environment: it may facilitate integration of renewable energies (e.g. self-consumption of electricity with solar power and electric vehicles);
- Service providers and retailers: it would give them opportunity to provide customers with innovative products and services.

In a broaden perspective, these benefits are also targeted by ITEA2 SEAS project, which aims at designing a global ecosystem to help manage and optimize energy consumption, production and storage. This will be made possible by providing innovative services designed for various energy stakeholders and energy-aware systems. Apart from smart charging services, SEAS ecosystem includes a large spectrum of services, as depicted in Figure 1, which all contribute to better manage energy availability and needs.

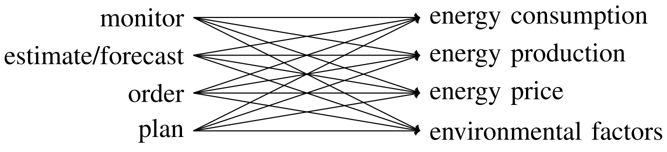

Figure 1. General services envisioned in SEAS ecosystem

The rest of this paper is structured as follows. Section II describes a Compagnie National du Rhône (CNR) Use Case (UC) that involves the concept of smart charging. The paper then focuses in Section III on CNR algorithm used to provide a smart charging service. Then, an overview of three of the main contributions of SEAS project follows: a SEAS ecosystem architecture (Section IV); an energy domain based ontology (Section V); and SPARQL-Generate protocol that drastically lowers the costs for SEAS partners to become semantically interoperable (Section VI). These contributions were used together to design an implementation of CNR smart charging service, whose deployment within SEAS ecosystem is described in Section VII. Finally, Section VIII concludes and presents how this work can be generalized in SEAS project.

II. CNR SMART CHARGING SCENARIO

This section describes the first contribution of this paper: the definition of an innovative UC for smart charging. It overviews the architectural, representational and interoperability needs arising from this UC, which are then answered in the following sections of this paper.

A. *Roles Description*

A charging station is an equipment comprised of one or several *Electric Vehicle Service Equipment* (EVSE). Each EVSE has a meter (m) to monitor any charging process and is connected to an electric junction via a metering place. This CNR UC targets private charging stations, which may be owned and used by : 1) households, to charge ones vehicle at home; 2) companies, to charge cars from corporate fleet at a workplace. Figure 2 illustrates this CNR Smart Charging UC.

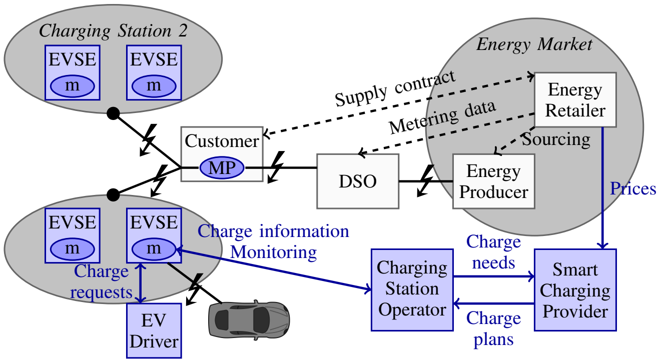

Figure 2. Illustration of CNR Smart Charging UC

Let us overview the main players of this scenario. The charging station is owned by a *Customer*, who pays electricity supply for the area to its *Energy Retailer* based on a Metering Point (MP) usually operated by a *DSO*. The charging station is used by *EV Drivers* – either a resident of an household or an employee of a given company – who plug their vehicles to an available EVSE. A charging station is controlled by a *Charging Station Operator* (CSO), which is responsible for monitoring and applying charge plans (which include switching on and off EVSE, but also charging with a limited power). The *CSO* entrusts a new actor, the *Smart Charging Provider* (SCP), with the establishment of an optimal charge plan for each EV based on information provided. The SCP may request additional information – e.g. Electricity Tariff – from other actors – e.g. an *Energy Retailer* – in order to define such charge plans.

B. *Interactions of the smart charging process*

In Figure 2, the power distribution is represented by a black line with a lightning bolt. Communications specific to this UC are represented by blue arrows, whereas other communications are represented by dashed arrows.

An EV Driver is authorized to use a charging station connected to the grid, and managed by a given CSO. When this EV Driver plugs its EV to an available EVSE, it first has to communicate with the CSO. The communication is made available either directly – via its smartphone or a web application – or through the charging station, in order for the EV Driver to specify the charging requirements : energy needs (related to battery situation) and preferences (in a given maximum charging time). This can boil down to the estimated departure time, but it may also include other information such as the price he is willing to pay, or whether he wants to consume only local green energy production.

The CSO takes these pieces of information into account along with several other parameters such as power constraints (limitation of maximum instantaneous power at the delivery point, energy requested by other EV Drivers connected to the same area) and asks the SCP for an optimized charge plan.

SCP combines the received information with other data such as prices information (e.g. dynamic hourly price of energy) and control signals (e.g. maximum power demand). It then runs optimization algorithms to settle the EV charge plan, which is a series of consecutive blocks of maximal power value (Pmax) for defined time periods.

The CSO, receiving the resulting charge plan from SCP, applies this plan and monitors the charging station in accordance. The EV controls the actual power delivered by the charging station to the battery, which should be lower than the Pmax defined by the charge plan – according to the mode 3 charging process (international standard IEC 61851 and IEC 62196).

At any time, an EV Driver can change its charging needs. For instance, he might request an immediate battery charging, if he actually need its battery fully charged in a short amount of time. Therefore, the charge plan may be re-optimized by the SCP on CSO requests and at any time during the charging process – especially if new EV charging events occurs (plug/unplug), or if an EV Driver modify its requirements but also and above all, if a modification of available power is notified.

Concretely, some incentives can be used to make EV Drivers accept the smart charging service: they can be economical (the charging will be cheaper), or environmental (the charging will save CO_2 emissions).

C. *Decoupling Roles in the UC*

Actually, CNR *virtually* already implements this UC for its charging stations. We use the term *virtually*, because CNR currently plays all the roles within this UC. Indeed, CNR is:

- The customer: CNR owns several charging stations located at its head office in Lyon (France) and at different energy production sites along the Rhône river. These charging stations are used by employees to charge CNR's EV fleet.

- The energy supplier: charging stations consume electricity supplied by CNR. Even if the electricity is delivered by the grid, CNR is the electricity supplier for each metering point, and has to balance supply with its renewable production.
- The CSO: charging stations are controlled remotely from the CNR's head office.
- The SCP: CNR uses its own Energy Management System that embeds optimization algorithms in order to provide optimized charge plans.

In order for any customer to use this smart charging service, it has been necessary to decouple each role. It has been a complex task and the methodology used was to progressively externalize roles from the original implementation by answering questions such as:

- How would it work if the EV user was not an employee of the CNR ?
- How would it work if the charging station was located in Turkey ?

As a consequence, any actor should be able to play any of the aforementioned roles. Yet, this modularity is not direct. Nevertheless, all of the information needed to run CNR's charge plan optimization algorithm is produced, modeled, exchanged, and processed internally in CNR Information System. Hence, any change of actor who plays a given role in the UC would require important integration efforts, which means important conception and development costs.

Sections IV to VI hence overview work that target seamless interoperability between actors, at the lowest possible cost. First, let us describe the charge plan optimization algorithm.

III. THE CHARGE PLAN OPTIMIZATION ALGORITHM

It is incontestable that smartgrid and energy management would benefit from smart charging. [1] conducted a survey on the effects of e-mobility in autumn 2014, which also lists all its potential and benefits. In addition, the literature includes many studies related to the problem of coordinated EV charging and discharging in a smart grid, to cite but a few, [3]–[8]. The various optimization approaches presented in these papers are based on either single or multi-objective optimization, according to solely current information, or including forecast-based solutions.

CNR is an hydroelectricity producer which has developed an electricity mixed renewable production (wind power, solar power, small hydro-power). CNR has therefore become an expert in managing an intermittent energy, by forecasting, optimizing, marketing and supervising production. CNR uses its own algorithm in order to optimize EV consumption according to several strategies. The smart charging strategy tested in CNR UC is based on forecast and day-ahead electricity prices, the available power at the metering point, the real-time connection of the vehicles at the charging station and the EV Driver requirements.

The goal of this optimization approach is to minimize the charging cost without negotiating the charging needs, as the customer satisfaction and the reliability of the charging service have higher priority than the system operating cost. It then integrates static and dynamic information related to:

- EV Drivers: their charging needs (maximum delay for charging completion);
- EV: minimal and maximal charging power, and battery State of Charge (SoC);
- Charging station: minimal and maximal charging power;
- Consumption place: network access tariff and load curve;
- Electricity contract with the Energy Retailer based on time-varying prices (e.g. spot prices);
- Forecast and day-ahead electricity prices.

Note that the aim in this paper is not to review the existing optimization algorithms, neither is to compare the CNR algorithm to the existing algorithms. Instead, we are interested in describing a methodology to make such an algorithm available, a) in a real deployment, b) at low cost, and c) to any actual CSO (via the Web). The result is the deployment of CNR SCP that runs a charge plan optimization algorithm. Any node on the Internet requiring a charge plan can contact this SCP for any types of EVs and EVSEs.

IV. ARCHITECTURE

One important task for SEAS project was to define an architecture to enable real-time interconnection of any energy actors. This interconnection will then help actors offer energy dedicated services to SEAS entities. Therefore, this architecture should meet some general requirements such as: a) being scalable, adaptable and dynamic; b) offering plug-and-play solutions (having as less manual configuration as possible); and c) providing secure communications and privacy of information.

Different UCs have been defined to demonstrate SEAS benefits on different domains (EV, House, Building, Microgrid, etc.). All these UCs have then been used to define functions and communication requirements that such an architecture should address. Several architectures exist such as [9] but none of them address all SEAS project requirements. That is the reason why SEAS partners define their own architecture, named *SEAS-Reference Architecture Model (S-RAM)*.

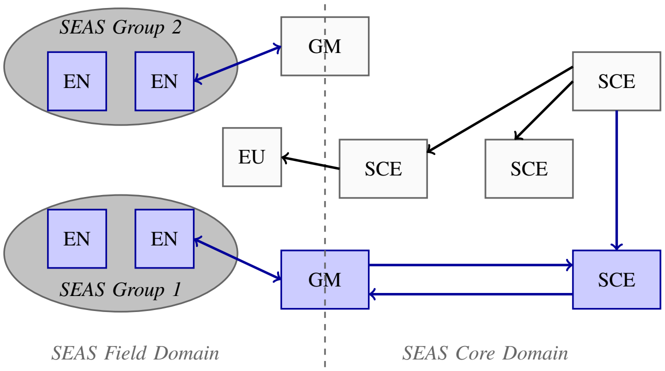

Figure 3. Illustration of SEAS Reference Architecture Model

Figure 3 is an illustration of S-RAM for CNR Smart Charging UC as presented in Section II. As depicted in Figure 3, S-RAM is divided in two domains, Field Domain (SFD) and Core Domain (SCD). Entities within SFD monitor and/or help control local load and generation. For instance, in CNR scenario, both EVSE's meter – called End Node (EN) in S-RAM — and Customer — called End User (EU) — help CSO monitor and control any charging process. In addition, SFD could be divided in SEAS Groups (SGs) in order to facilitate energy management and optimization. Each group is therefore managed or operated by a Group Manager (GM). This manager – the CSO in CNR UC – is aggregating data coming from all entities willing to participate in the group energy management. GMs might analyze data collected in the field in order to make a decision to better manage the energy of their SGs. GMs being at the edge between SCD and SFD, their decisions can also be taken considering information (informative or control) coming from outside the group. Indeed, SEAS Core Entities (SCE) within SCD might both send energy demands to SGs and/or provide information or services to help SGs in their energy management — for instance, SCP in CNR smart charging scenario. With this architecture, any node in SFD or any SG, via its GM, can participate in a Demand- Response (DR) system and so, help have better global energy consumption plan.

As any communication architecture, S-RAM requires to be secured so that information is not shared with untrustworthy entities. S-RAM relies on its security service that helps authenticate all entities participating in this architecture. Moreover, Internet Protocol (IP) is widely present in current objects deployed for energy related topics. And as it is assumed that it will be even more present in the future, SCD relies on IP and secured web protocols such as HTTPS. S-RAM SCD can therefore be seen as an overlay of IP/HTTPS.

The SEAS project being an European project, it has several partners and is not dedicated to only one domain of energy management. Instead, it focuses on any energy management domain. Data representation is therefore crucial. In fact, it is important that all these potential actors can understand each other and use common services without having to configure each possible case manually. Furthermore, the structure of energy networks is changing, and the current structure may not be the reference in coming years. This has to be taken into consideration in smart grid development, and, as mentioned previously, the SEAS project wants its architecture to be dynamic and adaptable, and so, auto-configurable. Therefore, S-RAM requires to rely on data standard providing a) links and relationships; b) abstraction in demands; and c) a common language. That is the reason why the Resource Description Framework (RDF) [10] formalism has been chosen as an abstract data model in S-RAM.

Within S-RAM, a charging station is a SG operated by a CSO. As mentioned previously, CNR smart charging service relies upon an algorithm that defines the charge plan based on information provided by the CSO and the Energy Retailer. CNR SCP is an SCE providing a smart charging service. S-RAM choices – especially with the usage of a common language based on ontologies – help any SEAS Entities discover, understand and have access to this service.

V. ONTOLOGIES

This section overviews one of the ontologies that has been developed in SEAS project, namely the SEAS ontology [11]. This ontology is used throughout SEAS ecosystem to ensure inter-operability. But first, let us recall some basics about Knowledge Representation and Semantic Web.

A. *Overview of the Semantic Web Stack*

In the domain of Smart Grids, a huge amount of knowledge is available and produced in heterogeneous and distributed manner. Knowledge Engineering and Semantic Web actually aim at answering generic needs that arise from the production of such knowledge. One wants to represent, manipulate, exchange, query, reason with, update, and validate the knowledge.

The Wold Wide Web Consortium (W3C) standardized a full stack of standards for Semantic Web on top of Unicode and Universal Resource Identifiers (URIs) standards. The first step towards inter-operationalization of data is to unambiguously name things with an URI. The second step uses RDF in order to describe anything in terms of a set of triples (*subject*, *predicate*, *object*). RDF is therefore an abstract data model (a directed acyclic graph), and has multiple concrete syntaxes such as RDF/XML [12], Turtle [13] or JSON-LD [14]. For instance, the Turtle snippet from Figure 4 serializes an RDF Graph with exactly five triples. This example describes the geolocation of a charging station.

```
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix geo: <http://www.w3.org/2003/01/geo/wgs84_pos#> .
@prefix seas: <http://purl.org/NET/seas#> .
@base <http://data.mycsocompany.org/rest/> .

<cs/10001> a seas:ChargingStation ;
 rdfs:comment "CSO Charging Station with id 10001."@en ;
 geo:location [ geo:lat 45.763084 ; geo:long 5.692196 ] ;
```

Figure 4. Turtle example describing the geolocation of a charging station.

There are multiple RDF *vocabularies* on the Web that can be used, each defining its own set of URIs. For instance, `geo:location` is a prefixed URI, whose expanded form is `http://www.w3.org/2003/01/geo/wgs84_pos#location`. URIs `geo:location`, `geo:lat`, `geo:long` are defined within the W3C Basic Geo (WGS84 lat/long) Vocabulary. Then, `<cs/10001>` is a relative URI, that needs to be resolved against some base URIs, which in this case is `http://data.mycsocompany.org/rest/`. These URIs are not chosen randomly. Indeed, except for the dummy CSO company website and the SAREF ontology, all URIs mentioned in this paper actually leads to some document. Moreover, The Linked Data principle defines four simple principles to publish RDF knowledge on the Web [15]: (1) Use URIs as names for things; (2) Use HTTP URIs so that people can look up those names; (3) When someone looks up for an URI, provide useful information, using the standards (RDF, SPARQL); and (4) Include links to other URIs, so that they can discover more things.

For reasoning with RDF, one must choose some formal semantics, and build inference engines (or reasoners) to understand such axioms and infer new knowledge (or reason) with RDF graphs. Among other, [16] define semantics for RDF and RDFS. [17] grounds the Web Ontology Language (OWL) constructors (e.g., **allValuesFrom**) and axioms (e.g., **subClassOf**) on the First Order Logics (FOL). In this way, RDF enables to represent knowledge about things that are identified by URIs, and ontologies enable to capture the semantics of this knowledge and to reason. For example, using OWL 2 direct semantics, the RDF Graph and the logical formula below are equivalent.

```
saref:Currency owl:oneOf ( om:euro om:United_States_dollar
    om:pound_sterling );
```

$$(\forall x)[\text{Currency}(x) \Rightarrow (x = \text{EUR}) \vee (x = \text{USD}) \vee (x = \text{GBP})]$$

This example illustrates a clear design issue in the current SAREF ontology. It also illustrates that extra care has to be taken when reusing existing ontologies.

B. The SEAS Ontology

Another important task in SEAS project was therefore to design ontologies to represent and reason with knowledge related to energy domain. We followed a three-step knowledge engineering methodology [18]: (1) agree on a conceptualization of the domain; (2) develop the ontology for the domain, formally grounded on an appropriate knowledge representation formalism; (3) operationalize it for the domain.

The first step has been achieved by organizing interviews between knowledge engineering researchers and energy domain experts during a dedicated workshop [19]. It helped us unveil the importance of representing knowledge such as time series, aggregated values, and quantity integration and derivations for the energy domain. Yet, there exists no ontology on the Web to represent this knowledge. Furthermore, the FOL formalism behind OWL is not appropriate to reason with time series and sums.

The result of the second step is an extension of the joint W3C-OGC Semantic Sensor Network (SSN) ontology [20]. This exension enables to describe processes such as sensing, actuating, forecasting, planning. All of these processes take as input and output estimations of qualities of a) concepts *systems*; b) *connections* between these systems; and c) *connection points* of a system where connections may occur. Inputs and outputs are described using the W3C Data Cube ontology [21].

Figure 5 illustrates the core of the SEAS ontology:

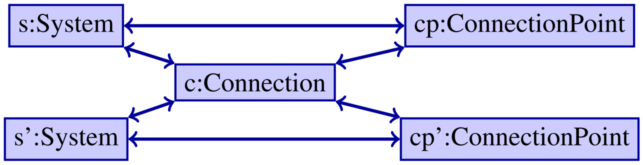

Figure 5. The core of the SEAS Ontology

The SEAS ontology also contains a module that defines classical qualities for systems, connections and connection points in the energy domain, as illustrated in Figure 6.

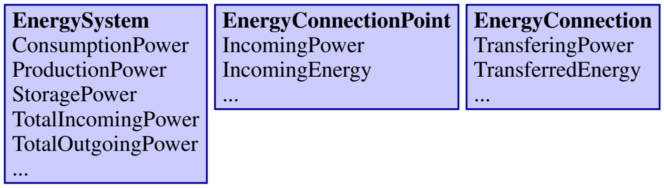

Figure 6. Extract of qualities defined for SEAS feature of interest.

This module is automatically generated from a JSON configuration file retrieved from SEAS GitHub repository [22]. And every expert in the SEAS project can contribute to this file. The SEAS ontology can also be reused for any other domain (e.g., water or waste management), provided that a new JSON configuration file is written for that domain. Among other, the SEAS ontology enables to describe time series, aggregations of quantities, derivations and integration of quantities.

As a result, this ontology is used to model the input and output of CNR SCP service: EVs and EVSEs are connected energy systems, whereas the need and the plans are commands or observations of the energy connections between these systems. It especially describes the TransferingPower measure with respect to the Time dimension.

VI. SEMANTIC AND SYNTACTIC INTEROPERABILITY

As previously mentioned, RDF is an abstract data model. Much like in communication models, the transmitter node must encode the RDF graph in a serialized form that next is sent to the receiver node, which must decode the message. The everlasting issue is then to ensure that the receiver "understands" the message exactly as the transmitter expected. This is almost impossible with human communication, but we want machines to do so.

With RDF, one trivial solution to this issue is to choose one of the concrete RDF syntaxes, and to impose every node to be able to encode and decode messages with respect to this syntax. Yet, this method is not practical for two reasons. First, SEAS partners want to keep on using their legacy system. Indeed, they are used to exchangeing messages with their legacy partners in CSV, XML or JSON, and it would be too expensive for them to completely switch to RDF. Second, using RDF will increase message payload and resource required to process them. In fact, it would be irrelevant for simple messages sent by resource constrained SEAS nodes (e.g., simple time series of consumption values)to be sent in RDF syntaxes.

As a consequence, one crucial piece of work in the SEAS project was to drastically lower the cost in order to adapt existing systems to RDF. The result of this work is to use a new RDF-based solution, namely SPARQL-Generate [23], which is both a language and a protocol.

The language part of SPARQL-Generate is an extension of SPARQL 1.1, which enables to declaratively describe how messages (in XML, CSV, JSON, or any other format) may be interpreted in RDF. This language is more expressive than SPARQL 1.1 itself, and is already implemented on top of Apache Jena [24].

The protocol part of SPARQL-Generate enables the two following scenarios:

- an HTTP client sends its request in a legacy format to a server *along with a SPARQL-Generate query*, thus the server may interpret the message properly in RDF using SPARQL-Generate.
- an HTTP server answers in a legacy format to its client *along with a SPARQL-Generate query*, thus the client may interpret the message properly in RDF using SPARQL-Generate.

CNR SCP implementation makes use of such SPARQL-Generate protocol: it sends a SPARQL-Generate query along with CNR legacy XML format information. As a result, it allows any client to properly interpret any response in RDF using SPARQL-Generate.

VII. IMPLEMENTATION OF CNR SCP ENTITY WITHIN SEAS PROJECT

The smart charging service offered by CNR SCP is implemented and deployed as a RESTful Web Service. This service defines two interactions with other SEAS Entities:

1) Requests for the execution of SCP algorithm. The requesting node sends an XML document with static information about the charging station, the EVSEs, and charging needs as formulated by EV Drivers. CNR SCP sends back an acknowledgment, that provides the location where the algorithm result will be retrievable.
2) Requests for an SCP algorithm execution result at a given location. If available, CNR SCP sends back an XML document containing the optimized charge plan, along with a link to a SPARQL-Generate query that can be used to interpret this XML document as RDF, according to SEAS ontologies.

This service is available for testing, and documented on the Web [25]. Moreover, the code is openly available on GitHub and other partners in SEAS project already started using it to implement their own service [26].

VIII. CONCLUSIONS AND PERSPECTIVES

This paper reported a joint work between partners in ITEA2 12004 SEAS project, which aims at developing an ecosystem to help entities better manage, coordinate and optimize energy consumption, production and storage. This ecosystem enables to deploy distributed services that target energy efficiency. This paper particularly focuses on CNR EV Smart Charging UC, which tackles the emerging need for electric mobility.

In this CNR scenario, an SCP offers to any entities in SEAS ecosystem the possibility to obtain EV charge plans. These plans are computed based on different collected information (economical or environmental). It has been made possible thanks to SEAS project contributions a) S-RAM, designed to enable real-time interconnection of any energy actors; b) the SEAS ontology, used to quantify systems and their interconnections; and c) the SPARQL-Generate language and protocol, designed to ensure semantic and syntactic interoperability at low cost.

Finally, we described the actual implementation and deployment of CNR SCP as a RESTful Web service. Its code is openly available on SEAS project GitHub. As a consequence, this UC can now be instantiated anywhere, and any SEAS entity can entrust CNR with the role of the SCP.

Further work includes the interconnection of this service with other energy optimization services, or data generation services. Furthermore, CNR SCP service – as any other RESTful HTTP Web service – can be made secure using HTTPS, but it also can be monetized.

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