European Common Energy Data Space Framework Enabling Data Sharing - Driven Across – and Beyond – Energy Services

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D3.3 ENERSHARE interoperability building blocks

Final version

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List of Acronyms

API	Application Programming Interface
CSV	Comma-Separated Values
DCAT-AP	Data Catalogue vocabulary (DCAT) Application Profile
DE	Digital Enabler
DME	Data Mashup Editor
DSO	Distribution System Operator
DTDL	Digital Twins Definition Language
EC	European Commission
EDSCP	Energy Data Space Cluster Projects
EO	Earth Observation
EV	Electric Vehicle
GUI	Graphical user Interface
HTTP	Hypertext Transfer Protocol
IDS	International Data Spaces
IDSA	International Data Spaces Association
int:net	Interoperability Network for the Energy Transition
IRI	Internationalized Resource Identifier
JSON	JavaScript Object Notation
JSON-LD	JavaScript Object Notation for Linked Data

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NGSI	Next Generation Service Interfaces
NGSI-LD	Next Generation Service Interface-Linked Data
OAS	Open API Specification
OEO	Open Energy Ontology
OWL	Web Ontology Language
PMSG	Permanent Magnet Synchronous Generator
R+D	Research and Development
RDF	Resource Description Framework
RML	RDF Mapping Language
SHACL	Shapes Constraint Language
SAREF	Smart Applications REFerence
SAREF4BUILDING	SAREF extension for Building (saref4bldg/)
SAREF4ENERGY	SAREF extension for Energy Flexibility (saref4ener)
SAREF4GRID	SAREF extension for Smart Grid (saref4grid)
SAREF4SYST	SAREF extension for typology of Systems and their inter-connections (saref4syst)
SDM	Smart Data Models
TSG	TNO Security Gateway
UC	Use Case
URI	Uniform Resource Identifier
URL	Uniform Resource Locator

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UTC	Universal Time Coordinated
UX	User Experience
WP	Work Package
XML	Extensible Markup Language

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Executive summary

The EU Strategy for Data acknowledges that Data Spaces should be interconnected and interoperable. Although data sharing and exchange within specific domains and sectors is already happening in existing initiatives, each of these initiatives follows its own approach, and therefore they are not always interoperable.

Creating the basis for the Energy Data Spaces primarily is not so much a technological challenge, as there are plenty of technical solutions and standards available. The main challenge hence is to move towards an Energy Data Space which offers: (i) Full intra-Data Space interoperability for cross-sector data sharing across energy sectors (electricity, heat, etc.) and with other energy (es. buildings/homes) and non-energy data hubs (es. Earth Observation (EO)-based data, weather data, energy efficient financial risks); (ii) Multiple use inter-data space interoperability for cross-domain data space data sharing, exchange, and reuse. The horizontal focus on the use of standards and interoperability will make it possible to scale up the European Energy Data Spaces and facilitate the single market for energy data.

This deliverable, which is the third of a series of 3 (alpha, beta and final version), presents the final results of the work in WP3, whose focus is on the design and development of the intra-energy and cross-sector Data Space interoperability building blocks, concretely: i) semantic data models (ontologies) specific for the energy sector and for other synergic cross domain sectors, ii) data exchange APIs that guarantee the interoperability of energy centred data driven services.

These results are:

- the ENERSHARE Semantic Data Model, i.e., a set of interconnected ontologies that cover the specific needs of the twelve use cases in the project,
- the data exchange Open APIs, jointly with the transformation and compliance rules, that guarantee the interoperability of the energy centred data driven services defined in WP6; and

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- a set of useful tools and services including: the Vocabulary Hub, the Data Mashup Editor, the Context Broker and the Transformation and Compliance services.

Finally, the activities that are upcoming from the collaboration with the sister projects are presented, as well as the plan to demonstrate the semantic interoperability across projects and energy data spaces.

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1 Introduction

1.1 About the project

The overall vision of ENERSHARE is to develop and demonstrate a European Common Energy Data Space which will deploy an 'intra-energy' and 'cross-sector' interoperable and trusted Energy Data Ecosystem. Private consumers, business (energy and non-energy) stakeholders and regulated operators will be able to access, share and reuse, based upon voluntary agreements (or legal obligations where such obligations are in force): (a) Large sources of currently fragmented and dispersed data; (b) Data-driven cross-value chain (energy and non-energy) services and Digital Twins for various purposes.

1.2 About this document

This deliverable, which is the third of a series of 3 (alpha, beta and final version), presents the final results of the work in WP3, whose focus is on the design and development of the intra-energy and cross-sector Data Space interoperability building blocks, concretely: i) semantic data models (ontologies) specific for the energy sector and broaden with others for other synergic cross domain sectors, ii) data exchange APIs that guarantee the interoperability of energy centred data driven services defined in WP6.

This document aims to be self-contained when presenting the final results. For this reason, the deliverable contains updated and summarized information of sections in deliverables D3.1 and D3.2, plus extra sections with the new results of this final version. Readers are referred to previous deliverables for detailed information (e.g., the methodology used to define the semantic data model is described in detail in deliverable D3.2 whereas deliverable D3.3 just briefly mentions its four steps).

In more detail, this report provides the updated architecture and a summary of the semantic interoperability building blocks described in detail in D3.2. Besides, it describes the results of the last step of the methodology used to create the ENERSHARE common semantic data model and presents the formalization of the

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ontological modules. Additionally, the document describes the final version of the components for semantic interoperability developed or enhanced in the project, i.e., the Vocabulary Hub, the Open APIs, RML mapping files and SHACL files, the Data Transformation and Compliance services and the Data Mashup Editor.

The deliverable also describes how the ENERSHARE data model has been mapped to FIWARE's initiative of Smart Data Models to support NGSI-LD serialization and to guarantee the maintenance and evolution of the models after the project ends.

Finally, the document describes the collaboration with the sister projects to support semantic interoperability across projects and across energy data spaces.

1.3 Intended audience

The intended audience for this deliverable is two-fold. On the one hand, all involved stakeholders of the project, the technical work packages and especially the partners developing connectors and services in the different use cases. On the other hand, any external partner to the project that would like to be part of the European Common Energy Data Space which will deploy an 'intra-energy' and 'cross-sector' interoperable and trusted Energy Data Ecosystem.

1.4 Reading recommendations

This document is divided into 7 chapters and 2 appendixes.

- Chapter 1 is this introduction and an overview of the updates from the beta version to the final version.
- Chapter 2 provides the updated architecture and summarizes the main functional components for data interoperability which have been identified in WP3. Detailed description is available in D3.2.
- Chapter 3 presents the results of the fourth step of the methodology used to define the Semantic Data Model, as well as the final serialization of the ENERSHARE ontology that covers the specific needs of the twelve use cases in the project. Besides, it explains how the vocabulary hub plays a supportive role in the adoption and use of the ENERSHARE models. Finally, it describes

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how ENERSHARE's data model is contributing to FIWARE's Smart Data Models initiative.

- Chapter 4 describes the updated status of the list of software components that make up the final version.
- Chapter 5 presents the activities that are being carried out among the sister projects to demonstrate the semantic interoperability across projects and energy data spaces.
- Chapter 6 presents the final conclusions and chapter 7 includes the list of references.
- Finally, appendix 8 provides the harmonized diagrams developed from step 3 of the methodology and appendix 9 provides a complete example for the input and output Open APIs of the hydraulic pitch system anomaly detection service, plus the RML mapping rules and the SHACL validation files.

1.5 Overview of the updates in final version

In this chapter, an overview of the work progress performed in this final version is presented.

1.5.1 Methodology and data model updates

As mentioned in previous deliverables, the methodology followed to create the ENERSHARE project is based on the one proposed and applied in the PLATOON project [1].

Deliverable D3.1 provided an overview of the PLATOON methodology and presented the application of the first two steps of the methodology, along with the progress of all pilots in the ENERSHARE Project.

Deliverable D3.2 provided a revised overview of the PLATOON methodology, including updates to the illustration of the methodology to reflect its real-world application in the ENERSHARE project. Additionally, deliverable D3.2 gives a detailed description of the fourth step of the methodology including the update added in the ENERSHARE project. The main contribution of the deliverable D3.2 is the illustration of the results of step 3, which focuses on the design of the conceptual semantic model for each use case among the 12 use cases defined across 7 pilots in the ENERSHARE project.

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In the deliverable D3.3, section 3.1 focuses on the presentation of the fourth step which is harmonization, formalization, modularisation and alignment. Appendix 8 shows, for each pilot, an example of one diagram to illustrate the harmonization task. To access to all the results, files are available here: https://w3id.org/enershare

1.5.2 Vocabulary hub updates

The vocabulary hub and its accompanying wizard component were introduced in the ENERSHARE deliverable D3.1 alpha release. Further development of this software component has been described in deliverable D3.2 beta release. In this final deliverable D3.3, we report the results of additional development activities in section 4.1. These activities were focused on validation of new functionality introduced with the Beta release, and the further development features supporting a 'bottom-approach' to semantic interoperability with the vocabulary hub. Section 3.2 describes how this new functionality of the vocabulary hub works and leads to better adoption and reuse of the ENERSHARE models.

1.5.3 Data exchange updates (Open APIs, Data Transformation and Compliance)

This final version includes a description of the methodology used to create the Open APIs, the RML mappings and the SHACL (Shapes Constraint Language) files for the pilot use cases. Besides, it includes the links to all the files that are accessible at: https://git.code.tecnalia.com/open/enershare/.

There have also been some updates in the data transformation service and compliance services. The new version of the data transformation service supports ad-hoc functions useful for ENERSHARE and includes some bugs correction to handle properly 0 values. The new version of the compliance service also supports JSON schema and XML schema validation in addition to semantic data validation.

1.5.4 Context broker updates

The NGSI-LD 1.8.1 specification [2], the specification basis for the context brokers, was released in March 2024, consequently software implementations are in the process of being created, tested, released, and integrated into solutions like the Data Mashup. Consequently, the context brokers implementations available (Orion-LD, Scorpio and Stellio) are based on NGSI-LD 1.6.1 and have some features of the

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1.7.1. Besides this, several fixes and other smart features are included, see specification at https://www.etsi.org/deliver/etsi_gs/CIM/001_099/009/01.08.01_60/gs_CIM009v010801p.pdf

1.5.5 Data Mashup updates

In the last period, the work has been focused on the integration between the Data Mashup Editor (DME) and the TNO Security Gateway (TSG), an IDS connector that allows the DME to be compliant to IDSA.

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2 In-depth architecture of the semantic interoperability building blocks

As explained in deliverable D2.3 "Description of Reference Architecture for the European Energy Data Space", the main objective of ENERSHARE WP3 is the development of the necessary building blocks to facilitate data interoperability, so that data can flow seamlessly between parties and domains. More in detail, WP3 provides two types of building blocks:

- Data Models and Formats (i.e., common formats) for model specifications and representation of data in data exchange payloads.
- Data Exchange APIs for facilitating the sharing and exchange of data, i.e., provisioning and consumption of data, between the data space participants.

2.1 Architecture

Figure 1 depicts the main functional components for data interoperability, which have been identified in WP3. In this final version, the vocabulary hub includes both the functionality of visualization portal and the functionality of vocabulary registry.

Figure 2 shows the internal and external relationships between the components in WP3 and with other components in ENERSHARE. The datasets published in the Metadata broker developed in WP5 are linked to the vocabulary hub through the DCAT-AP property "conforms to". The vocabulary hub stores the Open Energy Ontology and provides a wizard and editor to create Open APIs. These Open APIs define how to formalize the data to be exchanged in the payload of the messages transferred between data providers and consumers using IDS connectors or through the Context Broker. The Data Mashup editor allows defining the pipelines that need to be executed to transform the data according to the Open APIs.

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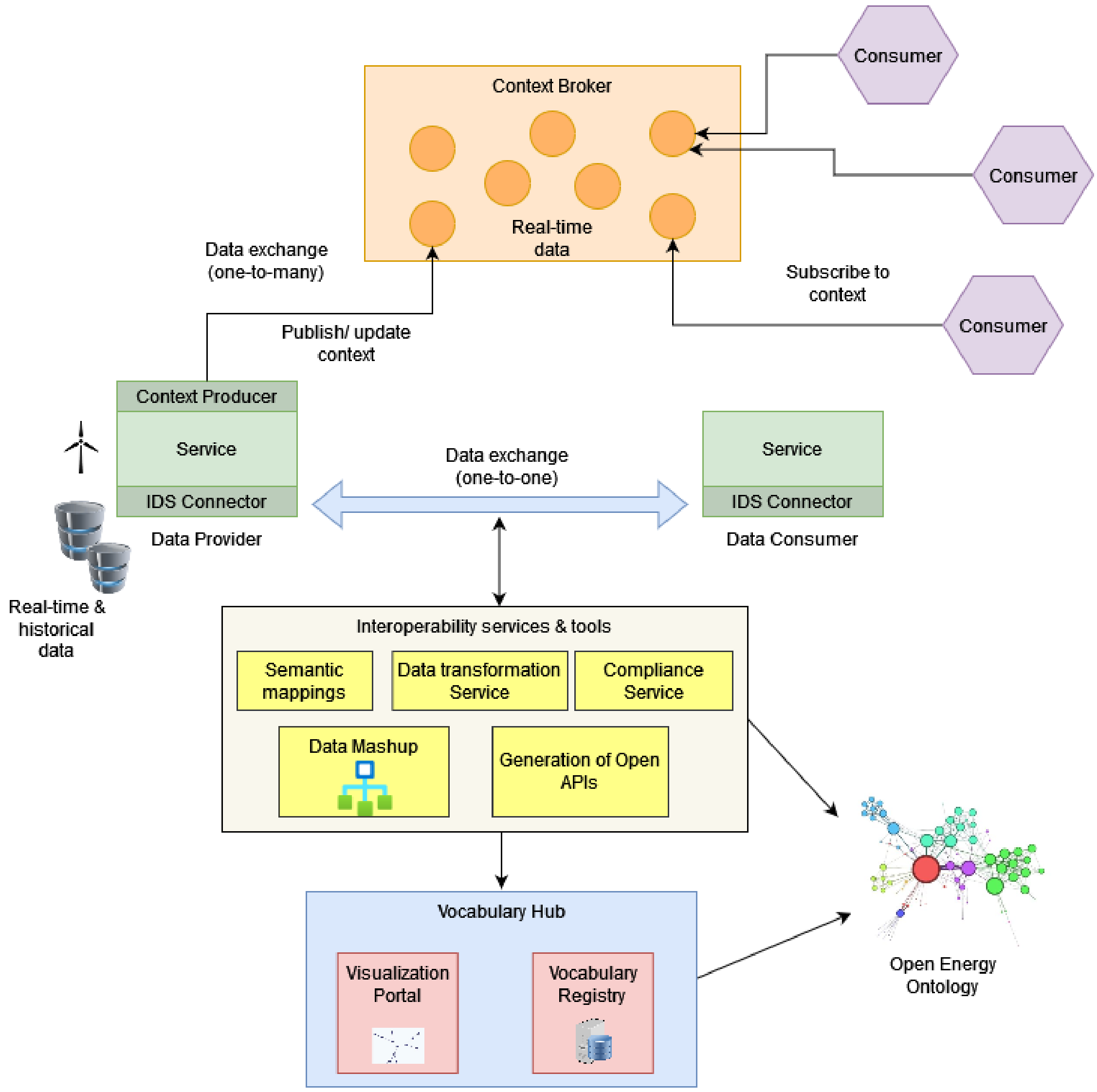

Figure 1: Functional components for data interoperability

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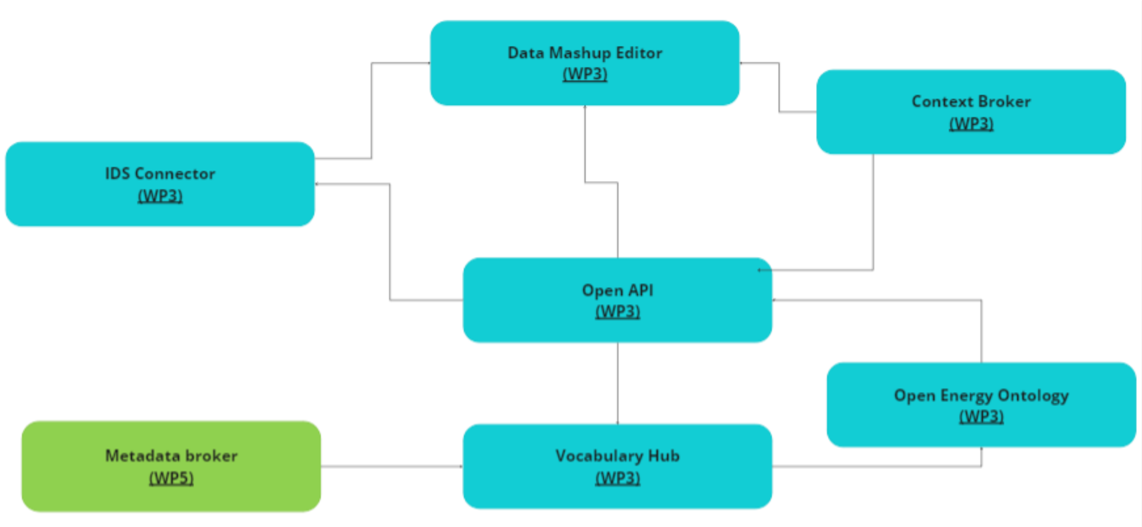

Figure 2: Internal and external relationships of WP3 components.

2.2 Data Models and Formats

The purpose of the building blocks under this category is two-fold. On the one hand, to provide a semantic model to represent the energy domain that will allow to unambiguously interpret all the concepts and the data exchanged in the ENERSHARE pilots. On the other hand, to provide the mechanisms or tools to query, interact with and foster the adoption of these semantic models.

The Open Energy Ontology (OEO) is the set of interconnected ontologies that are being developed to semantically model the energy data landscape (renewables, energy communities, flexibility and electromobility). Section 3.1 explains the methodology that has been followed to define the OEO ontology and the final status of the model.

The Vocabulary Hub is the tool that allows interaction with data models and offers two functionalities:

- A web-based vocabulary registry where all project stakeholders can find the data vocabularies relevant to the project. This includes both *standard vocabularies* (i.e., ontologies like OEO but also others like Smart Data Models) and *non-standard vocabularies* (i.e. data models specifically for a certain pilot use case).

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- A visualization portal or web-based GUI for the interactive visualization of ontologies. The user can interact with the ontologies and check the available properties and metadata information.

2.3 Data Exchange Interoperability in energy data spaces

Section 2 in the deliverable D3.2 provides a detailed description on the following aspects related with data exchange interoperability in energy data spaces. Please refer to this document for more information.

- The types of data that can be exchanged in an energy dataspace (regulated data, personal data, commercially sensitive data, sensor measurements and forecasted data). Usage control policies are managed in WP4.
- Two alternatives for exchanging data between services: one-to-one using IDS connectors and one-to-many using a publish/subscribe paradigm by means of the Context Broker.
- Interoperability services and tools to facilitate data exchange including data transformations, semantic mappings between data models, compliance of data models, the generation of Open APIs and a data mashup editor to combine data from different data sources. Section 4 describes the final software versions of these services and tools.
- The two data exchange interoperability levels: technical interoperability and semantic interoperability. At the time of writing this deliverable, the latest Data Spaces Blueprint was in version 1.0 [3]. Every six months a new version of the blueprint will be released, and the last version is expected in January 2026.
- The architecture proposed in ENERSHARE, based on a data transformation service, to address interoperability between different data spaces. This architecture addresses the question "*how can the same connector be interoperable at the same time with connectors from the data space A and with connectors from the data space B*?" and covers three use cases:

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1. Data exchange without transformations (for services developed from scratch). The data exchanged is formalized according to the common semantic data model defined by the data space.
2. Data transformations at the provider (for services in production). The data at origin needs to be transformed to a common semantic model before the data is provided by the connector.
3. Data transformations at the consumer (for low latency or big volume data exchange). The data at reception needs to be transformed by the data consumer in order to be understandable in the common semantic data model defined by the data space.

- Data Exchange in the electricity domain and how the ENERSHARE building blocks and the Data Space Protocol are compatible with the IEC 61850-7-2 principles [4] (in particular the client-server patterns and the time synchronization) and with the IEC 61968-100 standard [5] (as all the ENERSHARE data exchanges rely on XML RDF files or equivalent serializations like JSON-LD).

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3 ENERSHARE Data Model

As explained in section 2.2, the Open Energy Ontology (OEO) is the set of interconnected ontologies that semantically model the energy data landscape (renewables, energy communities, flexibility and electromobility). Section 3.1 explains the methodology that has been followed to define the OEO ontology and the status of the model.

Section 3.2 describes the supportive role that the vocabulary hub plays in the adoption and use of the ENERSHARE data models.

3.1 Methodology

The main steps of the methodology used in ENERSHARE to design and create the semantic model are listed below (see Figure 3). As noted in deliverable D3.2, some adjustments were made in steps 3 and 4 to accurately reflect the practical application of the methodology in the ENERSHARE project.

1) Ontology requirements specification: it aims to analyse each use case to: (i) assess and define the scope of the ontology according to the application domain, (ii) extract the relevant terms that need to model the use case (concepts and relationships), and (iii) specify a list of natural language questions that the ontology should answer to.

2) Ontology analysis: the goal of this step is to reuse well-known ontologies or to design new ontological modules by respecting the practices for ontology design patterns.

3) Design ontological Diagrams for each pilot: it targets a consolidation of all conceptual modules together and providing an example for each pilot. Interaction with stakeholders is maintained during all the designing process.

4) Harmonization & Formalization: the purpose of this step is to: (i) harmonize the diagrams of the different pilots, and (ii) formalize all ontological modules by using an ontology editor and a standard language and integrate all modules into an ontology system.

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In this deliverable, we focus on the application of step 4 of the methodology. Readers should refer to deliverable D3.2 for more details about the previous steps and the intermediate results.

In the following, the subsection 3.1.1, describes the step 4 of the methodology and the subsection 3.1.2, presents the diagrams of the modules created in the ENERSHARE project. Some results of harmonization diagrams are given in appendix 8.

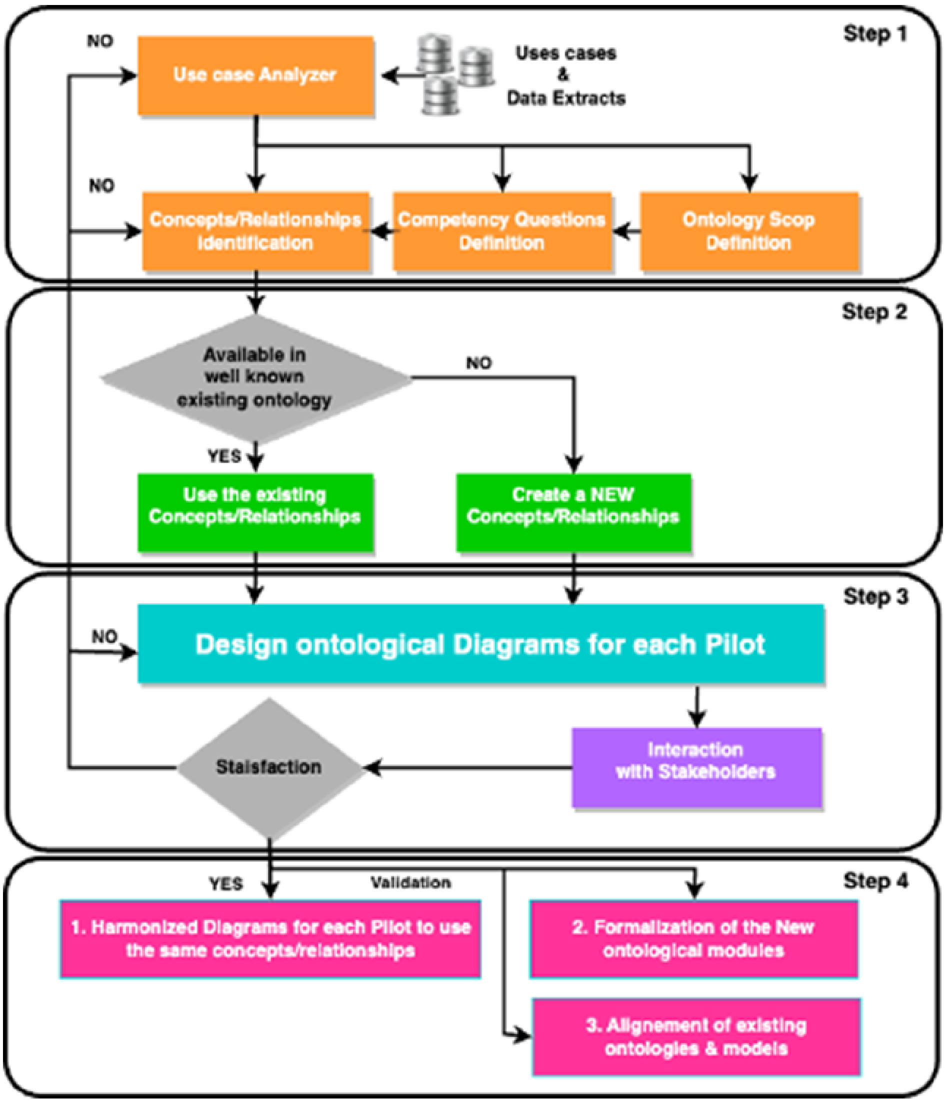

Figure 3: Steps of design methodology

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3.1.1 Application of Step 4 - Harmonization & Formalization

The objective of the fourth step of the methodology is to harmonize the whole ontological modules and to formalize the created modules by using OWL, the standardized Ontological Web Language.

However, because the methodology is interactive and is adaptable according to new identified needs, some stakeholders expressed new needs of some pilots while this step was being carried out. Therefore, the modelling step was continuing at the same time of the harmonization and formalising steps.

The fourth step consists of the following tasks (see Figure 3):

a) Diagrams Harmonization: the harmonization task aims at checking all the diagrams created for the different pilots to verify that the concepts and relations are correctly used. For all reused concepts and relations, a verification of its effective existence and correct spelling is carried out. We also verify that for the same notion we use the same concept and relation. In this manner, we guarantee that all pilots use the same concepts for the same meaning, and then increase the interoperability between them. Some of the harmonized diagrams for each pilot are presented in appendix 8. As noticed in the D2.3 the diagrams associated to each pilot, should be considered as a guide that helps the person in charge to create a knowledge of a use case to transform raw data into semantic data.

b) Ontology formalization & modularization: When the stakeholders express their satisfaction about the modelling, we proceed to the formalization process, which involves generating an OWL file for each new module. For instance, in the case of the pilot 1, five distinct modules were established: `ener-wind` for the wind turbine field, `ener-device` for devices, `ener-prop` for properties that are transversal in different fields, `ener-mnt` for maintenance and `ener-fail` for failure. Figure 4 presents an example of the formalization of an extract of the wind turbine module (`ener-wind`). It is important to note that these modules do not encompass the entire domain; rather, they specifically address the novel concepts and relationships required for the ENERSHARE project that do not already exist. For instance, the "`ener-device`" module focuses on a subset of devices essential to the ENERSHARE project, excluding those already defined in the Platoon ontology.

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Consequently, if a device, such as an anemometer, is already present in the Platoon ontology, we opt to reuse this concept, thereby eliminating the need to redefine it within the ENERSHARE device module.

Then, across the different use cases and pilots, we modularize the ENERSHARE ontology into 18 modules (see subsection 3.1.2). However, this modularization is a proposition of a subdivision and could be subject of discussion. Furthermore, to increase interoperability with Fiware, the annotation *`rdfs:seeAlso`* is added to each concept or relation that is close to a Fiware attribute, for example `ener-mrkt:Market` *`rdfs:seeAlso`* `fiware:Market`.

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```
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  rdfs:isDefinedBy ener-wind:WindTurbineOntology .

### https://w3id.org/enershare/windturbine/DoubleFedInductionGeneratorWindTurbine
ener-wind:DoubleFedInductionGeneratorWindTurbine a owl:Class ;
  rdfs:label "Double Fed Induction Generator Wind Turbine"@en ;
  rdfs:comment """Double Fed Induction Generator Wind Turbine is a  wind turbine that has Double Fed Induction Generator as a subsystem"""@en ;
  rdfs:subClassOf plt:WindTurbine,
                [ a owl:Restriction ; owl:onProperty seas:hasSubSystem; owl:someValuesFrom plt:DoubleFedInductionGenerator ];
  owl:equivalentClass [ owl:intersectionOf ( plt:WindTurbine [ rdf:type owl:Restriction ; owl:onProperty seas:hasSubSystem ; owl:someValuesFrom plt:DoubleFedInductionGenerator]) ] ;
  owl:equivalentClass [ owl:intersectionOf ( plt:WindTurbine[ rdf:type owl:Restriction ; owl:onProperty seas:hasSubSystem ; owl:qualifiedCardinality "1"^^xsd:nonNegativeInteger ; owl:onClass plt:DoubleFedInductionGenerator])
  owl:disjointWith ener-wind:PermanentMagnetGeneratorWindTurbine ;
  vs:term_status "testing" ;
  rdfs:isDefinedBy ener-wind:WindTurbineOntology .
```

Figure 4: Extract of formalization of the wind turbine ontology module

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a) Alignment

In addition to the OWL files corresponding to the created modules, we provide also an alignment file with the mappings if several concepts are represented in different ontologies. Figure 5 shows an extract for the alignment ontology.

```
#####################################
# Building and location             #
#####################################
bot:Zone owl:equivalentClass seas:Zone, brick:Zone ;
        rdfs:comment  """ can be linked to plt:EnergyConsumptionProperty  by the relation  plt:hasEnergyConsumption or plt:hasSelfEnergyConsumption,
                    can be linked to s4bldg:Building  by the relation  bot:containsZone.""".

s4bldg:Building owl:equivalentClass seas:Building,
                                    dogont:Building,
                                    bot:Building,
                                    th:Building,
                                    brick:Building,
                                    fiemser:Building.

plt:ResidentialBuilding  owl:equivalentClass seas:ResidentalBuilding.
plt:NonResidentialBuilding owl:equivalentClass seas:NonResidentalBuilding.

bot:Storey owl:equivalentClass seas:BuildingStorey,
                               dogont:Storey,
                               th:BuildingStorey,
                               brick:Storey.

cim:Location owl:equivalentClass sch:Place,
                                 gr:Location,
                                 brick:Location ,
                                 th:Location;
      rdfs:subClassOf bot:Zone .

s4city:City owl:equivalentClass sch:City,
                                seas:City;
      rdfs:subClassOf  bot:Zone.


bot:Site rdfs:subClassOf brick:Site . # Maybe equivalent as of other subclassings.
```

Figure 5: Extract of alignment ontology

3.1.2 ENERSHARE ontological modules

Ontology modularization can be defined as a technique used in the field of ontology engineering to manage the complexity and improve the usability of large ontologies by breaking them down into smaller, more manageable, and reusable modules.

In the ENERSHARE project, as the scope is related to 12 different use cases, it is not related to just one domain, but extends on cross transversal domains. For this reason, we create several related modules that can be manipulated separately or combined with other modules. The section below briefly describes these modules.

3.1.2.1 Chemical Ontology

This module represents chemical compounds (see Figure 6) such as Ethane, Methane, Hydrogen, etc. In the ENERSHARE project, three pilots expressed the need

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to represent these chemical compounds. In the pilot 4, the need was to represent the gas quality by defining its chemical composition (*ener-chem:hasChemicalConcentration*), and in the pilot 3 and the pilot 7, the need was to represent the emission target to determine, for example, that the target of the emission is CO2 (*ecfo:hasEmissionTarget* `ener-chem:CarbonDioxide`).

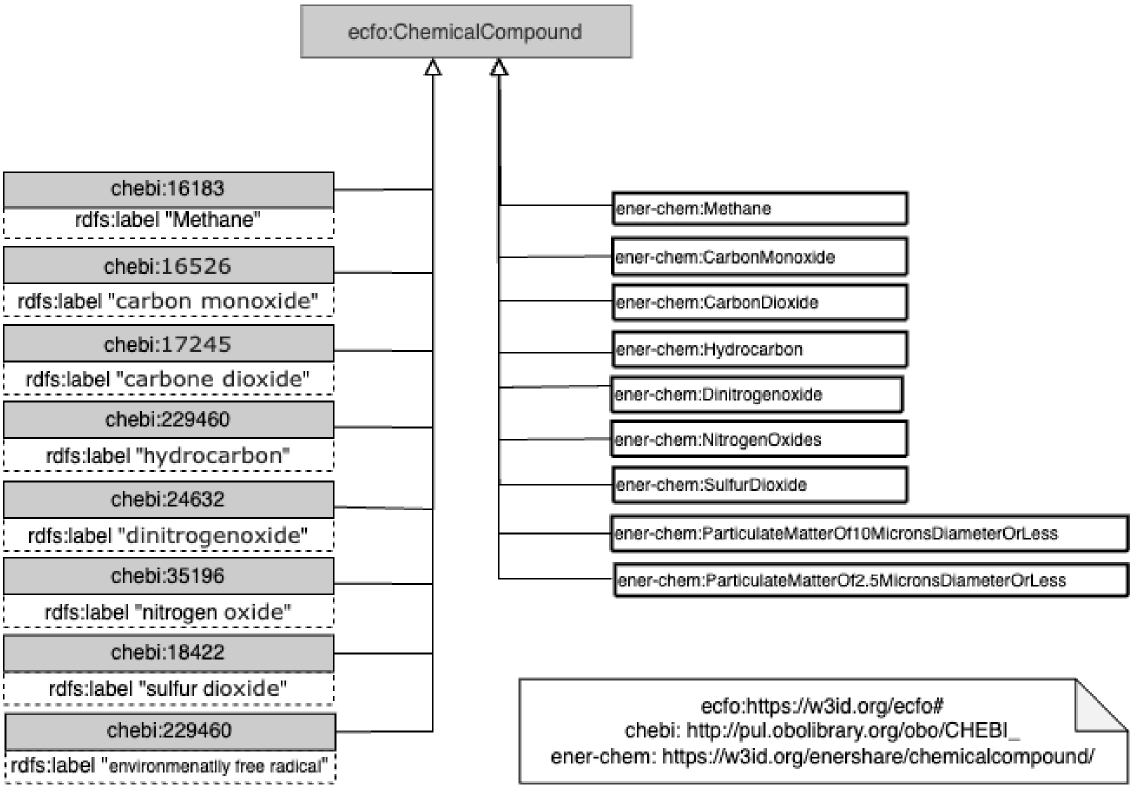

Figure 6: Extract of Chemical Compound Ontological Module

For enhanced interoperability and information enrichment, the chemical compound concepts of the chemical ontology are linked to the ChEBI ontology (Chemical Entities of Biological Interest) [6] whenever possible, for example, `ener-chem:Methane` *owl:equivalentClass* `chebi:16183`.

3.1.2.2 Building Ontology

This module focuses on the definition of the semantic relationships relevant to describe some characteristics of the building, such as, the presence of mansard (*ener-bldg:hasMansard*) or not, the number of floors (*ener-*

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bldg:hasNumberOfFloors) and the number of underground (*ener-bldg:hasNumberOfUnderground*), the first and second energy resource types used for heating, cooling, hot water and ventilation (*ener-bldg:hasFirstEnergyResourceForHeating*), and the different overall heat transfer coefficients (*ener-bldg:hasOverallHeatTransferCoefficient*) (see Figure 7). In the ENERSHARE project, three pilots (pilot 2, pilot 3 and pilot 7) expressed the need to represent buildings and their characteristics. This module does not include taxonomical aspects to determine the type of building because they exist in other ontologies such as the SEAS ontology which defines concepts like seas:ResidentalBuilding and seas:NonResidentalBuilding, which are needed, for example, in the pilot 3.

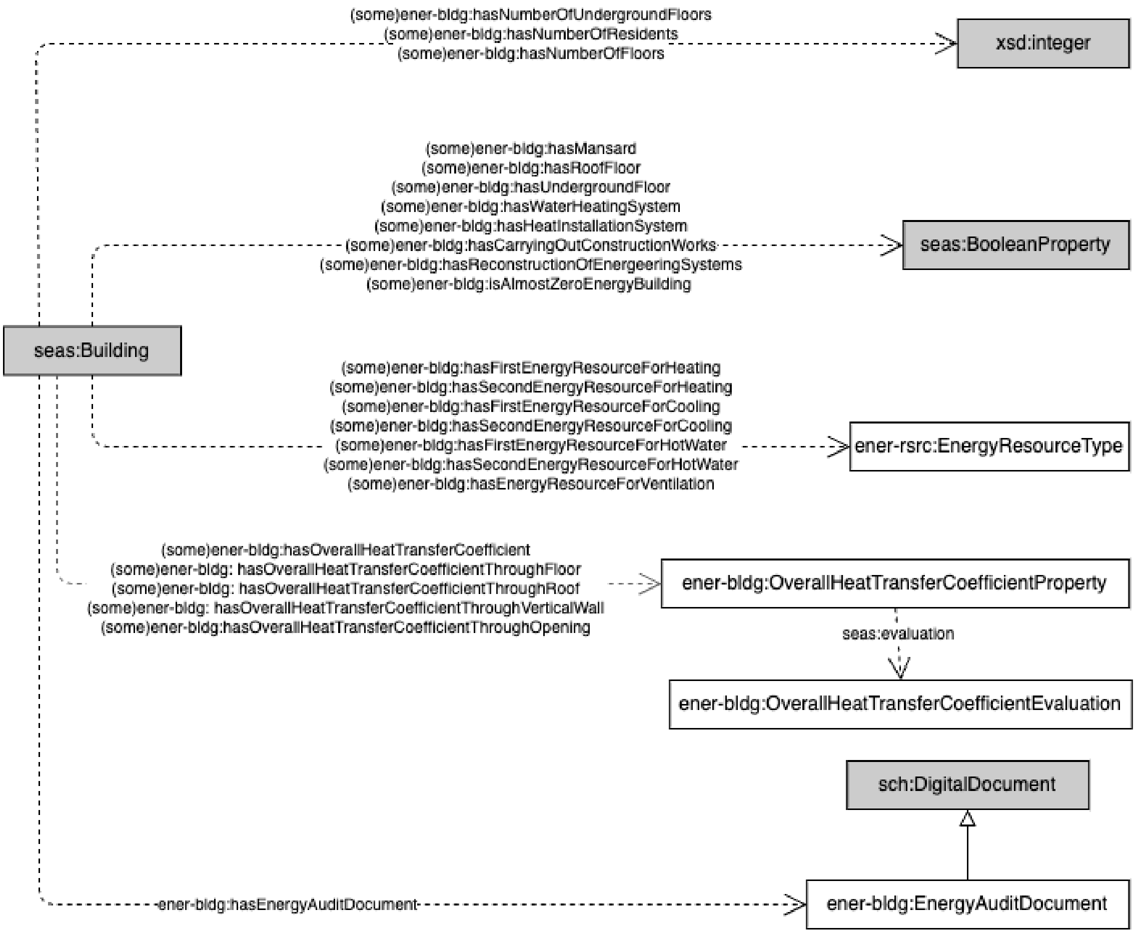

Figure 7: Building Properties Ontology Module

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3.1.2.3 Device Ontology

In the ENERSHARE project all pilots need the notion of device. However, most of the devices are already defined in existing ontologies. Therefore, this module focuses only on missed concepts that subsume existing concepts (see Figure 8). For example, the pilot 2 needs the specification of some appliances like washing machine (`ener-device:WashingMachine`), oven (`ener-device:Oven`) or dryer (`ener-device:Dryer`). The pilot 3 needs the concepts calorimeter (`ener-device:Calorimeter`) and heat flow meter (`ener-device: HeatFlowMeter`). The pilot 5 needs acoustic sensor (`ener-device: AcousticSensor`), power quality analyzer (`ener-device:PowerQualityAnalyser`), electricity smart meter (`ener-device:ElectricitySmartMeter`) and phasor measurement units (`ener-device: PhasorMeasurementUnits`).

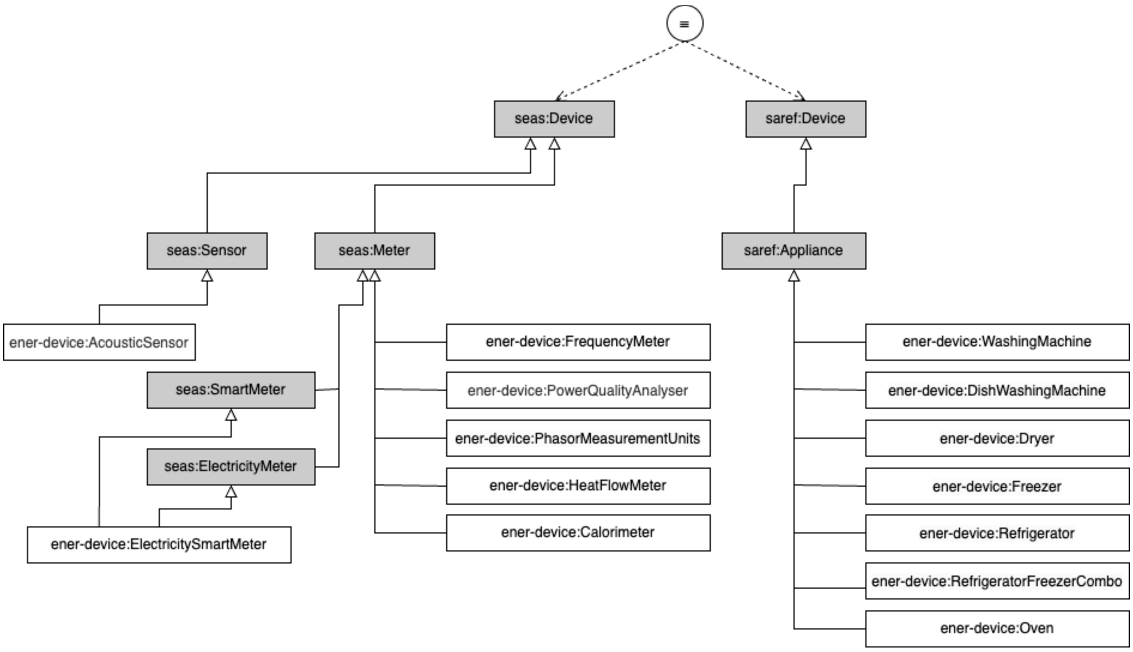

Figure 8: Taxonomy of device module

3.1.2.4 Digital Twin Ontology

This module presents the minimal concepts needed to represent a digital twin system according to the needs expressed in the pilot 4 and inspired by the work of C. Barros [7] and the Procedure Execution Ontology [8]. Three core concepts are defined (see Figure 9). The concept `ener-dt:DigitalTwin` subsums the

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pep:ProcedureExecutor and can have ener-dt:DigitalTwin as subsystem. It is related to the system that it represents, by using the relation ener-dt:isDigitalRepresentationOf. ener-dt:DigitalTwin implements (pep:implements) a twining algorithm (ener-dt:TwinningAlgorithm) and made (pep:made) the ener-dt:TwiningProcess which represents the one of the many executions of the digital twin that measures the state (ener-dt:measuresStateOf) of the system and used the procedure (pep:usedProcedure) ener-dt:TwinningAlgorithm. Because this work is use-case oriented, we do not pretend that the modeling covers all the needs. It should just cover the needs expressed in the pilot 4 use case.

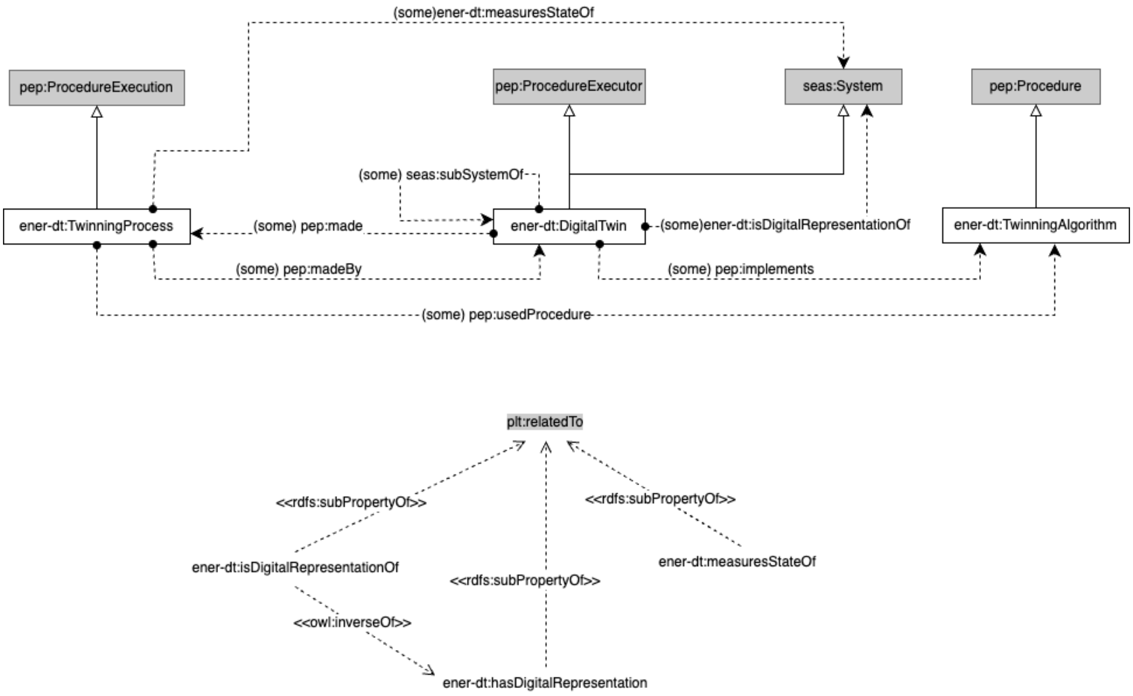

Figure 9: Digital Twin Ontology

3.1.2.5 Energy Resource ontology

This module was created to represent the energy resource type used in a system in general and in buildings in particular. The pilot 3, the pilot 4 and the pilot 7 express the need to represent these notions. The energy resource type is represented as instances of the concept ener-rsrc:EnergyResourceType (see Figure 10) like

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wood energy (`ener-rsrc:woodEnergy`), coal Energy (`ener-rsrc:coalEnergy`) and biofuel energy (`ener-rsrc:biofuelEnergy`).

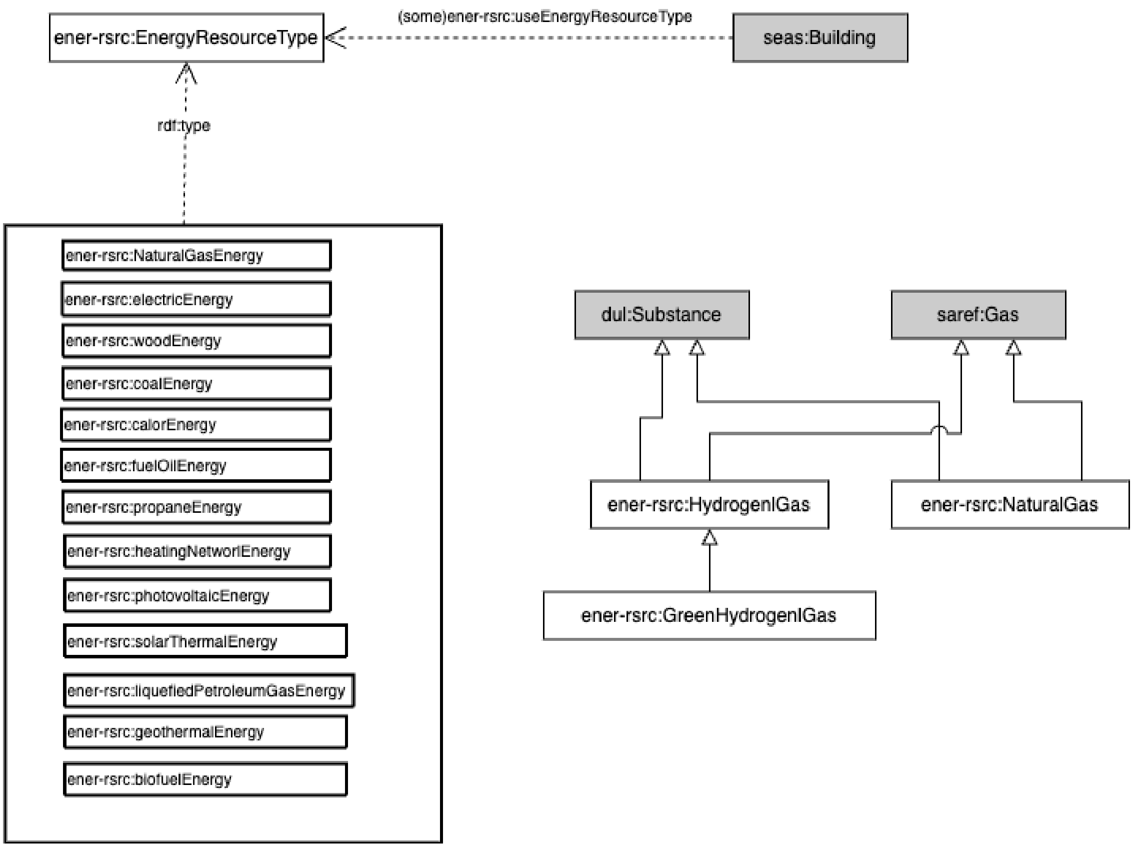

Figure 10: Energy Resource Type Module

3.1.2.6 Event Ontology

Like devices, in the ENERSHARE project all pilots need the notion of event. However, most of the event types are already defined in existing ontologies. Hence, this module focuses only on missed concepts that subsume existing concepts (see Figure 11). For example, the pilot 2 needs the representation of the cause of the alarm (`ener-evnt:AlarmCause`) and the signal irregularity alert (`ener-evnt:SignalIrregularityAlert`) in the context of health care of elderly people. The pilot 4 needs to represent the scheduled investment (`ener-evnt:ScheduledInvestment`). The charging session (`ener-evnt:ChargingStation`) and the micro payment (`ener-evnt:MicroPayment`) are events that are used in the pilot 5 and the pilot 6. The pilot 5 needs to represent

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grid events like the congestion event (`ener-evnt:GridCongestionEvent`) with the relation `ener-event:hasCongestion`, the reverse flow event (`ener-evnt:ReverseFlow`) with the relation `ener-evnt:hasReverseFlow`, and the optimization event (`ener-evnt:OptimizationEvent`) with the relation `ener-evnt:hasOptimization`.

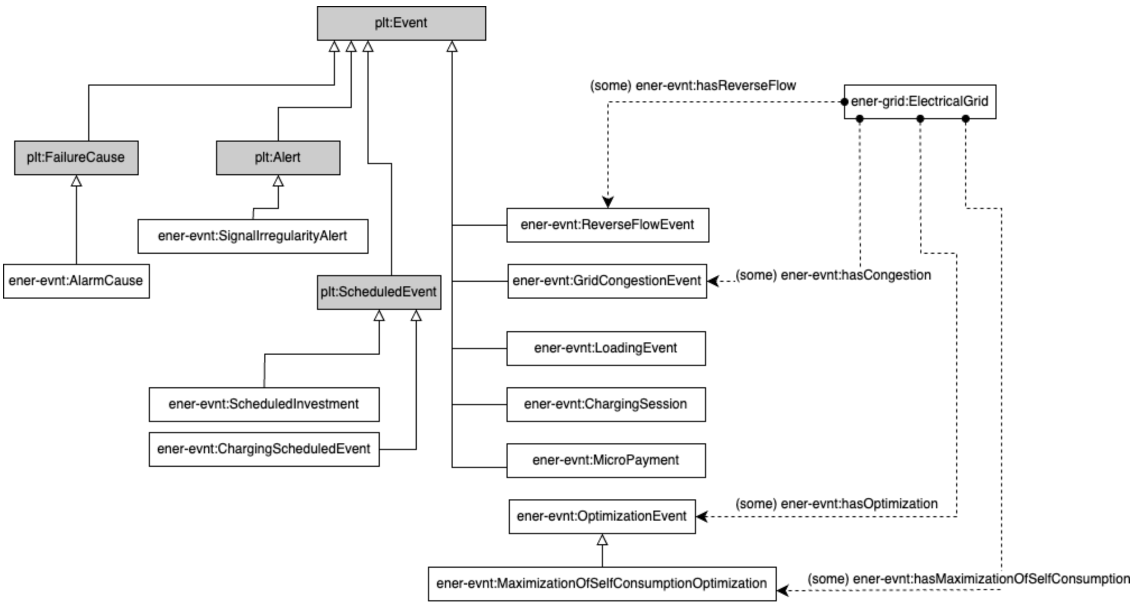

Figure 11: Event ontological Module

3.1.2.7 Failure Ontology

This module focuses on the working mode (`ener-fail:WorkingMode`) of a system using the relation (`ener-fail:isModeOf`). Either the system is working in healthy mode (`ener-fail:HealthyMode`) or in failure mode (`ener-fail:FailureMode`). The taxonomy of failure modes is added according to the need expresses in the pilot 1 to represent details in some failure's mode (see Figure 12) like leakage (`ener-fail:Leakage`), excessive friction (`ener-fail:ExcessiveFriction`) and abnormal speed (`ener-fail:AbnormalSpeed`). This module currently represents failure modes that may occur in the wind turbine domain. However, this module can be used and extended to express failures in other domains than the wind turbine ones.

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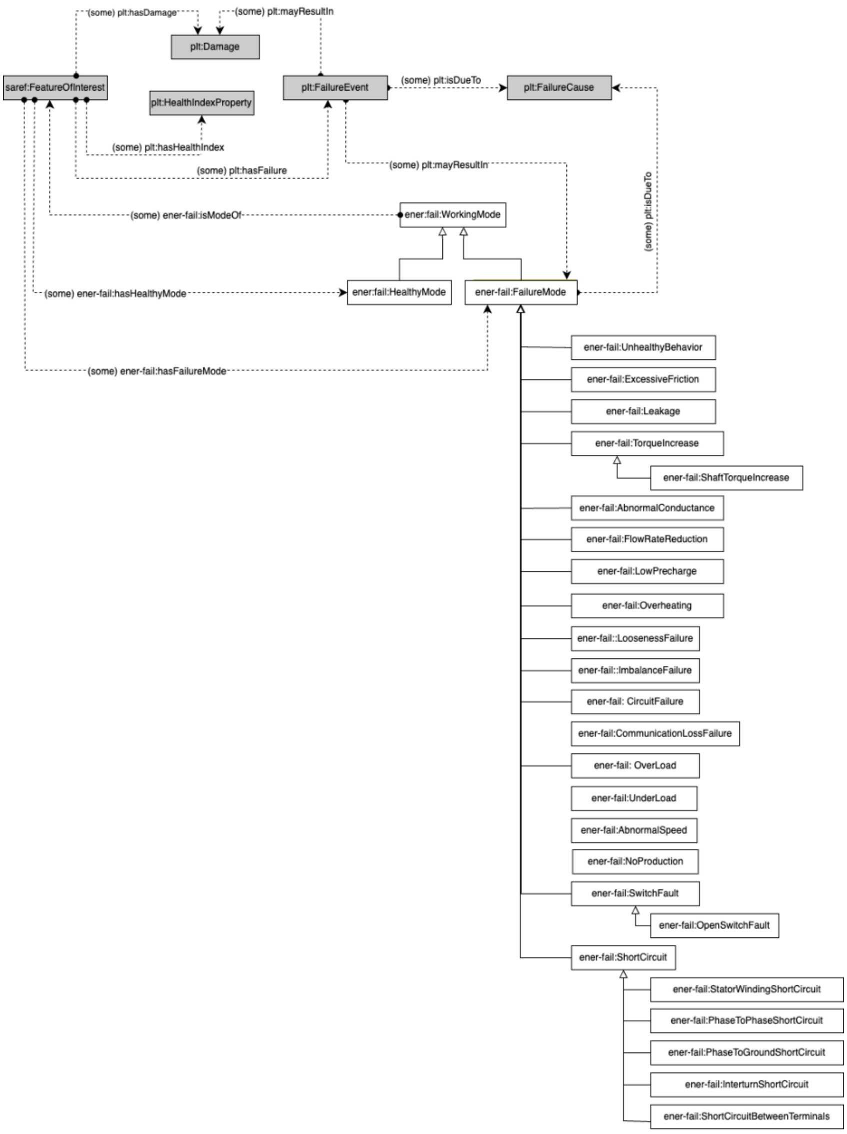

Figure 12: Failure Ontological Module

3.1.2.8 Flexibility Ontology

Energy flexibility refers to the ability of a system to adjust its energy consumption or production in response to external signals, such as price changes or grid demands. This concept is crucial for integrating renewable energy sources, improving energy efficiency, and maintaining grid stability. However, representing an entity's profile can help determine the system's flexibility. The aspects of demand and consumption are represented in the Property module because they are not related exclusively to the flexibility aspect. In the ENERSHARE project, four pilots express the need to

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represent profiles and their relations. Both the pilot 3 and the pilot 5 relate an entity (`seas:Building`, `seas:ElectricPowerSystem`, `plt:ThermalSystem`) to its flexibility profile (`ic-flex:FlexibilityProfile`) with the relation `ener-flex:hasflexibilityProfile`. In the pilot 5, more specific relations are needed such as `ener-flex:hasProvisionedFlexibilityProfile` and `ener-flex:estimatedFlexibilityProfile`. The pilot 5 and the pilot 6, in the use case related to the charging of electric vehicles, need to represent a charging profile (`ener-flex:ChargingProfile`) with the relation `ener-flex:hasChargingProfile`. In the pilot 2 it is needed to represent the typical consumption (`ener-flex:hasTypicalConsumptionProfile`) for a consumer. The preference profile (`ener-flex:PreferenceProfile`) was needed in the pilot 6.

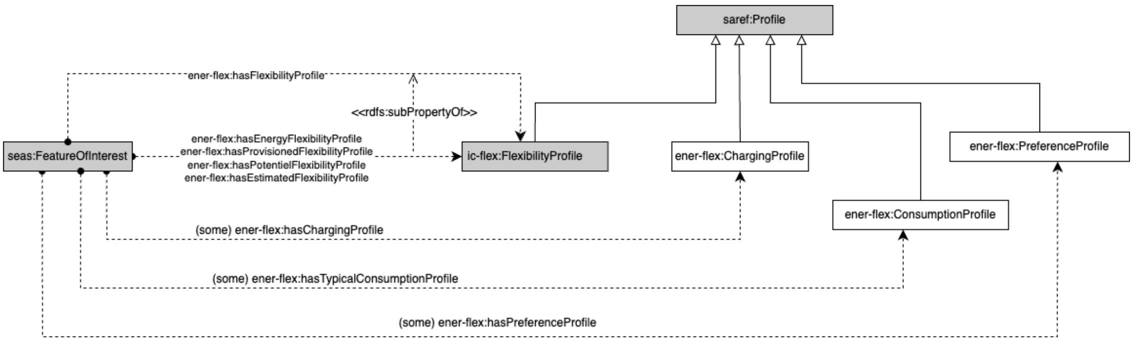

Figure 13: Flexibility Module

3.1.2.9 Forecast Ontology:

This module extends the PLATOON Forecast ontology, which in turn extends the SEAS Forecast ontology. The SEAS forecasting ontology provides the core concepts and relations that allow to represent the forecast context independently of the domains (`seas:Forecaster` that implements `seas:Forecasting` procedures and does `seas:Forecast`(s)). The forecasting ontology of PLATOON is reused to extend some generic concepts into more specific ones such as `ener-fc:ForecastOfEnergyProductionProperty` that extends `plt:ForecastOfEnergyProperty`.

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In the ENERSHARE project, several pilots expressed the need to represent new forecast of properties and/or entities and new semantical relations. Figure 14 shows the forecast ontology module that gives details on the new notions.

The pilot 2 expressed the need of the notions of the forecast of the buying price (`ener-fc:ForecastOfBuyingPriceProperty`) and the selling price (`ener-fc:ForecastOfSellingPriceProperty`) which forecast (`seas:forecastsProperty`) respectively, the property buying price (`seas:BuyingPriceProperty`) and selling price (`seas:SellingPriceProperty`).

The pilot 3 and the pilot 4, expressed the need to represent forecast of some demand (`ener-fc:ForecastOfDemandProperty`). Among these different types of concepts, we can cite: forecast of hydrogen demand (`ener-fc:ForecastOfHydrogenDemandProperty`), forecast of water demand (`ener-fc:ForecastOfDemandWaterProperty`), forecast of natural gas demand (`ener-fc:ForecastOf NaturalGasDemandProperty`) and forecast of energy demand (`ener-fc:ForecastOfEnergyDemandProperty`).

The pilot 4 expressed the need to specify the time prevision aspects of one forecast. Indeed, the forecast may have different time frames: short term (e.g., day ahead) medium term (e.g., week ahead, month ahead) and long term (e.g., year ahead).

For example, the forecast of the electric energy load property could be related to the system through several relations according to the frame time. The relations defined are: day ahead (`ener-fc:hasDayAheadForecastOfMaximumTotalEnergyLoadProperty`), week ahead (`ener-fc:hasWeek AheadForecastOfMaximumTotalEnergyLoadProperty`), month ahead (`ener-fc:hasMonthAheadForecastOfMaximumTotalEnergyLoadProperty`) and year ahead (`ener-fc:hasYearAheadForecastOfMaximumTotalEnergy LoadProperty`). See Figure 14 for more details.

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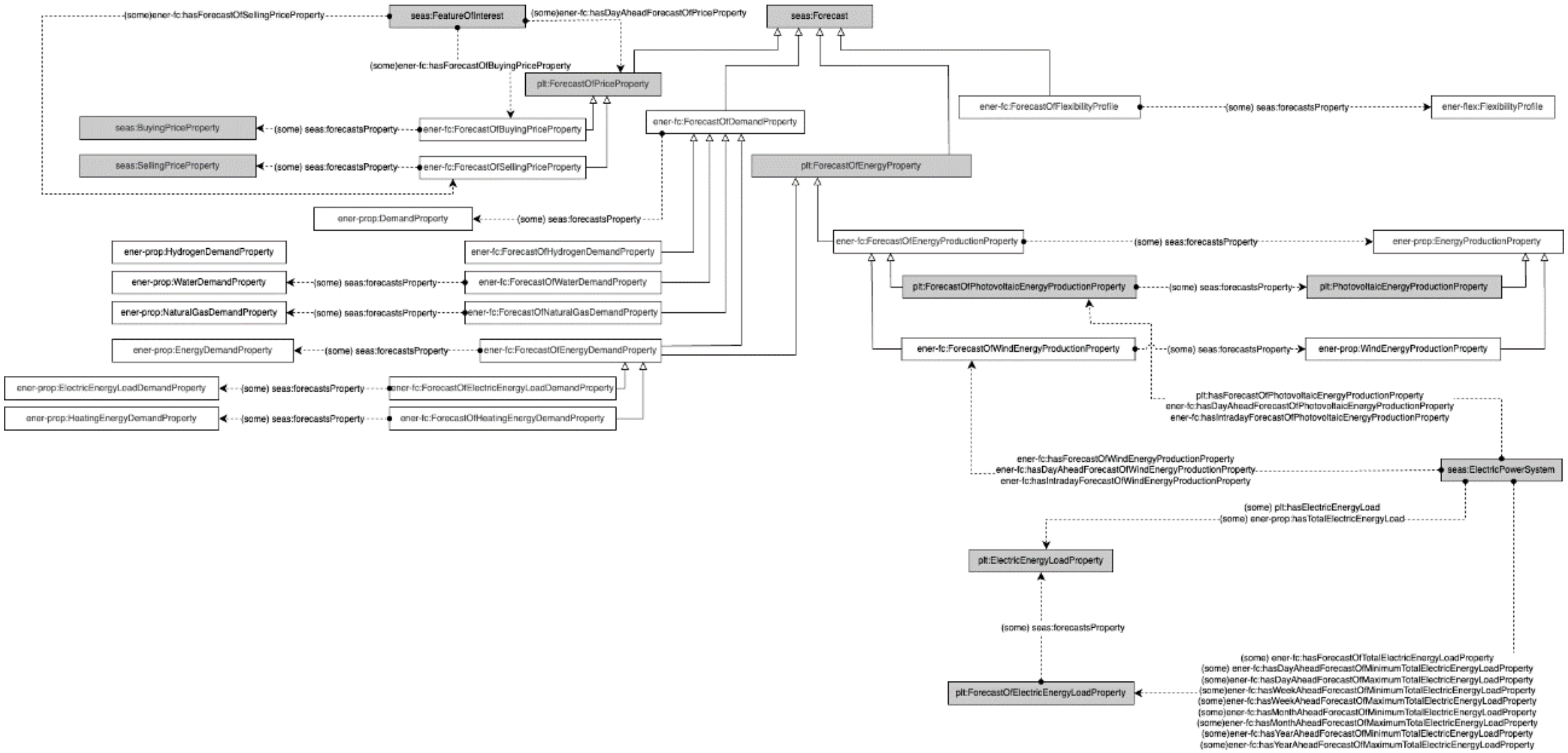

Figure 14: Forecast Module

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3.1.2.10 Grid Ontology

The grid module in the ENERSHARE project focuses on the representation of the taxonomy of grids to include different types of grids. One can distinguish between grids according to three axes (see Figure 15):

Geographical area: Two types of grids are defined according to the geographical area. i) Local grid (`ener-grid:LocalGrid`) which operates at a smaller scale, typically within a community, a campus or an industrial site. It can function independently or in conjunction with the national grid. ii) The national grid (`ener-grid:NationalGrid`) which is a large-scale network that connects the entire country.

Distance: Two types of grids are defined according to the distance: i) Transmission grid (`ener-grid:TransmissionGrid`), which connects large plants to a substation across vast region, ii) Distribution grid (`ener-grid:DistributionGrid`) which distributes the transported good or commodity over a shorter distance within cities, towns and local areas.

Commodity transported: Several grids could be defined according to the good transported. We can cite heating grid (`ener-grid:HeatingGrid`) which transports heating; Electrical Grid (`ener-grid:ElectricalGrid`) which transports electricity, and natural gas grid (`ener-grid:NaturalGasGrid`) which transports natural gas.

The combination of some of these axes, allows the definition of more specific types of grids such as high voltage transmission grid (`ener-grid:HighVoltageTransmissionGrid`) which is both electrical grid and transmission grid, and low voltage distribution grid (`ener-grid:LowVoltageDistributionGrid`) which is both electrical grid and distribution grid. In the ENERSHARE project, several pilots may need the representation of the connection to the grid, in particular, the pilots 2, 3, 4, and 5.

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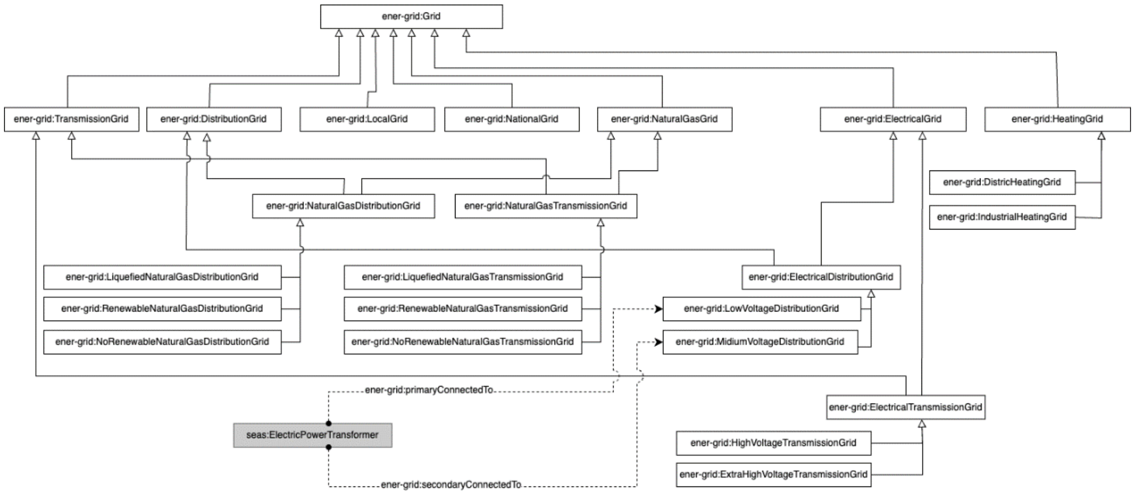

Figure 15: Grid Ontology Module

3.1.2.11 Maintenance Ontology

Maintenance is a critical aspect of ensuring the reliability, safety, and efficiency of assets. Proper maintenance practices help to prevent failures, extend the lifespan of equipment, and optimize the performance of assets. In ENERSHARE project, the pilot 1 is the main pilot that uses the maintenance aspect. However, some concepts may be used by other pilots in all domains where maintenance is considered. In this module (see Figure 16) distinction is made between scheduled maintenance (`ener-mnt:ScheduledMaintenance`) and unscheduled maintenance (`ener-mnt:UnscheduledMaintenance`). The scheduled maintenance is related to (`ener-mnt:hasMaintenanceShedule`) its maintenance schedule (`plt:MaintenanceSchedule`) where information about the last and the next date of maintenance are provided, and the expected cost if estimated. Unscheduled maintenance is generally related to a failure event, then `ener-mnt:isToRestore` relationship is provided to relate the maintenance to the failure mode. Three periodic maintenance types (`ener-mnt:PeriodicMaintenance`) are defined in the wind turbine domain: semiannual (`ener-mnt:SemiannualMaintenance`), annual (`ener-mnt:AnnualMaintenance`), and two years (`ener-mnt:TwoYearsMaintenance`). Other types of maintenance may occur in the life of an asset that may sometimes be scheduled or unscheduled depending on the context. An example of maintenance is the replacement maintenance (`ener-`

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`mnt:ReplacementMaintenance`) which can be scheduled periodically or happened after some failure.

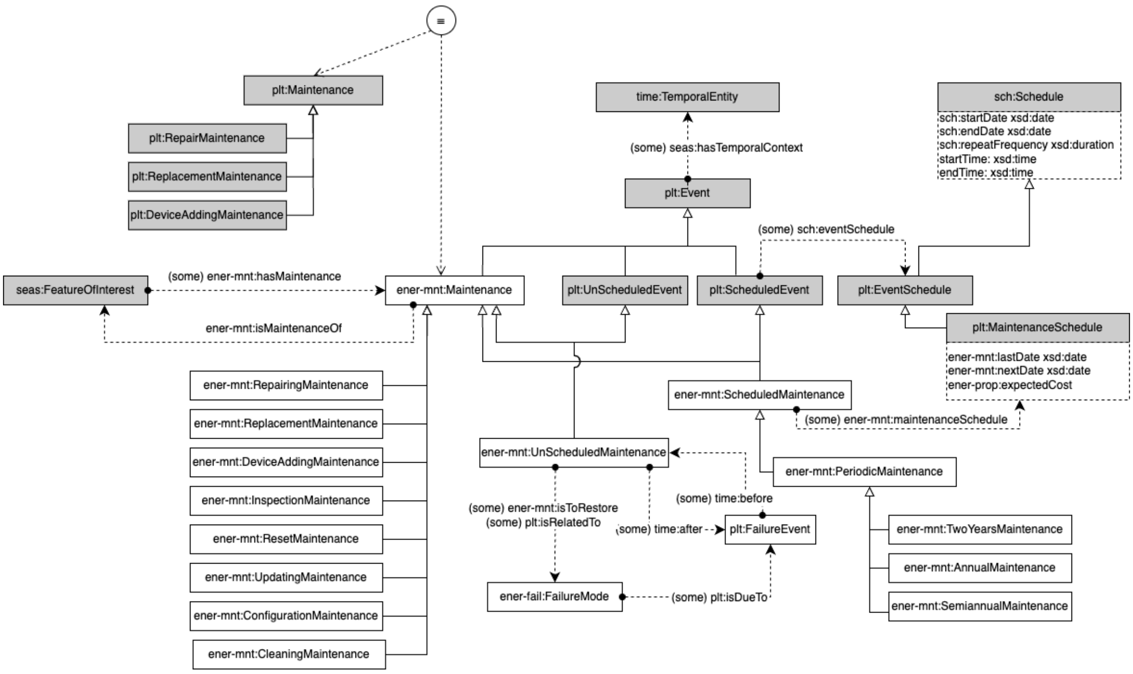

Figure 16: Maintenance Ontology Module

3.1.2.12 Market Ontology

This module focuses on the taxonomy of market types according to the need of the ENERSHARE project (see Figure 17). The pilot 2 is the one that expressed the need to represent different types of energy markets. One can distinguish between several types of markets according to the goods traded in this market. Then, energy market (`ener-mrkt:EnergyMarket`) is a market (`ener-mrkt:Market`) where energy commodities are traded. According to the type of energy, one can distinguish between the `ener-mrkt:NaturalGasMarket` where natural gas is traded, and the `ener-mrkt:ElectricityMarket` where electricity is traded. Internal electricity market (`ener-mrkt:InternalElectricityMarket`) and ancillary services market (`ener-mrkt:AncillaryServicesMarket`) are both types of electricity markets. The notion of Smart contract (`ener-mrkt:SmartContract`) is also a new notion needed in the pilot 2.

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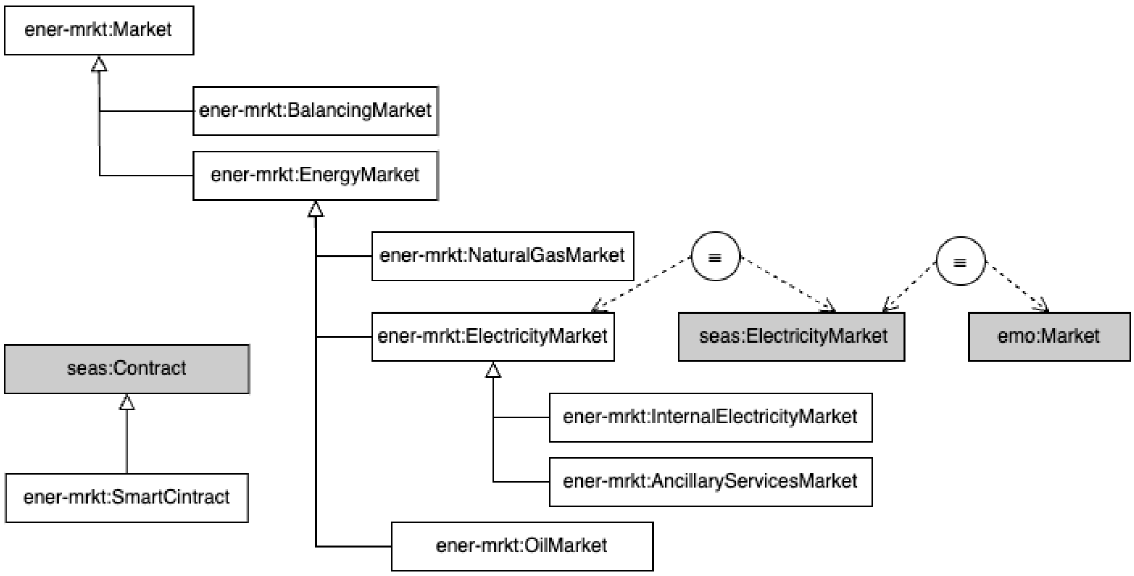

Figure 17: Market Taxonomy Module

3.1.2.13 Player Ontology

This module focuses on the taxonomy of players. In the ENERSHARE project all pilots use the notion of player including some types of providers (e.g., `ener-play:ServiceProvider`, `ener-play:DataProvider`), some types of owners (e.g., `ener-play:VehicleOwner`, `ener-play:DataOwner`), some types of consumers (e.g., `ener-play:DataConsumer`, `ener-play:ServiceConsumer`, `ener-play:EnergyConsumer`). The Figure 18 shows the players that are needed in the pilots and do not exist already in the SEAS Player ontology.

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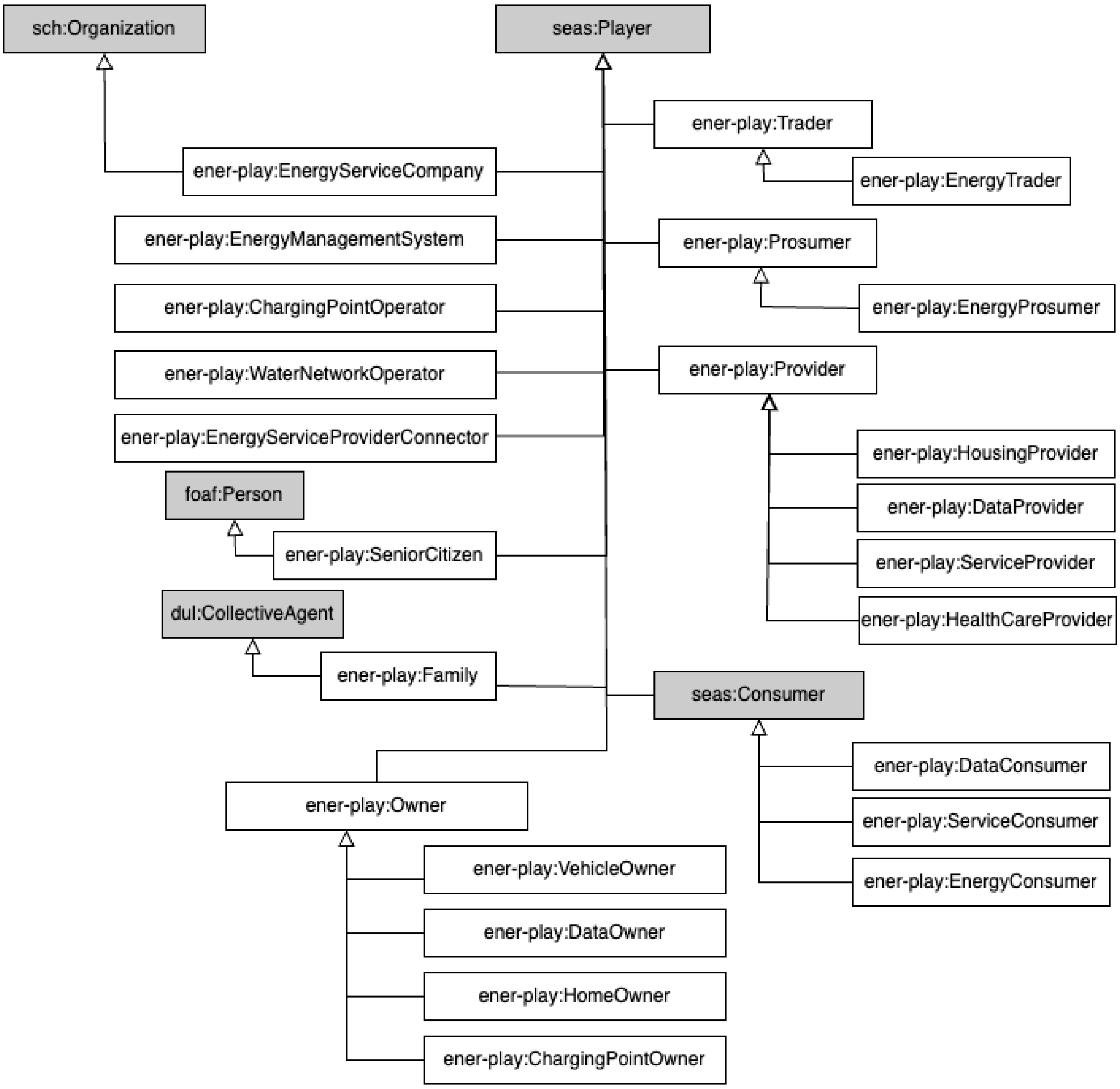

Figure 18: Player Ontological Module

3.1.2.14 Price Ontology

This module essentially adds semantic relations related to the price property. It is closely related to the SEAS Pricing ontology that already defines price concepts. In the ENERSHARE project, the pilots 2, 4, 6 and 7, expressed the need of price representation. The Figure 19 shows the new relations that are added to this module. We can cite investment cost price (`ener-price:hasInvestmentCostPrice`) and internal price (`ener-price:hasInternalPrice`).

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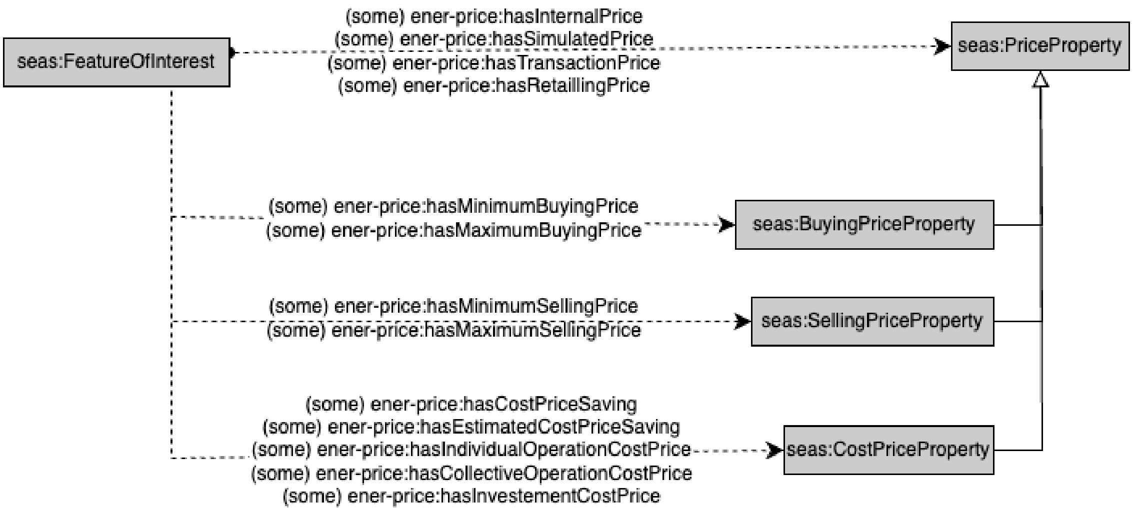

Figure 19: Price Property module

3.1.2.15 Property Ontology

This module focuses on defining properties of an entity (`seas:FeatureOfInterest`). This module may concern all domains to represent properties and their evaluation. This module extends SEAS ontology. The Figure 20 shows an extract of the properties ontology that concerns the representation of demand properties (`ener-prop:DemandProperty`) which are needed in pilots 2, 3, 4, and 5. This module is huge because it concerns all pilots, so it cannot be represented in detail in this report.

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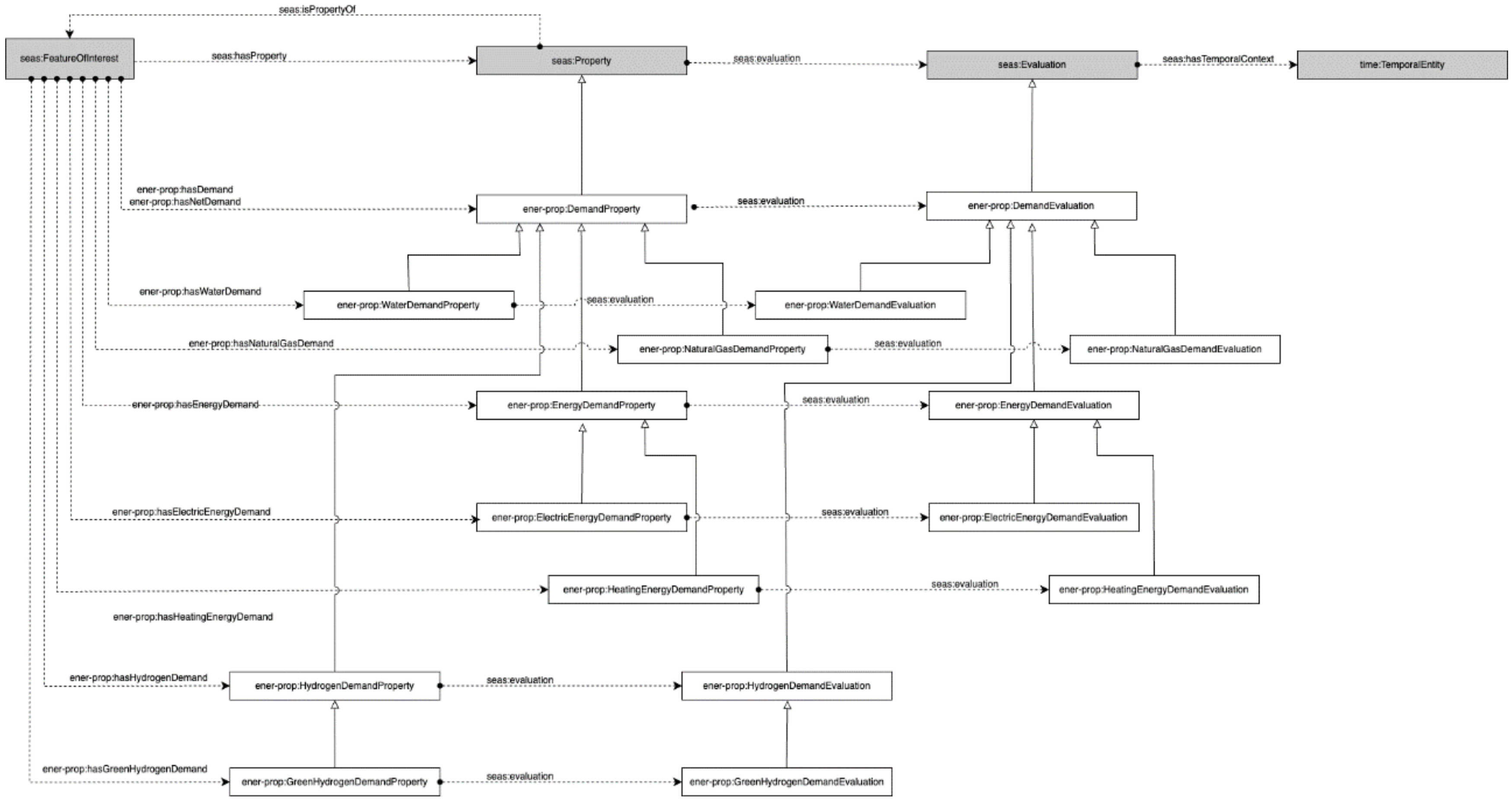

Figure 20: Extract of Property module

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3.1.2.16 Schedule Ontology

This module focuses on the representation of aspects related to a schedule. In the ENERSHARE project, a schedule is needed in the pilots 5 and 6. The Figure 21 shows the concepts and relations created in this module, in particular, the aspects related to the booking (`ener-scd:hasBooked`) of a charging schedule (`ener-scd:ChargingSchedule`) which is associated to an electric vehicle with the relation `ener-scd:hasChargingSchedule`.

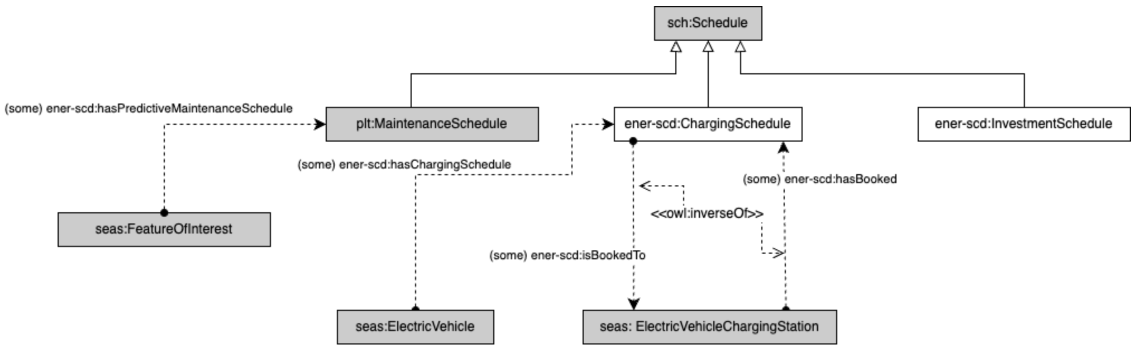

Figure 21: Schedule Ontology Module

3.1.2.17 System Ontology

This module focuses on the taxonomy of systems or assets. In the ENERSHARE project all pilots expressed the need to add some concepts related to systems. For example, the pilot 4 needs to represent the storage system of natural gas (`ener-sys:NaturalGasStorageSystem`) and the storage system of synthetic natural gas (`ener-sys:SyntheticNaturalGasStorageSystem`) which are both kinds of gas storage systems (`ener-sys:GasStorageSystem`). The pilot 2 needs to represent water storage systems (`ener-sys:WaterStorageSystem`) like the tank (`ener-sys:WaterTank`). The pilot 3 needs to represent the heat pipe (`ener-sys:HeatPipe`) and heat substation (`ener-sys:HeatSubstation`). The Figure 22 shows an extract of systems added in the context of the ENERSHARE Project.

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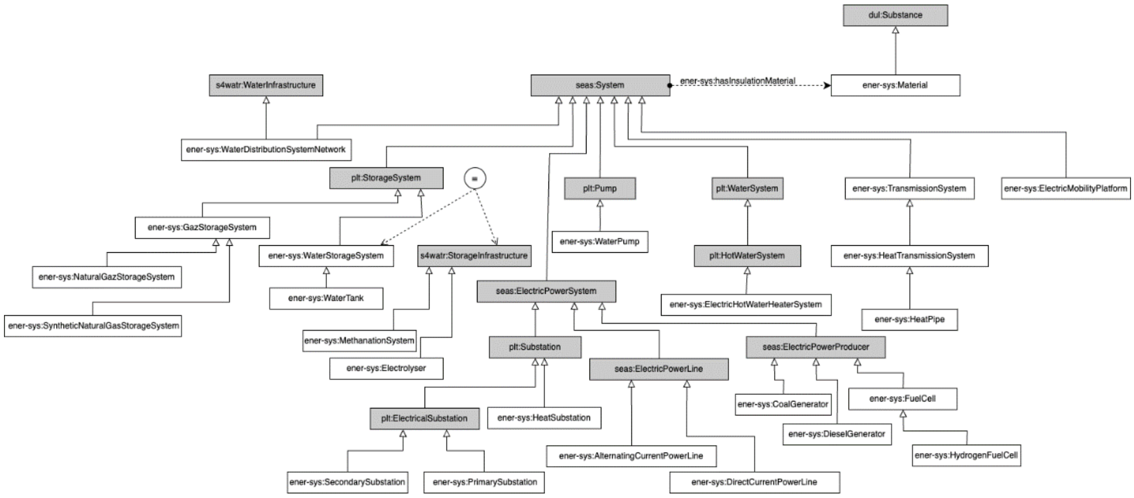

Figure 22: Extract of System ontology

3.1.2.18 Wind Turbine Ontology

This module focuses on the domain of the wind turbine field. It extends and completes the wind turbine ontology of the PLATOON ontology that already covers a large part of the domain. In the context of the pilot 1, two types of wind turbines are added according to the type of generator: `ener-wind:DoubleFedInductionGeneratorWindTurbine` that are wind turbines that have `plt:DoubleFedInductionGenerator` as a subsystem and `ener-wind:PermanentMagnetGeneratorWindTurbine` that are wind turbines that have `ener-wind:PermanentMagnetGenerator` as a subsystem (`seas:hasSubSystem`). Other components are added in this pilot 1, like the hydraulic pitch system (`ener-wind:HydrauliquePitchSystem`) with all its subcomponents such as `ener-wind:HydraulicPitchCylinder`, `ener-wind:HydrauliquePitchPump`, `ener-wind:HydrauliquePitchMotor`, and `ener-wind:HydrolicPitchAccumulator`. The Figure 23 shows the concepts and relations that are defined in the wind turbine module.

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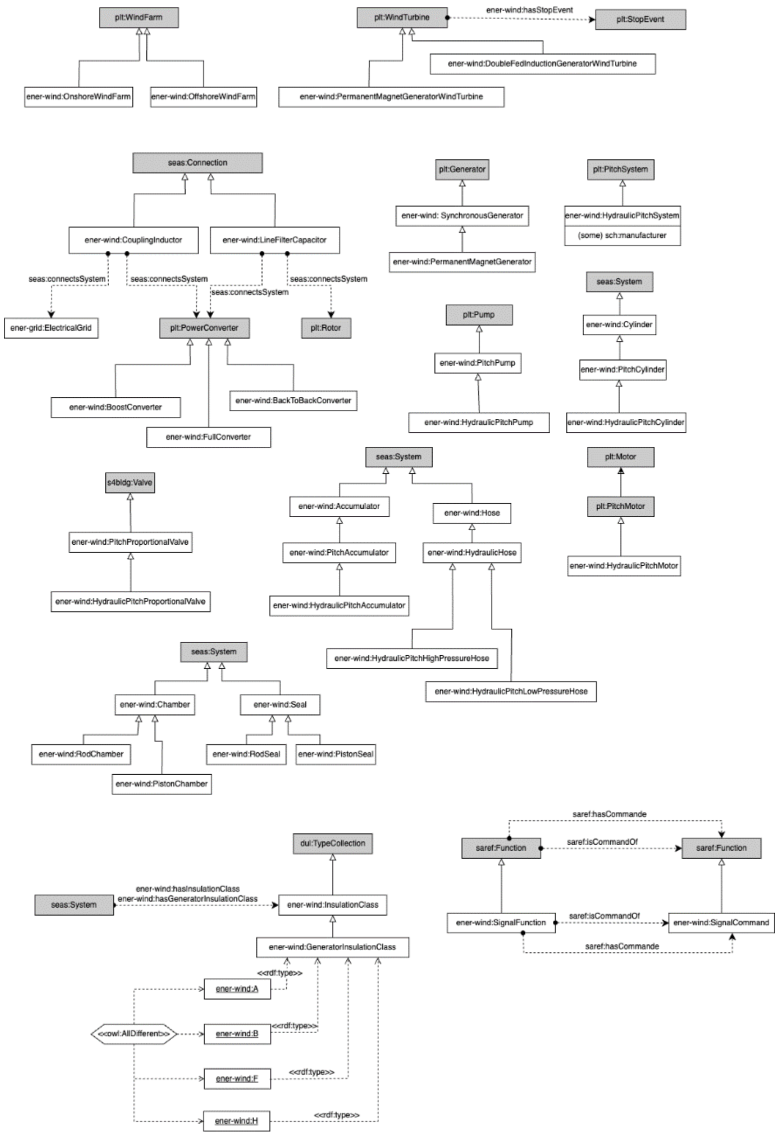

Figure 23: Wind Turbine Ontology

3.2 Vocabulary Hub

This section explains how the vocabulary hub plays a supportive role in the adoption and use of the ENERSHARE models.

As stated in deliverable D3.2, TNO has deployed their implementation of the vocabulary hub component at https://energy.vocabulary-hub.eu/. The scope of this vocabulary hub includes, but is not limited by, the models from the ENERSHARE

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project. The further development of the vocabulary hub as a software component is described in section 4.1, so it is not repeated here.

Figure 24 shows that the ENERSHARE ontological modules are findable and reusable in the vocabulary hub.

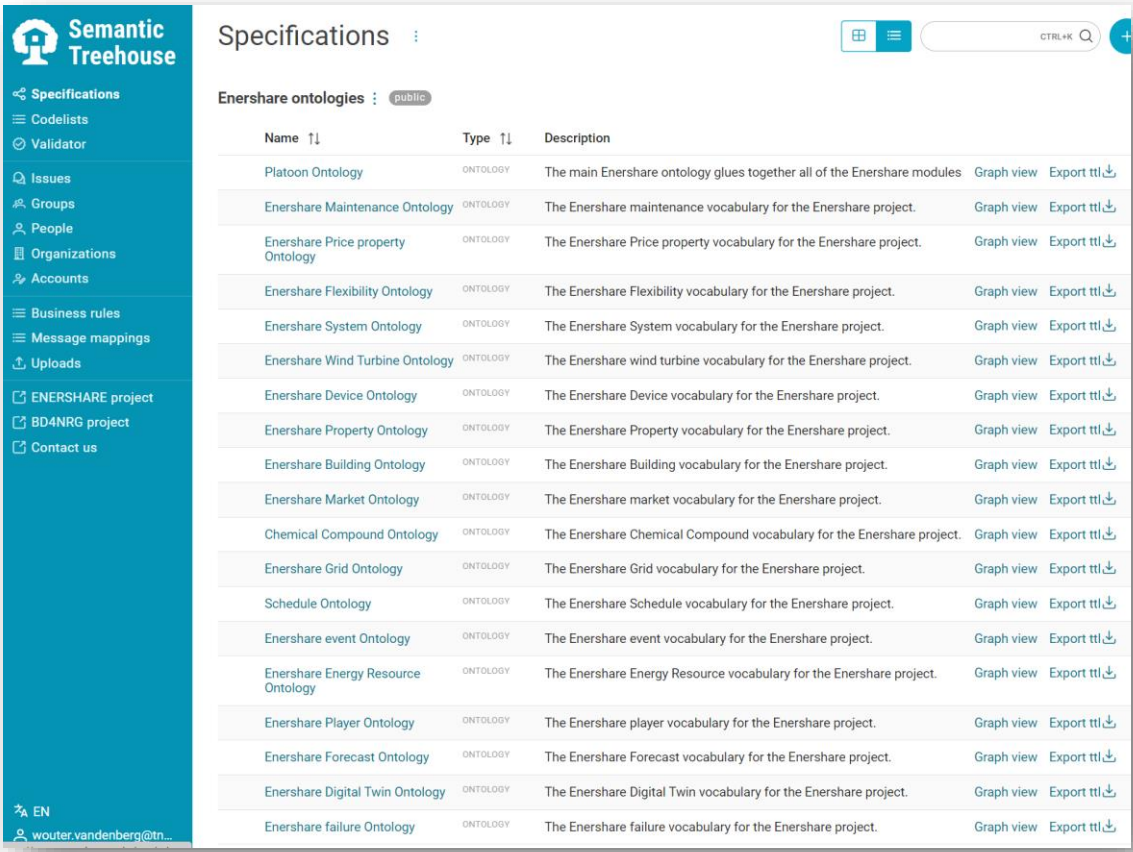

Figure 24: ENERSHARE ontological modules in the specifications' registry of the vocabulary hub

How does the vocabulary hub support users in adopting the ENERSHARE models for maximum interoperability? It provides two routes that the user can take:

1. Starting from the common ENERSHARE models and taking steps towards creating use case specific API specifications and schemas (i.e., a top-down approach).

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2. Starting from their use case specific data sample or schema and taking steps towards the common ENERSHARE models (i.e., a bottom-up approach).

3.2.1 Top-down approach

Figure 25 shows how the user can specify the root class (or starting point) for the message model.

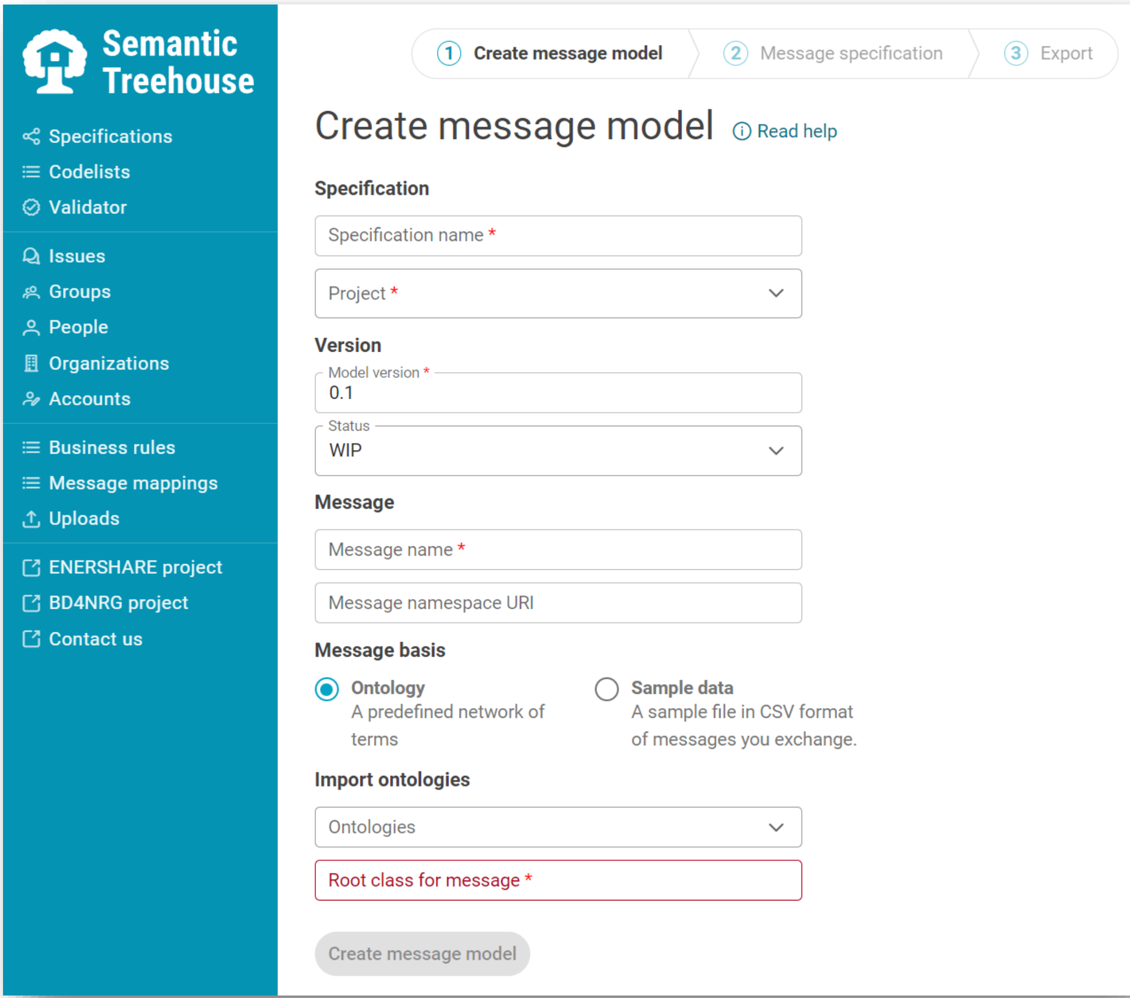

Figure 25: A new data model can be based on a pre-defined ontology or on a sample of your own data (see message basis)

Users that want to start with interoperability requirements in mind are advised to take the top-down approach and define their message exchange model using the

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ENERSHARE ontological modules. In the case of pilot 1, which involves data about the operating status of wind turbines, the WindTurbine class from the ENERSHARE Wind Turbine ontology is a good starting point and should be selected as the root class for the new message model:

`https://w3id.org/platoon/WindTurbine`.

Figure 26 shows how the user has progressed to step two of the wizard. The vocabulary hub now shows all the properties linked to the WindTurbine class coming from the ENERSHARE ontological modules. The user is supposed to select the properties from this list that they need for their message exchange model. Usually this is just a very small subset and, as we will see, the pilot 1 use case is not different.

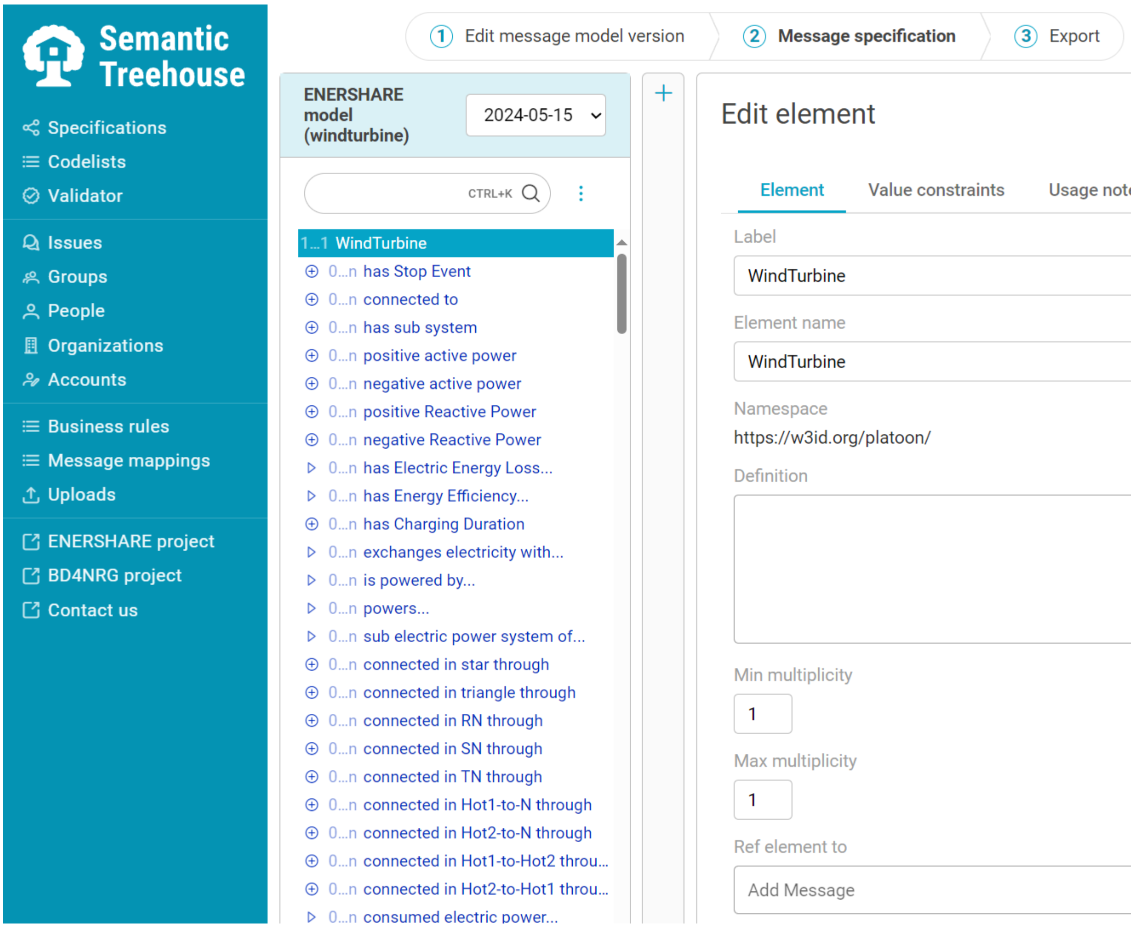

Figure 26: The user can select windturbine properties from the ENERSHARE modules (and others)

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There are different APIs in pilot 1, which means different datasets, but for this illustration we focus on just one: *Data-driven failure detection algorithms for wind turbine components*, specifically for anomaly detection in the Permanent Magnet Synchronous Generator (PMSG). See also section 4.2 for more info on the pilot 1 APIs. Supposedly the failure detection algorithms take as an input the average temperature of the nacelle, the blade pitch, the average windspeed, the average torque, the current and the active power of the generator. The user is thus tasked to find these information elements and the vocabulary hub provides further assistance through a search bar. The vocabulary hub shows the resulting message exchange model after the user is done selecting the ontological properties relevant for their use case.

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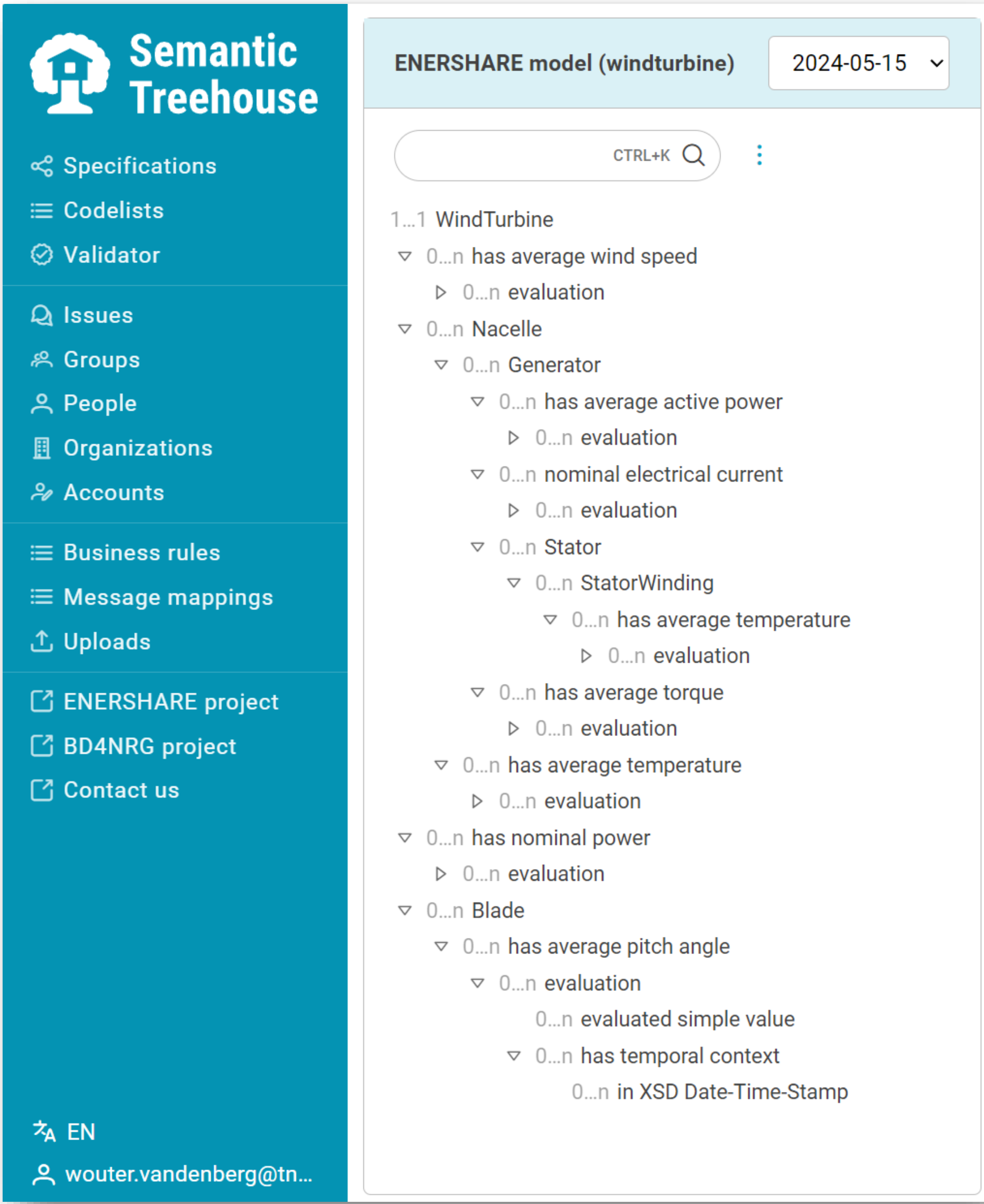

Figure 27: The user has selected the WindTurbine properties from the ENERSHARE modules that are required for their pilot use case

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Note that in the interest of brevity, the evaluation sub-tree is collapsed in all places in the model except at the bottom. There it shows that each evaluation consists of an evaluated simple value and a date-timestamp. This pattern originates from the SEAS Evaluation Ontology, which was reused in the ENERSHARE ontological modules, as mentioned in section 3.1.2.15.

As a final step, the vocabulary hub allows the user to export validation artefacts for the newly created message exchange model in the syntax of their choice (XML, JSON, RDF, OpenAPI Specification). Figure 28 shows how the GUI provides these options to the user. Note that the user is also provided with generated RML code, that can be used to transform any data that conforms to the generated schema into linked data conforming to the ENERSHARE vocabulary chosen at the start of this process.

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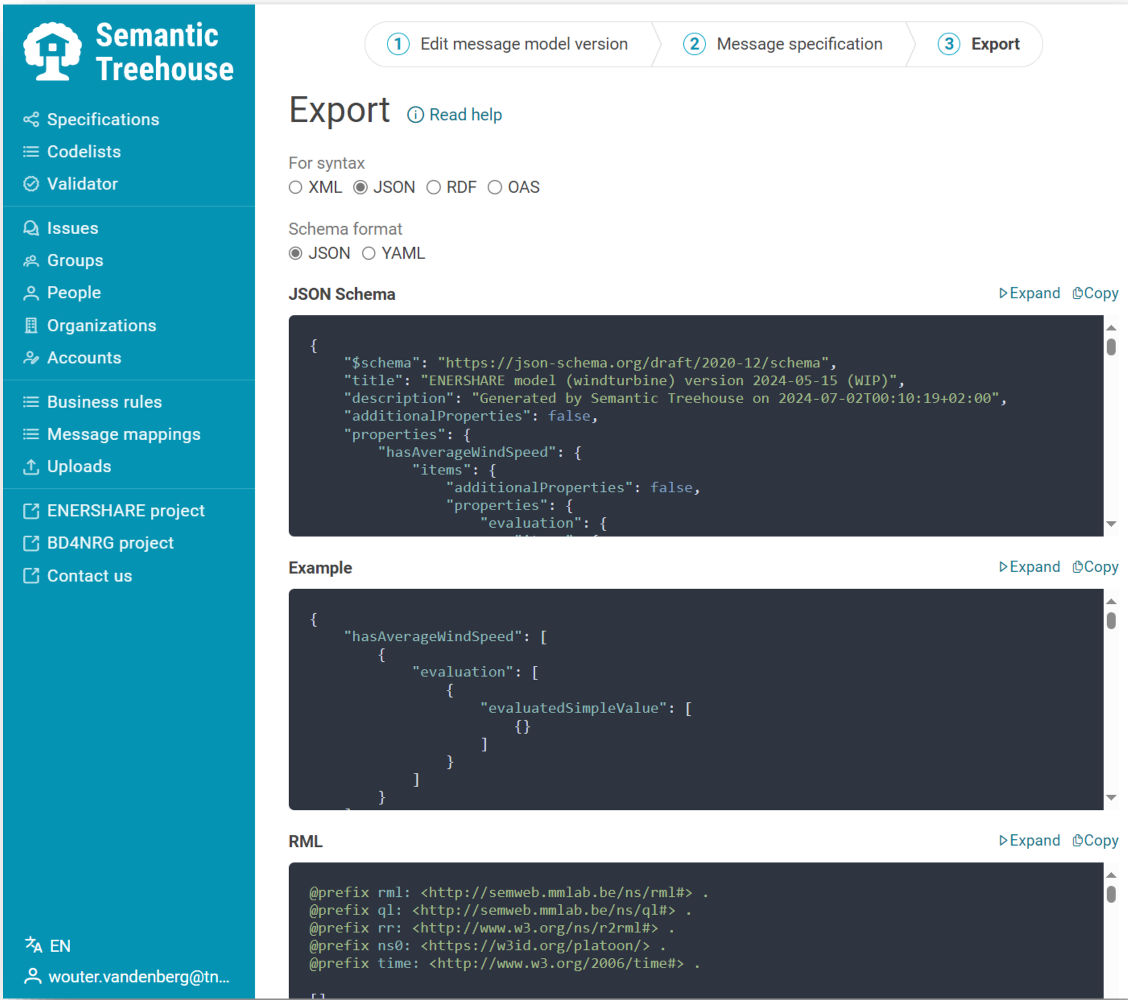

Figure 28: Export options provided by the vocabulary hub wizard

3.2.2 Bottom-up approach

The top-down approach benefits strongly from the fact that ENERSHARE's modelling activities have resulted in ontological modules that match the pilot use cases' needs. And even then, the prospected user is required to have some familiarity with these modules in order to successfully use them for their message exchange model. What if these prerequisites are not met? (Indeed, what if there is no shared set of ontological modules in the first place?)

The bottom-up approach starts with the assumption that the data provider already has implemented some API specifications and some data is made available this way.

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In these circumstances, the vocabulary hub can be used to start annotating the semantics of this API/data in a way that can be reused and adopted by others.

Just like with the top-down approach, the user journey starts by creating a new message exchange model in the vocabulary hub (see Figure 25) but this time the model is generalized from a sample of the data made available through their API.

Still using the wind turbine anomaly detection use case, let us assume the following example of instance data:


```
{
    "windfarm_id": "FRBRT",
    "windturbine_id": "91840",
    "timestamp": "2019-08-24T00:00:00Z",
    "nacelle_temperature": "27.54 Cel",
    "blade_pitch_angle": "450 deg",
    "windspeed": "9.32 m/s",
    "generator_active_power": "495.7 kW",
    "generator_current": "417.18 A",
    "generator torque": "3370.42 N.m",
    "stator_winding_temperature": "27.54 Cel"
}
```


Figure 29 shows this data is mirrored in a generalized message exchange model in the vocabulary hub.

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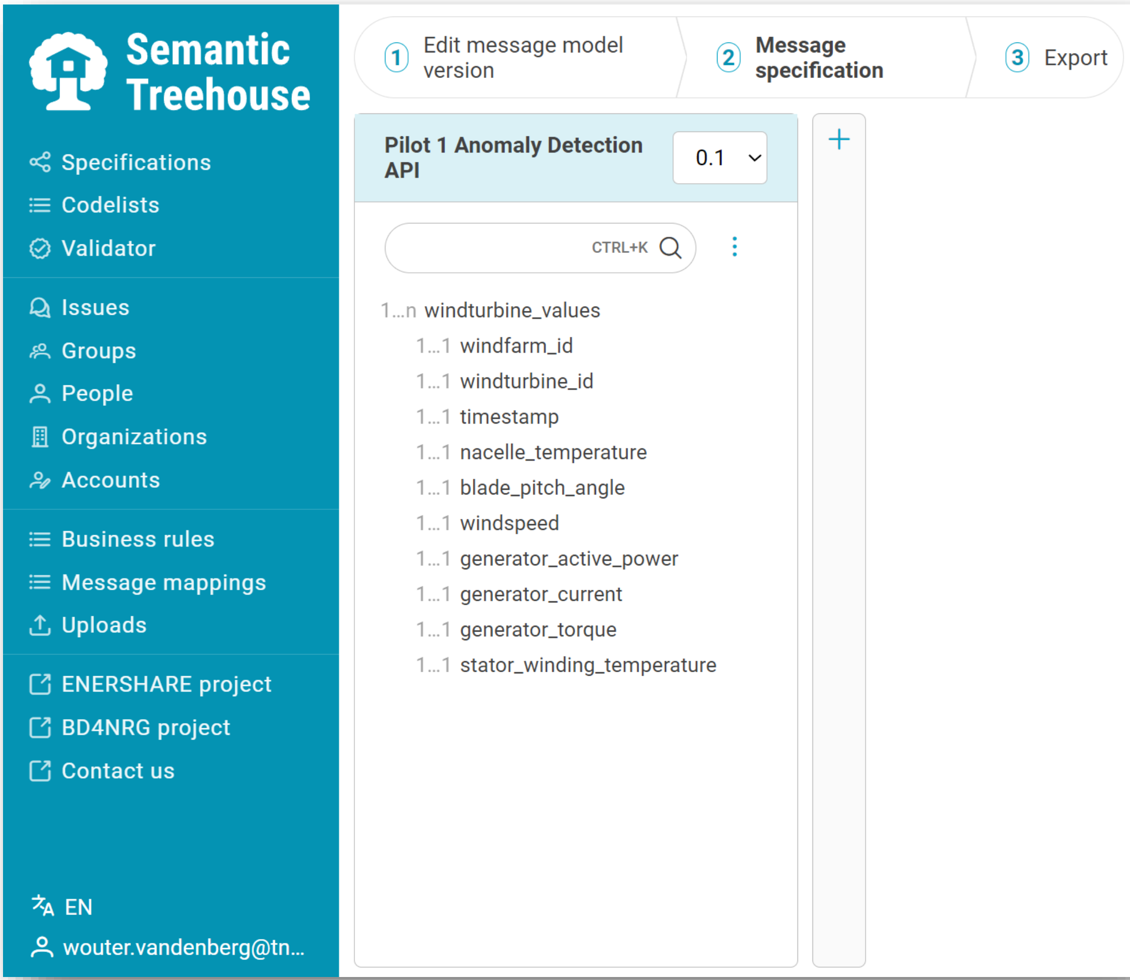

Figure 29: Generalized model based on instance data from an API

As soon as it is created by the user, this model is immediately findable and visible to other visitors of the vocabulary hub, as shown in Figure 30.

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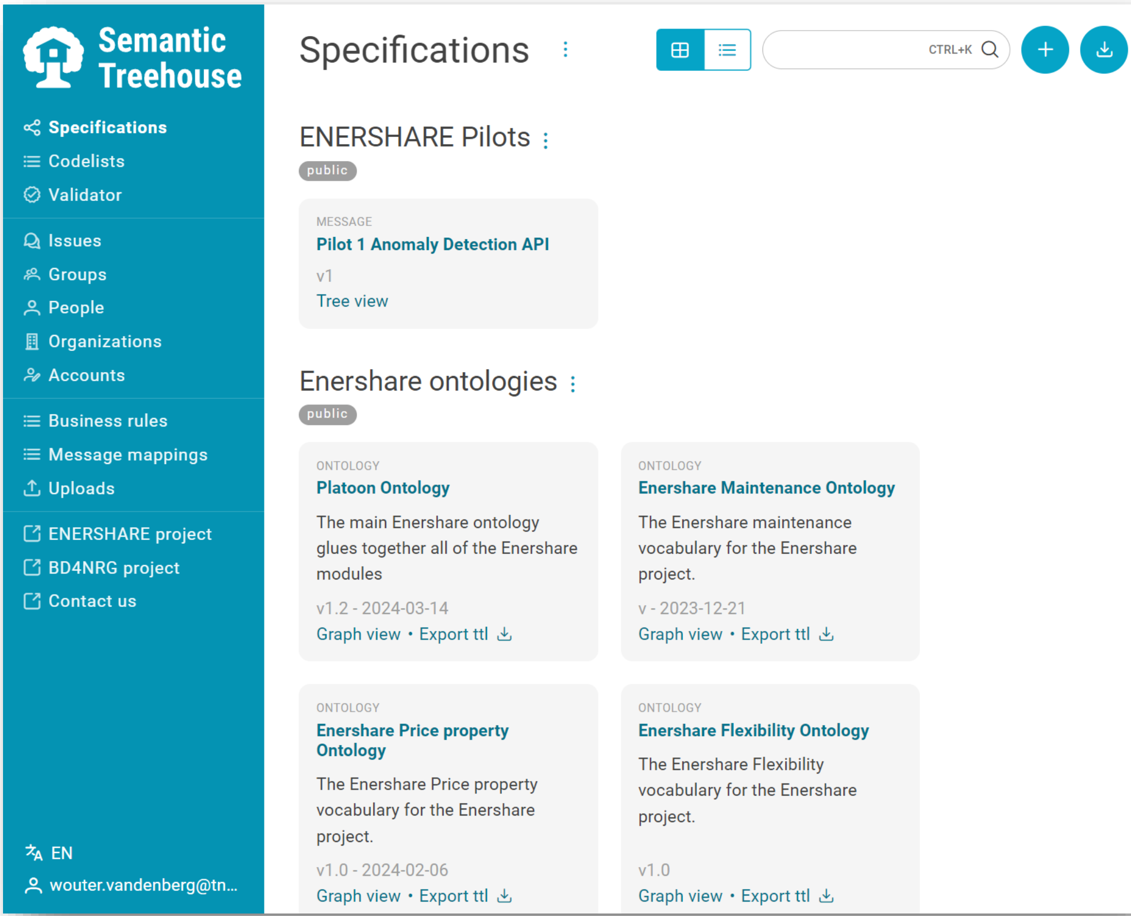

Figure 30: The pilot 1 model is immediately added to the vocabulary hub specification registry

Given the visibility and findability of the model in the vocabulary hub, the creator has an incentive to enrich the message exchange model with more information about what this data is. In turn, visitors can ask questions or raise issues about the data, as shown in Figure 31.

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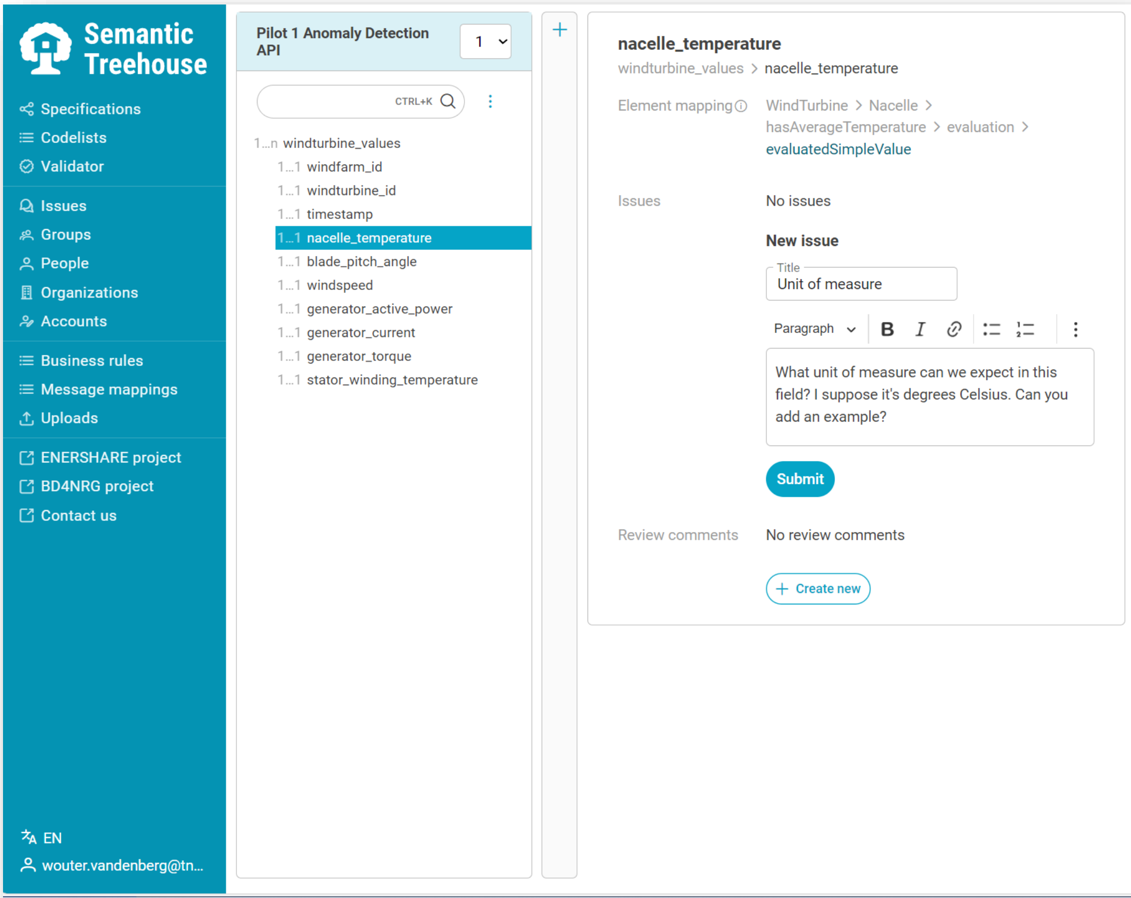

Figure 31: Issue creation and tracking foster collaboration in the vocabulary hub

One common type of question is "how does this message exchange model relate to [*xyz*]?". For instance, one could wonder how this pilot 1 API specific model relates to the ENERSHARE ontological modules. The vocabulary hub supports comparison activities by allowing users to view two models next to each other and create mapping highlights. Figure 32 shows how the model we created in the previous section (using the 'top-down approach') is added to the view for easy comparison. Clicking a different element in the pilot 1 model on the left will highlight the semantic equivalent in the ENERSHARE model to the right.

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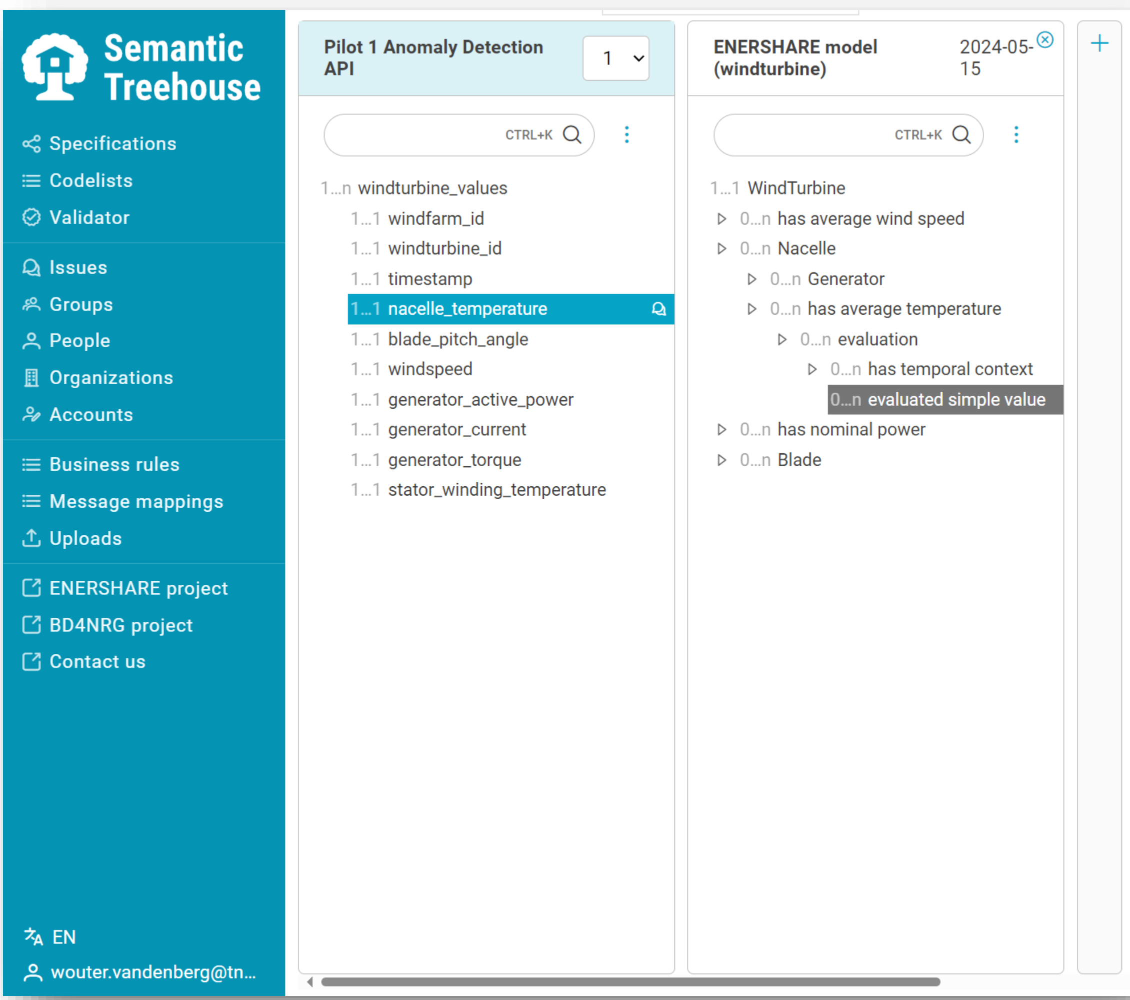

Figure 32: Comparison of the pilot 1 API specific data model and the general ENERSHARE model

3.2.3 Conclusion

The vocabulary hub plays a supportive role in the adoption and use of the ENERSHARE models. It goes beyond providing a simple registry of vocabularies. Instead, it fosters collaboration on the topic of semantic interoperability by providing data providers with two different approaches to create semantic descriptions of their data. We found that the bottom-up approach, in particular, complemented the centralized semantic modelling methodology because it is fast, simple, and

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decentralized. In addition, when top-down and bottom-up processes are carried out in parallel in the vocabulary hub, interesting comparison and mapping activities can arise when the two meet in the middle.

3.3 Contribution to FIWARE's Smart Data Models

ENERSHARE's data model is also contributing to the Smart Data Models initiative, SDM, which is a collaborative effort led by FIWARE Foundation[1], TM Forum[2], IUDX[3], and OASC[4] to create open, harmonized data models for multiple sectors including smart cities, smart agrifood, smart utilities, smart industry, and, of course, energy [9]. Currently, Energy is the domain that accounts for the largest number of data models.

Thanks to ENERSHARE, new data models are being created in the Energy domain of SDM or existing data models are being updated with new attributes.

3.3.1 Introduction to Smart Data Models' approach

The Smart Data Models initiative provides a multidomain approach that enables the users a holistic view. Besides, the self-contained approach of the data models simplifies their use. There are possible relationships between the different entities (named classes in the ontology domain) but the relation is not hierarchical, therefore there is not a need to browse the dependencies between the models to use them.

Currently SDM accounts for close to 1000 data models but the number grows steadily as long as more users contribute to the initiative. The agile standardization approach allows the creation of a data-model-in-a-week. The best practices of this approach are described in section 3.3.2.

Smart Data Models include three main elements:

1. The technical schema defining the data structure and types coded in JSON schema. Additionally, the schema is also exported in yaml and SQL formats.

[1] https://www.fiware.org/foundation/
[2] https://www.tmforum.org/
[3] https://iudx.org.in/
[4] https://oascities.org/

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2. A human-readable specification document, currently available in 8 languages (EN, FR, DE, SP, IT, JA, KO, ZH), including a textual description of the different objects and attributes and the type of information stored in them.
3. Payload examples for both NGSIv2 and NGSI-LD versions and exports in csv, DTDL.

Data models are grouped into subjects. Currently, every subject is a git repository. The subjects can belong to one or several domains. The domains represent industrial sectors[5].

Next, we provide the description of the contribution of ENERSHARE's use cases and ontology to the SDM as well as a summary table.

3.3.1.1 Chemical data models

Some of the chemical data models in ENERSHARE are related to the chemical quality of the gas generated. These concepts are brand new elements to be incorporated into the energy subject at the SDM. The data model will be named GasQuality and it is currently in the incubated repository.

URL of GasQuality subject in SDM (new): https://github.com/smart-data-models/incubated/tree/master/SMARTENERGY/dataModel.GasQuality/GasQuality

[5] https://www.fiware.org/smart-data-models/

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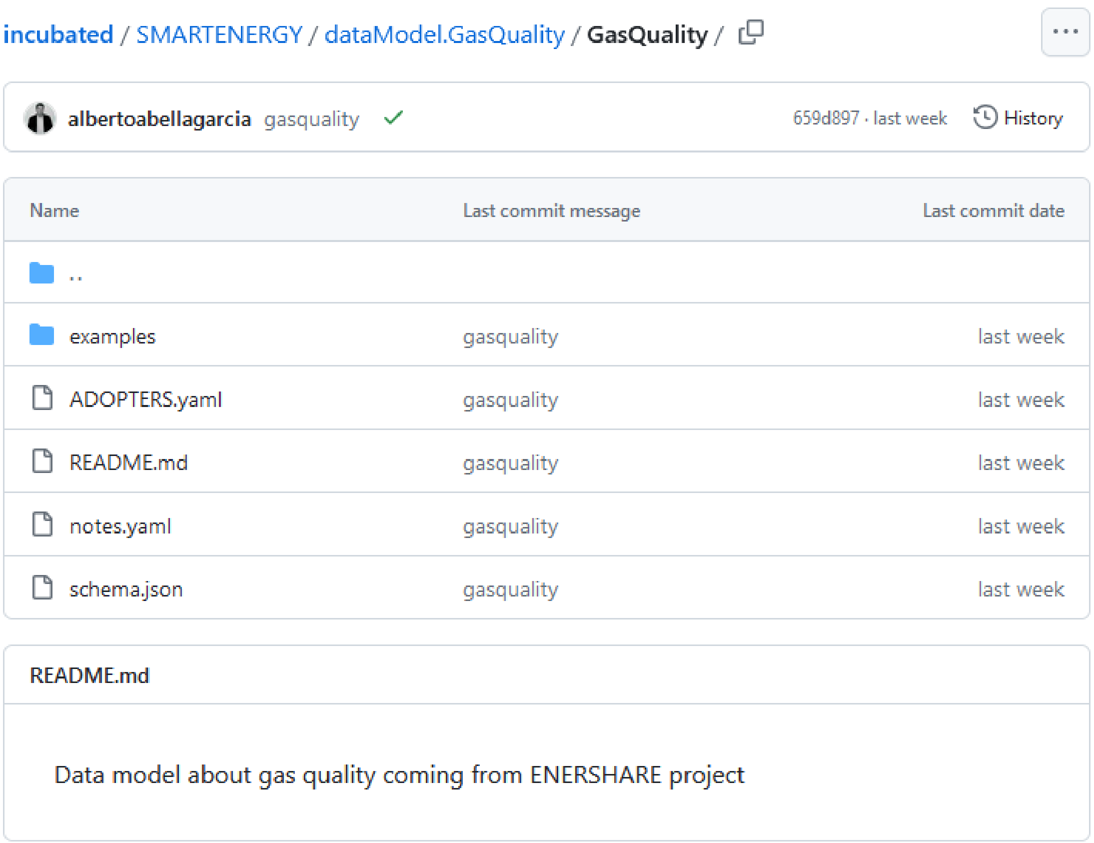

Figure 33: New GasQuality subject in SDM

3.3.1.2 Building data models

There is already a data model in SDM corresponding to Building. Consequently, there is not a need to create a new data model. However, some of the attributes required for ENERSHARE's use cases (e.g., the number of floors) were not present and a new version of the model will be published with the additional attributes.

URL of Building subject in SDM (updated): https://github.com/smart-data-models/dataModel.Building/tree/master/Building

3.3.1.3 Device data models

There is a data model in SDM corresponding to Device and lots of other data models coming from the Open Connectivity Foundation[6] (the largest devices makers

[6] https://openconnectivity.org/foundation/membership-list/

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association in the world) located in their own subject[7] . Initially, there is not a clear need to create new data models. However, as long as there are many implementations associated to the SAREF appliance subclass (Oven, Dryer, WashingMachine, Dishwashingmachine, Freezer, Refrigerator, RefrigeratorfreezerCombo) and several others related to the SAREF Meter subclass (FrequencyMeter, PowerQualityAnalizer, PhasorMeasurementUnits, HeatFlowMeter, electricitySmartMeter and calorimeter), it is possible that there would not be a clear matching and additional data models may need to be created.

URL of Device subject in SDM (updated): https://github.com/smart-data-models/dataModel.Device/tree/master/Device

3.3.1.4 Digital twin data models

There was not an equivalent subject in the SDM, therefore a new subject has been created and the corresponding data models.

URL of Digital Twin subject in SDM (new): https://github.com/smart-data-models/incubated/tree/master/CROSSSECTOR/dataModels.DigitalTwin

3.3.1.5 Energy resource type data models

This data model represents the different energy types and can be added to the energy resource type in SDM as an additional attribute with an enumeration of values, including: NaturalGasEnergy, electricEnergy, woodEnergy, coalEnergy, calorEnergy, fuelOilEnergy, propaneEnergy, heatingNetworkEnergy, photovoltaicEnergy,ThermalEnergy, geothermalEnergy, and biofuelEnergy. They will be added to the building data model.

3.3.1.6 Event data models

This data model exists in SDM under the denomination of Alert. The cause is already available as alertSource. There is a category attribute where all the types of alerts can be included, like signalIrregularityalert, ScheduledInversion, GirdCongestionEvent, ReverseFlow or OptimizationEvent.

[7] https://github.com/smart-data-models/dataModel.OCF

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URL of Alert subject in SDM (updated): https://github.com/smart-data-models/dataModel.Alert/tree/master/Alert

3.3.1.7 Failure data models

There is not a need to include new data models because the failure modes can be added to the data model system as a list of different enumerated values. There is a system data model at SDM coming from the mapping of the SAREF4SYST ontology. The point is to extend this data model.

URL of System subject in SDM (updated): https://github.com/smart-data-models/dataModel.S4SYST/tree/master/System

3.3.1.8 Flexibility data models

Flexibility is related to the ontology SAREF4ENERGY[8] which is not currently mapped at SDM although SAREF[9], SAREF4BUILDINGS[10] and SAREF4SYST[11] are. It will require the partial mapping of the ontology to allocate those parts of the data model used in the ENERSHARE use cases.

3.3.1.9 Forecast (price) data models

This group of data models include the forecasting of the energy prices (either selling or buying) and the forecast of resources' demand like gas, energy in different periods. New data models were needed in the existing Energy subject at SDM. Consequently, new data models with the names EnergyPriceForecast and EnergyResourcesForecast have been created in the incubated repository.

URL of Energy subject in SDM: https://github.com/smart-data-models/dataModel.Energy/

Incubated repository (new): https://github.com/smart-data-models/incubated/tree/master/SMARTENERGY

[8] https://saref.etsi.org/saref4ener/v1.2.1/
[9] https://github.com/smart-data-models/dataModel.SAREF/
[10] https://github.com/smart-data-models/dataModel.S4BLDG/
[11] https://github.com/smart-data-models/dataModel.S4SYST/

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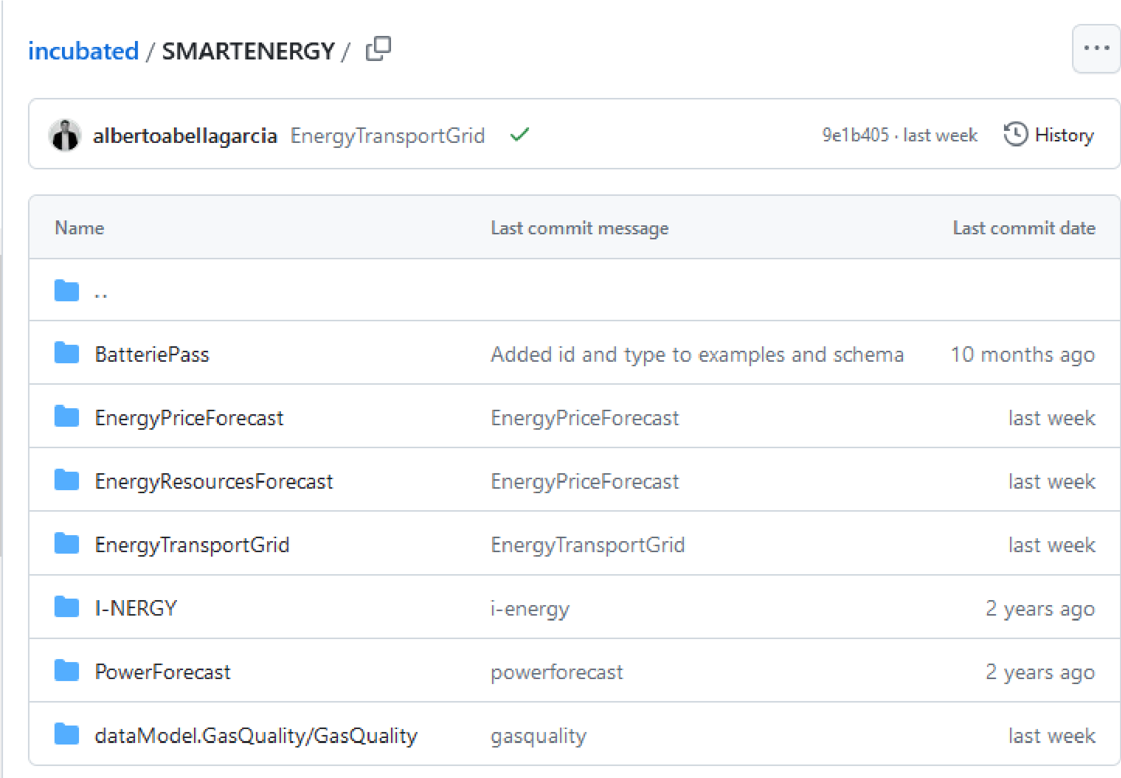

incubated / SMARTENERGY /

albertoabellagarcia EnergyTransportGrid 9e1b405 · last week History

Name	Last commit message	Last commit date
..		
BatteriePass	Added id and type to examples and schema	10 months ago
EnergyPriceForecast	EnergyPriceForecast	last week
EnergyResourcesForecast	EnergyPriceForecast	last week
EnergyTransportGrid	EnergyTransportGrid	last week
I-NERGY	i-energy	2 years ago
PowerForecast	powerforecast	2 years ago
dataModel.GasQuality/GasQuality	gasquality	last week

Figure 34: EnergyPriceForecast and EnergyResourcesForecast in SDM

3.3.1.10 Grid data models

The definitions of grid required by the ENERSHARE use cases implied the creation of a new data model for the qualification of the transport grids. The corresponding data model has been created at the subject energy and previously drafted in the incubated repository.

URL of Energy Transport Grid subject in SDM: https://github.com/smart-data-models/incubated/tree/master/SMARTENERGY/EnergyTransportGrid

3.3.1.11 Maintenance data models

These data models do not match any of the existing subjects in SDM. Therefore, a new group is being created in the Cross sector domain at SDM, initially named as dataModel.Maintenance.

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3.3.1.12 Market data models

There are not market data models at SDM. Therefore, there will be a new subject datamodel.EnergyMarket at the Energy domain with one or several data models. There will be several if the information included in the InternalElectricityMarket is quite different from AncilliaryElectricityMarket and NaturalGas Market and ElectricityMarket.

3.3.1.13 Player data models

There is not an equivalent data model for the player (participants) in the Energy dataspace. Consequently, a new data model will be created at the energy subject. Initially only one data model will be created, which is currently drafted in the incubated repository.

3.3.1.14 Price data models

There is not an equivalent data model in SDM covering the concepts related to prices which are needed in ENERSHARE's use cases. Consequently, a new data model will be created at the energy subject. Initially, only one data model with the several options required (minimum, maximum, etc) will be created, which is currently drafted in the incubated repository.

3.3.1.15 Property Data models

The property data models in ENERSHARE describe different types of properties and their evaluations. Therefore, they can be included in SDM as additional attributes of already existing data models, like those related to the demand and evaluation.

3.3.1.16 Schedule data models

The need for a schedule across the projects is being assessed and eventually based on the existing facilities provided by schema.org like OpeningHours and OpeningHoursSpecification.

3.3.1.17 System data models

The data models related to the system ontology include NaturalGasStorageSystem, SyntheticNaturalGasStorageSystem which potentially can be a new data model in the energy subject. This is the same case for the objects HeatSubstation and

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HeatPipe, that can require a new data model. For these two there are a similar data model for water that could be taken as a template, Pipe. However, for the WaterStorageSystem and WaterTank there is already one available data model, which is Tank.

URL of Pipe subject in SDM: https://github.com/smart-data-models/dataModel.WaterDistributionManagementEPANET/tree/master/Pipe

URL of Tank subject in SDM: https://github.com/smart-data-models/dataModel.WaterDistributionManagementEPANET/tree/master/Tank

3.3.1.18 Wind turbine data models

Two new data models will be required to address the WindTurbine ontology. There are many data models available at SDM coming from the mapping of the energy common information model IEC61970. And specifically, from the IEC Standard 61400-27-1. However, the requirements of the ENERSHARE use cases are related to some internal elements. Consequently, two new data models will be created for energy, windTurbine (either with DoubleFedInductionGenerator or PermanentMagnetGeneratorWindTurbine) and the HydraulicPitchSystem (either with HydraulicPitchCylinder or HydraulicPitchPump or HydraulicPitchMotor or HydraulicPitchAccumulator)

3.3.1.19 Summary table

Table 1 summarizes the contribution of ENERSHARE to the Smart Data Models initiative. The estimation is about 15 new data models and 3 new subjects (groups of data models) as a consequence of the use cases in ENERSHARE. These figures could be modified because in some of the models there still remain some uncertainties about the possible consolidation of data models or the use of existing ones with an extension.

Table 1. Summary table of ENERSHARE's contribution to SDM

Data model	New / existing	Action	Notes
GasQuality	New	Drafted in incubated repository	Domain Energy

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Data model	New / existing	Action	Notes
Building	Existing	Extension of the data model	Subject Building
Oven, Dryer, WashingMachine, Dishwashingmachine, Freezer, Refrigerator, RefrigeratorfreezerCombo	To be defined if one individual data model or an extended version of the device generic one		
FrequencyMeter, PowerQualityanalizer, PhasorMeasurementUnits, HeatFlowMeter, electricitySmartMeter and calorimeter	To be defined if versions of a mapped SAREF meter or individual data models		
Alert	Existing	Extension of the categories	Subject Alert
System	Existing	Extension of the categories	Subject S4SYST
Flexibility	New	Drafted in incubated repository	New subject S4ENERGY
EnergyPriceForecast	New	Drafted in incubated repository	Subject Energy
EnergyResourcesForecast	New	Drafted in incubated repository	Subject Energy
Grid	New	Drafted in incubated repository	Subject Energy
Maintenance	New	Drafted in incubated repository	New subject Maintenance
Market	New	Drafted in incubated repository	New subject Market

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Data model	New / existing	Action	Notes
Player	New	Drafted in incubated repository	Subject Energy
Price	New	Drafted in incubated repository	Subject Energy
StorageSystem	New	Drafted in incubated repository	Subject Energy
HeatSubstation and HeatPipe,	New	Drafted in incubated repository	Subject Energy
WindTurbine	New / existing		Subject Energy or EnergyCIM
HydrauliquePitchSystem	New	Drafted in incubated repository	TBD

3.3.2 The best practices of agile standardization

Agile standardization allows the creation of a data model in very short periods of time because the consensus procedures for classic standardization are mostly replaced by real examples working demonstrating the viability of the data model.

In the next paragraph are described the other seven best practices associated with this standardization method.

0. Don't just standardize, be agile and standardize

This fundamental best practice implies that activities must be as automated as possible and, with the least amount of human intervention possible. A standard appearing in an already dispersed market does not provide as many benefits as being launched in the first stages of a new subject. SDM relies on quite automatic procedures to reduce dramatically the need of human intervention and resulting in very short periods of time to launch or extend data models.

1. Do not reinvent the wheel

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The examples of the project are trusting, when available, on existing regulations and standards. There should not be created alternatives but extensions to aggregate knowledge whenever possible.

2. Normalize real cases

In ENERSHARE, it is clear that real use cases are normalized but this is not a general rule and sometimes standards and ontologies are created and then they look for users. At SDM this is **a must for the contribution to the initiative.**

3. Be open

In order to be agile, it is needed to be capable to create and extend the data models. Other licensing approaches different from an open licensing scheme would result in delays.

4. Don't be overly specific

Agile standardization must reach a consensus in order to make the model cover as many cases as possible, for example by limiting the number of mandatory attributes, without introducing complexities in the generated data models.

5. Flat not Deep

Models should be self-contained where possible. A model referencing another model which references another model may be ontologically correct and technically optimum, but it is a barrier for the use in real world use cases.

6. Sustainability is key

The last best practice is that of continuity. The agile standardization initiative shall only create models with continuous use and improvement in mind - this is not a "one and done" project-driven effort. Therefore, a sustainability mechanism should be in place to allow for the modification of the model as the market changes. SDM is sustained based on its participation in R+D projects and it does not depend on single supporters.

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4 List of components conforming the final version

This chapter describes the status of the components of the semantic interoperability building blocks, in this third and final release.

4.1 Vocabulary hub as a software component

The vocabulary hub building block and its wizard component have been introduced in ENERSHARE deliverables D3.1 and D3.2. The two development goals outlined in D3.2 are:

1. Support for JSON Schema-based data models
2. Implementation of a bottom-up approach to data model harmonization

The first involves extending the wizard to support standardized JSON vocabularies such as the Smart Data Models. The second concerns implementing the bottom-up approach, improving the ease of adoption for data providers new to semantic technologies and linked data principles. A bottom-up approach means a data model is created through generalisation of instance data, e.g., a data sample provided by the data provider. The newly created data model is completely based on one party's implementation, and not on some standard. In terms of the five-star framework mentioned in deliverable D3.2, this equates to two stars because there's a machine-readable data model that corresponds to achieving a two-star level of interoperability.

The update on both goals is further explained below.

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4.1.1 Development goal 1: support for JSON Schema-based data models

As of the v2.19.0 release of Semantic Treehouse[12], the ENERSHARE implementation of the vocabulary hub, this feature is now supported and therefore the development goal has been reached.

The wizard component of the Semantic Treehouse used to support only ontologies, but now also supports JSON schema as starting point. This means that models like Smart Data Models, HR Open and the Open Trip Model can now be used to start the model-driven development of data models, schemas, and Open API specifications.

This functionality was validated in two phases; phase A and B. Phase A focused on validating the direct import of JSON schemas into the vocabulary hub (publishing JSON schemas), while phase B investigated whether the imported schemas could effectively be reused to configure data models for specific use.

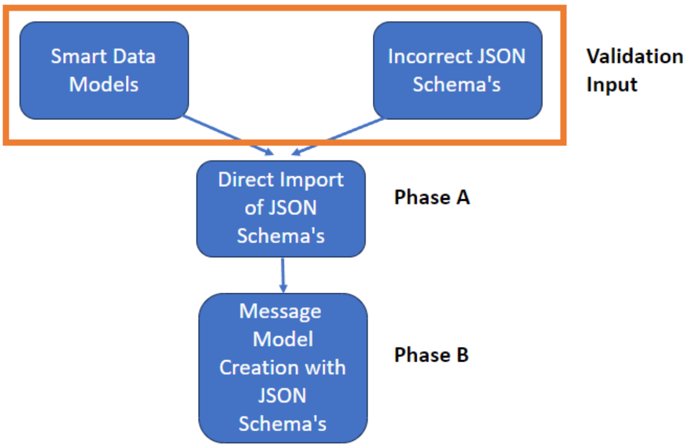

Figure 35: Overview of the validation process for the JSON Schema-based data models feature

Phase A

As mentioned, phase A focused on validating the direct import (publishing) of JSON schemas into the vocabulary hub. The validation criteria for phase A included syntax validation, compliance with JSON Schema draft-07, error handling, and performance considerations for large or complex schemas. By importing Smart Data Models JSON

[12] https://www.semantic-treehouse.nl/releases/#v2190--v300-alpha3-30-june-2023

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schemas into the vocabulary hub and deliberately introducing errors to these JSON Schemas, we were able to validate the above criteria and document our findings to enhance the functionality.

All JSON Schemas compliant to JSON Schema draft-07 can be imported in the vocabulary hub. Other key findings include the effective handling of syntax errors, but there is a need for more specific error messages. Semantic Treehouse correctly throws an error if the JSON schema is somehow invalid, but it does not specify exactly where the error is.

For the performance tests the largest JSON schema (6.6 MB) from Smart Data Models was imported into the vocabulary hub. This revealed that the vocabulary hub can handle large and complex schemas. However, there are some edge cases that require more careful consideration where strict compliance to the JSON Schema specification is not enough. For example, importing empty schemas is valid (because it is a valid JSON Schema) but not appropriate for the purpose of the vocabulary hub.

Phase B

Phase B focused on an examination of the wizard's ability to effectively interpret and utilize the imported JSON schemas for further use in vocabulary hub workflows. This involved confirming that all elements from the JSON schemas could be accurately represented within the wizard's interface, allowing the user to select a JSON schema as a starting point instead of an ontology, and validating the accurate representation of constraints specified in the JSON schemas. The latter one includes handling of 'required' properties, cardinalities, boolean values, example values, maximum and minimum constraints, codelists, and descriptions associated with schema elements.

Observations during the validation process of phase B highlighted several usability issues within the vocabulary hub. One of them is specifying your starting point (i.e., root) somewhere in the schema from where you can build your custom data model tree. This is done by setting the JSON pointer towards an object in the JSON Schema in the form during wizard step 1. Although the documentation describes[13] how this is

[13] https://www.semantic-treehouse.nl/docs/wizard/json-schema-input

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done, the design of the user experience might be improved further to ease the process.

In general, our tests showed that the information within the JSON Schema is well-handled, such as value constraints, boolean checks, and data types detection. However, just like in phase A we found edge cases that require further attention. For example, a small improvement is needed to efficiently represent an optional array with a `minItems` constraint. In JSON Schema, your schema can specify an optional field of `"type" : "array"` - say, `"list"` - and that array type specifies a minimum number of items – say, 4. For example:

```
{
  "type": "object",
  "required": [
    "documentId"
  ],
  "properties": {
    "documentId" : {},
    "list" : {
      "type": "array",
      "minItems": 4
    }
  }
}
```

The current JSON Schema import feature does not support this nuance and instead translates it to a required element with min cardinality 4. Of course, as with all elements reused from the JSON Schema, the user creating the data model can make changes to the default cardinalities.

Conclusion

The loading of JSON schemas (e.g., from Smart Data Models) to the vocabulary hub fosters reuse and interoperability by allowing the creation of application specific profiles. The benefit of this is that participants in the data space are encouraged to take a standard data model as starting point for defining the semantics and structure of their data offering. By fostering reuse and adoption of data standards by data providers, the vocabulary hub helps increase the semantic interoperability of the whole data ecosystem.

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4.1.2 Development goal 2: implementing the bottom-up approach

Based on evolving insights, this development goal has been renamed to 'implementing the bottom-up approach' compared to deliverable D3.2's 'implementing the five-star model of vocabulary use', since the latter is a means to achieve the former. The core idea remains unchanged: the vocabulary hub should provide data providers to incrementally improve the semantics of their data, starting from nothing (that is to say, just their instance data without annotations of any kind). This contrasts with a top-down approach to interoperability, which starts with a standard data model that is somehow imposed on the data provider for adoption. The top-down approach is the usual approach to interoperability, which is hampered because it requires the target user (the data provider in this case) to get acquainted with a new standard and, possibly, with new technology such as semantic technology.

In contrast, the benefit of a bottom-up approach is that it is easy and starts small. It is fine if data providers are new to semantic technologies and linked data principles, or are unfamiliar to related data standards. These are all of later concern. With the bottom up approach, data providers are simply aided by the vocabulary hub in improving the semantic annotation of their data one step at a time, by generalizing a data model from a data sample. As they progress, the vocabulary hub will help them connect their work to relevant vocabularies, and through mappings and new iterations of their own model with vocabularies in mind, interoperability starts to arise.

In deliverable D3.2 it was stated that the next steps towards this second development goal included: 1) refinement and implementation of the preliminary UX design of this feature, and 2) further validation of the added value of this functionality, and 3) further implementing the five-star framework for promoting vocabulary use.

Step 1 has been completed: users are now able to generalize a data model based on a sample of their instance data (in CSV format). Validation of this functionality (step 2) has also been completed and is documented below. The final step, step 3, has been omitted to allow more time for validating the ENERSHARE Data Model using the vocabulary hub (see chapter 3 previously).

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The validation was conducted using sample data from various pilot partners within the ENERSHARE project. In many cases, the pilot data samples came in CSV format. The focus of our tests was on checking proper syntax validation, error messaging, support for different CSV delimiters, properly handling missing information in the CSV files, and finally user-friendliness. Different CSV files from the partners were tested and some errors were deliberately introduced to assess the functionality.

An example of generalization of sample data based on CSV from pilot 1 is shown in the figures below. Figure 36 shows the step of importing the CSV sample data in the vocabulary hub, and Figure 37 displays the end results of the generalization of the sample data into an abstract data model. (Note that the GUI speaks of 'message model'; it's intended meaning is synonymous to 'data model'.)

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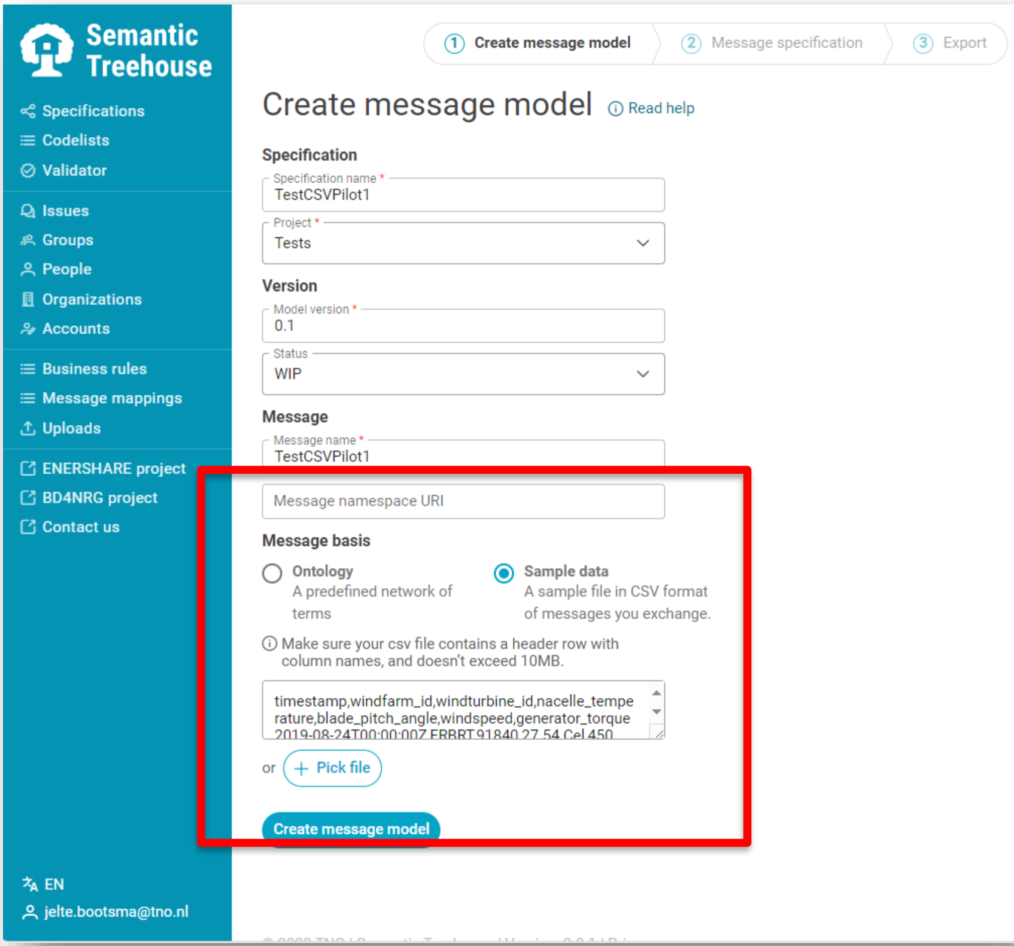

Figure 36: Importing sample data in CSV to create a message model

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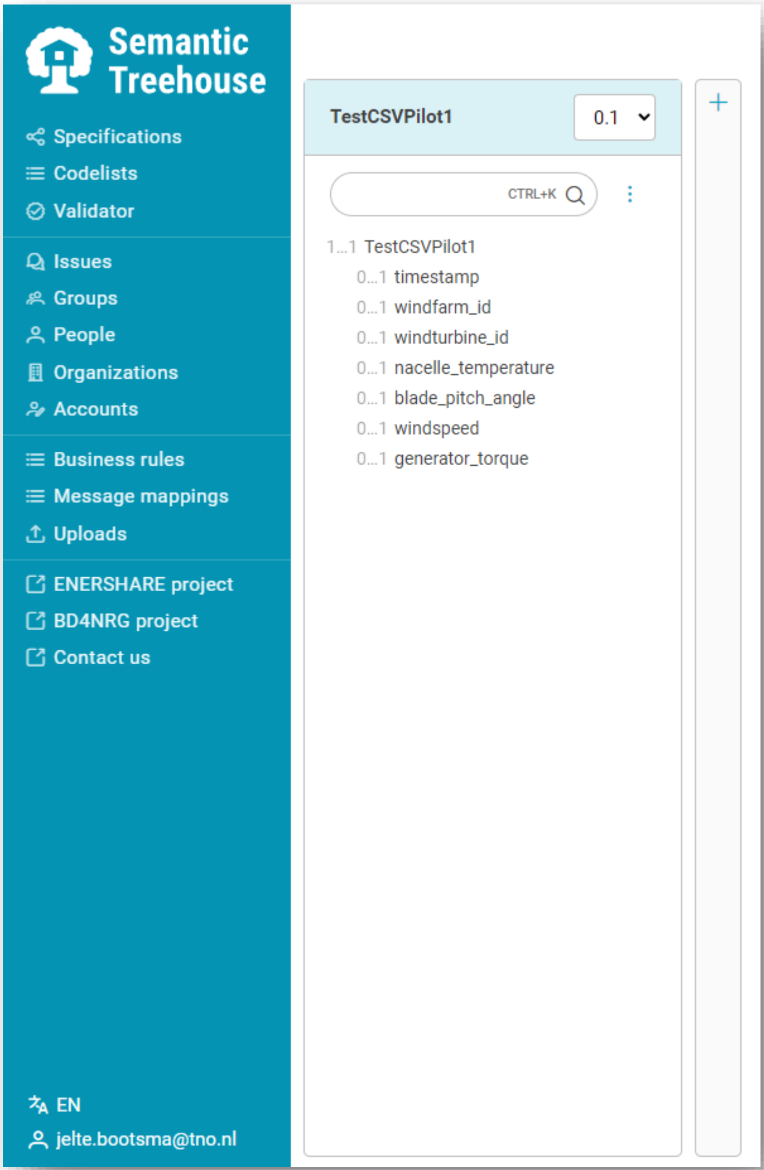

Figure 37: Generalization of sample data in the vocabulary hub

The key findings of the validation process for the bottom-up approach are as follows:

- When importing a CSV file via Semantic Treehouse web GUI through copying from clipboard, the data is pasted in an untidy manner.

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- The functionality provides a clear error message if the CSV file is too large or too long. However, when importing file types other than CSV, such as XML, the error message is not accurate.
- When importing a (invalid) CSV file, user could not return to the previous step to fix the issue, forcing them to start over entirely in those cases.
- When parsing CSV column names to instantiate a data model, the vocabulary hub would wrongly give error message for missing column names or forbidden characters like spaces or symbols in the column names. This bug was related to functionality that ensured the imported model consisted of proper XML paths.
- No knowledge was extracted from the data itself, such as the automatic inference of the column ranges (e.g. 'integer', 'string' or 'datetime'), or their cardinality (if every cell within a column is filled with data, the cardinality is 1..1; otherwise, it is 0..1, in other words an optional field).

Because of these issues, an additional development iteration of the vocabulary hub Semantic Treehouse was carried out by TNO. The result was that every issue on the list has been addressed and fixed in the most recent release.

With the increasing number of deployments of the Semantic Treehouse implementation of the vocabulary hub, more experience will be gained with (edge) use cases. These provide further opportunities to build on and refine the work for ENERSHARE project as reported in this document.

The bottom-up approach enhances the accessibility of semantic technologies and linked data principles for new data providers. This feature enables data providers to generate their own generalized data models using sample data in CSV format. It allows data providers to first describe their own vocabulary use in the data (i.e., terms and definitions), which prepares them for 'moving up', i.e., collaborating with other parties to reach interoperability on a local level, or linking their model to some common vocabulary for wider interoperability.

Future research and development

Future research and development will explore the use of generative AI to refine the process of generalizing data models from instance data. Presently, the bottom-up approach generates generalized models without extracting knowledge directly from

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the data, meaning that the semantics is manual input. Investigating generative AI aims to automate this process, potentially leveraging existing standards to pre-fill semantic details such as definitions and cardinalities based on existing standards. This approach could also involve mapping sample data to existing standards within relevant domains of the data provider.

As sharing data across different domains becomes more important, making sure that data is semantically interoperable across these fields is crucial. This means we need to deal with the different vocabularies and standards used in different domains and various vocabulary hubs. Therefore, we are working on creating a standardized method to connect these vocabulary hubs such that vocabularies will be discoverable across domains. The goal is to make it easy to import and export data models between vocabulary hubs, even if they are different by design and are in different data spaces. Future research will be focused on exploring the use of DCAT to create catalogs of vocabularies and enable standardized vocabulary exchange between vocabulary hubs.

4.2 ENERSHARE's Open APIs, RML mappings and SHACL files

This chapter describes the methodology used to define the Open APIs for ENERSHARE's data services, the RML mapping rules for data transformation and the SHACL (Shapes Constraint Language) files for checking data compliance against the Open APIs. Finally, there is a subchapter per pilot with the summary of Open APIs.

The complete list of open APIs, RML mappings and SHACL files for the 7 pilots in ENERSHARE project is available at https://git.code.tecnalia.com/open/enershare/.

4.2.1 Open APIs definition methodology

Open APIs based on a common semantic data model are needed to ensure semantic interoperability in data spaces because they define how the data should be formalized in the payload of the messages transferred between data providers and consumers using IDS connectors or through the Context Broker. This way, data providers can describe and publish their data sources in such a way that these become easily findable and usable for data consumers.

In ENERSHARE, Open APIs have been created for each of the data services (both for input and output data) in the pilots that exchange information in the energy data space. The steps of the methodology that has been used is described in Figure 38.

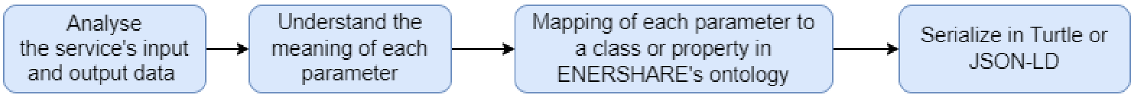

Figure 38: Steps of the methodology for Open APIs definition

The first and second steps for the creation of the Open API for the different services, have been to analyse the input and output data of each of them and to understand the meaning of each of the parameters. For example, in the case of the failure/anomaly detection algorithm for the hydraulic pitch system of a wind turbine, the service needs as input the following parameters described in Table 2: the identifiers of the wind farm and wind turbine, the timestamp when the measurements were taken and the values of the pressure of the hydraulic system, the pressure of the accumulator, the temperature of the oil, the position of the cylinder, the command of the valve, the charging time of the pump, the pressure of the cylinder in the rod chamber and the pressure of the cylinder in the piston chamber.

Next, each concept and attribute in the input and output has been mapped to a concrete class or property in the ENERSHARE semantic model described in section 3.1.2. To do so, we use the harmonized diagrams from the ENERSHARE data model (see 3.1.1 and appendix 8). Figure 39 highlights in yellow some of these mappings.

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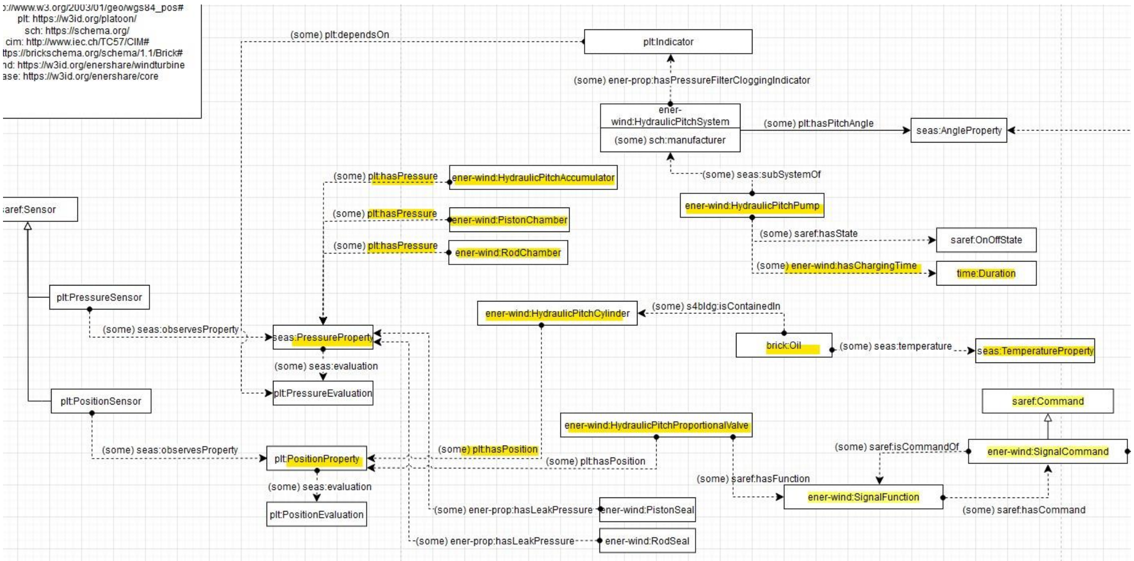

Figure 39: Mapping of parameters to classes and properties in the ENERSHARE ontology

Figure 40 shows a high-level view of the concepts and properties used in the input payload of the anomaly detection service.

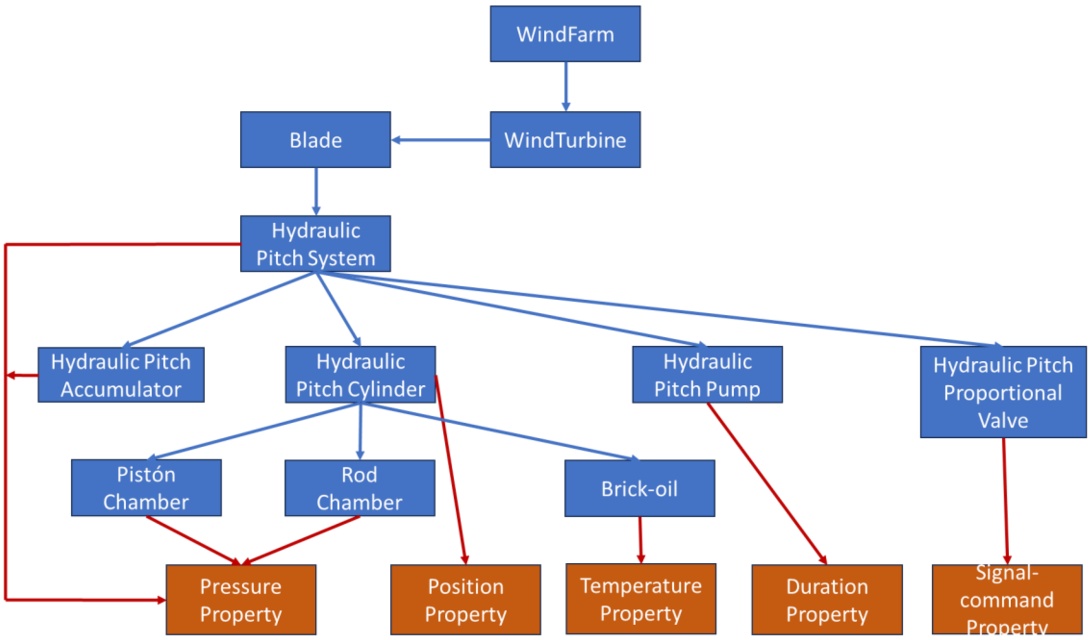

Figure 40: Summary diagram of the concepts and properties used in the service input

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Finally, once the mappings are clear, the inputs and outputs can be serialized according to ENERSHARE semantic data format as described in the column "ontology mapping" in Table 2. Appendix 9 contains the complete Open APIs for this service both in JSON-LD and Turtle formats.

Table 2: Input parameters of the failure/anomaly detection algorithm for the hydraulic pitch system of a wind turbine

Input param		
name	**ontology mapping**	**example**
timestamp	time:Instant xsd:inXSDDateTime	2019-08-24T00:00:00Z
windfarm id	plt:WindFarm rdfs:label	FRBRT
windturbine id	plt:OnshoreWindTurbine rdfs:label	91840
hydraulic system pressure	ener-wind:HydraulicPitchSystem ener-prop:hasMainSystemPressure seas:pressureProperty seas:evaluation plt:pressureEvaluation	"@type" : "cdt:pressure", "@value" : "300 bar"
accumulator pressure	ener-wind:HydraulicPitchAccumulator plt:hasPressure seas:pressureProperty seas:evaluation plt:pressureEvaluation	"@type" : "cdt:pressure", "@value" : "450 bar"
oil temperature	brick:oil seas:temperature seas:temperatureProperty seas:TemperatureEvaluation	"@type" : "cdt:temperature", "@value" : "60.32 Cel"
cylinder position	ener-wind:HydraulicPitchCylinder plt:hasPosition plt:PositionProperty seas:evaluation plt:PositionEvaluation	"@type" : "cdt:ucum", "@value" : "60.32 nm"
proportional valve commands	ener-wind:HydraulicPitchProportionalValve saref:hasFunction ener-wind:SignalFunction	"@type" : "cdt:ucum", "@value" : "A"

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Input param		
name	ontology mapping	example
	saref:hasCommand ener-wind:SignalCommand	
Pump charging time	ener-wind:HydraulicPitchPump ener-wind:hasChargingTime time:Duration	"@type" : "cdt:time", "@value" : "10 s"
cylinder piston chamber pressure	ener-wind:PistonChamber plt:hasPressure seas:pressureProperty seas:evaluation plt:pressureEvaluation	"@type" : "cdt:pressure", "@value" : "27.54 bar"
cylinder rod chamber pressure	ener-wind:RodChamber plt:hasPressure seas:pressureProperty seas:evaluation plt:pressureEvaluation	"@type" : "cdt:pressure", "@value" : "67.54 bar"

4.2.2 RML Mapping rules for data transformation

As explained in section 2.3, when developing services from scratch, users can directly provide inputs and outputs according to the open APIs defined in JSON-LD format. However, in most cases, services are already in production and the data (usually in JSON, XML or CSV formats) needs to be transformed according to the common data model of the dataspace. For this reason, for each open API we provide at least one alternative data schema in JSON, XML or CSV formats and an RML mapping file with the rules that define the necessary transformations. The data in JSON, XML or CSV jointly with the RML mapping file can be provided to the Data Transformation Service (see 4.3) which automatically generates the JSON-LD compliant with the ENERSHARE ontology.

For example, the input payload of the Digital Twin service for a Permanent Magnet Synchronous Generator (PMSG) can have a lightweight representation in JSON (see Table 3), XML (see Table 4) or CSV (see Table 5).

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Table 3. Lightweight representation in JSON of the digital twin service (PMSG) in pilot 1


```
{
        "windturbine_values":
        [
                {
                        "windfarm_id": "FRBRT",
                        "windturbine_id": "91840",
                        "timestamp": "2019-08-24T00:00:00Z",
                        "nacelle_temperature": "27.54 Cel",
                        "blade_pitch_angle": "450 deg",
                        "windspeed": "9.32 m/s",
                        "generator_torque": "3370.42 N.m"
                },
                {
                        "windfarm_id": "FRBRT",
                        "windturbine_id": "91840",
                        "timestamp": "2019-08-24T01:00:00Z",
                        "nacelle_temperature": "27.66 Cel",
                        "blade_pitch_angle": "451 deg",
                        "windspeed": "9.45 m/s",
                        "generator_torque": "3370.38 N.m"
                }

        ]
}
```


Table 4. Lightweight representation in XML of the digital twin service (PMSG) in pilot 1


```
<?xml version="1.0"?>

<windturbine_values>
  <windturbine_value>
    <windfarm_id>FRBRT</windfarm_id>
    <windturbine_id>91840</windturbine_id>
    <timestamp>2019-08-24T00:00:00Z</timestamp>
    <nacelle_temperature>27.54 Cel</nacelle_temperature>
    <blade_pitch_angle>450 deg</blade_pitch_angle>
    <windspeed>9.32 m/s</windspeed>
    <generator_torque>3370.42 N.m</generator_torque>
  </windturbine_value>
  <windturbine_value>
    <windfarm_id>FRBRT</windfarm_id>
    <windturbine_id>91840</windturbine_id>
    <timestamp>2019-08-24T01:00:00Z</timestamp>
    <nacelle_temperature>27.66 Cel</nacelle_temperature>
    <blade_pitch_angle>451 deg</blade_pitch_angle>
    <windspeed>9.45 m/s</windspeed>
    <generator_torque>3370.38 N.m</generator_torque>
  </windturbine_value>
</windturbine_values>
```


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Table 5. Lightweight representation in CSV of the digital twin service (PMSG) in pilot 1

```
timestamp,windfarm_id,windturbine_id,nacelle_temperature,blade_pitch
_angle,windspeed,generator_torque
2019-08-24T00:00:00Z,FRBRT,91840,27.54 Cel,450 deg,9.32 m/s,3370.42
N.m
2019-08-24T01:00:00Z,FRBRT,91840,27.66 Cel,451 deg,9.45 m/s,3370.38
N.m
```

When defining the RML mapping rules, the first thing is to indicate the name of the source that contains the data to be transformed and the language to parse it.

For JSON files:

```
<#LogicalSourceWTVal> a rml:BaseSource ;
  rml:source "pilot1_generator_digital_twin_input_simplejson.json" ;
  rml:referenceFormulation ql:JSONPath;
  rml:iterator "$.windturbine_values[*]" .
```

For XML files:

```
<#LogicalSourceWTVal> a rml:BaseSource ;
  rml:source "pilot1_generator_digital_twin_input_xml.xml" ;
  rml:referenceFormulation ql:XPath;
  rml:iterator "/windturbine_values/windturbine_value" .
```

For CSV files:

```
<#LogicalSourceWTVal> a rml:BaseSource ;
  rml:source "pilot_1_generator_digital_twin_input.csv" ;
  rml:referenceFormulation ql:CSV .
```

Next, we need to define the triples (subject-predicate-object). Predicates for the same subject are grouped together in a rr:TriplesMap. For example, in the code below, there are 3 properties related to a wind turbine (subject): the label, its location and the average wind speed. Information between curly brackets (e.g., {windfarm_id}) indicates that the value will be replaced with the content of this key in the JSON file.

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```
<#OnshoreWindTurbine> a rr:TriplesMap;
    rml:logicalSource <#LogicalSourceWTVal> ;

    rr:subjectMap [
        rr:class plt:OnshoreWindTurbine;
        rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturb
ine/{windturbine_id}"
    ];

    rr:predicateObjectMap [
        rr:predicate rdfs:label ;
        rr:objectMap [
            rml:reference "windturbine_id"
        ]
    ];

    rr:predicateObjectMap [
        rr:predicate brick:hasLocation ;
        rr:objectMap [
            rr:termType rr:IRI;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}"
        ]
    ];

    rr:predicateObjectMap [
            rr:predicate plt:hasAverageSpeed ;
            rr:objectMap [
            rr:termType rr:IRI;
                rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturb
ine/{windturbine_id}/property/windspeed/average"
            ]
    ] .
```

In the case of data type properties, object maps can have constant values or refer to data in the JSON source file. For example:

- `rr:objectMap [rr:constant "Hydraulic Pitch System"]`
- `rr:objectMap [rml:reference "windturbine_id"]`

In the case of object type properties, the URI is defined as follows:

```
rr:objectMap [
            rr:termType rr:IRI;
```

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```
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/blade"
        ]
```

Finally, the RML Mapping Language provides some already predefined functions that allow, for example, to transform data into lower/upper case, to perform some math calculations or to concatenate different parameters. Besides, it allows defining specific functions useful to your use case. In ENERSHARE, functions have been used, among others, to map failure integer constants into classes in the ontology.

The function named `to_hydraulic_pitch_failure_code` transforms from an integer value to the URI of the hydraulic pitch's failure code, as follows:

- 1 = Leakage (https://w3id.org/enershare/failure/Leakage)
- 2 = Excessive friction (https://w3id.org/enershare/failure/ExcessiveFriction)
- 3 = Low precharge (https://w3id.org/enershare/failure/LowPrecharge)
- 4 = Flow rate reduction (https://w3id.org/enershare/failure/FlowRateReduction)
- 5 = Shaft torque increase (https://w3id.org/enershare/failure/ShaftTorqueIncrease)
- 6 = Abnormal conductance (https://w3id.org/enershare/failure/AbnormalConductance)

In RML, in order to apply a function to an object we use the following syntax where `FailureFunctionMap` is the name given to point to the code containing the description of the function.

```
rr:predicateObjectMap [
            rr:predicate rdf:type;
            rr:objectMap <#FailureFunctionMap> ;
        ];


<#FailureFunctionMap>
fnml:functionValue [
    rml:logicalSource <#Mode> ;
    rr:predicateObjectMap [
```

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```
        rr:predicate fno:executes ;
        rr:objectMap [rr:template
tecfns:to_hydraulic_pitch_failure_code ]
    ];
    rr:predicateObjectMap [
        rr:predicate grel:valueParameter ;
        rr:objectMap [rml:reference "failure_mode"]
    ]
] .
```

Appendix 9 contains the complete RML mappings for transforming the JSON input and output of the hydraulic pitch system anomaly detection service.

As the process of creating RML mapping files requires technical skills, the wizard of the vocabulary hub can be used as described in section 3.2.

4.2.3 SHACL files for checking data compliance with open APIs

When a data provider receives some request, it is useful to check whether the input payload is serialized correctly according to the open API. To do so, language formats have their language validation schema, e.g., JSON uses JSON schema, XML uses XML schema and semantic models like RDF/XML, JSON-LD or Turtle use SHACL.

For this reason, for each open API we also provide the SHACL files that can be provided to the Data Compliance Service (see 4.4) which automatically generates a report informing whether the data is compliant to the open APIs or listing the violations.

SHACL files are very easy to define. Each subject in a triple (subject-predicate-object) has a shape with the rules that need to be checked. These rules indicate the minimum and maximum values for each property (predicate) and the range of the property (e.g., string, integer, IRI, etc.)

```
ener:WindTurbineShape
    a sh:NodeShape ;
    sh:property [
        sh:path rdfs:label ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:datatype xsd:string ;
    ] ;
    sh:property [
        sh:path brick:hasLocation ;
        sh:minCount 0 ;
```

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```
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:property [
        sh:path plt:hasAverageSpeed ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:targetClass plt:OnshoreWindTurbine .
```

To indicate that there must be at least one instance of a given class, in this case, wind farm, we use the following syntax,

```
ener:WindFarmCountShape
    a sh:NodeShape ;
    sh:targetNode plt:WindFarm ;
    sh:property [
        sh:path [ sh:inversePath rdf:type ] ;
        sh:minCount 1 ;
    ] .
```

Appendix 9 contains the complete SHACL files for checking the JSON-LD or Turtle input and output of the hydraulic pitch system anomaly detection service.

4.2.4 Pilot 1 Open APIs

4.2.4.1 Digital Twin based O&M algorithms and generation of synthetic failures data

Digital Twin for synthetic data generation, both for the Permanent Magnet Synchronous Generator (PMSG) and for the Hydraulic Pitch System of a wind turbine.

a) Digital Twin for the Permanent Magnet Synchronous Generator (PMSG)

- Service input files:
    - Input data in JSON format ; RML mapping for JSON format ; Compliance JSON schema
    - Input data in XML format ; RML mapping for XML format ; Compliance XML Schema
    - Input data in CSV format ; RML mapping for CSV format

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- o Input data in JSON-LD format ; Compliance SHACL file
- Service output files:
  - o Output data in JSON format ; RML mapping for JSON format
  - o Output data in JSON-LD format ; Compliance SHACL file

b) Digital Twin for the Hydraulic Pitch System

- Service input files:
  - o Input data in JSON format ; RML mapping for JSON format
  - o Input data in JSON-LD format ; Compliance SHACL file
- Service output files:
  - o Output data in JSON format ; RML mapping for JSON format
  - o Output data in JSON-LD format ; Compliance SHACL file

4.2.4.2 Data-driven failure detection algorithms for wind turbine components

a) Permanent magnet synchronous generator (PMSG) anomaly detection

- Service input files:
  - o Input data in JSON format ; RML mapping for JSON format
  - o Input data in JSON-LD format ; Compliance SHACL file
- Service output files:
  - o Output data in JSON format ; RML mapping for JSON format
  - o Output data in JSON-LD format ; Compliance SHACL file

b) Hydraulic pitch system anomaly detection

- Service input files:
  - o Input data in JSON format ; RML mapping for JSON format
  - o Input data in JSON-LD format ; Compliance SHACL file
- Service output files:
  - o Output data in JSON format ; RML mapping for JSON format
  - o Output data in JSON-LD format ; Compliance SHACL file

c) Gearbox anomaly detection

- Service input files:
  - o Input data in JSON format ; RML mapping for JSON format
  - o Input data in JSON-LD format ; Compliance SHACL file
  - o Input data in CSV format ; RML mapping for CSV format

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  - Input data in JSON-LD format ; Compliance SHACL file
- Service output files:
  - Output data in JSON format ; RML mapping for JSON format
  - Output data in JSON-LD format ; Compliance SHACL file
  - Output data in CSV format ; RML mapping for CSV format
  - Output data in JSON-LD format ; Compliance SHACL file

4.2.5 Pilot 2 Open APIs

4.2.5.1 Service to extract metadata from a participant

- Output data in JSON format ; RML mapping for JSON format
- Output data in JSON-LD format; Compliance SHACL file

4.2.5.2 Service to get the actual readings from a participant

- Output data in JSON format ; RML mapping for JSON format
- Output data in JSON-LD format; Compliance SHACL file

4.2.6 Pilot 3 Open APIs

4.2.6.1 Multi-energy flexibility potential assessment

- Service output files:
  - Output data in JSON format ; RML mapping for JSON format
  - Output data in JSON-LD format ; Compliance SHACL file

4.2.6.2 Energy prediction service given the heat profile of the house from district heating

- Service output files:
  - Output data in JSON format ; RML mapping for JSON format
  - Output data in JSON-LD format ; Compliance SHACL file

4.2.6.3 Energy prediction service given the electric power profile of the house, with disaggregation of load

- Service output files:

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- Output data in JSON format ; RML mapping for JSON format
- Output data in JSON-LD format ; Compliance SHACL file

4.2.7 Pilot 4 Open APIs

4.2.7.1 Power-to-Gas optimal planning

- Service output files:
  - Output data in CSV format; RML mapping for CSV format
  - Output data in JSON-LD format ; Compliance SHACL file

4.2.8 Pilot 5 Open APIs

4.2.8.1 EV charging monitoring and remote management

- Service output files:
  - Output data in CSV format; RML mapping for CSV format
  - Output data in JSON-LD format ; Compliance SHACL file

4.2.9 Pilot 6 Open APIs

4.2.9.1 Aggregation of flexibility from end users

a) History of grid frequency measurements

- Service output files:
  - Output data in JSON format; RML mapping for JSON format
  - Output data in JSON-LD format ; Compliance SHACL file

4.2.10 Pilot 7 Open APIs

4.2.10.1 ML-based models for assessing renovation actions in residential buildings

a) Service 1 - Increase energy efficiency

- Service input files:
  - Input data in JSON format; RML mapping for JSON format
  - Output data in JSON-LD format ; Compliance SHACL file

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- Service output files:
  - Output data in JSON format; RML mapping for JSON format
  - Output data in JSON-LD format ; Compliance SHACL file

b) Service 2 - Install Solar panels

- Service input files:
  - Input data in JSON format; RML mapping for JSON format
  - Output data in JSON-LD format ; Compliance SHACL file
- Service output files:
  - Output data in JSON format; RML mapping for JSON format
  - Output data in JSON-LD format ; Compliance SHACL file

4.3 Data Transformation Service

Although the data transformation service was already described in deliverable D3.2, a new version of the service has been released to support ad-hoc functions useful for ENERSHARE such as the function `to_hydraulic_pitch_failure_code` described in 4.2.2. Besides, some bugs have been corrected to handle properly 0 integer values.

The data transformation service is defined as a REST service (implemented in Python language) which, given any data in a structured source format (JSON, XML or CSV) and a mapping file with rules written in RDF Mapping Language (RML), transforms the data to RDF and provides the output in the requested serialization format including n3, json-ld, hext, nquads, pretty-xml, trig, trix, turtle, longturtle and xml.

The service offers three methods:

- /test: to test the connection with the service endpoint.
- /transformationService/convertFile: converts the data into RDF, where both the URLs of the data source and the mapping files are provided as input
- /transformationService/convertModel: converts the data into RDF, where both the content of the data source and the mapping files are provided as input strings

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Transformation service - Swagger UI endpoint:
https://transformation.enershare.urban.tecnalia.dev/docs

Docker image: https://hub.docker.com/r/sbilbao/transformation_service

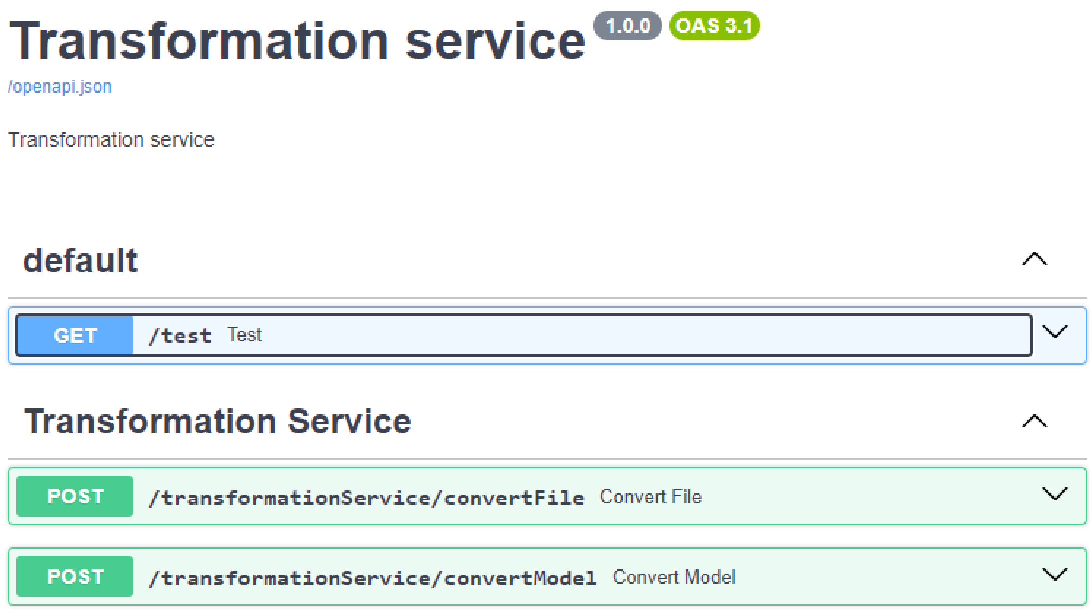

Figure 41: Swagger file of the Data Transformation rest service

Table 6: Method to test the connection with the service endpoint

Title	Test connection
URL	
/test	
Method	
GET	
Data Params	
No parameters	
Success response	
200	"OK"
Error response	
404	Not found
Sample call	
`curl -X 'GET' \`	

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```
  'http://XXX.XX.XX.XX:XXXX/test' \
  -H 'accept: application/json'
```

Table 7: Method to convert data given the URLs of the data source and mapping files

Title	convert data given the URLs of the data source and the mapping files
URL	
/transformationService/convertFile	
Method	
POST	
Data Params	
Required:	
json_file_url	the URL of the data source
mapping_file_url	the URL of the mapping file with rules written in RML
Optional:	
serialize_format	the serialization format for the data model provided as output. Default value: turtle. Possible values: n3, json-ld, hext, nquads, pretty-xml, trig, trix, turtle, longturtle, xml.
Success response	
200	Semantic data model in the requested serialization format. Examples are available in Turtle and in JSON-LD in appendix 9.
Error response	
422	Transformation error
Sample call	

```
curl -X 'POST' \
'http://XXX.XX.XX.XX:XXXX/transformationService/convertFile?json_file_url=https%3A%2F%2Fgit.
code.tecnalia.com%2Fopen%2Fenershare%2F-
%2Fraw%2Fmain%2Fmappings%2Fpilot1_windturbine_simplejson.json&mapping_file_url=https%3A%2F%2
Fgit.code.tecnalia.com%2Fopen%2Fenershare%2F-%2Fraw%2Fmain%2Fmappings%2Fpilot1-windturbine-
mapping-json.ttl&serialize_format=turtle' \
  -H 'accept: application/json' \
  -d ''
```

Table 8: Method to convert data given the content of the data source and mapping files

Title	convert data given the content of the data source and the mapping files
URL	
/transformationService/convertModel	

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Method	
POST	
Data Params	
Required:	
json_file_data	the content of the data source file
mapping_file_data	the content of the mapping file with rules written in RML
Optional:	
serialize_format	the serialization format for the data model provided as output. Default value: turtle. Possible values: n3, json-ld, hext, nquads, pretty-xml, trig, trix, turtle, longturtle, xml.
Success response	
200	Semantic data model in the requested serialization format. Examples are available in Turtle and in JSON-LD in appendix 9.
Error response	
422	Transformation error

4.4 Compliance Service

Although the compliance service was already described in deliverable D3.2, a new version of this service has been released to support JSON schema and XML schema validations in addition to SHACL rules.

The compliance service is defined as a REST service which, given a data source and a validation schema (JSON or XML schema) or rules (SHACL shapes), validates the input data (JSON, XML or RDF graph) against the set of conditions specified in the schema or shapes graph. The service is implemented in Python language.

This service allows connectors to validate their APIs against the shapes (SHACL files) provided for each Open API, so that interoperability in the data space is guaranteed.

The service offers seven methods:

- Test connection
    - `/test`: to test the connection with the service endpoint.

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- Compliance Service for RDF & JSON-LD
    - `/complianceService/validateGraphFile`: validates the RDF graph, where both the URLs of the data model and the shapes files are provided as input
    - `/complianceService/validateGraphModel`: validates the RDF graph, where both the content of the data model and the shapes files are provided as input strings

- Compliance Service for JSON
    - `/complianceService/validateJSONFile`: validates the JSON data against a given schema, where both the URLs of the JSON data and the schema files are provided as input
    - `/complianceService/validateJSONData`: validates the JSON data, where both the content of the JSON data and the schema files are provided as input strings

- Compliance Service for XML
    - `/complianceService/validateXMLFile`: validates the XML data, where both the URLs of the XML data and the schema files are provided as input
    - `/complianceService/validateXMLData`: validates the XML data, where both the content of the XML data and the schema files are provided as input strings

Compliance service - Swagger UI endpoint: https://compliance.enershare.urban.tecnalia.dev/docs

Docker image: https://hub.docker.com/r/sbilbao/compliance_service

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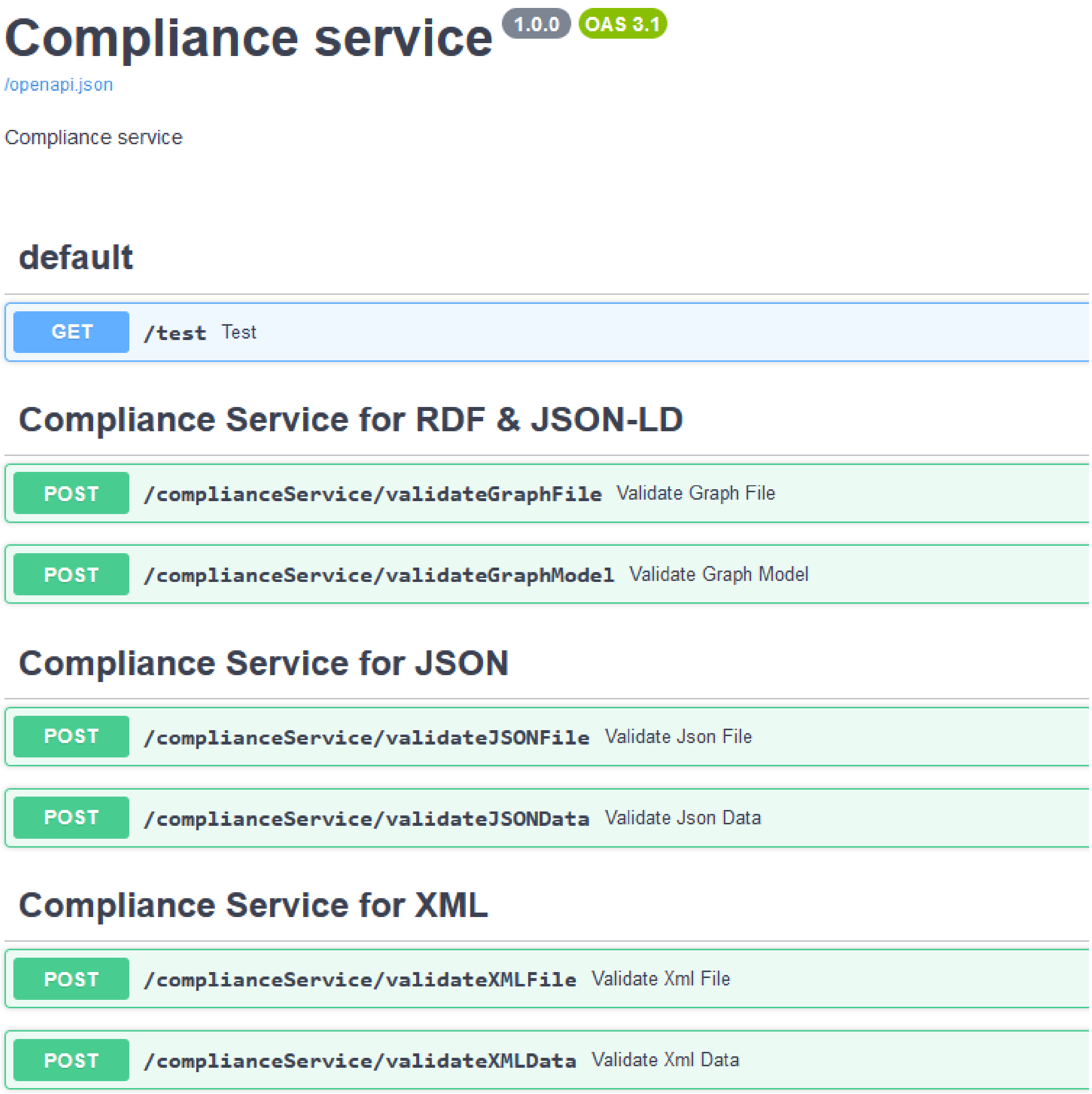

Figure 42: Swagger file of the Compliance rest service

Table 9: Method to test the connection with the service endpoint

Title	Test connection
URL	
/test	
Method	
GET	

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Data Params	
No parameters	
Success response	
200	"OK"
Error response	
404	Not found
Sample call	

```
curl -X 'GET' \
  'http://XXX.XX.XX.XX:XXXX/test' \
  -H 'accept: application/json'
```

Table 10: Method to validate the data given the URLs of the data model and shapes files

Title	Validate the RDF graph given the URLs of the data model and the shapes files
URL	
/complianceService/validateFile	
Method	
POST	
Data Params	
Required:	
json_file_url	the URL of the data model
shacl_file_url	the URL of the shapes file written in SHACL (see example in appendix 9)
Success response	

200	Json object:
	- conforms: Boolean indicating if the graph is correct.
	- report: content of the validation report
	
	Example 1 (correct model):
	`{ "conforms": true, "report": "Validation Report\nConforms: True\n" }`
	
	Example 2 (incorrect model):
	`{ "conforms": false, "report": "Validation Report\nConforms: False\nResults (1):\nConstraint Violation in MinCountConstraintComponent (http://www.w3.org/ns/shacl#MinCountConstraintComponent):\n\tSeverity: sh:Violation\n\tSource Shape: [sh:minCount Literal(\"1\", datatype=xsd:integer) ; sh:path [sh:inversePath rdf:type]]\n\tFocus Node: seas:PitchAngleProperty\n\tResult Path: [sh:inversePath rdf:type]\n\tMessage: Less than 1 values on seas:PitchAngleProperty->[sh:inversePath rdf:type]\n"`

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	}
Error response	
422	Validation error
Sample call	

```
curl -X 'POST' \
'http://XXX.XX.XX.XX:XXXX/complianceService/validateFile?jsonld_file_url=https%3A%2F%2Fgit.code.tecnalia.com%2Fopen%2Fenershare%2F-%2Fraw%2Fmain%2Fmappings%2Fpilot1_windturbine_generated.jsonld&shacl_file_url=https%3A%2F%2Fgit.code.tecnalia.com%2Fopen%2Fenershare%2F-%2Fraw%2Fmain%2Fshacl%2Fpilot1_anomaly_detection_input.shacl.ttl' \
  -H 'accept: application/json' \
  -d ''
```

Table 11: Method to validate data given the content of the data model and shapes files

Title	Validate the RDF graph given the content of the data model and the shapes files
URL	
/complianceService/validateModel	
Method	
POST	
Data Params	
Required:	
graph_file_data	the content of the data model
shacl_file_data	the content of the shapes file written in SHACL
Optional:	
data_file_format	the serialization format of the data model Default value: json-ld.
shapes_file_format	the serialization format of the shapes model Default value: turtle.
Success response	
200	Json object: - conforms: Boolean indicating if the graph is correct. - report: content of the validation report Examples (same as above for validateFile)
Error response	
422	Validation error

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Table 12: Method to validate the JSON data given the URLs of the data and schema files

Title	Validate the JSON data given the URLs of the data and the schema files
URL	
/complianceService/validateJSONFile	
Method	
POST	
Data Params	
Required:	
json_file_url	the URL of the JSON data
schema_file_url	the URL of the JSON schema file
Success response	
200	Success message
Error response	
422	Validation error

Table 13: Method to validate JSON data given the content of the data and schema files

Title	Validate the JSON data given the content of the data and the schema files
URL	
/complianceService/validateJSONData	
Method	
POST	
Data Params	
Required:	
json_file_data	the content of the JSON data
schema_file_data	the content of the JSON schema file
Success response	
200	Success message
Error response	
422	Validation error

Table 14: Method to validate the XML data given the URLs of the data and schema files

Title	Validate the XML data given the URLs of the data and the schema files
URL	

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/complianceService/validateXMLFile	
Method	
POST	
Data Params	
Required:	
xml_file_url	the URL of the XML data
xml_schema_file_url	the URL of the XML schema file
Success response	
200	Success message
Error response	
422	Validation error

Table 15: Method to validate XML data given the content of the data and schema files

Title	Validate the XML data given the content of the data and the schema files
URL	
/complianceService/validateXMLData	
Method	
POST	
Data Params	
Required:	
xml_file_data	the content of the XML data
xml_schema_file_data	the content of the XML schema file
Success response	
200	Success message
Error response	
422	Validation error

4.5 Context Broker

An NGSI-LD context broker is a key component in the NGSI-LD (Next Generation Service Interfaces with Linked Data) architecture, which is used for managing context information. It acts as the primary access point to context information for context consumers (sensors, legacy applications, microservices, etc), allowing them to store, retrieve, and subscribe to context information.

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In this sense, some data space connectors, like the True Connector, use a Context Broker implementation for managing context information, in this case, the Orion-LD Context Broker.

The following FIWARE Context Broker implementations, supporting the ETSI NGSI-LD 1.6.1 API specifications or higher are available:

- The Orion-LD Context Broker Generic Enabler [11] is an implementation of the NGSI-LD Context Broker written in C/C++, which supports both NGSI-LD and the NGSI-v2 APIs. It is a standalone executable and therefore small, fast, lightweight, and easy to handle.
- The Scorpio Broker Generic Enabler [12] is an implementation of the NGSI-LD Broker which can also be used in federated environments. Two interaction styles are supported, a synchronous query-response, and an asynchronous subscribe/notify, where notifications can be based on a change in property or relationship, or on a fixed time interval. In addition to the regular context interface that provides the most current properties and relationships for each entity, Scorpio implements NGSI-LD's optional temporal interface for requesting historic information, e.g., the property values measured within a specified time interval.
- The Stellio Context Broker Generic Enabler [13] is another implementation of the NGSI-LD Broker. It is built around a Kafka message broker for improved extensibility, scalability, and decoupling of services. These services embed a graph database (Neo4J) for context management as well as a timeseries (TimescaleDB) and geospatial (PostGIS) database to manage temporal and geospatial properties.

A detailed comparison, based on functional and performance evaluation, between Orion-LD, Scorpio and Stellio can be found in deliverable D3.1 and in FIWARE Catalogue GitHub README. In the context of the ENERSHARE project, the Context Broker in the Digital Enabler [14], which is an "Ecosystem" platform developed by Engineering, has been upgraded to Orion-LD that supports Linked Data capabilities.

4.6 Data Mashup Editor

4.6.1 Description

The Data Mashup Editor (DME) is a versatile tool that can be used in a variety of use cases, including data harmonization and data transformation. Data harmonization involves the process of bringing together data from various sources and making it consistent, accurate, and usable. Data transformation, on the other hand, involves the process of converting data from one format to another, or from one system to another. The Data Mashup Editor can be used at runtime e.g., by connectors, to create data transformation workflows that can convert data stored in the provider's systems into the NGSI-LD format defined according to the OpenAPIs before sending the data to the consumer.

Please refer to deliverable D3.1 for a more detailed description of the existing implementation offered by the Digital Enabler.

4.6.2 Developments within ENERSHARE

In the ENERSHARE project, the Data Mashup Editor has been provided in version 2.3 as runtime for data transformation and harmonization. Thanks to the provided functionalities it is possible to connect data from heterogeneous sources and compose complex business logics in a graphical way simply connecting existing atomic operators. The graphical representation of the Mashup process allows us to easily understand and monitor our data processing in real-time, making it an ideal choice for the runtime aspect of our project.

An important aspect of the Data Mashup Editor features is the support to the common semantic data model defined in ENERSHARE. In the ICT architecture, the vocabulary hub acts as a registry of data models for the energy domain and its wizard facilitates the creation, at design time, of the Open APIs specifications.

The Data Mashup Editor is also used to trigger the created flow through the IDS Connector. In particular, the DME has been already integrated with the True Connector. According to ENERSHARE project requirements, the Data Mashup Editor is evolving with the possibility to add custom operators (defined by the user through a JSON Schema) to integrate data models coming from the vocabulary hub and make them available to the pilots.

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4.6.3 Final version developments for ENERSHARE

For the final version, Engineering completed the integration with the TSG connector [10], an IDS connector that allows DME to be compliant to IDSA.

In particular, the DME can act as a consumer as well as a producer within the data space enabling the communication through the TNO Security Gateway.

To achieve this, the DME adds the TSG Contract Negotiation APIs as a new data source, as shown in Figure 43.

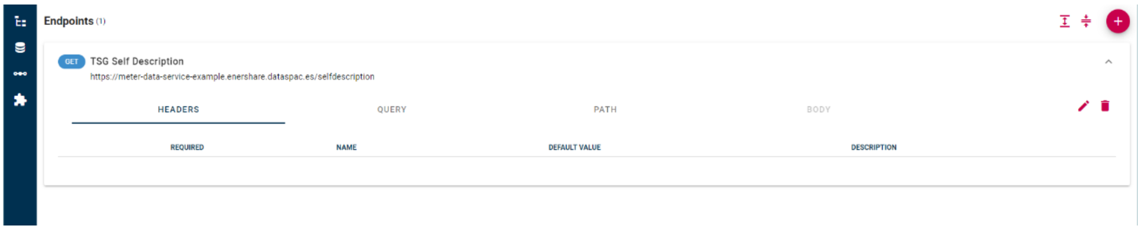

Figure 43: TSG connector as Data Source in DME

A data source in the DME is a container of REST endpoints that you can use as input in the mashup.

In the following figure (Figure 44), an example useful to add a new endpoint in the DME is shown.

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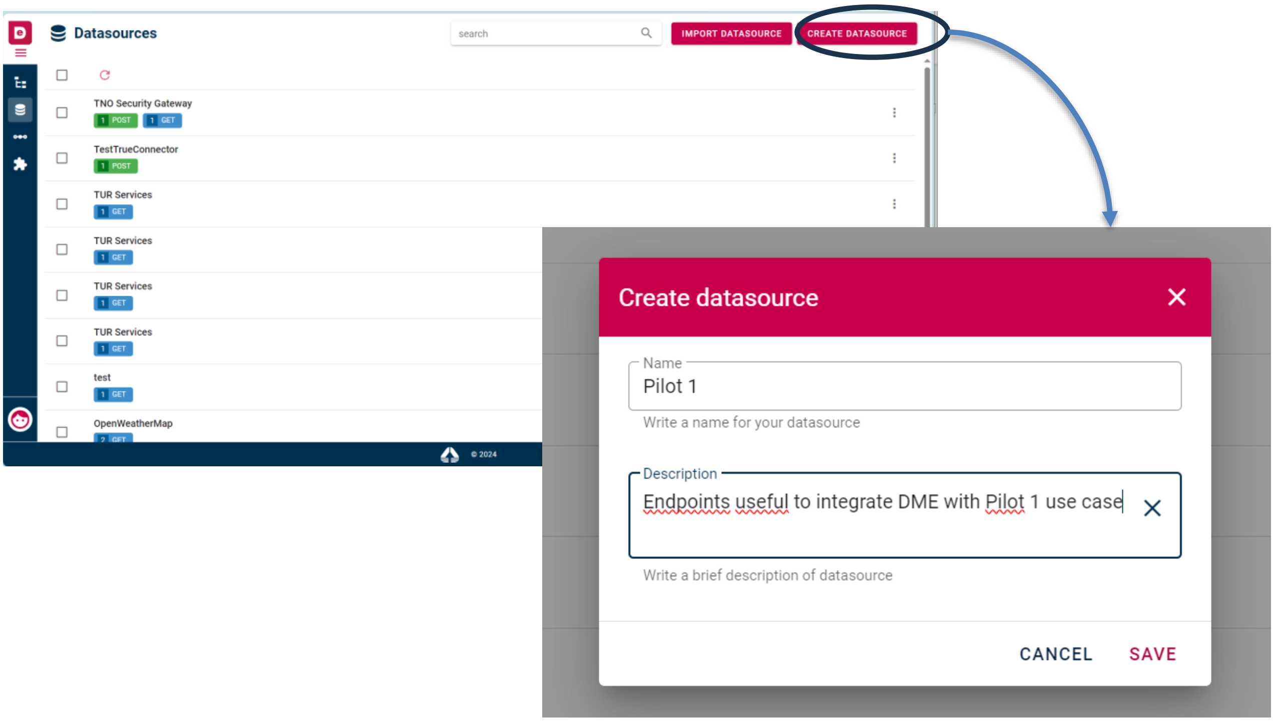

Figure 44: Creation of a new data source

We added the endpoints required to trigger the communication between a data consumer and a data provider through the TSG connector.

The communication follows the steps required by the connector itself.

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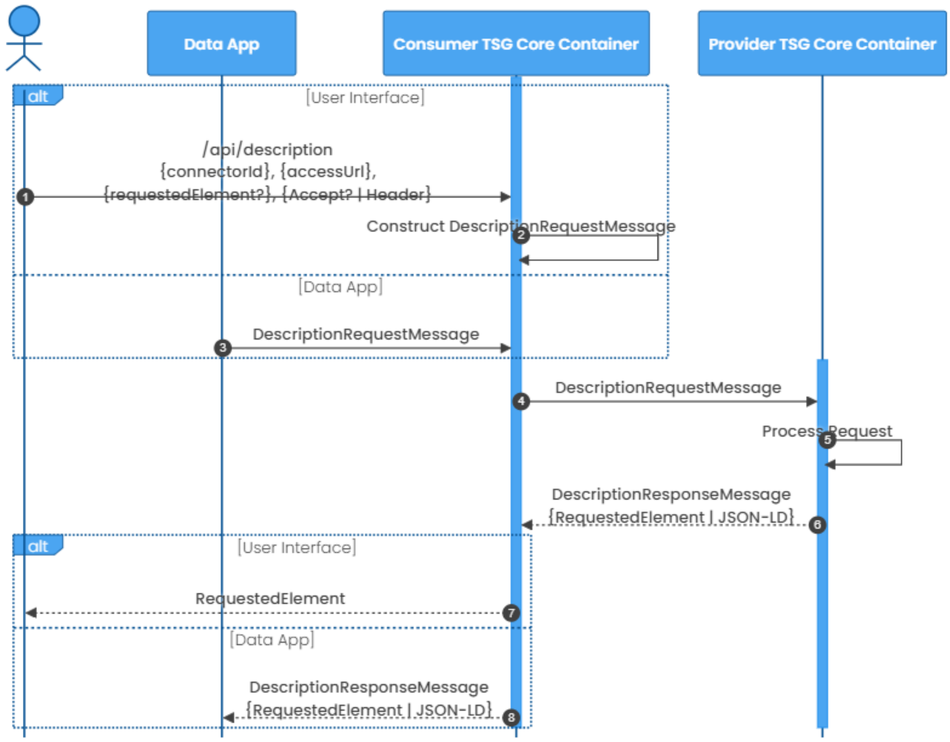

Figure 45: TSG connector messages flow

To consume data from the data space, the DME acts as the actor shown in the sequence diagram of the TSG endpoints to trigger the trusted communication with the data provider.

To achieve this goal, we created a specific mashup (a data manipulation process) to invoke the different endpoints and get the RequestedElement coming from the Data Provider.

The mashup to get the RequestedElement from the Data provider is shown in Figure 46.

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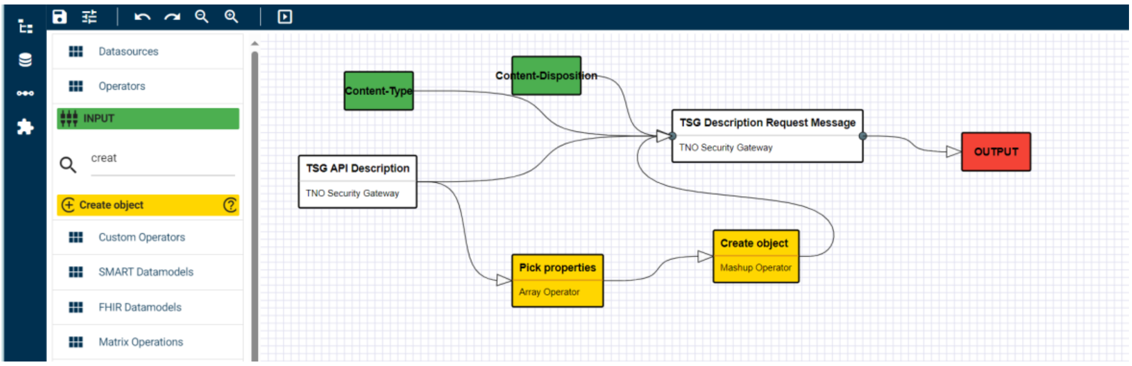

Figure 46: Mashup to get data from data provider

The RequestedElement for the Pilot 1 use case is related to the wind turbine values.


```
{
        "windturbine_values":
        [
                {
                        "windfarm_id": "FRBRT",
                        "windturbine_id": "91840",
                        "timestamp": "2019-08-24T00:00:00Z",
                        "nacelle_temperature": "27.54 Cel",
                        "blade_pitch_angle": "450 deg",
                        "windspeed": "9.32 m/s",
                        "generator_torque": "3370.42 N.m"
                },
                {
                        "windfarm_id": "FRBRT",
                        "windturbine_id": "91840",
                        "timestamp": "2019-08-24T01:00:00Z",
                        "nacelle_temperature": "27.66 Cel",
                        "blade_pitch_angle": "451 deg",
                        "windspeed": "9.45 m/s",
                        "generator_torque": "3370.38 N.m"
                }

        ]
}
```


With a similar approach, the DME can act as data provider and send the RequestedElement to the consumers.

The flow is the following:

1. The data consumer asks the wind turbine data to the DME.

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2. The data consumer triggers the contract negotiation through the TSG Connector.
3. After the contract negotiation, the DME invokes the Data Transformation Service (see 4.3) to transform the data according to the ENERSHARE data model.
4. After that, the DME sends the wind turbine data to the data consumer.

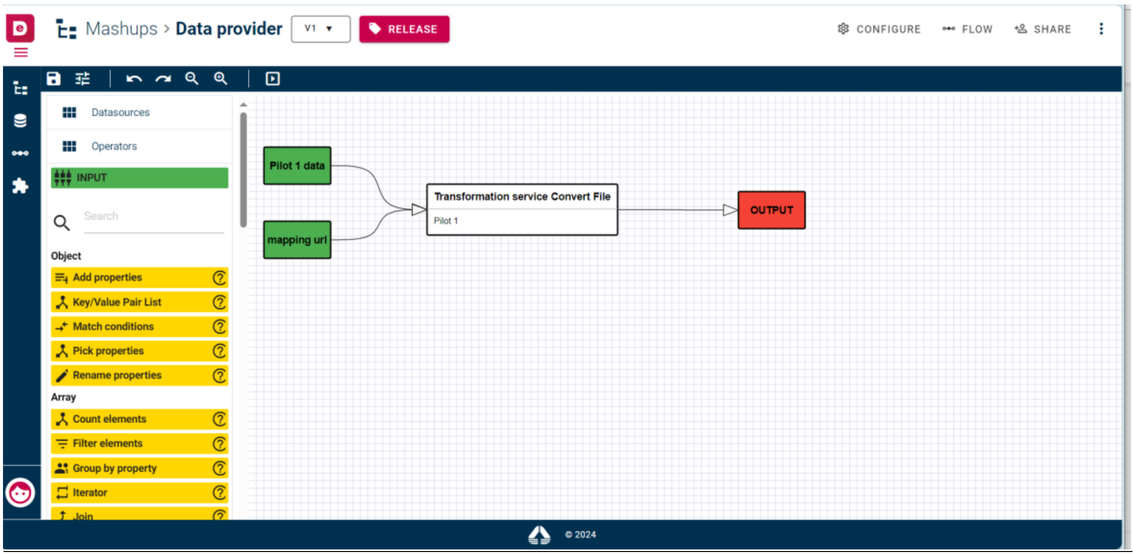

Figure 47: Mashup to allow DME to be a data provider

After creating the mashup as a data manipulation process, the DME can create a so-called flow, that basically is a running mashup. To achieve this goal, the user has to:

- Release the mashup (Figure 48);
- Create a flow (Figure 49);
- Select a target HTTP. The target HTTP allows that the output data of the mashups will be sent through a REST API (Figure 50).

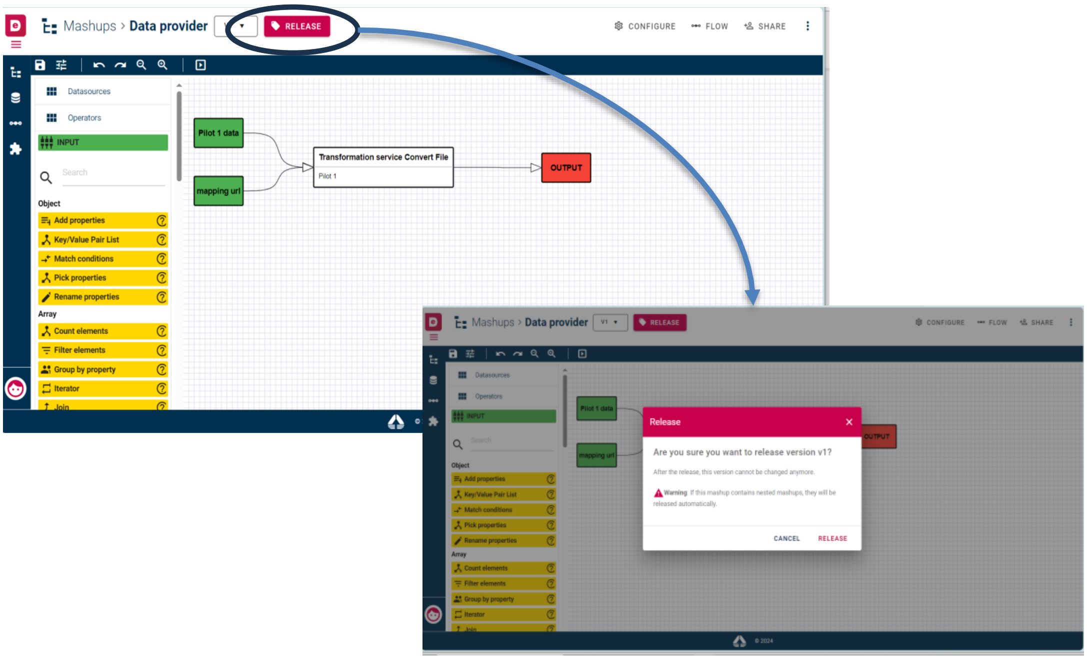

Figure 48: Release the mashup

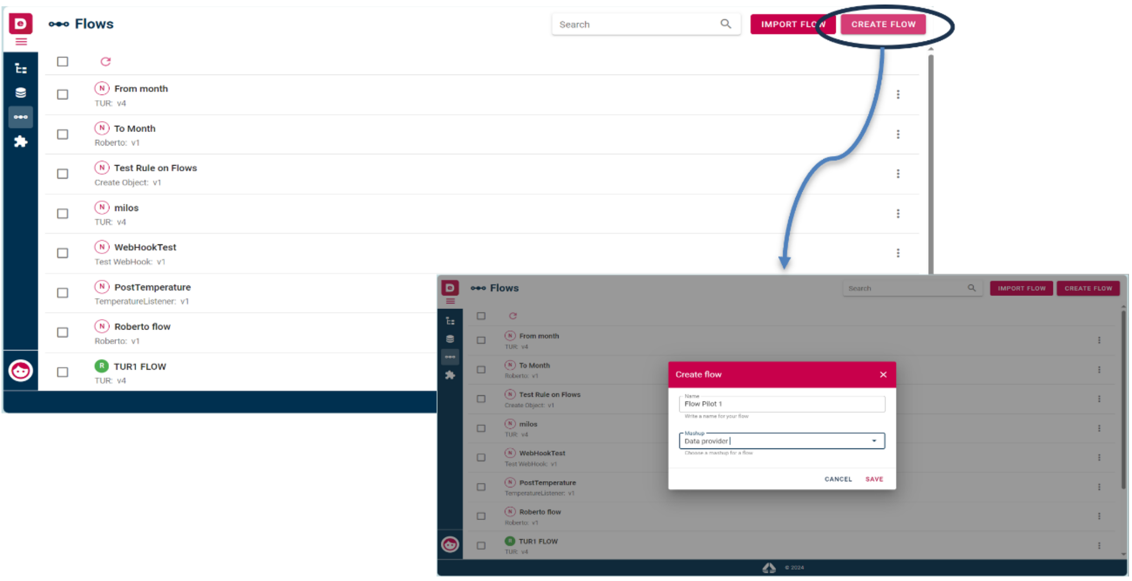

Figure 49: Create a flow for the released mashup

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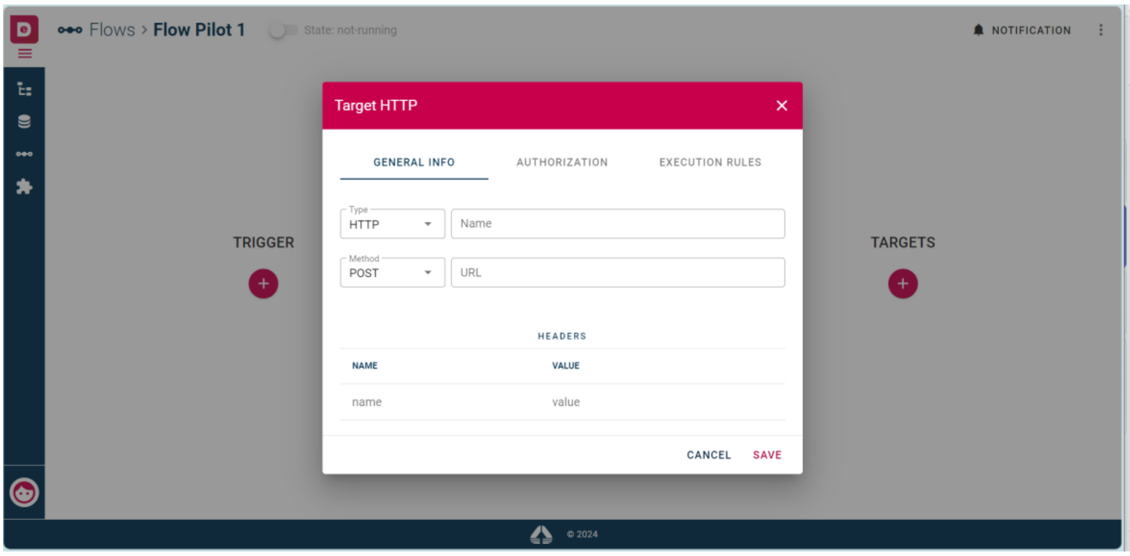

Figure 50: HTTP Target for the flow

4.7 Summary table of open-source software results

This chapter summarizes the links to all the open-source results in WP3 for achieving semantic interoperability.

Description	URL
Pilot diagrams and ENERSHARE data model	https://w3id.org/enershare https://github.com/EnershareProject/EnershareOntologies
Vocabulary Hub	https://energy.vocabulary-hub.eu/ https://www.semantic-treehouse.nl/releases/
Open APIs + RML mappings + SHACL files	https://git.code.tecnalia.com/open/enershare/
Data transformation service	Swagger UI endpoint: https://transformation.enershare.urban.tecnalia.dev/docs Docker image: https://hub.docker.com/r/sbilbao/transformation_service
Compliance service	Swagger UI endpoint: https://compliance.enershare.urban.tecnalia.dev/docs Docker image: https://hub.docker.com/r/sbilbao/compliance_service

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Smart data models	https://smartdatamodels.org/index.php/about/
FIWARE Orion-LD	https://github.com/FIWARE/context.Orion-LD

5 Semantic interoperability with sister projects

The Interoperability Network for the Energy Transition (int:net) is an EU initiative that aims to bring together all stakeholders relevant for the European energy sector to jointly work on developing, testing and deploying interoperable energy services.

int:net has cooperated with the sister projects of the same call as ENERSHARE project (OMEGA-X, SYNERGIES, DATA CELLAR and EDDIE), forming the Energy Data Space Cluster Projects (EDSCP).

Among the different activities currently ongoing in the EDSCP, an important one corresponds to the demonstration of semantic interoperability between the different projects and different energy data spaces. Semantic Interoperability is understood as a scenario where connectors, both providers and consumers, can seamlessly share data across dataspaces that could use different semantic information models, without having to develop or rewrite new connectors.

This scenario is illustrated in Figure 51, and considers the Transformation Service developed in ENERSHARE project, as well as the parser developed in OMEGA-X as the key tools to facilitate the semantic interoperability across energy data spaces.

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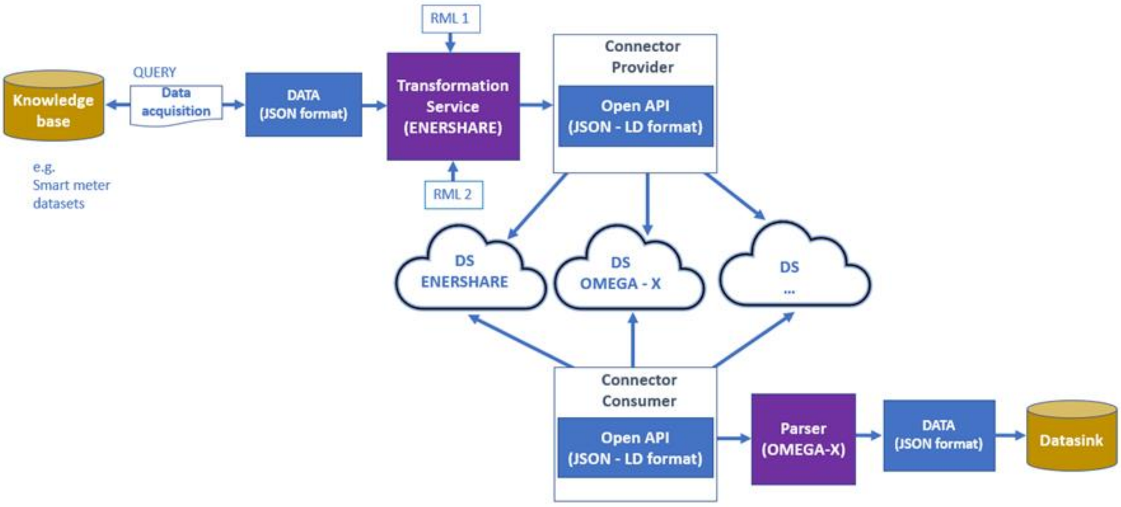

Figure 51: Semantic interoperability and data sharing across data spaces

In real-life scenarios, where connectors want to share data with consumers from different data spaces, they will require to modify the data payloads to match the common data model understood within each data space, prior to providing the information to the consumer.

The data transformation service (developed in ENERSHARE) enables these payload transformations without the need to rewrite the code of the connector. The service takes as input the data to be transformed and a template with the transformation rules, written in the standard language RML, and provides as output the original information structured in accordance with the common data model that is comprehensible to the data consumers in each data space. This way, a single connector can achieve interoperability within different data spaces, simply by just transforming at run-time the data in line with the appropriate template rules, depending on the specific data space where the data exchange occurs. Consequently, there is no need to modify the service that is currently in operation.

Similarly, in order for a data consumer to understand and process data coming from dataspaces with different information models, the parser from OMEGA-X enables to define a template that contains queries in SPARQL or CYPHER standard languages, which can extract the relevant information. This way, the code in the connector, currently in operation, does not need to be rewritten.

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So, with the objective of demonstrating the semantic interoperability across energy projects and data spaces, a plan has been defined. A first meeting of EDSCP for discussing this issue was carried out at the beginning of June 2024, detecting as a potential use case the application of Smart meter data using EUMED-CIM. BRIDGE Data Management Working Group released some EUMED related webinars[14]. OMEGA-X D4.4 published in April 2024 provided also some annexes about EUMED profiles.

Besides, the following activities are expected:

- A webinar (online) where projects will present their methodology and semantic data models (reused standard ontologies, use cases, terms/properties), with the objective of analyzing how to adapt the existing developments, and which data to share. (Date: 22nd of July 2024).
- A workshop (online) to define a system use case and the key aspects to demonstrate semantic interoperability: data (e.g., smart meter data), format (e.g., JSON-LD), data flow (e.g., data transformation rules and mappings for OMEGA-X and ENERSHARE tools, according to Figure 51), software requirements, etc. (Planed: September 2024).
- A semantic interoperability test (in site), that will consist in a live demonstration of the defined system use case. (Planed: November/December 2024), in Tecnalia's Digital Energy Lab (Bilbao).

Taking into account that ENERSHARE WP3 (semantic interoperability) will end in August with the delivery of D3.3, the demonstration of the semantic interoperability will be developed in WP9 (ENERSHARE real-life demonstration).

[14] https://www.youtube.com/playlist?list=PLbOXprZa0an2aPvjwVMNWzk_eDK9-LpAe

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6 Conclusions

Data exchange interoperability occurs at two levels: technical interoperability and semantic interoperability. At technical level, interoperability among connectors is guaranteed by the Dataspace Protocol Specification. At semantic level, a common data model is needed.

ENERSHARE data model is a set of interconnected ontologies that model the information needed in 12 energy use cases. However, as models and formats evolve and it is not realistic to assume, in real case scenarios, that all applications or parties will agree on a common data model or common data format to share data, ENERSHARE supports the idea of a data transformation service, which given a data schema and some mapping rules allows transforming any data model and format (JSON, CSV, XML) into the data model expected by the data space to ensure interoperability between data providers and consumers. This approach is also suitable for cross-domain interoperability, for services deployed in production and for low latency or big volume data exchange.

Besides, as one of the factors that hinders the adoption of semantic technologies is the complexity and the need of technical skills, ENERSHARE has dedicated effort to develop or enhance tools and services to facilitate the work both at design and at run-time.

At design time, the Vocabulary Hub allows interaction with data models and provides a wizard to interactively create APIs and data transformation mappings based on existing data models. At run-time, the Data Mashup Editor facilitates the work to create pipelines to transform the data before being published, and to integrate with the connectors like the True Connector or the TSG connector.

In addition, the compliance service allows to easily validate that connectors' inputs and outputs are compliant with the Open APIs specification. This deliverable provides the RML mapping rules and SHACL files for the 7 pilots in ENERSHARE.

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7 References

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[12] FIWARE Scorpio Broker: https://scorpio.readthedocs.io/en/latest/

[13] FIWARE Stellio Context Broker: https://stellio.readthedocs.io/en/latest/

[14] Digital Enabler. https://www.eng.it/en/our-platforms-solutions/digital-enabler

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8 Appendix: Harmonized Diagrams from steps 3 & 4

This appendix presents the result of the work realised for each pilot during the step 3 and harmonized during the step 4 of the methodology for the ENERSHARE data model.

Although each pilot has multiple diagrams, this appendix presents only 1 diagram for each pilot. One can discover all diagrams and owl files in this git hub: https://w3id.org/enershare

8.1 Pilot 1: Wind farm integrated predictive maintenance and supply chain optimization [Spain] - TECN, ENGIE, ACE, HINE

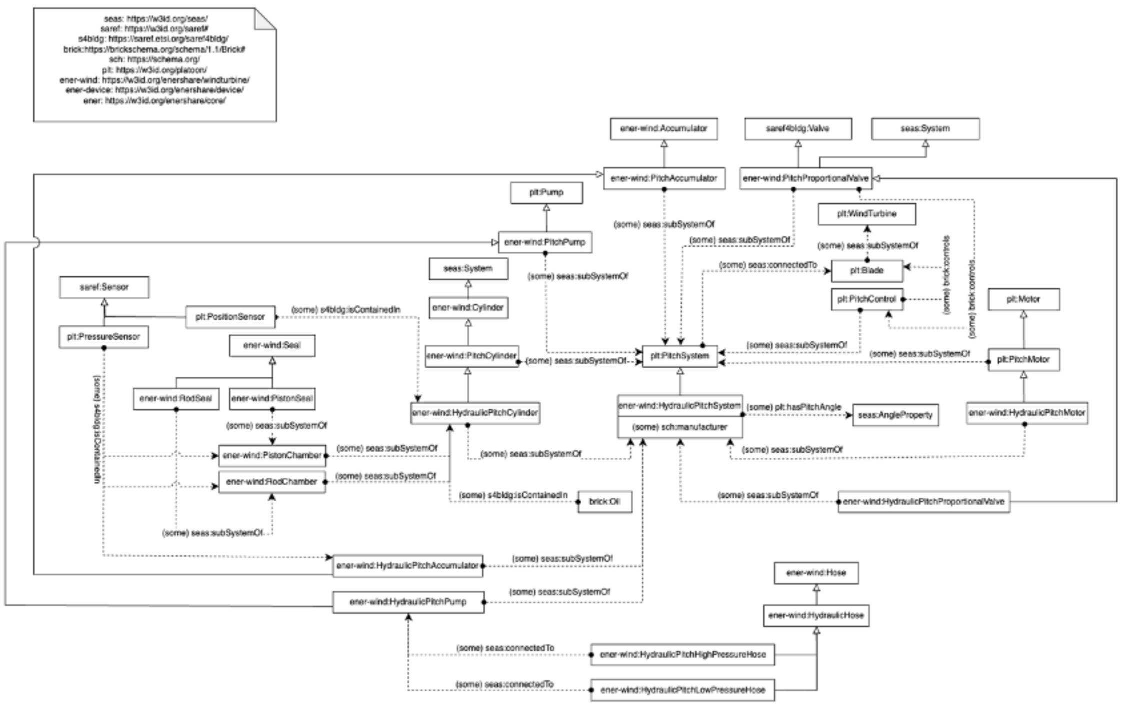

Figure 52: Modelling extract of Hydraulic system

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8.2 Pilot 2: Cross-value chain smart buildings/smart mobility/ smart grid services for Local Energy Communities and power network operators [Portugal] - INESC TEC, SEL, NESTER

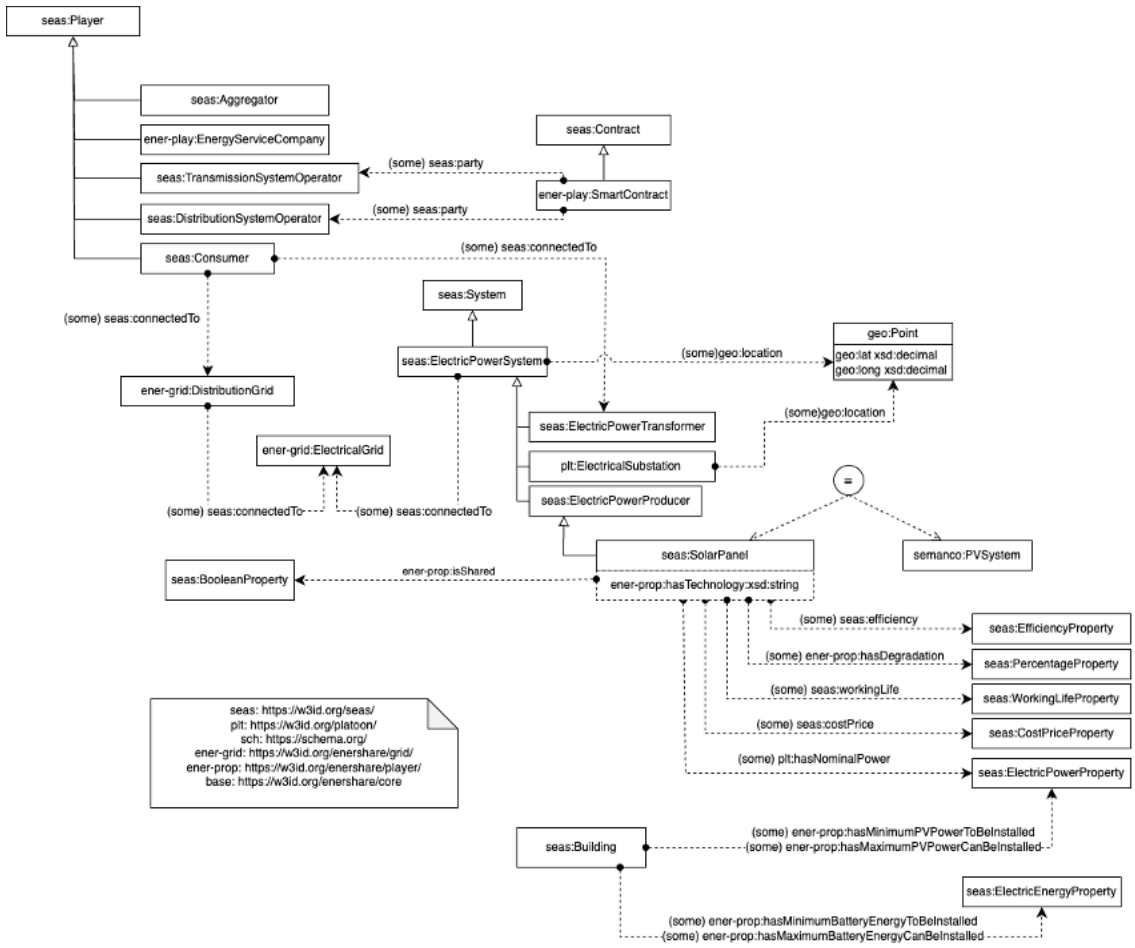

Figure 53: Extract of modeling of use cases of pilot 2

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8.3 Pilot 3: Optimal multi-energy vector planning -electricity vs heat [Slovenia] - COMS, ENVIRODUAL, ELES, KPV, EKL

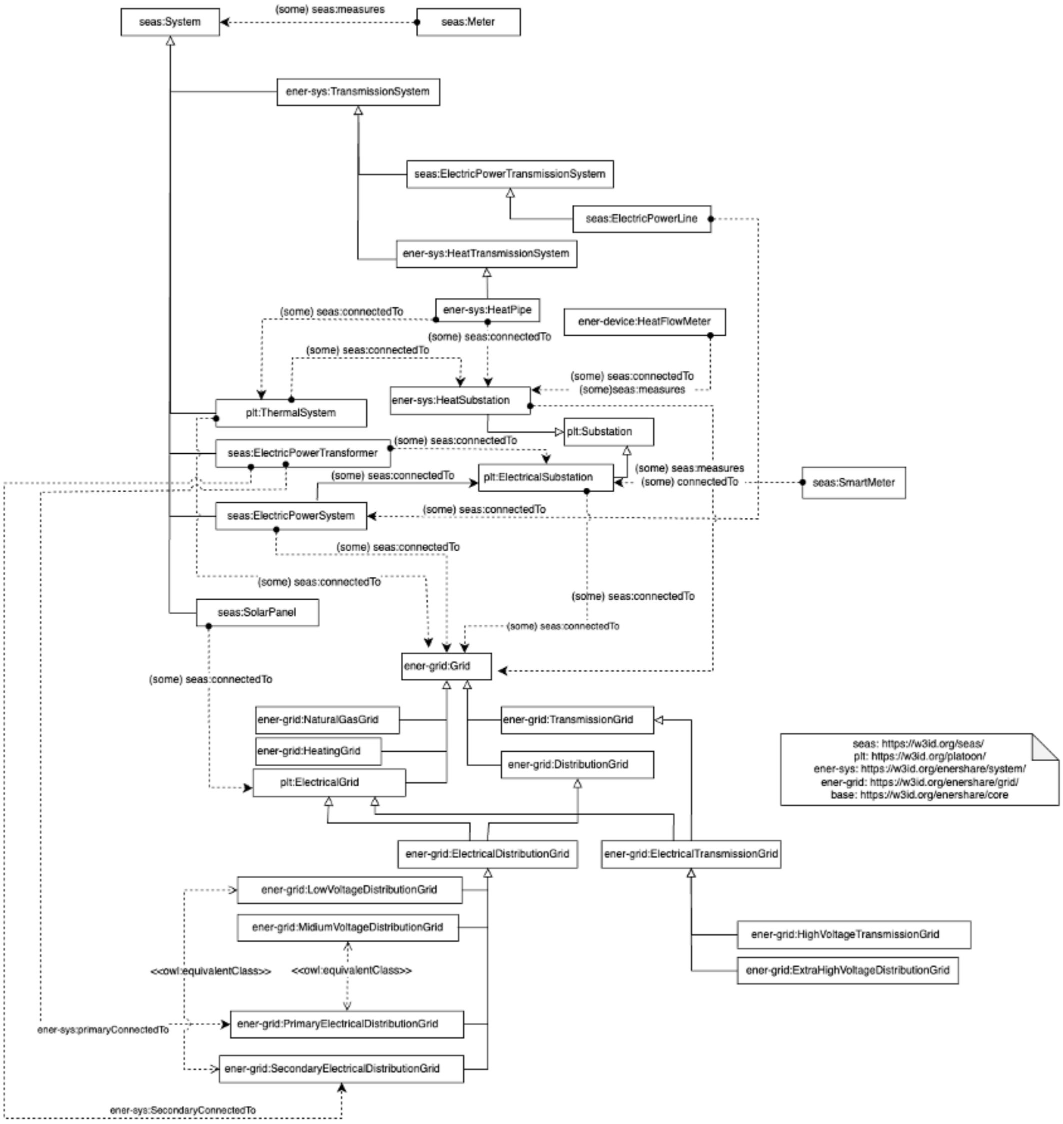

Figure 54: Extract of grid in pilot 3

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8.4 Pilot 4: Digital Twin for optimal data-driven Power-to-Gas optimal planning [Greece] - NTUA, DEPA

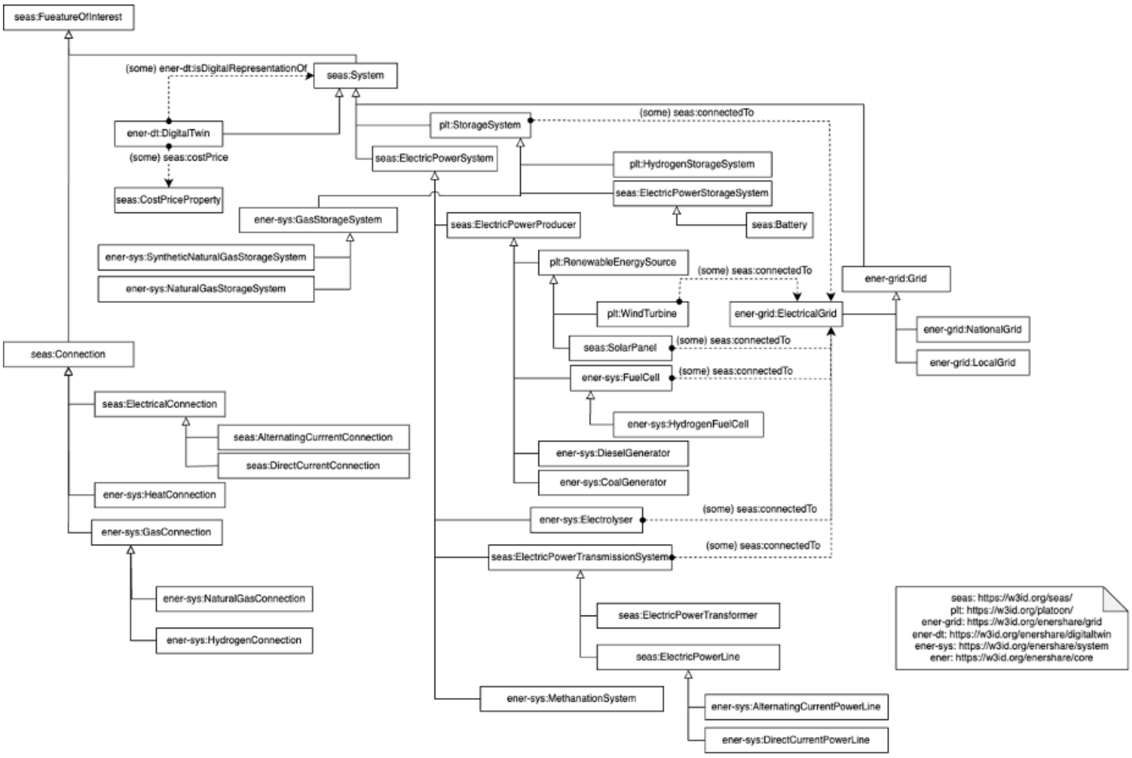

Figure 55: Extract of modeling of Systems on pilot 4

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8.5 Pilot 5: Cross-value chain data community-centered services for optimising DSO-level grid operation while coordinating with e-mobility and water sectors [Italy] - ASM, EMOT, ENG

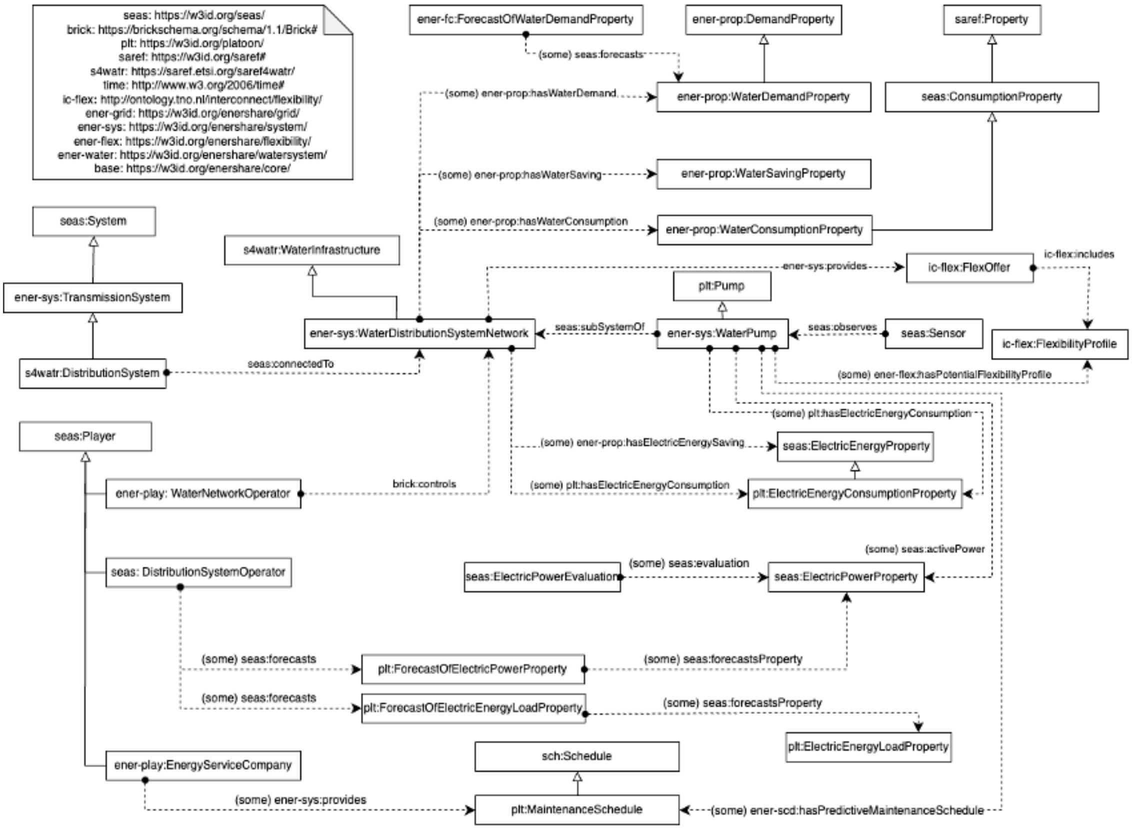

Figure 56: Extract of Modelling of water use case in pilot 5

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8.6 Pilot 6: Aggregation of available flexibility from the behind-the-meter consumers [Sweden] – FORTUM

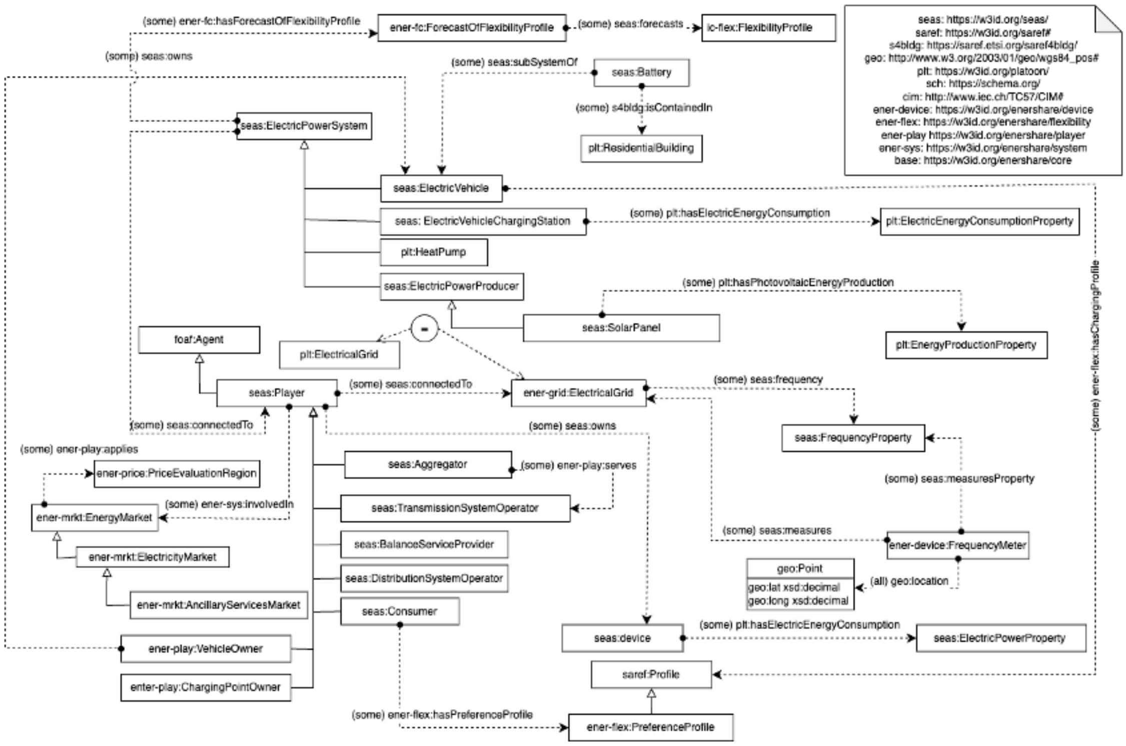

Figure 57: Extract of modelling of pilot 6

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8.7 Pilot 7: Cross-value chain services for energy-data driven green financing [Latvia] - LEIF, NTUA

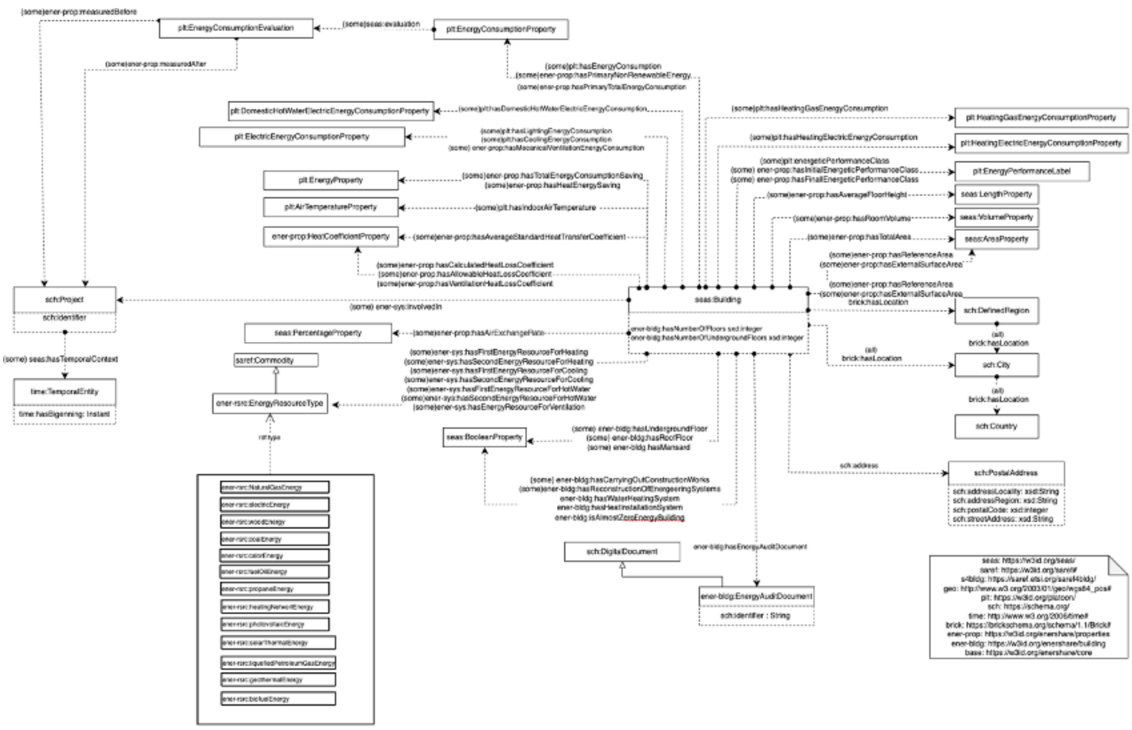

Figure 58: Modelling extract of pilot 7

9 Appendix: Hydraulic pitch system anomaly detection example

This appendix contains an example of the open APIs for the input and output of the hydraulic pitch system anomaly detection service in pilot 1. Input and output are provided in JSON format and transformed into JSON-LD and Turtle using RML mapping rules. The SHACL files for checking the compliance of JSON-LD files with these open APIs are also included.

The complete set of open APIs is available at:

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https://git.code.tecnalia.com/open/enershare/

9.1 Service input files

9.1.1 Input data in JSON format


```
{
    "windturbine_values":[
    {
        "windfarm_id": "FRBRT",
        "windturbine_id": "91840",
        "blade_id": 1,
        "timestamp": "2019-08-24T00:00:00Z",
        "Hydraulic_system_pressure": "300 bar",
        "Accumulator_pressure": "450 bar",
        "Oil_temperature": "60.32 Cel",
        "Cylinder_position": "495.7 nm",
        "Proportional_valve_commands": "A",
        "Pump_charging_time": "10 s",
        "Cylinder_piston_chamber_pressure": "27.54 bar",
        "Cylinder_rod_chamber_pressure": "67.54 bar"
    },
    {
        "windfarm_id": "FRBRT",
        "windturbine_id": "91840",
        "blade_id": 1,
        "timestamp": "2019-08-24T00:05:00Z",
        "Hydraulic_system_pressure": "350 bar",
        "Accumulator_pressure": "460 bar",
        "Oil_temperature": "61.32 Cel",
        "Cylinder_position": "495.9 nm",
        "Proportional_valve_commands": "A",
        "Pump_charging_time": "10 s",
        "Cylinder_piston_chamber_pressure": "27.94 bar",
        "Cylinder_rod_chamber_pressure": "68.54 bar"
    }]
}
```


9.1.2 RML mapping for the input JSON format

```
@prefix rr: <http://www.w3.org/ns/r2rml#> .
@prefix rml: <http://semweb.mmlab.be/ns/rml#> .
@prefix ql: <http://semweb.mmlab.be/ns/ql#> .
@prefix brick: <https://brickschema.org/schema/1.1/Brick#> .
@prefix cdt: <http://w3id.org/lindt/custom_datatypes#> .
@prefix plt: <https://w3id.org/platoon/> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix seas: <https://w3id.org/seas/> .
@prefix time: <http://www.w3.org/2006/time#> .
```

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```
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
@prefix ener-wind: <https://w3id.org/enershare/windturbine/> .
@prefix ener-prop: <https://w3id.org/enershare/property/>.
@prefix s4bldg: <https://w3id.org/def/saref4bldg#> .
@prefix saref: <https://w3id.org/saref#> .

<#LogicalSourceWTVal> a rml:BaseSource ;
  rml:source
"pilot1_hydraulic_pitch_anomaly_detection_input_simplejson.json" ;
  rml:referenceFormulation ql:JSONPath;
  rml:iterator "$.windturbine_values[*]" .

<#WindFarmMapping> a rr:TriplesMap;
    rml:logicalSource <#LogicalSourceWTVal> ;

    rr:subjectMap [
        rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}";
        rr:class plt:WindFarm
    ];

    rr:predicateObjectMap [
        rr:predicate rdfs:label ;
        rr:objectMap [
            rml:reference "windfarm_id"
        ]
    ].

<#Time> a rr:TriplesMap;
    rml:logicalSource <#LogicalSourceWTVal> ;

    rr:subjectMap [
        rr:template
"http://engie.com/enershare/resource/timestamp/{timestamp}";
        rr:class time:Instant
    ];

    rr:predicateObjectMap [
        rr:predicate time:inXSDDateTime ;
        rr:objectMap [
            rml:reference "timestamp";
            rr:datatype  xsd:dateTime
        ]
    ] .

<#OnshoreWindTurbine> a rr:TriplesMap;
    rml:logicalSource <#LogicalSourceWTVal> ;

    rr:subjectMap [
        rr:class plt:OnshoreWindTurbine;
        rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}"
```

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```
    ];

    rr:predicateObjectMap [
        rr:predicate rdfs:label ;
        rr:objectMap [
            rml:reference "windturbine_id"
        ]
    ];

    rr:predicateObjectMap [
        rr:predicate brick:hasLocation ;
        rr:objectMap [
            rr:termType rr:IRI;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}"
        ]
    ];

    rr:predicateObjectMap [
            rr:predicate seas:isMemberOf ;
            rr:objectMap [
            rr:termType rr:IRI;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}"
            ]
    ] .

<#HydraulicPitchSystem> a rr:TriplesMap;
    rml:logicalSource <#LogicalSourceWTVal> ;

    rr:subjectMap [
        rr:class ener-wind:HydraulicPitchSystem;
        rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem"
    ];

    rr:predicateObjectMap [
        rr:predicate rdfs:label ;
        rr:objectMap [
             rr:constant "Hydraulic Pitch System"
        ]
    ];

    rr:predicateObjectMap [
        rr:predicate seas:connectedTo ;
        rr:objectMap [
            rr:termType rr:IRI;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/blade"
        ]
    ];
```

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```
    rr:predicateObjectMap [
        rr:predicate ener-prop:hasMainSystemPressure;
        rr:objectMap [
            rr:termType rr:IRI;
                rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/property/pressure/average"
            ]
    ] .

    <#Blade> a rr:TriplesMap;
        rml:logicalSource <#LogicalSourceWTVal> ;

        rr:subjectMap [
            rr:class plt:Blade;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/blade"
        ];

        rr:predicateObjectMap [
            rr:predicate rdfs:label ;
            rr:objectMap [ rml:reference "blade_id" ]
        ];

        rr:predicateObjectMap [
                rr:predicate seas:subSystemOf ;
                rr:objectMap [
                rr:termType rr:IRI;
                rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}"
                ]
    ].


    <#HydraulicSystemPressureProperty> a rr:TriplesMap;
        rml:logicalSource <#LogicalSourceWTVal> ;

        rr:subjectMap [
            rr:class seas:PressureProperty;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/property/pressure/average"
        ];

        rr:predicateObjectMap [
            rr:predicate rdfs:label ;
            rr:objectMap [ rr:constant "Hydraulic System Pressure
Average" ]
        ];
```

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```
        rr:predicateObjectMap [
                rr:predicate seas:evaluation ;
                rr:objectMap [
                rr:termType rr:IRI;
                rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/property/pressure/average/evaluation
/{timestamp}"
            ]
    ]  .

    <#HydraulicSystemPressureEvaluation> a rr:TriplesMap;
        rml:logicalSource <#LogicalSourceWTVal> ;

        rr:subjectMap [
            rr:class plt:PressureEvaluation;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/property/pressure/average/evaluation
/{timestamp}"
        ];

        rr:predicateObjectMap [
                rr:predicate seas:evaluatedSimpleValue ;
                rr:objectMap [
                rml:reference "Hydraulic_system_pressure";
                rr:datatype  cdt:pressure
            ]
        ];

        rr:predicateObjectMap [
                rr:predicate seas:hasTemporalContext ;
                rr:objectMap [
                rr:termType rr:IRI;
                rr:template
"http://engie.com/enershare/resource/timestamp/{timestamp}"
                ]
        ].

    <#PitchAccumulatorPressureProperty> a rr:TriplesMap;
        rml:logicalSource <#LogicalSourceWTVal> ;

        rr:subjectMap [
            rr:class seas:PressureProperty;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchaccumulator/property/pressure/a
verage"
        ];

        rr:predicateObjectMap [
            rr:predicate rdfs:label ;
```

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```
            rr:objectMap [ rr:constant "Hydraulic Pitch Accumulator
Pressure Average" ]
        ];

        rr:predicateObjectMap [
                rr:predicate seas:evaluation ;
                rr:objectMap [
                rr:termType rr:IRI;
                rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchaccumulator/property/pressure/a
verage/evaluation/{timestamp}"
            ]
    ]  .

    <#PitchAccumulatorPressureEvaluation> a rr:TriplesMap;
        rml:logicalSource <#LogicalSourceWTVal> ;

        rr:subjectMap [
            rr:class plt:PressureEvaluation;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchaccumulator/property/pressure/a
verage/evaluation/{timestamp}"
        ];

        rr:predicateObjectMap [
                rr:predicate seas:evaluatedSimpleValue ;
                rr:objectMap [
                rml:reference "Accumulator_pressure";
                rr:datatype  cdt:pressure
            ]
        ];

        rr:predicateObjectMap [
                rr:predicate seas:hasTemporalContext ;
                rr:objectMap [
                rr:termType rr:IRI;
                rr:template
"http://engie.com/enershare/resource/timestamp/{timestamp}"
                ]
        ].

<#CylinderPistonChamberPressureProperty> a rr:TriplesMap;
        rml:logicalSource <#LogicalSourceWTVal> ;

        rr:subjectMap [
            rr:class seas:PressureProperty;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchcylinder/pistonchamber/property
/pressure/average"
        ];
```

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```
        rr:predicateObjectMap [
            rr:predicate rdfs:label ;
            rr:objectMap [ rr:constant "Cylinder Piston chamber
Pressure Average" ]
        ];

        rr:predicateObjectMap [
                rr:predicate seas:evaluation ;
                rr:objectMap [
                rr:termType rr:IRI;
                rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchcylinder/pistonchamber/property
/pressure/average/evaluation/{timestamp}"
            ]
    ]   .

    <#CylinderPistonChamberPressureEvaluation> a rr:TriplesMap;
        rml:logicalSource <#LogicalSourceWTVal> ;

        rr:subjectMap [
            rr:class plt:PressureEvaluation;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchcylinder/pistonchamber/property
/pressure/average/evaluation/{timestamp}"
        ];

        rr:predicateObjectMap [
                rr:predicate seas:evaluatedSimpleValue ;
                rr:objectMap [
                rml:reference "Cylinder_piston_chamber_pressure";
                rr:datatype  cdt:pressure
            ]
        ];

        rr:predicateObjectMap [
                rr:predicate seas:hasTemporalContext ;
                rr:objectMap [
                rr:termType rr:IRI;
                rr:template
"http://engie.com/enershare/resource/timestamp/{timestamp}"
                ]
        ].

<#CylinderRodChamberPressureProperty> a rr:TriplesMap;
        rml:logicalSource <#LogicalSourceWTVal> ;

        rr:subjectMap [
            rr:class seas:PressureProperty;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
```

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```
e/{windturbine_id}/hydpitchsystem/pitchcylinder/rodchamber/property/pr
essure/average"
        ];

        rr:predicateObjectMap [
            rr:predicate rdfs:label ;
            rr:objectMap [ rr:constant "Cylinder Rod chamber Pressure
Average" ]
        ];

        rr:predicateObjectMap [
                rr:predicate seas:evaluation ;
                rr:objectMap [
                 rr:termType rr:IRI;
                 rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchcylinder/rodchamber/property/pr
essure/average/evaluation/{timestamp}"
            ]
    ]  .

    <#CylinderRodChamberPressureEvaluation> a rr:TriplesMap;
        rml:logicalSource <#LogicalSourceWTVal> ;

        rr:subjectMap [
            rr:class plt:PressureEvaluation;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchcylinder/rodchamber/property/pr
essure/average/evaluation/{timestamp}"
        ];

        rr:predicateObjectMap [
                rr:predicate seas:evaluatedSimpleValue ;
                rr:objectMap [
                 rml:reference "Cylinder_rod_chamber_pressure";
                 rr:datatype  cdt:pressure
            ]
        ];

        rr:predicateObjectMap [
                rr:predicate seas:hasTemporalContext ;
                rr:objectMap [
                 rr:termType rr:IRI;
                 rr:template
"http://engie.com/enershare/resource/timestamp/{timestamp}"
                ]
        ].

<#HydraulicPitchAccumulator> a rr:TriplesMap;
    rml:logicalSource <#LogicalSourceWTVal> ;

    rr:subjectMap [
```

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```
        rr:class ener-wind:HydraulicPitchAccumulator ;
        rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchaccumulator"
    ];

    rr:predicateObjectMap [
        rr:predicate rdfs:label ;
        rr:objectMap [
             rr:constant "Hydraulic Pitch Accumulator"
        ]
    ];

    rr:predicateObjectMap [
        rr:predicate seas:subSystemOf;
        rr:objectMap [
            rr:termType rr:IRI;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem"
        ]
    ];

    rr:predicateObjectMap [
        rr:predicate plt:hasPressure;
        rr:objectMap [
            rr:termType rr:IRI;
               rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchaccumulator/property/pressure/a
verage"
           ]
    ] .

<#CylinderPistonChamber> a rr:TriplesMap;
    rml:logicalSource <#LogicalSourceWTVal> ;

    rr:subjectMap [
        rr:class ener-wind:PistonChamber ;
        rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchcylinder/pistonchamber"
    ];

    rr:predicateObjectMap [
        rr:predicate rdfs:label ;
        rr:objectMap [
             rr:constant "Cylinder Piston Chamber"
        ]
    ];

    rr:predicateObjectMap [
        rr:predicate seas:subSystemOf;
```

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```
        rr:objectMap [
            rr:termType rr:IRI;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/{windturbi
ne_id}/hydpitchsystem/pitchcylinder"
        ]
    ];

    rr:predicateObjectMap [
        rr:predicate plt:hasPressure;
        rr:objectMap [
            rr:termType rr:IRI;
                rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchcylinder/pistonchamber/property
/pressure/average"
            ]
    ] .


<#CylinderRodChamber> a rr:TriplesMap;
    rml:logicalSource <#LogicalSourceWTVal> ;

    rr:subjectMap [
        rr:class ener-wind:RodChamber ;
        rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchcylinder/rodchamber"
    ];

    rr:predicateObjectMap [
        rr:predicate rdfs:label ;
        rr:objectMap [
             rr:constant "Cylinder Rod Chamber"
        ]
    ];

    rr:predicateObjectMap [
        rr:predicate seas:subSystemOf;
        rr:objectMap [
            rr:termType rr:IRI;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/{windturbi
ne_id}/hydpitchsystem/pitchcylinder"
        ]
    ];

    rr:predicateObjectMap [
        rr:predicate plt:hasPressure;
        rr:objectMap [
            rr:termType rr:IRI;
                rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
```

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```
e/{windturbine_id}/hydpitchsystem/pitchcylinder/rodchamber/property/pr
essure/average"
            ]
    ] .

<#HydraulicPitchCylinder> a rr:TriplesMap;
    rml:logicalSource <#LogicalSourceWTVal> ;

    rr:subjectMap [
        rr:class ener-wind:HydraulicPitchCylinder ;
        rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchcylinder"
    ];

    rr:predicateObjectMap [
        rr:predicate rdfs:label ;
        rr:objectMap [
             rr:constant "Hydraulic Pitch Cylinder"
        ]
    ];

    rr:predicateObjectMap [
        rr:predicate seas:subSystemOf;
        rr:objectMap [
            rr:termType rr:IRI;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem"
        ]
    ];

    rr:predicateObjectMap [
        rr:predicate plt:hasPosition;
        rr:objectMap [
            rr:termType rr:IRI;
                rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchcylinder/property/position/aver
age"
            ]
    ] .

<#CylinderPositionProperty> a rr:TriplesMap;
        rml:logicalSource <#LogicalSourceWTVal> ;

        rr:subjectMap [
            rr:class plt:PositionProperty;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchcylinder/property/position/aver
age"
        ];
```

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```
        rr:predicateObjectMap [
            rr:predicate rdfs:label ;
            rr:objectMap [ rr:constant "Cylinder Position Property
Average" ]
        ];

        rr:predicateObjectMap [
                rr:predicate seas:evaluation ;
                rr:objectMap [
                 rr:termType rr:IRI;
                 rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchcylinder/property/position/aver
age/evaluation/{timestamp}"
            ]
    ]  .

    <#CylinderPositionEvaluation> a rr:TriplesMap;
        rml:logicalSource <#LogicalSourceWTVal> ;

        rr:subjectMap [
            rr:class plt:PositionEvaluation;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchcylinder/property/position/aver
age/evaluation/{timestamp}"
        ];

        rr:predicateObjectMap [
                rr:predicate seas:evaluatedSimpleValue ;
                rr:objectMap [
                 rml:reference "Cylinder_position";
                 rr:datatype  cdt:ucum
            ]
        ];

        rr:predicateObjectMap [
                rr:predicate seas:hasTemporalContext ;
                rr:objectMap [
                 rr:termType rr:IRI;
                 rr:template
"http://engie.com/enershare/resource/timestamp/{timestamp}"
                ]
        ].

<#BrickOil> a rr:TriplesMap;
    rml:logicalSource <#LogicalSourceWTVal> ;

    rr:subjectMap [
        rr:class brick:Oil ;
```

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```
        rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchcylinder/oil"
    ];

    rr:predicateObjectMap [
        rr:predicate rdfs:label ;
        rr:objectMap [
             rr:constant "Brick Oil"
        ]
    ];

    rr:predicateObjectMap [
        rr:predicate s4bldg:isContainedIn;
        rr:objectMap [
            rr:termType rr:IRI;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchcylinder"
        ]
    ];

    rr:predicateObjectMap [
        rr:predicate seas:temperature;
        rr:objectMap [
            rr:termType rr:IRI;
                rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchcylinder/oil/property/temperatu
re/average"
            ]
    ] .

<#OilTemperatureProperty> a rr:TriplesMap;
        rml:logicalSource <#LogicalSourceWTVal> ;

        rr:subjectMap [
            rr:class seas:TemperatureProperty;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchcylinder/oil/property/temperatu
re/average"
        ];

        rr:predicateObjectMap [
            rr:predicate rdfs:label ;
            rr:objectMap [ rr:constant "Oil Temperature Property  "]
        ];

        rr:predicateObjectMap [
                rr:predicate seas:evaluation ;
                rr:objectMap [
                rr:termType rr:IRI;
```

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```
                rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchcylinder/oil/property/temperatu
re/average/evaluation/{timestamp}"
            ]
    ]  .

    <#OilTemperatureEvaluation> a rr:TriplesMap;
        rml:logicalSource <#LogicalSourceWTVal> ;

        rr:subjectMap [
            rr:class seas:TemperatureEvaluation;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchcylinder/oil/property/temperatu
re/average/evaluation/{timestamp}"
        ];

        rr:predicateObjectMap [
                rr:predicate seas:evaluatedSimpleValue ;
                rr:objectMap [
                rml:reference "Oil_temperature";
                rr:datatype  cdt:temperature
            ]
        ];

        rr:predicateObjectMap [
                rr:predicate seas:hasTemporalContext ;
                rr:objectMap [
                rr:termType rr:IRI;
                rr:template
"http://engie.com/enershare/resource/timestamp/{timestamp}"
                ]
        ].

<#HydraulicPitchProportionalValve> a rr:TriplesMap;
    rml:logicalSource <#LogicalSourceWTVal> ;

    rr:subjectMap [
        rr:class ener-wind:HydraulicPitchProportionalValve ;
        rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchproportionalvalve"
    ];

    rr:predicateObjectMap [
        rr:predicate rdfs:label ;
        rr:objectMap [
             rr:constant "Hydraulic Pitch Proportional Valve"
        ]
    ];

    rr:predicateObjectMap [
```

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```
        rr:predicate seas:subSystemOf;
        rr:objectMap [
            rr:termType rr:IRI;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem"
        ]
    ];

    rr:predicateObjectMap [
        rr:predicate saref:hasFunction;
        rr:objectMap [
            rr:termType rr:IRI;
                rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchproportionalvalve/property/func
tion"
            ]
    ] .

<#ProportionalValveProperty> a rr:TriplesMap;
        rml:logicalSource <#LogicalSourceWTVal> ;

        rr:subjectMap [
            rr:class ener-wind:SignalFunction;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchproportionalvalve/property/func
tion"
        ];

        rr:predicateObjectMap [
            rr:predicate rdfs:label ;
            rr:objectMap [ rr:constant "Proportional Valve Property"]
        ];

        rr:predicateObjectMap [
                rr:predicate saref:hasCommand ;
                rr:objectMap [
                rr:termType rr:IRI;
                rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchproportionalvalve/property/func
tion/evaluation/{timestamp}"
            ]
    ]  .

    <#ProportionalValveEvaluation> a rr:TriplesMap;
        rml:logicalSource <#LogicalSourceWTVal> ;

        rr:subjectMap [
            rr:class ener-wind:SignalCommand;
```

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```
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchproportionalvalve/property/func
tion/evaluation/{timestamp}"
        ];

        rr:predicateObjectMap [
                rr:predicate seas:evaluatedSimpleValue ;
                rr:objectMap [
                rml:reference "Proportional_valve_commands";
                rr:datatype  cdt:ucum
            ]
        ];

        rr:predicateObjectMap [
                rr:predicate seas:hasTemporalContext ;
                rr:objectMap [
                rr:termType rr:IRI;
                rr:template
"http://engie.com/enershare/resource/timestamp/{timestamp}"
                ]
        ].

<#HydraulicPitchPump> a rr:TriplesMap;
    rml:logicalSource <#LogicalSourceWTVal> ;

    rr:subjectMap [
        rr:class ener-wind:HydraulicPitchPump ;
        rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchpump"
    ];

    rr:predicateObjectMap [
        rr:predicate rdfs:label ;
        rr:objectMap [
             rr:constant "Hydraulic Pitch Pump"
        ]
    ];

    rr:predicateObjectMap [
        rr:predicate seas:subSystemOf;
        rr:objectMap [
            rr:termType rr:IRI;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem"
        ]
    ];

    rr:predicateObjectMap [
        rr:predicate ener-prop:hasChargingDuration;
        rr:objectMap [
```

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```
            rr:termType rr:IRI;
                rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchpump/property/chargingduration/
{timestamp}"
            ]
    ] .

<#HydraulicPitchPumpChargingProperty> a rr:TriplesMap;
        rml:logicalSource <#LogicalSourceWTVal> ;

        rr:subjectMap [
            rr:class time:Duration;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem/pitchpump/property/chargingduration/
{timestamp}"
        ];

        rr:predicateObjectMap [
            rr:predicate rdfs:label ;
            rr:objectMap [ rr:constant "Pitch Pump Charging Property"]
        ];

    rr:predicateObjectMap [
        rr:predicate time:unitType ;
        rr:objectMap [
            rr:termType rr:IRI;
            rr:template time:unitSecond
        ]
    ];

    rr:predicateObjectMap [
        rr:predicate time:numericDuration ;
        rr:objectMap [
            rml:reference "Pump_charging_time"
        ]
    ].
```

9.1.3 Input data in JSON-LD format

```
{
  "@context": {
    "owl": "http://www.w3.org/2002/07/owl#",
    "rdf": "http://www.w3.org/1999/02/22-rdf-syntax-ns#",
    "rdfs": "http://www.w3.org/2000/01/rdf-schema#",
    "xsd": "http://www.w3.org/2001/XMLSchema#"
  },
  "@graph": [
    {
```

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```
      "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchpump",
      "@type":
"https://w3id.org/enershare/windturbine/HydraulicPitchPump",
      "https://w3id.org/enershare/property/hasChargingDuration": [
        {
          "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchpump/property/chargingduration/2019_08_24t00:00:00
z"
        },
        {
          "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchpump/property/chargingduration/2019_08_24t00:05:00
z"
        }
      ],
      "https://w3id.org/seas/subSystemOf": {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem"
      },
      "rdfs:label": "Hydraulic Pitch Pump"
    },
    {
      "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchproportionalvalve/property/function/evaluation/201
9_08_24t00:05:00z",
      "@type": "https://w3id.org/enershare/windturbine/SignalCommand",
      "https://w3id.org/seas/evaluatedSimpleValue": {
        "@type": "http://w3id.org/lindt/custom_datatypes#ucum",
        "@value": "A"
      },
      "https://w3id.org/seas/hasTemporalContext": {
        "@id":
"http://engie.com/enershare/resource/timestamp/2019_08_24t00:05:00z"
      }
    },
    {
      "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/property/position/average/evaluation/2019
_08_24t00:00:00z",
      "@type": "https://w3id.org/platoon/PositionEvaluation",
      "https://w3id.org/seas/evaluatedSimpleValue": {
        "@type": "http://w3id.org/lindt/custom_datatypes#ucum",
        "@value": "495.7 nm"
      },
      "https://w3id.org/seas/hasTemporalContext": {
```


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```
          "@id":
"http://engie.com/enershare/resource/timestamp/2019_08_24t00:00:00z"
        }
      },
      {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchaccumulator/property/pressure/average/evaluation/2
019_08_24t00:05:00z",
        "@type": "https://w3id.org/platoon/PressureEvaluation",
        "https://w3id.org/seas/evaluatedSimpleValue": {
          "@type": "http://w3id.org/lindt/custom_datatypes#pressure",
          "@value": "460 bar"
        },
        "https://w3id.org/seas/hasTemporalContext": {
          "@id":
"http://engie.com/enershare/resource/timestamp/2019_08_24t00:05:00z"
        }
      },
      {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
blade",
        "@type": "https://w3id.org/platoon/Blade",
        "https://w3id.org/seas/subSystemOf": {
          "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840"
        },
        "rdfs:label": "1"
      },
      {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/pistonchamber",
        "@type": "https://w3id.org/enershare/windturbine/PistonChamber",
        "https://w3id.org/platoon/hasPressure": {
          "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/pistonchamber/property/pressure/average"
        },
        "https://w3id.org/seas/subSystemOf": {
          "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/91840/hydpitchsyst
em/pitchcylinder"
        },
        "rdfs:label": "Cylinder Piston Chamber"
      },
      {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/oil/property/temperature/average/evaluati
on/2019_08_24t00:05:00z",
        "@type": "https://w3id.org/seas/TemperatureEvaluation",
```


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```
        "https://w3id.org/seas/evaluatedSimpleValue": {
          "@type": "http://w3id.org/lindt/custom_datatypes#temperature",
          "@value": "61.32 Cel"
        },
        "https://w3id.org/seas/hasTemporalContext": {
          "@id":
"http://engie.com/enershare/resource/timestamp/2019_08_24t00:05:00z"
        }
      },
      {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchpump/property/chargingduration/2019_08_24t00:00:00
z",
        "@type": "http://www.w3.org/2006/time#Duration",
        "http://www.w3.org/2006/time#numericDuration": "10 s",
        "http://www.w3.org/2006/time#unitType": {
          "@id": "http://www.w3.org/2006/time#unitSecond"
        },
        "rdfs:label": "Pitch Pump Charging Property"
      },
      {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/property/pressure/average/evaluation/2019_08_24t00:00:0
0z",
        "@type": "https://w3id.org/platoon/PressureEvaluation",
        "https://w3id.org/seas/evaluatedSimpleValue": {
          "@type": "http://w3id.org/lindt/custom_datatypes#pressure",
          "@value": "300 bar"
        },
        "https://w3id.org/seas/hasTemporalContext": {
          "@id":
"http://engie.com/enershare/resource/timestamp/2019_08_24t00:00:00z"
        }
      },
      {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/rodchamber/property/pressure/average",
        "@type": "https://w3id.org/seas/PressureProperty",
        "https://w3id.org/seas/evaluation": [
          {
            "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/rodchamber/property/pressure/average/eval
uation/2019_08_24t00:05:00z"
          },
          {
            "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/rodchamber/property/pressure/average/eval
uation/2019_08_24t00:00:00z"
```


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```
        }
      ],
      "rdfs:label": "Cylinder Rod chamber Pressure Average"
    },
    {
      "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchaccumulator/property/pressure/average/evaluation/2
019_08_24t00:00:00z",
      "@type": "https://w3id.org/platoon/PressureEvaluation",
      "https://w3id.org/seas/evaluatedSimpleValue": {
        "@type": "http://w3id.org/lindt/custom_datatypes#pressure",
        "@value": "450 bar"
      },
      "https://w3id.org/seas/hasTemporalContext": {
        "@id":
"http://engie.com/enershare/resource/timestamp/2019_08_24t00:00:00z"
      }
    },
    {
      "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchpump/property/chargingduration/2019_08_24t00:05:00
z",
      "@type": "http://www.w3.org/2006/time#Duration",
      "http://www.w3.org/2006/time#numericDuration": "10 s",
      "http://www.w3.org/2006/time#unitType": {
        "@id": "http://www.w3.org/2006/time#unitSecond"
      },
      "rdfs:label": "Pitch Pump Charging Property"
    },
    {
      "@id": "http://engie.com/enershare/resource/windfarm/frbrt",
      "@type": "https://w3id.org/platoon/WindFarm",
      "rdfs:label": "FRBRT"
    },
    {
      "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/property/position/average/evaluation/2019
_08_24t00:05:00z",
      "@type": "https://w3id.org/platoon/PositionEvaluation",
      "https://w3id.org/seas/evaluatedSimpleValue": {
        "@type": "http://w3id.org/lindt/custom_datatypes#ucum",
        "@value": "495.9 nm"
      },
      "https://w3id.org/seas/hasTemporalContext": {
        "@id":
"http://engie.com/enershare/resource/timestamp/2019_08_24t00:05:00z"
      }
    },
    {
```


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```
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/rodchamber/property/pressure/average/eval
uation/2019_08_24t00:05:00z",
        "@type": "https://w3id.org/platoon/PressureEvaluation",
        "https://w3id.org/seas/evaluatedSimpleValue": {
          "@type": "http://w3id.org/lindt/custom_datatypes#pressure",
          "@value": "68.54 bar"
        },
        "https://w3id.org/seas/hasTemporalContext": {
          "@id":
"http://engie.com/enershare/resource/timestamp/2019_08_24t00:05:00z"
        }
      },
      {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/pistonchamber/property/pressure/average/e
valuation/2019_08_24t00:05:00z",
        "@type": "https://w3id.org/platoon/PressureEvaluation",
        "https://w3id.org/seas/evaluatedSimpleValue": {
          "@type": "http://w3id.org/lindt/custom_datatypes#pressure",
          "@value": "27.94 bar"
        },
        "https://w3id.org/seas/hasTemporalContext": {
          "@id":
"http://engie.com/enershare/resource/timestamp/2019_08_24t00:05:00z"
        }
      },
      {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/rodchamber",
        "@type": "https://w3id.org/enershare/windturbine/RodChamber",
        "https://w3id.org/platoon/hasPressure": {
          "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/rodchamber/property/pressure/average"
        },
        "https://w3id.org/seas/subSystemOf": {
          "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/91840/hydpitchsyst
em/pitchcylinder"
        },
        "rdfs:label": "Cylinder Rod Chamber"
      },
      {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/oil/property/temperature/average",
        "@type": "https://w3id.org/seas/TemperatureProperty",
        "https://w3id.org/seas/evaluation": [
          {
```


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```
          "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/oil/property/temperature/average/evaluati
on/2019_08_24t00:05:00z"
        },
        {
          "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/oil/property/temperature/average/evaluati
on/2019_08_24t00:00:00z"
        }
      ],
      "rdfs:label": "Oil Temperature Property  "
    },
    {
      "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchaccumulator",
      "@type":
"https://w3id.org/enershare/windturbine/HydraulicPitchAccumulator",
      "https://w3id.org/platoon/hasPressure": {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchaccumulator/property/pressure/average"
      },
      "https://w3id.org/seas/subSystemOf": {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem"
      },
      "rdfs:label": "Hydraulic Pitch Accumulator"
    },
    {
      "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840"
,
      "@type": "https://w3id.org/platoon/OnshoreWindTurbine",
      "https://brickschema.org/schema/1.1/Brick#hasLocation": {
        "@id": "http://engie.com/enershare/resource/windfarm/frbrt"
      },
      "https://w3id.org/seas/isMemberOf": {
        "@id": "http://engie.com/enershare/resource/windfarm/frbrt"
      },
      "rdfs:label": "91840"
    },
    {
      "@id":
"http://engie.com/enershare/resource/timestamp/2019_08_24t00:00:00z",
      "@type": "http://www.w3.org/2006/time#Instant",
      "http://www.w3.org/2006/time#inXSDDateTime": {
        "@type": "xsd:dateTime",
        "@value": "2019-08-24T00:00:00+00:00"
      }
```


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```
    },
    {
      "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/pistonchamber/property/pressure/average",
      "@type": "https://w3id.org/seas/PressureProperty",
      "https://w3id.org/seas/evaluation": [
        {
          "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/pistonchamber/property/pressure/average/e
valuation/2019_08_24t00:00:00z"
        },
        {
          "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/pistonchamber/property/pressure/average/e
valuation/2019_08_24t00:05:00z"
        }
      ],
      "rdfs:label": "Cylinder Piston chamber Pressure Average"
    },
    {
      "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/pistonchamber/property/pressure/average/e
valuation/2019_08_24t00:00:00z",
      "@type": "https://w3id.org/platoon/PressureEvaluation",
      "https://w3id.org/seas/evaluatedSimpleValue": {
        "@type": "http://w3id.org/lindt/custom_datatypes#pressure",
        "@value": "27.54 bar"
      },
      "https://w3id.org/seas/hasTemporalContext": {
        "@id":
"http://engie.com/enershare/resource/timestamp/2019_08_24t00:00:00z"
      }
    },
    {
      "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/oil",
      "@type": "https://brickschema.org/schema/1.1/Brick#Oil",
      "https://w3id.org/def/saref4bldg#isContainedIn": {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder"
      },
      "https://w3id.org/seas/temperature": {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/oil/property/temperature/average"
      },
      "rdfs:label": "Brick Oil"
```


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```
    },
    {
      "@id":
"http://engie.com/enershare/resource/timestamp/2019_08_24t00:05:00z",
      "@type": "http://www.w3.org/2006/time#Instant",
      "http://www.w3.org/2006/time#inXSDDateTime": {
        "@type": "xsd:dateTime",
        "@value": "2019-08-24T00:05:00+00:00"
      }
    },
    {
      "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/oil/property/temperature/average/evaluati
on/2019_08_24t00:00:00z",
      "@type": "https://w3id.org/seas/TemperatureEvaluation",
      "https://w3id.org/seas/evaluatedSimpleValue": {
        "@type": "http://w3id.org/lindt/custom_datatypes#temperature",
        "@value": "60.32 Cel"
      },
      "https://w3id.org/seas/hasTemporalContext": {
        "@id":
"http://engie.com/enershare/resource/timestamp/2019_08_24t00:00:00z"
      }
    },
    {
      "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchproportionalvalve/property/function",
      "@type":
"https://w3id.org/enershare/windturbine/SignalFunction",
      "https://w3id.org/saref#hasCommand": [
        {
          "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchproportionalvalve/property/function/evaluation/201
9_08_24t00:05:00z"
        },
        {
          "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchproportionalvalve/property/function/evaluation/201
9_08_24t00:00:00z"
        }
      ],
      "rdfs:label": "Proportional Valve Property"
    },
    {
      "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/property/pressure/average/evaluation/2019_08_24t00:05:0
0z",
      "@type": "https://w3id.org/platoon/PressureEvaluation",
```

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```
        "https://w3id.org/seas/evaluatedSimpleValue": {
          "@type": "http://w3id.org/lindt/custom_datatypes#pressure",
          "@value": "350 bar"
        },
        "https://w3id.org/seas/hasTemporalContext": {
          "@id":
"http://engie.com/enershare/resource/timestamp/2019_08_24t00:05:00z"
        }
      },
      {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchaccumulator/property/pressure/average",
        "@type": "https://w3id.org/seas/PressureProperty",
        "https://w3id.org/seas/evaluation": [
          {
            "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchaccumulator/property/pressure/average/evaluation/2
019_08_24t00:00:00z"
          },
          {
            "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchaccumulator/property/pressure/average/evaluation/2
019_08_24t00:05:00z"
          }
        ],
        "rdfs:label": "Hydraulic Pitch Accumulator Pressure Average"
      },
      {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/property/position/average",
        "@type": "https://w3id.org/platoon/PositionProperty",
        "https://w3id.org/seas/evaluation": [
          {
            "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/property/position/average/evaluation/2019
_08_24t00:00:00z"
          },
          {
            "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/property/position/average/evaluation/2019
_08_24t00:05:00z"
          }
        ],
        "rdfs:label": "Cylinder Position Property  Average"
      },
      {
```


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```
      "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchproportionalvalve",
      "@type":
"https://w3id.org/enershare/windturbine/HydraulicPitchProportionalValv
e",
      "https://w3id.org/saref#hasFunction": {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchproportionalvalve/property/function"
      },
      "https://w3id.org/seas/subSystemOf": {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem"
      },
      "rdfs:label": "Hydraulic Pitch Proportional Valve"
    },
    {
      "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchproportionalvalve/property/function/evaluation/201
9_08_24t00:00:00z",
      "@type": "https://w3id.org/enershare/windturbine/SignalCommand",
      "https://w3id.org/seas/evaluatedSimpleValue": {
        "@type": "http://w3id.org/lindt/custom_datatypes#ucum",
        "@value": "A"
      },
      "https://w3id.org/seas/hasTemporalContext": {
        "@id":
"http://engie.com/enershare/resource/timestamp/2019_08_24t00:00:00z"
      }
    },
    {
      "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/property/pressure/average",
      "@type": "https://w3id.org/seas/PressureProperty",
      "https://w3id.org/seas/evaluation": [
        {
          "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/property/pressure/average/evaluation/2019_08_24t00:00:0
0z"
        },
        {
          "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/property/pressure/average/evaluation/2019_08_24t00:05:0
0z"
        }
      ],
      "rdfs:label": "Hydraulic System Pressure Average"
```


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```
    },
    {
      "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/rodchamber/property/pressure/average/eval
uation/2019_08_24t00:00:00z",
      "@type": "https://w3id.org/platoon/PressureEvaluation",
      "https://w3id.org/seas/evaluatedSimpleValue": {
        "@type": "http://w3id.org/lindt/custom_datatypes#pressure",
        "@value": "67.54 bar"
      },
      "https://w3id.org/seas/hasTemporalContext": {
        "@id":
"http://engie.com/enershare/resource/timestamp/2019_08_24t00:00:00z"
      }
    },
    {
      "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder",
      "@type":
"https://w3id.org/enershare/windturbine/HydraulicPitchCylinder",
      "https://w3id.org/platoon/hasPosition": {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/property/position/average"
      },
      "https://w3id.org/seas/subSystemOf": {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem"
      },
      "rdfs:label": "Hydraulic Pitch Cylinder"
    },
    {
      "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem",
      "@type":
"https://w3id.org/enershare/windturbine/HydraulicPitchSystem",
      "https://w3id.org/enershare/property/hasMainSystemPressure": {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/property/pressure/average"
      },
      "https://w3id.org/seas/connectedTo": {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
blade"
      },
      "rdfs:label": "Hydraulic Pitch System"
    }
  ]
```


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```
}
```

9.1.4 Input data in Turtle format

```
@prefix ns1: <https://w3id.org/seas/> .
@prefix ns2: <https://w3id.org/def/saref4bldg#> .
@prefix ns3: <https://w3id.org/saref#> .
@prefix ns4: <https://w3id.org/platoon/> .
@prefix ns5: <https://w3id.org/enershare/property/> .
@prefix ns6: <http://www.w3.org/2006/time#> .
@prefix ns7: <https://brickschema.org/schema/1.1/Brick#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchaccumulator> a
<https://w3id.org/enershare/windturbine/HydraulicPitchAccumulator> ;
    rdfs:label "Hydraulic Pitch Accumulator" ;
    ns4:hasPressure
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchaccumulator/property/pressure/average> ;
    ns1:subSystemOf
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/oil> a ns7:Oil ;
    rdfs:label "Brick Oil" ;
    ns2:isContainedIn
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder> ;
    ns1:temperature
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/oil/property/temperature/average> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/pistonchamber> a
<https://w3id.org/enershare/windturbine/PistonChamber> ;
    rdfs:label "Cylinder Piston Chamber" ;
    ns4:hasPressure
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/pistonchamber/property/pressure/average>
;
    ns1:subSystemOf
<http://engie.com/enershare/resource/windfarm/frbrt/91840/hydpitchsyst
em/pitchcylinder> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/rodchamber> a
<https://w3id.org/enershare/windturbine/RodChamber> ;
    rdfs:label "Cylinder Rod Chamber" ;
```

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```
    ns4:hasPressure
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/rodchamber/property/pressure/average> ;
    ns1:subSystemOf
<http://engie.com/enershare/resource/windfarm/frbrt/91840/hydpitchsyst
em/pitchcylinder> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchproportionalvalve> a
<https://w3id.org/enershare/windturbine/HydraulicPitchProportionalValv
e> ;
    rdfs:label "Hydraulic Pitch Proportional Valve" ;
    ns3:hasFunction
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchproportionalvalve/property/function> ;
    ns1:subSystemOf
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchpump> a
<https://w3id.org/enershare/windturbine/HydraulicPitchPump> ;
    rdfs:label "Hydraulic Pitch Pump" ;
    ns5:hasChargingDuration
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchpump/property/chargingduration/2019_08_24t00:00:00
z>,

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchpump/property/chargingduration/2019_08_24t00:05:00
z> ;
    ns1:subSystemOf
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840>
a ns4:OnshoreWindTurbine ;
    rdfs:label "91840" ;
    ns7:hasLocation
<http://engie.com/enershare/resource/windfarm/frbrt> ;
    ns1:isMemberOf
<http://engie.com/enershare/resource/windfarm/frbrt> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
blade> a ns4:Blade ;
    rdfs:label "1" ;
    ns1:subSystemOf
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840>
.

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchaccumulator/property/pressure/average> a
ns1:PressureProperty ;
```

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```
    rdfs:label "Hydraulic Pitch Accumulator Pressure Average" ;
    ns1:evaluation
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchaccumulator/property/pressure/average/evaluation/2
019_08_24t00:00:00z>,

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchaccumulator/property/pressure/average/evaluation/2
019_08_24t00:05:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchaccumulator/property/pressure/average/evaluation/2
019_08_24t00:00:00z> a ns4:PressureEvaluation ;
    ns1:evaluatedSimpleValue "450
bar"^^<http://w3id.org/lindt/custom_datatypes#pressure> ;
    ns1:hasTemporalContext
<http://engie.com/enershare/resource/timestamp/2019_08_24t00:00:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchaccumulator/property/pressure/average/evaluation/2
019_08_24t00:05:00z> a ns4:PressureEvaluation ;
    ns1:evaluatedSimpleValue "460
bar"^^<http://w3id.org/lindt/custom_datatypes#pressure> ;
    ns1:hasTemporalContext
<http://engie.com/enershare/resource/timestamp/2019_08_24t00:05:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder> a
<https://w3id.org/enershare/windturbine/HydraulicPitchCylinder> ;
    rdfs:label "Hydraulic Pitch Cylinder" ;
    ns4:hasPosition
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/property/position/average> ;
    ns1:subSystemOf
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/oil/property/temperature/average> a
ns1:TemperatureProperty ;
    rdfs:label "Oil Temperature Property  " ;
    ns1:evaluation
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/oil/property/temperature/average/evaluati
on/2019_08_24t00:00:00z>,

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/oil/property/temperature/average/evaluati
on/2019_08_24t00:05:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/oil/property/temperature/average/evaluati
on/2019_08_24t00:00:00z> a ns1:TemperatureEvaluation ;
```

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```
    ns1:evaluatedSimpleValue "60.32
Cel"^^<http://w3id.org/lindt/custom_datatypes#temperature> ;
    ns1:hasTemporalContext
<http://engie.com/enershare/resource/timestamp/2019_08_24t00:00:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/oil/property/temperature/average/evaluati
on/2019_08_24t00:05:00z> a ns1:TemperatureEvaluation ;
    ns1:evaluatedSimpleValue "61.32
Cel"^^<http://w3id.org/lindt/custom_datatypes#temperature> ;
    ns1:hasTemporalContext
<http://engie.com/enershare/resource/timestamp/2019_08_24t00:05:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/pistonchamber/property/pressure/average>
a ns1:PressureProperty ;
    rdfs:label "Cylinder Piston chamber Pressure Average" ;
    ns1:evaluation
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/pistonchamber/property/pressure/average/e
valuation/2019_08_24t00:00:00z>,

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/pistonchamber/property/pressure/average/e
valuation/2019_08_24t00:05:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/pistonchamber/property/pressure/average/e
valuation/2019_08_24t00:00:00z> a ns4:PressureEvaluation ;
    ns1:evaluatedSimpleValue "27.54
bar"^^<http://w3id.org/lindt/custom_datatypes#pressure> ;
    ns1:hasTemporalContext
<http://engie.com/enershare/resource/timestamp/2019_08_24t00:00:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/pistonchamber/property/pressure/average/e
valuation/2019_08_24t00:05:00z> a ns4:PressureEvaluation ;
    ns1:evaluatedSimpleValue "27.94
bar"^^<http://w3id.org/lindt/custom_datatypes#pressure> ;
    ns1:hasTemporalContext
<http://engie.com/enershare/resource/timestamp/2019_08_24t00:05:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/property/position/average> a
ns4:PositionProperty ;
    rdfs:label "Cylinder Position Property  Average" ;
    ns1:evaluation
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/property/position/average/evaluation/2019
_08_24t00:00:00z>,

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
```

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```
hydpitchsystem/pitchcylinder/property/position/average/evaluation/2019
_08_24t00:05:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/property/position/average/evaluation/2019
_08_24t00:00:00z> a ns4:PositionEvaluation ;
    ns1:evaluatedSimpleValue "495.7
nm"^^<http://w3id.org/lindt/custom_datatypes#ucum> ;
    ns1:hasTemporalContext
<http://engie.com/enershare/resource/timestamp/2019_08_24t00:00:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/property/position/average/evaluation/2019
_08_24t00:05:00z> a ns4:PositionEvaluation ;
    ns1:evaluatedSimpleValue "495.9
nm"^^<http://w3id.org/lindt/custom_datatypes#ucum> ;
    ns1:hasTemporalContext
<http://engie.com/enershare/resource/timestamp/2019_08_24t00:05:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/rodchamber/property/pressure/average> a
ns1:PressureProperty ;
    rdfs:label "Cylinder Rod chamber Pressure Average" ;
    ns1:evaluation
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/rodchamber/property/pressure/average/eval
uation/2019_08_24t00:00:00z>,

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/rodchamber/property/pressure/average/eval
uation/2019_08_24t00:05:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/rodchamber/property/pressure/average/eval
uation/2019_08_24t00:00:00z> a ns4:PressureEvaluation ;
    ns1:evaluatedSimpleValue "67.54
bar"^^<http://w3id.org/lindt/custom_datatypes#pressure> ;
    ns1:hasTemporalContext
<http://engie.com/enershare/resource/timestamp/2019_08_24t00:00:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchcylinder/rodchamber/property/pressure/average/eval
uation/2019_08_24t00:05:00z> a ns4:PressureEvaluation ;
    ns1:evaluatedSimpleValue "68.54
bar"^^<http://w3id.org/lindt/custom_datatypes#pressure> ;
    ns1:hasTemporalContext
<http://engie.com/enershare/resource/timestamp/2019_08_24t00:05:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchproportionalvalve/property/function> a
<https://w3id.org/enershare/windturbine/SignalFunction> ;
    rdfs:label "Proportional Valve Property" ;
```

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```
    ns3:hasCommand
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchproportionalvalve/property/function/evaluation/201
9_08_24t00:00:00z>,

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchproportionalvalve/property/function/evaluation/201
9_08_24t00:05:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchproportionalvalve/property/function/evaluation/201
9_08_24t00:00:00z> a
<https://w3id.org/enershare/windturbine/SignalCommand> ;
    ns1:evaluatedSimpleValue
"A"^^<http://w3id.org/lindt/custom_datatypes#ucum> ;
    ns1:hasTemporalContext
<http://engie.com/enershare/resource/timestamp/2019_08_24t00:00:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchproportionalvalve/property/function/evaluation/201
9_08_24t00:05:00z> a
<https://w3id.org/enershare/windturbine/SignalCommand> ;
    ns1:evaluatedSimpleValue
"A"^^<http://w3id.org/lindt/custom_datatypes#ucum> ;
    ns1:hasTemporalContext
<http://engie.com/enershare/resource/timestamp/2019_08_24t00:05:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchpump/property/chargingduration/2019_08_24t00:00:00
z> a ns6:Duration ;
    rdfs:label "Pitch Pump Charging Property" ;
    ns6:numericDuration "10 s" ;
    ns6:unitType ns6:unitSecond .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/pitchpump/property/chargingduration/2019_08_24t00:05:00
z> a ns6:Duration ;
    rdfs:label "Pitch Pump Charging Property" ;
    ns6:numericDuration "10 s" ;
    ns6:unitType ns6:unitSecond .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/property/pressure/average> a ns1:PressureProperty ;
    rdfs:label "Hydraulic System Pressure Average" ;
    ns1:evaluation
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/property/pressure/average/evaluation/2019_08_24t00:00:0
0z>,

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/property/pressure/average/evaluation/2019_08_24t00:05:0
0z> .
```

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```
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/property/pressure/average/evaluation/2019_08_24t00:00:0
0z> a ns4:PressureEvaluation ;
    ns1:evaluatedSimpleValue "300
bar"^^<http://w3id.org/lindt/custom_datatypes#pressure> ;
    ns1:hasTemporalContext
<http://engie.com/enershare/resource/timestamp/2019_08_24t00:00:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/property/pressure/average/evaluation/2019_08_24t00:05:0
0z> a ns4:PressureEvaluation ;
    ns1:evaluatedSimpleValue "350
bar"^^<http://w3id.org/lindt/custom_datatypes#pressure> ;
    ns1:hasTemporalContext
<http://engie.com/enershare/resource/timestamp/2019_08_24t00:05:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt> a ns4:WindFarm ;
    rdfs:label "FRBRT" .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem> a
<https://w3id.org/enershare/windturbine/HydraulicPitchSystem> ;
    rdfs:label "Hydraulic Pitch System" ;
    ns5:hasMainSystemPressure
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem/property/pressure/average> ;
    ns1:connectedTo
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
blade> .

<http://engie.com/enershare/resource/timestamp/2019_08_24t00:00:00z> a
ns6:Instant ;
    ns6:inXSDDateTime "2019-08-24T00:00:00+00:00"^^xsd:dateTime .

<http://engie.com/enershare/resource/timestamp/2019_08_24t00:05:00z> a
ns6:Instant ;
    ns6:inXSDDateTime "2019-08-24T00:05:00+00:00"^^xsd:dateTime .
```

9.1.5 SHACL file for input compliance

```
@prefix sh:    <http://www.w3.org/ns/shacl#> .
@prefix rdf:   <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs:  <http://www.w3.org/2000/01/rdf-schema#> .
@prefix plt:   <https://w3id.org/platoon/> .
@prefix xsd:   <http://www.w3.org/2001/XMLSchema#> .
@prefix ontowind:
<http://www.semanticweb.org/ontologies/2011/9/Ontology1318785573683.ow
l#> .
@prefix seas:  <https://w3id.org/seas/> .
@prefix brick: <https://brickschema.org/schema/1.1/Brick#> .
@prefix cdt: <http://w3id.org/lindt/custom_datatypes#> .
```

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```
@prefix time:  <http://www.w3.org/2006/time#> .
@prefix saref: <https://w3id.org/saref#> .
@prefix ener: <https://enershare.eu/shapes/p1#> .
@prefix ener-wind: <https://w3id.org/enershare/windturbine/> .
@prefix ener-prop: <https://w3id.org/enershare/property/> .
@prefix ener-fail: <https://w3id.org/enershare/failure/>.
@prefix s4bldg: <https://w3id.org/def/saref4bldg#> .

ener:WindFarmShape
    a sh:NodeShape ;
    sh:property [
        sh:path rdfs:label ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:datatype xsd:string ;
    ] ;
    sh:targetClass plt:WindFarm, ontowind:WindPowerPlant .

ener:WindFarmCountShape
    a sh:NodeShape ;
    sh:targetNode plt:WindFarm ;
    sh:property [
        sh:path [ sh:inversePath rdf:type ] ;
        sh:minCount 1 ;
    ] .

ener:WindTurbineShape
    a sh:NodeShape ;
    sh:property [
        sh:path rdfs:label ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:datatype xsd:string ;
    ] ;
    sh:property [
        sh:path seas:isMemberOf ;
        sh:minCount 0 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:property [
        sh:path brick:hasLocation ;
        sh:minCount 0 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:targetClass plt:OnshoreWindTurbine .

ener:TemporalContextShape
    a sh:NodeShape ;
    sh:property [
        sh:path time:inXSDDateTime ;
        sh:minCount 1 ;
```

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```
        sh:maxCount 1 ;
        sh:datatype xsd:dateTime ;
    ] ;
    sh:targetClass time:Instant .

ener:HydraulicPitchSystemShape
    a sh:NodeShape ;
    sh:property [
        sh:path rdfs:label ;
        sh:minCount 0 ;
        sh:maxCount 1 ;
        sh:datatype xsd:string ;
    ] ;
    sh:property [
        sh:path seas:connectedTo ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:property [
        sh:path ener-prop:hasMainSystemPressure ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:targetClass ener-wind:HydraulicPitchSystem .

ener:BladeShape
    a sh:NodeShape ;
    sh:property [
        sh:path rdfs:label ;
        sh:minCount 0 ;
        sh:maxCount 1 ;
        sh:datatype xsd:string ;
    ] ;
    sh:property [
        sh:path seas:subSystemOf ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:targetClass plt:Blade .

ener:PressurePropertyShape
    a sh:NodeShape ;
    sh:property [
        sh:path rdfs:label ;
        sh:minCount 0 ;
        sh:maxCount 1 ;
        sh:datatype xsd:string ;
    ] ;
    sh:property [
        sh:path seas:evaluation ;
```

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```
            sh:minCount 1 ;
            sh:nodeKind sh:IRI ;
        ] ;
        sh:targetClass seas:PressureProperty .

ener:PressureEvaluationShape
        a sh:NodeShape ;
        sh:property [
            sh:path seas:evaluatedSimpleValue ;
            sh:minCount 1 ;
            sh:maxCount 1 ;
            sh:datatype cdt:pressure ;
        ] ;
        sh:property [
            sh:path seas:hasTemporalContext ;
            sh:minCount 1 ;
            sh:maxCount 1 ;
            sh:nodeKind sh:IRI ;
        ] ;
        sh:targetClass plt:PressureEvaluation .

ener:PressureEvaluationPropertyShape
        a sh:NodeShape ;
        sh:targetNode plt:PressureEvaluation ;
        sh:property [
            sh:path [ sh:inversePath rdf:type ] ;
            sh:minCount 1 ;
        ] .

ener:HydraulicPitchAccumulatorShape
        a sh:NodeShape ;
        sh:property [
            sh:path rdfs:label ;
            sh:minCount 0 ;
            sh:maxCount 1 ;
            sh:datatype xsd:string ;
        ] ;
        sh:property [
            sh:path seas:subSystemOf ;
            sh:minCount 1 ;
            sh:maxCount 1 ;
            sh:nodeKind sh:IRI ;
        ] ;

        sh:property [
            sh:path plt:hasPressure ;
            sh:minCount 1 ;
            sh:maxCount 1 ;
            sh:nodeKind sh:IRI ;
        ] ;
        sh:targetClass ener-wind:HydraulicPitchAccumulator .

ener:CylinderPistonChamberShape
```

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```
    a sh:NodeShape ;
    sh:property [
        sh:path rdfs:label ;
        sh:minCount 0 ;
        sh:maxCount 1 ;
        sh:datatype xsd:string ;
    ] ;
    sh:property [
        sh:path seas:subSystemOf ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:property [
        sh:path plt:hasPressure ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:targetClass ener-wind:PistonChamber .

ener:CylinderRodChamberShape
    a sh:NodeShape ;
    sh:property [
        sh:path rdfs:label ;
        sh:minCount 0 ;
        sh:maxCount 1 ;
        sh:datatype xsd:string ;
    ] ;
    sh:property [
        sh:path seas:subSystemOf ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:property [
        sh:path plt:hasPressure ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:targetClass ener-wind:RodChamber .

ener:HydraulicPitchCylinderShape
    a sh:NodeShape ;
    sh:property [
        sh:path rdfs:label ;
        sh:minCount 0 ;
        sh:maxCount 1 ;
        sh:datatype xsd:string ;
    ] ;
    sh:property [
        sh:path seas:subSystemOf ;
```

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```
            sh:minCount 1 ;
            sh:maxCount 1 ;
            sh:nodeKind sh:IRI ;
        ] ;
        sh:property [
            sh:path plt:hasPosition ;
            sh:minCount 1 ;
            sh:maxCount 1 ;
            sh:nodeKind sh:IRI ;
        ] ;
        sh:targetClass ener-wind:HydraulicPitchCylinder .

ener:PositionPropertyShape
        a sh:NodeShape ;
        sh:property [
            sh:path rdfs:label ;
            sh:minCount 0 ;
            sh:maxCount 1 ;
            sh:datatype xsd:string ;
        ] ;
        sh:property [
            sh:path seas:evaluation ;
            sh:minCount 1 ;
            sh:nodeKind sh:IRI ;
        ] ;
        sh:targetClass plt:PositionProperty .

ener:PositionPropertyEvaluationShape
        a sh:NodeShape ;
        sh:property [
            sh:path seas:evaluatedSimpleValue ;
            sh:minCount 1 ;
            sh:maxCount 1 ;
            sh:datatype cdt:ucum ;
        ] ;
        sh:property [
            sh:path seas:hasTemporalContext ;
            sh:minCount 1 ;
            sh:maxCount 1 ;
            sh:nodeKind sh:IRI ;
        ] ;
        sh:targetClass plt:PositionEvaluation .

ener:PositionPropertyEvaluationPropertyShape
        a sh:NodeShape ;
        sh:targetNode plt:PositionEvaluation ;
        sh:property [
            sh:path [ sh:inversePath rdf:type ] ;
            sh:minCount 1 ;
        ] .

ener:BrickOilShape
        a sh:NodeShape ;
```

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```
    sh:property [
        sh:path rdfs:label ;
        sh:minCount 0 ;
        sh:maxCount 1 ;
        sh:datatype xsd:string ;
    ] ;
    sh:property [
        sh:path s4bldg:isContainedIn ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:property [
        sh:path seas:temperature ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:targetClass brick:Oil .

ener:TemperaturePropertyShape
    a sh:NodeShape ;
    sh:property [
        sh:path rdfs:label ;
        sh:minCount 0 ;
        sh:maxCount 1 ;
        sh:datatype xsd:string ;
    ] ;
    sh:property [
        sh:path seas:evaluation ;
        sh:minCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:targetClass seas:TemperatureProperty .

ener:TemperatureEvaluationShape
    a sh:NodeShape ;
    sh:property [
        sh:path seas:evaluatedSimpleValue ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:datatype cdt:temperature ;
    ] ;
    sh:property [
        sh:path seas:hasTemporalContext ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:targetClass seas:TemperatureEvaluation .

ener:TemperatureEvaluationPropertyShape
    a sh:NodeShape ;
```

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```
    sh:targetNode seas:TemperatureEvaluation ;
    sh:property [
        sh:path [ sh:inversePath rdf:type ] ;
        sh:minCount 1 ;
    ] .

ener:HydraulicPitchProportionalValveShape
    a sh:NodeShape ;
    sh:property [
        sh:path rdfs:label ;
        sh:minCount 0 ;
        sh:maxCount 1 ;
        sh:datatype xsd:string ;
    ] ;
    sh:property [
        sh:path seas:subSystemOf ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:property [
        sh:path saref:hasFunction ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:targetClass ener-wind:HydraulicPitchProportionalValve .

ener:ProportionalValvePropertyShape
    a sh:NodeShape ;
    sh:property [
        sh:path rdfs:label ;
        sh:minCount 0 ;
        sh:maxCount 1 ;
        sh:datatype xsd:string ;
    ] ;
    sh:property [
        sh:path saref:hasCommand ;
        sh:minCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:targetClass ener-wind:SignalFunction .

ener:ProportionalValveEvaluationShape
    a sh:NodeShape ;
    sh:property [
        sh:path seas:evaluatedSimpleValue ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:datatype cdt:ucum ;
    ] ;
    sh:property [
        sh:path seas:hasTemporalContext ;
```

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```
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:targetClass ener-wind:SignalCommand .


ener:ProportionalValveEvaluationPropertyShape
    a sh:NodeShape ;
    sh:targetNode ener-wind:SignalCommand ;
    sh:property [
        sh:path [ sh:inversePath rdf:type ] ;
        sh:minCount 1 ;
    ] .

ener:HydraulicPitchPumpShape
    a sh:NodeShape ;
    sh:property [
        sh:path rdfs:label ;
        sh:minCount 0 ;
        sh:maxCount 1 ;
        sh:datatype xsd:string ;
    ] ;
    sh:property [
        sh:path seas:subSystemOf ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:property [
        sh:path ener-prop:hasChargingDuration ;
        sh:minCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:targetClass ener-wind:HydraulicPitchPump .

ener:PumpChargingPropertyShape
    a sh:NodeShape ;
    sh:property [
        sh:path rdfs:label ;
        sh:minCount 0 ;
        sh:maxCount 1 ;
        sh:datatype xsd:string ;
    ] ;
    sh:property [
        sh:path time:unitType ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:property [
        sh:path time:numericDuration ;
        sh:minCount 1 ;
```

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```
        sh:maxCount 1 ;
        sh:datatype xsd:string ;
    ] ;
    sh:targetClass time:Duration .
```

9.2 Service output files

9.2.1 Output data in JSON format

```
{
    "windturbine_results": [
    {
        "windfarm_id": "FRBRT",
        "windturbine_id": "91840",
        "blade_id":"1",
        "timestamp": "2019-08-24T00:00:00Z",
        "failure_mode": 0
    },
    {
        "windfarm_id": "FRBRT",
        "windturbine_id": "91840",
        "blade_id":"1",
        "timestamp": "2019-08-24T00:05:00Z",
        "failure_mode": 1
    }]
}
```

9.2.2 RML mapping for the output JSON format

```
@prefix rr: <http://www.w3.org/ns/r2rml#> .
@prefix rml: <http://semweb.mmlab.be/ns/rml#> .
@prefix ql: <http://semweb.mmlab.be/ns/ql#> .
@prefix brick: <https://brickschema.org/schema/1.1/Brick#> .
@prefix cdt: <http://w3id.org/lindt/custom_datatypes#> .
@prefix plt: <https://w3id.org/platoon/> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix seas: <https://w3id.org/seas/> .
@prefix time: <http://www.w3.org/2006/time#> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
@prefix ener-wind: <https://w3id.org/enershare/windturbine/> .
@prefix ener-prop: <https://w3id.org/enershare/property/>.
@prefix s4bldg: <https://w3id.org/def/saref4bldg#> .
@prefix saref: <https://w3id.org/saref#> .
@prefix ener-fail: <https://w3id.org/enershare/failure/>.
@prefix tecfns: <http://www.tecnalia.com/function/fns.ttl#> .
@prefix fnml: <http://semweb.mmlab.be/ns/fnml#> .
```

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```
@prefix fno: <https://w3id.org/function/ontology#> .
@prefix grel: <http://users.ugent.be/~bjdmeest/function/grel.ttl#> .


<#LogicalSourceWTVal> a rml:BaseSource ;
  rml:source
"pilot1_hydraulic_pitch_anomaly_detection_output_simplejson.json" ;
  rml:referenceFormulation ql:JSONPath;
  rml:iterator "$.windturbine_results[*]" .

<#WindFarmMapping> a rr:TriplesMap;
    rml:logicalSource <#LogicalSourceWTVal> ;

    rr:subjectMap [
        rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}";
        rr:class plt:WindFarm
    ];

    rr:predicateObjectMap [
        rr:predicate rdfs:label ;
        rr:objectMap [
            rml:reference "windfarm_id"
        ]
    ].

<#Time> a rr:TriplesMap;
    rml:logicalSource <#LogicalSourceWTVal> ;

    rr:subjectMap [
        rr:template
"http://engie.com/enershare/resource/timestamp/{timestamp}";
        rr:class time:Instant
    ];

    rr:predicateObjectMap [
        rr:predicate time:inXSDDateTime ;
        rr:objectMap [
            rml:reference "timestamp";
            rr:datatype  xsd:dateTime
        ]
    ] .

<#OnshoreWindTurbine> a rr:TriplesMap;
    rml:logicalSource <#LogicalSourceWTVal> ;

    rr:subjectMap [
        rr:class plt:OnshoreWindTurbine;
        rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}"
    ];
```

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```
    rr:predicateObjectMap [
        rr:predicate rdfs:label ;
        rr:objectMap [
            rml:reference "windturbine_id"
        ]
    ];

    rr:predicateObjectMap [
        rr:predicate brick:hasLocation ;
        rr:objectMap [
            rr:termType rr:IRI;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}"
        ]
    ];

    rr:predicateObjectMap [
            rr:predicate seas:isMemberOf ;
            rr:objectMap [
            rr:termType rr:IRI;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}"
            ]
    ] .

<#HydraulicPitchSystem> a rr:TriplesMap;
    rml:logicalSource <#LogicalSourceWTVal> ;

    rr:subjectMap [
        rr:class ener-wind:HydraulicPitchSystem;
        rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/hydpitchsystem"
    ];

    rr:predicateObjectMap [
        rr:predicate rdfs:label ;
        rr:objectMap [
             rr:constant "Hydraulic Pitch System"
        ]
    ];

    rr:predicateObjectMap [
        rr:predicate seas:connectedTo ;
        rr:objectMap [
            rr:termType rr:IRI;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/blade"
        ]
    ] .

    <#Blade> a rr:TriplesMap;
```

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```
        rml:logicalSource <#LogicalSourceWTVal> ;

        rr:subjectMap [
            rr:class plt:Blade;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/blade"
        ];

        rr:predicateObjectMap [
            rr:predicate rdfs:label ;
            rr:objectMap [ rml:reference "blade_id" ]
        ];

        rr:predicateObjectMap [
                rr:predicate seas:subSystemOf ;
                rr:objectMap [
                 rr:termType rr:IRI;
                 rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}"
                ]
        ];

        rr:predicateObjectMap [
            rr:predicate ener-fail:hasMode;
            rr:objectMap [
                rr:termType rr:IRI;
                rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/blade/mode/{timestamp}"
            ]
        ].


<#Mode> a rr:TriplesMap;
   rml:logicalSource <#LogicalSourceWTVal> ;

        rr:subjectMap [
            rr:class ener-fail:WorkingMode;
            rr:template
"http://engie.com/enershare/resource/windfarm/{windfarm_id}/windturbin
e/{windturbine_id}/blade/mode/{timestamp}"
        ];

        rr:predicateObjectMap [
            rr:predicate rdf:type;
            rr:objectMap <#FailureFunctionMap> ;
        ];

        rr:predicateObjectMap [
            rr:predicate rdfs:label ;
            rr:objectMap [ rr:constant "Pitch system failure mode" ]
```

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```
        ];

        rr:predicateObjectMap [
                rr:predicate seas:hasTemporalContext ;
                rr:objectMap [
                rr:termType rr:IRI;
                rr:template
"http://engie.com/enershare/resource/timestamp/{timestamp}"
                ]
        ] .

<#FailureFunctionMap>
fnml:functionValue [
    rml:logicalSource <#Mode> ;
    rr:predicateObjectMap [
        rr:predicate fno:executes ;
        rr:objectMap [rr:template
tecfns:to_hydraulic_pitch_failure_code ]
    ];
    rr:predicateObjectMap [
        rr:predicate grel:valueParameter ;
        rr:objectMap [rml:reference "failure_mode"]
    ]
] .
```

9.2.3 Output data in JSON-LD format

```
{
  "@context": {
    "owl": "http://www.w3.org/2002/07/owl#",
    "rdf": "http://www.w3.org/1999/02/22-rdf-syntax-ns#",
    "rdfs": "http://www.w3.org/2000/01/rdf-schema#",
    "xsd": "http://www.w3.org/2001/XMLSchema#"
  },
  "@graph": [
    {
      "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
blade/mode/2019_08_24t00:00:00z",
      "@type": [
        "https://w3id.org/enershare/failure/WorkingMode",
        "https://w3id.org/enershare/failure/HealthyMode"
      ],
      "https://w3id.org/seas/hasTemporalContext": {
        "@id":
"http://engie.com/enershare/resource/timestamp/2019_08_24t00:00:00z"
      },
      "rdfs:label": "Pitch system failure mode"
    },
    {
```

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```
        "@id":
"http://engie.com/enershare/resource/timestamp/2019_08_24t00:05:00z",
        "@type": "http://www.w3.org/2006/time#Instant",
        "http://www.w3.org/2006/time#inXSDDateTime": {
          "@type": "xsd:dateTime",
          "@value": "2019-08-24T00:05:00+00:00"
        }
      },
      {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
blade/mode/2019_08_24t00:05:00z",
        "@type": [
          "https://w3id.org/enershare/failure/Leakage",
          "https://w3id.org/enershare/failure/WorkingMode"
        ],
        "https://w3id.org/seas/hasTemporalContext": {
          "@id":
"http://engie.com/enershare/resource/timestamp/2019_08_24t00:05:00z"
        },
        "rdfs:label": "Pitch system failure mode"
      },
      {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
blade",
        "@type": "https://w3id.org/platoon/Blade",
        "https://w3id.org/enershare/failure/hasMode": [
          {
            "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
blade/mode/2019_08_24t00:00:00z"
          },
          {
            "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
blade/mode/2019_08_24t00:05:00z"
          }
        ],
        "https://w3id.org/seas/subSystemOf": {
          "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840"
        },
        "rdfs:label": "1"
      },
      {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem",
        "@type":
"https://w3id.org/enershare/windturbine/HydraulicPitchSystem",
        "https://w3id.org/seas/connectedTo": {
```


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```
          "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
blade"
        },
        "rdfs:label": "Hydraulic Pitch System"
      },
      {
        "@id":
"http://engie.com/enershare/resource/timestamp/2019_08_24t00:00:00z",
        "@type": "http://www.w3.org/2006/time#Instant",
        "http://www.w3.org/2006/time#inXSDDateTime": {
          "@type": "xsd:dateTime",
          "@value": "2019-08-24T00:00:00+00:00"
        }
      },
      {
        "@id": "http://engie.com/enershare/resource/windfarm/frbrt",
        "@type": "https://w3id.org/platoon/WindFarm",
        "rdfs:label": "FRBRT"
      },
      {
        "@id":
"http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840"
,
        "@type": "https://w3id.org/platoon/OnshoreWindTurbine",
        "https://brickschema.org/schema/1.1/Brick#hasLocation": {
          "@id": "http://engie.com/enershare/resource/windfarm/frbrt"
        },
        "https://w3id.org/seas/isMemberOf": {
          "@id": "http://engie.com/enershare/resource/windfarm/frbrt"
        },
        "rdfs:label": "91840"
      }
    ]
}
```


9.2.4 Output data in Turtle format

```
@prefix ns1: <https://w3id.org/seas/> .
@prefix ns2: <http://www.w3.org/2006/time#> .
@prefix ns3: <https://brickschema.org/schema/1.1/Brick#> .
@prefix ns4: <https://w3id.org/enershare/failure/> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
hydpitchsystem> a
<https://w3id.org/enershare/windturbine/HydraulicPitchSystem> ;
    rdfs:label "Hydraulic Pitch System" ;
```

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```
    ns1:connectedTo
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
blade> .

<http://engie.com/enershare/resource/timestamp/2019_08_24t00:00:00z> a
ns2:Instant ;
    ns2:inXSDDateTime "2019-08-24T00:00:00+00:00"^^xsd:dateTime .

<http://engie.com/enershare/resource/timestamp/2019_08_24t00:05:00z> a
ns2:Instant ;
    ns2:inXSDDateTime "2019-08-24T00:05:00+00:00"^^xsd:dateTime .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840>
a <https://w3id.org/platoon/OnshoreWindTurbine> ;
    rdfs:label "91840" ;
    ns3:hasLocation
<http://engie.com/enershare/resource/windfarm/frbrt> ;
    ns1:isMemberOf
<http://engie.com/enershare/resource/windfarm/frbrt> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
blade> a <https://w3id.org/platoon/Blade> ;
    rdfs:label "1" ;
    ns4:hasMode
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
blade/mode/2019_08_24t00:00:00z>,

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
blade/mode/2019_08_24t00:05:00z> ;
    ns1:subSystemOf
<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840>
.

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
blade/mode/2019_08_24t00:00:00z> a ns4:WorkingMode,
        "https://w3id.org/enershare/failure/HealthyMode" ;
    rdfs:label "Pitch system failure mode" ;
    ns1:hasTemporalContext
<http://engie.com/enershare/resource/timestamp/2019_08_24t00:00:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt/windturbine/91840/
blade/mode/2019_08_24t00:05:00z> a ns4:WorkingMode,
        "https://w3id.org/enershare/failure/Leakage" ;
    rdfs:label "Pitch system failure mode" ;
    ns1:hasTemporalContext
<http://engie.com/enershare/resource/timestamp/2019_08_24t00:05:00z> .

<http://engie.com/enershare/resource/windfarm/frbrt> a
<https://w3id.org/platoon/WindFarm> ;
    rdfs:label "FRBRT" .
```

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9.2.5 SHACL file for output compliance

```
@prefix sh:    <http://www.w3.org/ns/shacl#> .
@prefix rdf:   <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs:  <http://www.w3.org/2000/01/rdf-schema#> .
@prefix plt:   <https://w3id.org/platoon/> .
@prefix xsd:   <http://www.w3.org/2001/XMLSchema#> .
@prefix seas:  <https://w3id.org/seas/> .
@prefix brick: <https://brickschema.org/schema/1.1/Brick#> .
@prefix ontowind:
<http://www.semanticweb.org/ontologies/2011/9/Ontology1318785573683.ow
l#> .
@prefix cdt: <http://w3id.org/lindt/custom_datatypes#> .
@prefix time:  <http://www.w3.org/2006/time#> .
@prefix saref: <https://w3id.org/saref#> .
@prefix ener: <https://enershare.eu/shapes/p1#> .
@prefix ener-wind: <https://w3id.org/enershare/windturbine/> .
@prefix ener-prop: <https://w3id.org/enershare/property/> .
@prefix ener-fail: <https://w3id.org/enershare/failure/>.
@prefix s4bldg: <https://w3id.org/def/saref4bldg#> .

ener:WindFarmShape
    a sh:NodeShape ;
    sh:property [
        sh:path rdfs:label ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:datatype xsd:string ;
    ] ;
    sh:targetClass plt:WindFarm, ontowind:WindPowerPlant .

ener:WindFarmCountShape
    a sh:NodeShape ;
    sh:targetNode plt:WindFarm ;
    sh:property [
        sh:path [ sh:inversePath rdf:type ] ;
        sh:minCount 1 ;
    ] .

ener:WindTurbineShape
    a sh:NodeShape ;
    sh:property [
        sh:path rdfs:label ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:datatype xsd:string ;
    ] ;
    sh:property [
        sh:path seas:isMemberOf ;
        sh:minCount 0 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
```

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```
    sh:property [
        sh:path brick:hasLocation ;
        sh:minCount 0 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:targetClass plt:OnshoreWindTurbine .

ener:TemporalContextShape
    a sh:NodeShape ;
    sh:property [
        sh:path time:inXSDDateTime ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:datatype xsd:dateTime ;
    ] ;
    sh:targetClass time:Instant .

ener:HydraulicPitchSystemShape
    a sh:NodeShape ;
    sh:property [
        sh:path rdfs:label ;
        sh:minCount 0 ;
        sh:maxCount 1 ;
        sh:datatype xsd:string ;
    ] ;
    sh:property [
        sh:path seas:connectedTo ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:targetClass ener-wind:HydraulicPitchSystem .

ener:BladeShape
    a sh:NodeShape ;
    sh:property [
        sh:path rdfs:label ;
        sh:minCount 0 ;
        sh:maxCount 1 ;
        sh:datatype xsd:string ;
    ] ;
    sh:property [
        sh:path seas:subSystemOf ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:property [
        sh:path ener-fail:hasMode ;
        sh:minCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
```

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```
    sh:targetClass plt:Blade .

ener:ModeShape
    a sh:NodeShape ;
    sh:property [
        sh:path rdfs:label ;
        sh:minCount 0 ;
        sh:maxCount 1 ;
        sh:datatype xsd:string ;
    ] ;
    sh:property [
        sh:path rdf:type ;
        sh:minCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:property [
        sh:path seas:hasTemporalContext ;
        sh:minCount 1 ;
        sh:maxCount 1 ;
        sh:nodeKind sh:IRI ;
    ] ;
    sh:targetClass ener-fail:WorkingMode .
```

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