Interoperable solutions connecting smart homes, buildings, and grids

WP4 – Smart Grids Framework for an Interoperable Energy System

A DSO Standard Interface to support grid management.

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1. INTRODUCTION.

The decarbonisation of the energy sector comes with a set of challenges to current system operators' planning and operational practices. To tackle them several innovation projects have been launched. A key finding is that increasing energy flexibility use is necessary to mitigate potential mismatches in supply and demand induced by renewable generation. [1][1] Among others, smart grids and smart buildings play an important role in the provision of flexibility services. Flexibility services are a range of solutions provided by the electricity system users to help the system operators to balance demand and supply in the grid and support its efficient use [2].[2]

Already in 2019, the EU regulation on the internal market for electricity established that the future electricity system should integrate all the available sources of flexibility making use of digitalisation and innovative technologies.[3] As a response, technology providers have come up with solutions to enable system planning and operation in line with this new reality. These solutions include not only a better monitoring of the network but also allowing consumers to control their energy appliances. However, a major barrier is posed by the lack of interoperability between devices, systems, and domains (e.g., buildings, digital platforms, and the grid). For years, these technologies have evolved in different ways with different stakeholders and standards. As such, it is now particularly challenging to make these separate realities work together and communicate with each other in a common way.

In this context, the InterConnect project was launched to foster interoperability in buildings and electric grids. The project defines a reference architecture based on open data exchange practices and creates an interoperability framework that is made available for service providers to make their services interoperable. More specifically, InterConnect moves from the use of syntactic data models and explores semantic data exchange to address the lack of interoperability. With the creation of a Semantic Interoperability Framework (SIF) based on the SAREF ontology, the project brings interoperability enablers to all stakeholders creating new value services based on information exchange.[4] The SIF allows for the translation of existing data models into SAREF to make them interoperable.

In particular, the DSO Interface (DSOi) leverages on the SIF to enable the communication between DSOs and household devices. This technology allows data transactions between DSO and service providers for a more efficient system operation and to integrate consumers into the energy value chain. The usage of SIF implies that the data objects exchanged with the flexibility service providers are SAREF-based, that is, a SAREF-based graph pattern was created for each message that needed to be exchanged. This system was tested in the Portuguese Pilot of the InterConnect project, and it has been further adapted to be replicated to other demonstrations to enable compliance with the Common European Reference Framework (CERF) for consumer energy saving applications as envisioned in the EU Digitalisation of Energy Action Plan. This paper examines the innovation brought by the DSOi and initiates a discussion on identified barriers and goals for replicability and scalability to interoperable solutions. Eventually, the position paper provides recommendations for next steps to take by stakeholders and policy makers to enable both the scalability and replication of this innovative solution.

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[1] ETIPSNET, Flexibility for resilience. How can flexibility support power grids resilience? p.12-15
[2] Project Leo, Understanding Flexibility services in https://project-leo.co.uk/the-context/flexibility-services/
[3] Regulation (EU) 2019/943 of the EU parliament and the Council of 5 June 2019 on the internal market for electricity, Preamble n.7
[4] InterConnect Project, Semantic Interoperability Framework in https://interconnectproject.eu/resources/semantic-interoperability-framework-sif/

2. TECHNICAL AND FUNCTIONAL SPECIFICATIONS OF THE DSOI.

2.1 THE INTERCONNECT USE CASES FOR THE DSOI

The DSOi was developed to address the interoperable data exchange between the DSO and other market parties, such as services providers and flexibility aggregators. Particularly, the DSOi supports a set of use cases related to data sharing, flexibility provisioning, and grid observability.

Flexibility

For day-ahead and intraday operations within electricity distribution grids, the DSOi includes a module designed to mobilize and provide for upward and/or downward flexibility. This module is used to address local and regional congestion management and voltage control. Flexibility sources can be located at both the medium voltage level, like in commercial supermarkets, and the low voltage level, as in the case of residential appliances.

Data Sharing

To enable flexibility mechanisms and the provision of energy services by third-party entities, the DSOi establishes mechanisms that provide necessary information for the emergence of these services to stakeholders. At the same time, it ensures compliance with GDPR (General Data Protection Regulation) and the protection of business information.

Enhanced Observability

The service will use Home Energy Management Systems (HEMS) and monitoring devices to allow the Distribution System Operator (DSO) to access customer-side data for network operations, including fault detection. This approach will enhance the detection and observation of outages in Low Voltage (LV) grids. Authorized access to data from household smart appliances, processed through the HEMS, will enable grid operators to better observe and address faults. This will improve service quality and reduce outage durations.

2.2 WALK THROUGH THE DSOI

The development of the DSOi architecture (Figure 1) was achieved by aligning the use cases for grid-related processes and the early functional specifications from the early specifications defined by the InterConnect pilots to support the use case implementation.[5] When defining the development requirements, there was an emphasis on ensuring scalability and extensibility of a solution that was designed to accommodate additional use cases in the future. Consequently, the selected technologies and infrastructure needed to be modular, secure, and cloud-based, adhering to the internal guidelines of DSOs but also considering those from E-REDES, the Portuguese DSO leading the Pilot in which the chosen technologies and key components of the DSOi are illustrated in Figure 2. This setup involves utilizing a distinct sub-environment within the DSO's technical infrastructure based in Azure. It ensures data exchange with legacy systems

[5] InterConnect, Deliverable 4.1. Functional Specifications of the DSO Standard Interface Application, in https://interconnectproject.eu/wp-content/uploads/2022/02/InterConnect_D41_revJan2022_v0.pdf

through a dedicated data lake, where the essential information from these legacy systems is stored.

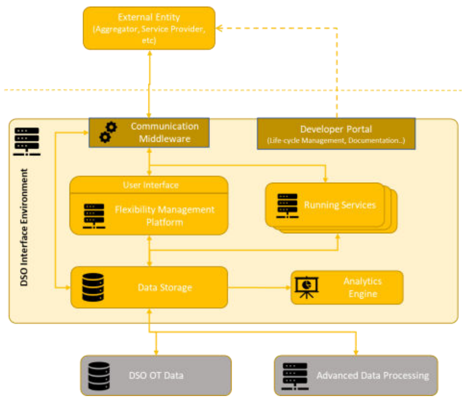

Figure 1 - DSOi Architecture

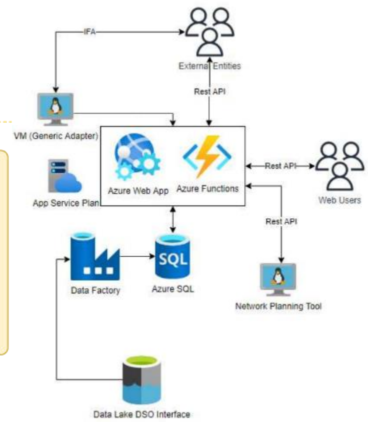

Figure 2 - DSOi technical Architecture

2.2.1 NETWORK SIMULATION TOOL

In the DSOi environment, one of the key services is a network simulation tool: DPLAN. This tool conducts grid analysis for selected timeframes (day-ahead and intraday). This analysis utilizes MV and LV forecasts, which are derived from internal forecasting tools for MV and obtained from customers' HEMS for LV scenarios.

DPLAN primarily performs a load flow analysis to identify potential voltage and current constraints in the grid's elements and branches. Once these constraints are detected, DPLAN forwards the analysis results to the DSOi portal. This data is then integrated into the information about flexibility needs, which is subsequently communicated to the registered Flexibility Service Providers (FSPs). Following this, DPLAN analyses the flexibility offers received from FSPs and selects the most suitable ones based on a techno-economic assessment. This process aims to address the identified constraints effectively. The final decision about which offers to procure and activate is relayed back to the DSOi portal and shared with the FSPs, ensuring interoperable communication through the SIF processes.

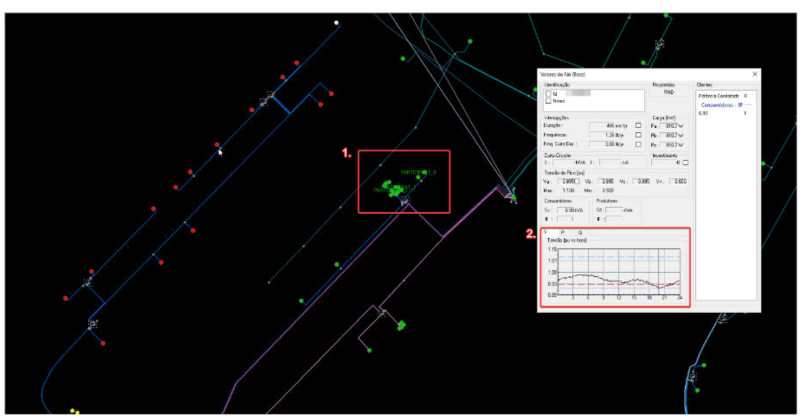

Figure 1 - LV grid from residential demonstration site in DPLAN with voltage issues

Figure 1 shows a section of a LV grid experiencing voltage problems in several nodes (in red). It also highlights three LV installations within the Interconnect project capable of offering flexibility services using controlled appliances. A flexibility need arises if these voltage issues can be addressed by adjusting the load from these three installations that are prepared to provide flexibility services. It's important to note that the installations experiencing the voltage issues may not be the same ones capable of providing the flexibility services.

Resulting from the analysis, Table 1 provides an example of the flexibility need generated that will then be shared with the flexibility service providers.

Table 1 - Example flexibility request sent to the DSOi

requestId	Dplan_202402191845
StartTime	2024-02-04T18:45:00
EndTime	2024-02-04T22:15:00
direction	down
need	110.91
unit	kW
ExternalIDs	PARTICIPANT_1
	PARTICIPANT_2
	PARTICIPANT_3

2.2.2 SIF INTEGRATION

The DSOi is seen as a digital platform that promotes the integration of the SIF, the interoperable reference architecture developed within the InterConnect project.

For effective integration in the SIF, the DSOi is required to use two key set of components: the Generic Adapter (GA) and the Service Specific Adapter (SSA). The GA serves a utilitarian software tool, responsible for handling operations such as authentication, service registration, data exchange, etc. Its role is to provide a standard, uniform way of interacting with the framework. On the other hand, the SSA is tailored for data exchange needs. Unlike the GA, each SSA is developed with a specific purpose and data exchange scenario in mind, ensuring that requirements of each service are set.

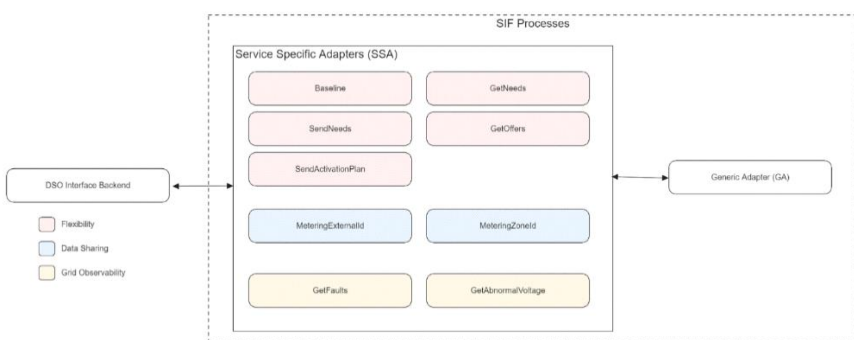

Figure 2 - SIF Components in the DSOi

In the context of the DSOi, a total of 9 SSAs - Figure 2 - SIF Components in the DSOi - have been developed. Each of these SSAs corresponds to a distinct service. The use of the GA allows the connection to the Service Store and Knowledge Engine Runtime (see D5.5 (interconnectproject.eu) for additional information).

SAREF-based graph patterns were created for each message that needed to be exchanged via the SIF. For example, the graph patterns to communicate flexibility in the DSOi (depicted in pink in Figure 4), contain flexibility needs (defined by using the <s4ener:FlexRequest> class), received offers (defined by using <s4ener:FlexOffer> class) and an activation plan (defined by using <s4ener:FlexibilityInstruction> class). Flexibility needs are exchanged to determine the flexibility a device (or a set of devices managed by an EMS) can provide; flexibility offers are sent as a response to a Flexibility Request, indicating the device (or EMS) flexibility potential; the activation plan describes the choice made among the possibilities expressed in the flexibility offer that will finally be executed.

2.2.3 THE USER INTERFACE

The DSOi has a set of different components, including a dedicated Human Machine Interface (HMI) – the DSOi Portal – that enables manual intervention and visualization capabilities on the data flowing through the interface. This intuitive user interface is composed of the following pages and subpages.

1. User Management – Page dedicated to the visualisation and permission setting to service providers and users participating in the flexibility.
    - Entities
    - Clients
2. Flexibility Procurement Management – Page that allow the visualisation of automatically and manually-generated flexibility needs, received offers, and allows the manual activation of the offers
    - Needs
    - Offer
    - Activation
3. Observability and Fault Notification – This page is dedicated to the observability use case, and is responsible for logging the received notifications about potential LV outages and voltage violations
    - Services Manager
    - Failure History
    - On-demand Viewer
4. Operations – The operations page is dedicated to the visualisation of system logs.

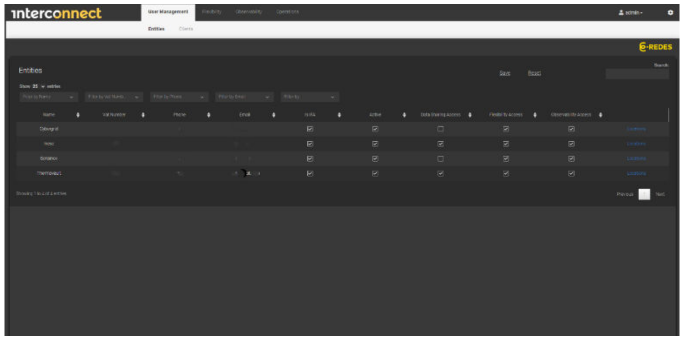

Figure 3 - DSOi Portal User Interface

2.3 MAIN INNOVATIONS BROUGHT BY THE DSOI

As can be seen in the previous chapter, the innovations brought by the DSOi are manifold such as:

1. The automatic mobilization of demand-side flexibility from HEMS and BEMS (Building Energy Management Systems), through semantically interoperable data models, enables electricity demand changes from typical Internet of Things (IoT) residential appliances to be accessible to the general population. These appliances include Electric Vehicle (EV) chargers, heat pumps, washing machines, dryers, etc., regardless of the manufacturer and underlying technical information. The same models and system integration approach are used to mobilize demand response from larger tertiary buildings by modifying the setpoints of the electrical resources, such as refrigeration systems in supermarket chains.
2. The DSOi brings user data sharing to a new level by making metering data available to the end user through several channels, such as REST API and the SIF. Each HEMS may, in a fully interoperable manner, request metering data from the DSOi and dynamically display it to the user. This information can also be used by service providers to build added-value functionalities for the user, such as energy optimization algorithms, eco tips, etc. Additionally, the interface makes available anonymous aggregated metering data and historical flexibility needs data for the locations where it is needed.
3. It leverages Distributed Energy Resources (DERs) and home appliances to gain increased observability over the LV network, most of which are still passive and not actively monitored. This allows for faster identification of potential outages and electricity quality issues, such as voltage violations. By identifying abnormal measurements, or even the absence of measurements, the energy system manager may submit a notification to the DSOi regarding the potential issue.
4. In line with the goal of developing the first generation of CERF-based consumer energy saving applications, the DSOi will be capable of directly transmitting the power system's needs to final consumers' energy applications, thereby dynamically influencing demand from a mass perspective. Ultimately, this will serve as an extremely important tool for operating the distribution system, optimizing the use of infrastructure in the most cost-effective manner.

3. POTENTIAL FOR SCALABILITY AND REPLICABILITY OF THE DSOI.

Within InterConnect, the Portuguese pilot demonstrated that the DSOi facilitates the interaction between DSOs and external agents, acting as a solution to support communications between different devices and stakeholders for the following use cases:

I) Data sharing.
II) Flexibility management.
III) Enhanced Network Observability.

However, a remaining challenge to integrate demand side flexibility at an EU level is to allow for its replication considering the differences within the existing DSO legacy systems in each Member State (MS). In view of that, the innovation brought by the interface has been presented to DSOs in different MS both inside and outside the project, including the DSOs that will participate in the development of the Energy Saving Applications within the framework of the InterConnect project to discuss the benefits and potential drawbacks of using a SIF-based interface.

This section summarizes these discussions, with a specific focus on the benefits, most interesting features of the interface and potential use cases that the DSOi can support but also considers the concerns raised by the different grid-side representatives, to identify recommendations for the replicability of the DSOi in the future.

3.1 MAIN BENEFITS AND POTENTIAL FOR AN EU-WIDE REPLICATION OF THE DSOI.

To start with, the DSOi is a major innovation because it concretely and actively brought together DSOs with other energy and buildings stakeholders, manufacturers and end-users (all with different interests, using different standards and systems) to deploy end to end interoperability for demand side flexibility using common standards, like SAREF.

The main benefits that emerged from the testing activities of the InterConnect Portuguese pilot are related to the mobilization of low voltage flexibility, data sharing and enhanced observability. Semantic data modelling and standardized data sharing are seen as the main innovative aspects integration of the interface in the management and operation activities of DSOs. This would leverage on the information provided by smart appliances, enhancing data availability and tapping of flexibility potential without (too much) effort from final users. The interface demonstrates the benefits of interoperability in action, and it provides clear instructions to be replicated paving the way for more DSOs in different countries to adopt and extend it with more data and additional use cases.

In this line, other DSOs participating in InterConnect have shown interest in following the results of InterConnect as they consider that interoperable data frameworks drive efficiency, collaboration, and innovation and some of them are testing similar solutions. Moreover, participants are confident of the DSOi potential to support additional use cases. In the high-level prequalification, provision of baseline data and programmed activation have been suggested as potential use cases for the interface. All in all, this makes clear that the use of a platform that enables the aggregation and provision of flexibility to enable grid operation is seen as an accelerator in the integration of renewable energy in the distribution network. However, there are also challenges and concerns when considering its replication in different MS.

3.2 OBSTACLES AND POTENTIAL BARRIERS TO EU-WIDE REPLICATION OF THE DSOI.

The analysis of the outcomes of the InterConnect Portuguese pilot allowed to identify some of the remaining obstacles to the implementation of DSOi functionalities. As technical examples, the initial complexity making the data exchange objects SAREF-compliant, the amount of overhead verbose data, and the technical specificities of developing the SSAs have been reported as potential barriers to the replication of the interface in other areas outside the demonstration site. However, further developments of support tools to streamline these setup hurdles may ease the adoption. In addition, the DSOs participating in InterConnect have suggested the existence of additional barriers. These can be distinguished between technical, regulatory, and social barriers as it can be seen in the table below.

Technical	**Regulatory**	**Social**
Existence of a huge amount of heterogeneous data that needs to be processed.	Data privacy concerns to use customer data and integrate it with the project Home Energy Management Systems	Resistance of stakeholders to share their data and adopt interoperability measures.
Excessive effort required to standardize data formats and protocols across diverse systems and MS.	Legal and Compliance Costs: Achieving and maintaining GDPR compliance is expensive.	Lack of qualified personnel to guide the integration of more sectors and data sources into the interface.

3.3 DSOI CONTRIBUTION TO THE CERF

After the successful testing and implementation of the DSOi, the InterConnect project was tasked with the development of the first generation of the CERF (Common European Reference Framework) for energy saving applications. The CERF is meant to help consumers in Europe reduce their energy consumption and costs. It aims to improve electricity grid stability by managing how and when consumers use energy. The framework serves as a guideline for countries to implement similar systems, providing technical and non-technical information, including system architecture and interface specifications. The DSOi is a key part of the CERF that aims to enhance electricity grid stability providing information of the network at a local level. It does this by providing energy saving applications with information about potential stress situations in the distribution grid specific to a user's location. This required the development of additional backbone features and functionalities to allow the DSOi exchange local grid information to mobile applications.

InterConnect implementation of the CERF is based on the concept of the Interoperable Recommender (IR). The IR issues load increase/decrease hourly recommendations for each European country with the objective to increase the country-level resilience to energy scarcity events considering the different energy exchanges expected to occur among the member states interconnections and the renewable based generation present in the European system. These recommendations are sent to the DSOi to be specialized at a local level considering the distribution grid state and underlying infrastructure and then communicated to the energy saving applications, that should induce the desired behaviours in the final users.

The DSOi utilizes three methodologies to relay recommendations to the energy-saving apps:

- Specialization of the country-level signals from the IR.
- Local-level signals stemming from potential distribution grid constraints.
- Manual input from the control room operator.

The energy app functionality is integrated as an additional module within the DSOi, which will be made publicly available for other DSOs and interested parties to test in operational scenarios. Operational tests will be performed within InterConnect in the Portuguese, Greek and Dutch Pilot with the aim to adapt consumption to mitigate local grid problems (MV\LV congestions) and adapt consumption to align with local RES generation.

a. The case for the Greek Pilot

In this context, the Greek DSO, HEDNO, adopted the DSOi to apply two use cases, related to the objectives of the InterConnect project. The use case aims to increase the exploitation of Photovoltaic (PV) production, by providing to the energy app the PVs' power output based on open-access, insensitive data. For the second use case, DSOi is used to inform the users of the energy app about potential congestion issues of the part of the energy distribution system they are connected to.

b. The case for the Dutch Pilot

In the case of the Dutch pilot, the DSO Stedin will use the DSOi to make available to third parties as well as the generic recommender the fault and predicted faults of the Medium Voltage (MV) transformer in its demonstrator. The transformer that this applies to is either overloaded due to solar panels in the area (too much production) or overloaded due to EV charging (too much consumption). Stedin can predict when this will happen through machine learning on the transformer logs as well as combining internal logs with the ENTSO-E Transparency Portal and weather forecasts.

c. The case for the Portuguese Pilot

In Portugal, E-REDES will use the energy app to issue national-level recommendations for load changes to strengthen the resiliency of the grid in the day-ahead timeframe. In this context, the DSOi is used to send specialized recommendations for the different regions of the country on top of the data retrieve from the EU-wide transmission data.

4. RECOMMENDATIONS

When considering the replicability of the DSOi, an important analysis concerns data sharing. On the one hand, it is not desirable for a DSO to disclose to the external environment sensitive data, i.e., user or network data. Such data can then be represented only at internal level using the DSO-specific data model, as implemented in the DSOi through a traditional API. In fact, this data exchange is related to a domain where semantic interoperability is not necessary as the data do not need to be shared externally. Moreover, the DSO internal specific data model is known to the system, thus avoiding risks of misinterpretation.

On the other hand, other data such as flexible needs, received offers and activation of these offers greatly benefit from being shared by the DSO with the external environment. Data can be translated into SAREF and SAREF4ENER, as a common language among stakeholders that use different data models and integrated into the SIF by developing a GA and a set of SSAs on top of the traditional APIs (see section 2.2.2). This allows a high level of interoperability, i.e., semantic interoperability.

However, as mentioned in section 3.2 and elaborated in InterConnect D2.4[6] the translation into SAREF and the integration through the SIF require an additional effort from the traditional software developers that are not acquainted with semantic technologies. This means that not all data needs to always become interoperable with the external environment. This effort is justified only when high-level interoperability is key. It is also important to mention that full semantic interoperability on a huge amount of heterogeneous data has an impact into the processing time (higher degree of reasoning on data requires higher processing time).

Based on this analysis, the following lines outline a few technical recommendations for future projects and initiatives that aim to replicate the DSOi.When considering the replicability of the DSOi, an important analysis concerns data sharing. On the one hand, it is not desirable for a DSO to disclose to the external environment sensitive data, i.e., user or network data. Such data can then be represented only at internal level using the DSO-specific data model, as implemented in the DSOi through a traditional API. In fact, this data exchange is related to a domain where semantic interoperability is not necessary as the data do not need to be shared externally.

Moreover, the DSO internal specific data model is known to the system, thus avoiding risks of misinterpretation. On the other hand, other data such as flexible needs, received offers and activation of these offers greatly benefit from being shared by the DSO with the external environment. Data can be translated into SAREF and SAREF4ENER, as a common language among stakeholders that use different data models and integrated into the SIF by developing a GA and a set of SSAs on top of the traditional APIs (see section 2.2.2). This allows a high level of interoperability, i.e., semantic interoperability. However, as mentioned in section 3.2 and elaborated in InterConnect D2.4[7] the translation into SAREF and the integration through the SIF require an additional effort from the traditional software developers that are not acquainted with

[6] Interconnect, D.2.1, Secure Interoperable IoT Smart Home/Building and Smart Energy system Reference Architecture, in https://interconnectproject.eu/wp-content/uploads/2022/03/D2.1-Secure-Interoperable-Smart-Home-Building-and-Smart-Energy-System-Reference-Architecture_FR_v2.pdf

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Based on this analysis, the following lines outline a few technical recommendations for future projects and initiatives that aim to replicate the DSOi.In order to spend the resources efficiently, the project recommends to the DSOs to identify the use cases that require interoperability with external stakeholders that can truly benefit from data sharing via the SIF and SAREF, in addition to the use cases already implemented in InterConnect. The reason is that once the use cases are identified, only the data required for the specific use cases should be SAREF-ized to avoid spending too many resources in SAREF-izing data that does not need to be shared. The project also recommend that more efforts are allocated to further optimize the processing time and reasoning on semantic data and, as urgently needed for the uptake of the SIF and SAREF (and semantic interoperability in general), it is recommended to invest in the creation of more user friendly tools to ease the process of translation of data into SAREF and integration into the SIF via GAs and SSAs.

Moving now to data privacy, the use of customer data and its integration with the project HEMS has been identified as a potential barrier to the replication and scalability of the DSOi. The issue lies in the fact that the services provided by the DSOi in connection with HEMS will be hard to convey into seamless replicable processes because they're dependent on consumers personal data which poses privacy concerns. To address this challenge, the project recommends the adoption of a data privacy policy for HEMS considering their crucial role on the integration of RES into the distribution grid. This policy should establish a solid framework for the ethical and lawful use of customer data in HEMS that prioritizes data privacy and security.

Still connected to data privacy issues, another barrier identified is related to the compliance costs of implementing the GDPR among the DSOi users. Costs arise from the need to invest in technology, human resources, processes and systems to ensure compliance with the GDPR. In this regard, it is essential to establish a cost-effective GDPR compliance framework that minimizes legal and compliance costs. A way forward could be adopting a privacy by design approach to the development of new services.

The resistance of stakeholders that are protective of their data or hesitant to adopt interoperability measures may hinder the replicability of the DSOi. We propose a two layered recommendation to overcome the resistance of stakeholders: The first layer of this recommendation is offering incentives and benefits to the different stakeholders. This can range from financial incentives or rewards to stakeholders for sharing valuable data to access to better insights and services derived from their shared data. Second, it is essential to create awareness of the relevance of data sharing. Workshops and other methods can be employed at every stage of the adoption and replication of the DSOi.

Another challenge is achieving a standard usage across different countries considering different practices at a national level. In this sense, public consultations that guarantee the participation of all the relevant stakeholders can play a crucial role to solve this social issue. The personnel acquainted with the semantic interoperability concepts to guide the integration of more sectors and data sources into the interface constitutes a significant barrier that needs further engagement. In this case, a proactive approach should be undertaken. To that end, the project proposes a double-scale recommendation. At EU scale, both the governments and institutions should promote initiatives to tackle the digital skills shortage. Those may include incentives to upskill and reskill workers and programmes to attract new talents. At the scale of the DSOi community, our recommendation is to make sure that enough qualified personnel are available to guide its further development. This would be possible through preparation of training activities on how to use semantic data representations for interested stakeholders and provide practical examples on how to integrate the DSOi in existing IT frameworks.

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