BD4NRG
Big Data for Next Generation Energy

D4.5: An implementation of semantic interoperable components in the BD4NRG platform for selected use cases in the energy domain (related to pilots)

WP4 – Data Modelling & Open Modular AI-based edge-level Analytics

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Preface

BD4NRG focuses on addressing emerging challenges in big data management for energy sector with an innovative open holistic solution for smart grid-tailored, near real time, energy-specific and AI-based open Big Data Analytics modular framework. The vision is to deliver holistic services for techno-economic optimal management of Electric Power and Energy Systems value chain. Services range from optimal risk assessment for energy efficiency investments planning, to optimized management of grid and non-grid owned assets, improved efficiency, and reliability of electricity networks operation, while at the same time contributing to achieve fair energy prices to the consumers and laying the foundations for an EU-level energy-tailored data sharing economy. The BD4NRG Toolbox will be implemented and validated in real-life pilots in 12 large-scale demo sites across 8 countries for:

- Increasing the efficiency and reliability of the electricity network BD-4-NET
- Optimising the management of assets connected to the grid BD-4-DER

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- De-risking investments in energy efficiency and increasing the efficiency and comfort of buildings BD-4-ENEF

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History of Changes

Date and Version	Relevant Section	Description
V1.1 04/10/2024	Section 2.4.2.2	Removed blank page
V1.1 04/10/2024	Section 2.4.3.1	Removed blank page
V1.1 04/10/2024	Section 3.5	Updated link to repository
V1.1 04/10/2024	Section 4.3	Removed blank page
V1.1 04/10/2024	Section 5.2	Updated link to repository
V1.1 04/10/2024	Table of content	Updated
V1.1 04/10/2024	List of figures	Updated.
V1.1 04/10/2024	List of tables	Updated.

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Executive Summary

Task 4.2 of the BD4NRG project is entitled 'Semantic Business and Platform Interoperability Management'. It deals with the technological implications of the architecture specifications (defined in BD4NRG task T2.4). More specific, to enable the discovery and interoperability of the various artefacts that reside in the BD4NRG environment, such as Data, Services, Edge Resources and Machine Learning models. Meta-data definitions and APIs are used that are based on semantic technology.

BD4NRG Task 4.2 will provide the necessary functionalities to support data analytics service users to join the BD4NRG platform and to search and discover services that match their goals and business needs. In a similar manner, BD4NRG Task 4.2 will provide the means for data analytics service providers to make use of interoperable data formats when developing their services, as well as register, publish and make them discoverable through semantic meta-data descriptions.

BD4NRG deliverable D4.5 is titled "An implementation of semantic interoperable components in the BD4NRG platform for selected use cases in the energy domain (related to pilots)". In this deliverable, the semantic components that were identified and described in the previous deliverables of BD4NRG task T4.2 (BD4NRG deliverables D4.2 and D4.3) were implemented: the Federated Catalogue and the Vocabulary Hub.

Both the Federated Catalogue and the Vocabulary Hub have been delivered as working software components. The current report D4.5 accompanies the implementation of the Federated Catalogue and the Vocabulary Hub. It describes the technical implementation of these components and the alignment with the large scale pilots (LSPs).

The Federated Catalogue provides the essential functionality for managing resource descriptions. It contains interfaces for publishing, searching and accessing metadata of resources and a vocabulary to describe them. The Federated Catalogue extends on intra-data space Federated Catalogues (i.e. catalogues within a single data space), which are usually addressed through data space building blocks such as the Metadata Brokers in the IDSA or GAIA-X initiatives. The Federated Catalogue in the current report has been designed as an extension to existing inter-data space catalogue implementations. It consists of an ontology that contains common definitions of resources are required across catalogues to achieve semantic interoperability between catalogues, and API specifications for a standardized interface that enables a uniform approach to communicate with catalogs across contexts and domains.

The Vocabulary Hub took the Semantic Treehouse application (developed by TNO) as a starting point. The major Vocabulary Hub developments in BD4NRG were (1) Added Open API Specifications (OAS) as an output for the Data Space Connector Configurator, (2) Added support for SHACL vocabularies as an input for the Configurator, (3) documentation of the Vocabulary Hub, and (4) publication of the Vocabulary Hub code base as open source software under Apache License 2.0.

The resulting components were applied in BD4NRG Large Scale Pilots (LSPs), namely LSP1, LSP8 and LSP12. The 5-star model of vocabulary usage was successfully used to create metadata descriptions for the three LSPs.

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1 Introduction

1.1 List of acronyms

Table 1: list of acronyms used in the document

API	Application Programming Interface
BD4NRG	Big Data for Next Generation Energy
CB	Circuit Breakers
CIM	Common Information Model
CSV	Comma Separated Values
CSVW	CSV on the Web
D*.*	Deliverable with number, e.g. D4.5
DOME	Decentralized Open Marketplace Ecosystem
DSBA	Data Space Business Alliance
EPES	Electrical Power Energy System
ePO	European eProcurement Ontology
ETSI	European Telecommunications Standards Institute
EU	European Union
HTTP	Hypertext Transfer Protocol
IDS	International Data Spaces
IEC	International Electrotechnical Commission
IM	Information Model
JSON-LD	JSON Linked Data
LiDAR	Light Detection And Ranging
LSP	Large Scale Pilot

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OAS	Open API Specification
OHL	Overhead Line
OWL	Web Ontology Language
RAM	Reference Architecture Model
RES	Renewable Energy Sources
RDF	Resource Description Framework
RDFS	Resource Description Framework Schema
SAREF	Smart Applications Reference Ontology
SDM	Smart Data Models
SHACL	Shapes Constraint Language
T*.*	Task with number, e.g. T4.2
TOGAF ADM	The Open Group architectural framework architecture development method
TSO	Transmission System Operator
UC	Use Case
URL	Uniform Resource Locator
XML	Extensible Markup Language
XSD	XML Schema Definition

1.2 BD4NRG Task 4.2

Task 4.2 of the BD4NRG project is entitled 'Semantic Business and Platform Interoperability Management'. It deals with the technological implications of the architecture specifications (defined in BD4NRG task T2.4). More specific, to enable the discovery and interoperability of the various artefacts that reside in the BD4NRG environment, such as Data, Services, Edge Resources and Machine Learning models. Meta-data definitions and APIs are used that are based on semantic technology.

BD4NRG Task 4.2 will provide the necessary functionalities to support data analytics service users to join the BD4NRG platform and to search and discover services that match their goals and business needs. In a similar manner, BD4NRG Task 4.2 will provide the means for data analytics service providers

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to make use of interoperable data formats when developing their services, as well as register, publish and make them discoverable through semantic meta-data descriptions.

A framework for orchestrating semantic interoperability will be developed to register, expose, and access data services and data analytics services, based on the International Data Spaces (IDS) initiative. IDS is currently gaining major international traction for realizing federated and interoperable data spaces. The IDS Reference Architecture Model (RAM) version 3.0 [1] provides the foundation to develop interoperable data spaces. It aligns very well with the 12 building blocks in the soft infrastructure stack, as defined by the EU OPEN DEI initiative [2] in its report on design principles for data spaces [3].

1.3 BD4NRG deliverable 4.5

BD4NRG deliverable D4.5 is titled "An implementation of semantic interoperable components in the BD4NRG platform for selected use cases in the energy domain (related to pilots)". In this deliverable, the semantic components that were identified and described in the previous deliverables of BD4NRG task T4.2 (BD4NRG deliverables D4.2 – 'Report on Existing Methods Tools and Prototype Implementations to realize the Semantic Interoperability Toolbox, Framework and Platform' and D4.3 – 'D4.3 Architecture document on the integration of selected existing methods, tools, platforms in the BD4NRG platform') were implemented. These semantic components are:

- The Federated Catalogue,
- The Vocabulary Hub.

Both the Federated Catalogue and the Vocabulary Hub have been delivered as working software components. The current report accompanies the implementation of the Federated Catalogue and the Vocabulary Hub. It describes the technical implementation of these components and the alignment with the large scale pilots (LSPs).

1.4 BD4NRG D4.5 in the context of BD4NRG deliverables

Figure 1 shows the BD4NRG Deliverable D4.5 – 'D4.5 An implementation of semantic interoperable components in the BD4NRG platform for selected use cases in the energy domain' in relation to other Task 4.2 deliverables and adjacent WP2 and WP4 project deliverables.

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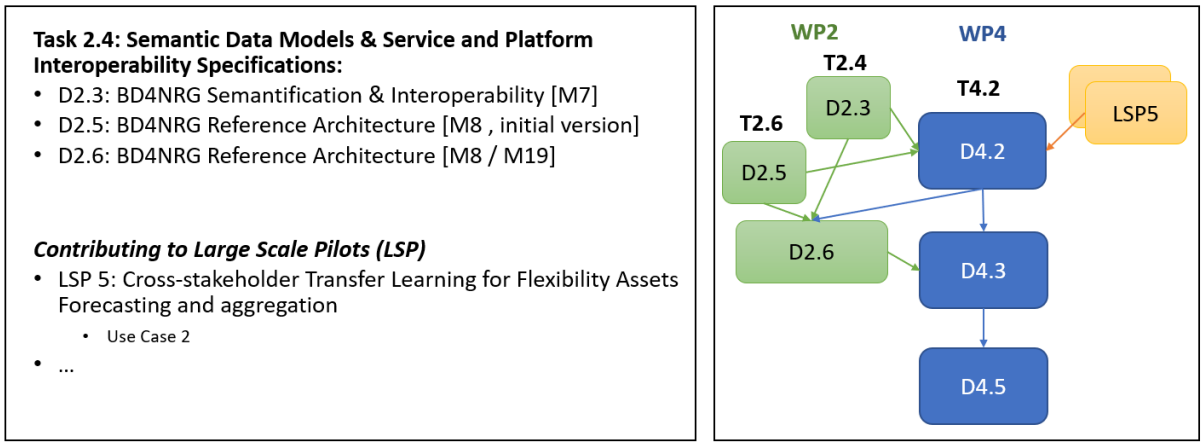

Figure 1: BD4NRG Deliverable D4.5 in relation to adjacent BD4NRG project deliverables

D4.5 uses the BD4NRG WP4 deliverables D4.2 and D4.3 as input. The input of these deliverables is summarized in the following paragraphs.

1.4.1 Input from BD4NRG deliverable D4.2

Deliverable D4.5 follows the work done in BD4NRG deliverables D4.2 "Report on Existing Methods, Tools and Prototype Implementations to realize the Semantic Interoperability Toolbox, Framework and Platform". D4.2 was the first report of BD4NRG's Task 4.2 and addressed the different types of semantic building blocks that were required in the subsequent phases of semantic management of the various artefacts within a federated and open data space approach, as pursued by BD4NRG. These building blocks were identified as meta-data brokering, providing vocabularies, data transformation and data validation. Two components were defined to implement the building blocks: the *Federated Catalogue* and the *Vocabulary Hub*.

1.4.2 Input from BD4NRG deliverable D4.3

BD4NRG deliverable D4.3 was titled 'Architecture document on the integration of selected existing methods, tools, platforms in BD4NRG' and described on the architecture of two components that were identified for development in BD4NRG deliverable D4.2:

- The Federated Catalogue,
- The Vocabulary Hub.

D4.3 adopted the Open Group architectural framework architecture development method (TOGAF ADM) [4] to describe the architecture for the Federated Catalogue and the Vocabulary Hub. Figure 2 shows the phases of the TOGAF ADM.

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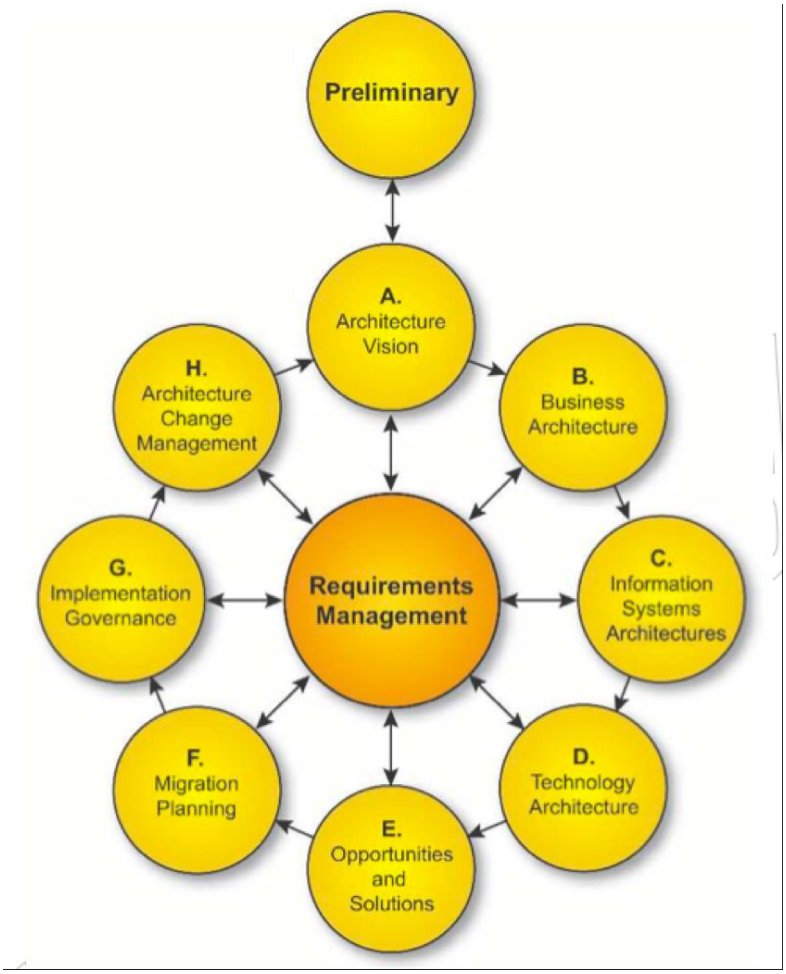

Figure 2: TOGAF ADM phases

Source: [4]

BD4NRG deliverable D4.3 – 'D4.3 Architecture document on the integration of selected existing methods, tools, platforms in the BD4NRG platform' addressed the architecture of both components according to phases A to C of the TOGAF ADM:

- Phase A: Architecture vision
- Phase B: Business architecture
- Phase C: Information systems architecture

The current deliverable D4.5 elaborates on D4.3 and describes phase D of the TOGAF ADM, Technology architecture, for the Federated Catalogue and the Vocabulary Hub.

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2 Federated Catalogue implementation

2.1 Introduction

As described in BD4NRG deliverable D4.3, the Federated Catalogue is part of the 'Metadata and Discovery services' building blocks in the OPEN DEI soft infrastructure, and is designed to be minimal yet extensible in implementation. The Federated Catalogue provides the essential functionality for managing resource descriptions. It contains interfaces for publishing, searching and accessing metadata of resources and a vocabulary to describe them.

The Federated Catalogue extends on intra-data space Federated Catalogues (i.e. catalogues within a single data space), which are usually addressed through data space building blocks such as the Metadata Brokers in the IDSA or GAIA-X initiatives. These building blocks rely on standardized interfaces and vocabularies within such data spaces.

Different standards of catalogue interfaces and -vocabularies within different data spaces lead to a lack of both technical- and semantic interoperability across data spaces. Distributed Catalogues are often suggested as an alternative to create a (virtual) shared repository of metadata across data spaces, for instance the Decentralized Open Marketplace Ecosystem (DOME) proposed by the Data Space Business Alliance (DSBA) [6]. Here, inter-data space Federated Catalogues form a network of catalogues with a flexible coupling strategy (Figure 3), which interact according to different interaction patterns (section 2.5).

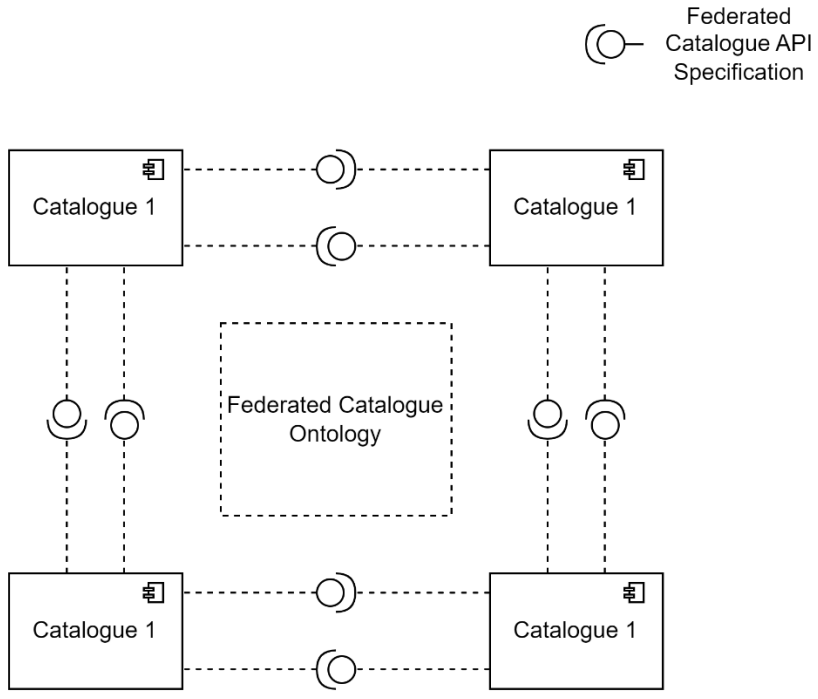

Figure 3: Federated Catalogue architecture overview

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2.2 System context

The Federated Catalogue in the current report has been designed as an extension to existing inter-data space catalogue implementations. It consists of an ontology (vocabulary) and API specification:

- Vocabulary – Common definitions of resources are required across catalogues to achieve semantic interoperability between catalogues, i.e. to enable participants to understand metadata descriptions across catalogues. Extending upon well-established standards such as the DCAT ontological standard is the industry standard approach for interoperability, and we define a minimal ontological extensions for our purpose. Section 4 defines the ontological extension we use for the Federated Catalogue.
- API specification – A standardized interface enables a uniform approach to communicate with catalogs across contexts and domains, and enables the technical interoperability we require for the Federated Catalogue. The HTTP protocol is the backbone of the internet, and we use it to define an API for catalog interaction in a Federated Catalog. Section 2.4 defines the API specification in greater detail.

Here, the Federated Catalogue was implemented as an extension to the IDS Metadata Broker, catalogue component that is part of the IDS-RAM [1].

2.3 Federated Catalogue ontology

The assumption for the Federated Catalogue ontology was to enable a catalogue that contains (a) resources that are published and consumed by (b) participants. The Federated Catalogue ontology therefore defines two classes: 'Participant' and 'Resource' (Figure 4).

- A Participant is defined as a concept of an entity that publishes and consumes resources and subclasses basic ontologies so as to be extensible.
- A Resource is defined as a concept of a singular resource published by an entity and subclasses basic ontologies so as to be extensible.

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```
:Participant a owl:Class ;
    rdfs:label "Federated Catalogue Participant" ;
    rdfs:comment "Concept of a singular entity publishing and consuming
resources and subclassing basic ontologies so as to be extensible" ;
    rdfs:subClassOf org:Organization,
        foaf:Organization .

:Resource a owl:Class ;
    rdfs:label "Federated Catalogue Resource" ;
    rdfs:comment "Concept of a singular resource published by an entity and
subclassing basic ontologies so as to be extensible" ;
    rdfs:subClassOf dcat:Resource .
```

Figure 4: Federated Catalogue ontology

The ontology also includes two object properties specific to the IDS information Model (IM) (Figure 5):

- The "inCatalog" property: used to reference the Resource Catalog in which the resource is published, and its domain is the "Resource" class. The "inCatalog" property range is the "dcat:Catalog" and "ids:Catalog" classes, referencing that it is published as part of a catalog in an IDS Connector.
- The "inIDSConnector" property: used to reference the IDS Connector with which the resource is published. Its domain is the "Resource" class, and its range is the "ids:Connector" class.

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```
:inCatalog a owl:ObjectProperty ;
    rdfs:label "Present in catalog"@en ;
    rdfs:comment "Reference to the Resource Catalog into which the resource is published."@en ;
    rdfs:domain :Resource ;
    rdfs:range dcat:Catalog,
        ids:Catalog .

:inIDSConnector a owl:ObjectProperty ;
    rdfs:label "Present in IDS Connector"@en ;
    rdfs:comment "Reference to the IDS Connector with which the resource is published."@en ;
    rdfs:domain :Resource ;
    rdfs:range ids:Connector .
```

Figure 5: Federated Catalogue ontology and IDS information model

This ontology provides a vocabulary for describing a federated catalogue system that enables participants to publish and consume resources, with support for the IDS framework. Other catalogue implementations may extend the "Participant" and "Resource" concepts in a similar way, with additional catalogue-specific properties defined contextually.

2.4 API specification

The Federated Catalogue API specification was based on functionalities provided by standard catalogue implementations, and primarily the GAIA-X Federated Catalogue API Specification[1]. The API specification is described in the following paragraphs.

Please note that the (minimal) implementation used here does not specify extensive query parameters. The deployed version of the Federated Catalogue (section 5.1) supports a query parameter 'format' to specify the output of the response according to multiple semantic web formats, including Turtle, JSON-LD and N3. Specific Catalogues may extend the API functionality as required, with custom filters, pagination and possibly additional endpoints.

[1] https://gaia-x.gitlab.io/data-infrastructure-federation-services/cat/architecture-document/architecture/catalogue-architecture.html

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2.4.1 Query

2.4.1.1 Direct querying of the semantic database

This endpoint allows users to perform direct SPARQL queries on the semantic database (Table 2).

Table 2: direct querying request method of the Federated Catalogue

Method	Path
POST	/query

Request

The request body should contain a SPARQL query string (Table 3).

Table 3: direct querying request body of the Federated Catalogue

Example Body

PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX fedcat: <http://ontology.tno.nl/federatedCatalogue/>
PREFIX dcterms: <http://purl.org/dc/terms/>
 	
SELECT ?title WHERE {
?resource rdf:type fedcat:Resource .
?resource dcterms:title ?title .
}

Response

The response is a SPARQL result object in JSON format (Table 4).

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Table 4: direct querying response of the Federated Catalogue

Code	Example Response
200	{ "head": { "vars": ["title"] }, "results": { "bindings": [{ "title": { "type": "literal", "value": "Example Resource 1" } }, { "title": { "type": "literal", "value": "Example Resource 2" } }, ...] } }

2.4.2 Resource

2.4.2.1 Get resources

This endpoint retrieves a list of all Resource objects in the semantic database (Table 5).

Table 5: resources request method of the Federated Catalogue

Method	Path
GET	/resources

Request parameters

None.

Response

The response is a JSON array of Resource objects, each represented as an RDF instance graph (Table 6).

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Table 6: resources response of the Federated Catalogue

Code	Example Response

200	[
	{
	"@context": {
	"fedcat": "http://ontology.tno.nl/federatedCatalogue/",
	"dcterms": "http://purl.org/dc/terms/",
	"foaf": "http://xmlns.com/foaf/0.1/"
	},
	"@id": "https://example.com/resource/1",
	"@type": "fedcat:Resource",
	"dcterms:title": "Example Resource",
	"dcterms:description": "This is an example resource",
	"foaf:homepage": {
	"@id": "https://example.com"
	}
	},
	{
	"@context": {
	"fedcat": "http://ontology.tno.nl/federatedCatalogue/",
	"dcterms": "http://purl.org/dc/terms/",
	"foaf": "http://xmlns.com/foaf/0.1/"
	},
	"@id": "https://example.com/resource/2",
	"@type": "fedcat:Resource",
	"dcterms:title": "Another Resource",
	"dcterms:description": "This is another example resource",
	"foaf:homepage": {
	"@id": "https://example.com"
	}
	}

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Code	Example Response
	]

2.4.2.2 Get specific resource

This endpoint retrieves the RDF instance graph of the Resource object with the given resource_id (Table 7).

Table 7: specific resource request of the Federated Catalogue

Method	Path
GET	/resources/{resource_id}

Request parameters

resource_id (string, required): The ID of the Resource object to retrieve.

Response

The response is the RDF instance graph of the Resource object (Table 8).

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Table 8: specific resource response of the Federated Catalogue

Code	Example Response

200	{
	"@context": {
	"fedcat": "http://ontology.tno.nl/federatedCatalogue/",
	"dcterms": "http://purl.org/dc/terms/",
	"foaf": "http://xmlns.com/foaf/0.1/"
	},
	"@id": "https://example.com/resource/1",
	"@type": "fedcat:Resource",
	"dcterms:title": "Example Resource",
	"dcterms:description": "This is an example resource",
	"foaf:homepage": {
	"@id": "https://example.com"
	}
	}

2.4.2.3 Publish resource

This endpoint creates a new Resource object in the semantic database (Table 9).

Table 9: resource publication method of the Federated Catalogue

Method	Path
POST	/resources

Request parameters

None.

Request body

The request body should contain an RDF instance graph of a Resource object (Table 10).

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Table 10: resource publication body of the Federated Catalogue

Example Body
{ "@context": { "fedcat": "http://ontology.tno.nl/federatedCatalogue/", "dcterms": "http://purl.org/dc/terms/", "foaf": "http://xmlns.com/foaf/0.1/" }, "@id": "https://example.com/resource/1", "@type": "fedcat:Resource", "dcterms:title": "Example Resource", "dcterms:description": "This is an example resource", "foaf:homepage": { "@id": "https://example.com" } }

Response

The response is an HTTP status code indicating whether the operation was successful (Table 11).

Table 11: resource publication response of the Federated Catalogue

Code	Example Response
200	-

2.4.2.4 Update specific resource

This endpoint updates the RDF instance graph of the Resource object with the given resource_id (Table 12).

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Table 12: resource update method of the Federated Catalogue

Method	Path
PUT	/resources/{resource_id}

Request parameters

resource_id (string, required): The ID of the Resource object to update.

Request body

The request body should contain an RDF instance graph of a Resource object (Table 13).

Table 13: resource update body of the Federated Catalogue

Example Body

```
{
  "@context": {
    "fedcat": "http://ontology.tno.nl/federatedCatalogue/",
    "dcterms": "http://purl.org/dc/terms/",
    "foaf": "http://xmlns.com/foaf/0.1/"
  },
  "@id": "https://example.com/resource/1",
  "@type": "fedcat:Resource",
  "dcterms:title": "Updated Resource",
  "dcterms:description": "This is an example updated resource",
  "foaf:homepage": {
    "@id": "https://example.com"
  }
}
```

Response

The response is an HTTP status code indicating whether the operation was successful (Table 14).

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Table 14: resource update response of the Federated Catalogue

Code	Example Response
200	-

2.4.2.5 Delete specific resource

This endpoint updates the RDF instance graph of the Resource object with the given resource_id (Table 15).

Table 15: resource delete method of the Federated Catalogue

Method	Path
DELETE	/resources/{resource_id}

Request parameters

resource_id (string, required): The ID of the Resource object to update.

Request body

None

Response

The response is an HTTP status code indicating whether the operation was successful (Table 16).

Table 16: resource delete response of the Federated Catalogue

Code	Example Response
200	-

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2.4.3 Participants

2.4.3.1 Get participants

This endpoint retrieves a list of all Participant objects in the semantic database (Table 17).

Table 17: participants request method of the Federated Catalogue

Method	Path
GET	/participants

Request parameters

None.

Response

The response is a JSON array of Participant objects, each represented as an RDF instance graph (Table 18).

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Table 18: participants response of the Federated Catalogue

Code	Example Response

200	[
	{
	"@context": {
	"fedcat": "http://ontology.tno.nl/federatedCatalogue/",
	"foaf": "http://xmlns.com/foaf/0.1/"
	},
	"@id": "https://example.com/participant/1",
	"@type": "fedcat:Participant",
	"foaf:name": "Example Organization",
	"foaf:mbox": {
	"@id": "mailto:info@example.com"
	}
	},
	{
	"@context": {
	"fedcat": "http://ontology.tno.nl/federatedCatalogue/",
	"foaf": "http://xmlns.com/foaf/0.1/"
	},
	"@id": "https://example.com/participant/2",
	"@type": "fedcat:Participant",
	"foaf:name": "Another Organization",
	"foaf:mbox": {
	"@id": "mailto:info@another.org"
	}
	}
	]

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2.4.3.2 Get specific participant

This endpoint retrieves the RDF instance graph of the Participant object with the given participant_id (Table 19).

Table 19: specific participant request of the Federated Catalogue

Method	Path
GET	/participants/{participant_id}

Request parameters

participant_id (string, required): The ID of the Participant object to retrieve.

Response

The response is the RDF instance graph of the Participant object (Table 20).

Table 20: specific participant response of the Federated Catalogue

Code	Example Response
200	{ "@context": { "fedcat": "http://ontology.tno.nl/federatedCatalogue/", "foaf": "http://xmlns.com/foaf/0.1/" }, "@id": "https://example.com/participant/1", "@type": "fedcat:Participant", "foaf:name": "Example Organization", "foaf:mbox": { "@id": "mailto:info@example.com" } }

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2.4.3.3 Publish participant

This endpoint creates a new Participant object in the semantic database (Table 21).

Table 21: participant publish method of the Federated Catalogue

Method	Path
POST	/participants

Request parameters

None.

Request body

The request body should contain an RDF instance graph of a Participant object (Table 22).

Table 22: participant publish body of the Federated Catalogue

Example Body

```
{
  "@context": {
    "fedcat": "http://ontology.tno.nl/federatedCatalogue/",
    "foaf": "http://xmlns.com/foaf/0.1/"
  },
  "@id": "https://example.com/participant/1",
  "@type": "fedcat:Participant",
  "foaf:name": "Example Organization",
  "foaf:mbox": {
    "@id": "mailto:info@example.com"
  }
}
```

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Response

The response is an HTTP status code indicating whether the operation was successful (Table 23).

Table 23: participant publish response of the Federated Catalogue

Code	Example Response
200	

2.4.3.4 Update specific participant

This endpoint updates the RDF instance graph of the Participant object with the given participant_id (Table 24).

Table 24: participant update method of the Federated Catalogue

Method	Path
PUT	/participants/{participant_id}

Request parameters

participant_id (string, required): The ID of the Participant object to update.

Request body

The request body should contain an RDF instance graph of a Participant object (

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Table 25).

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Table 25: participant update body of the Federated Catalogue

Example Body
{ "@context": { "fedcat": "http://ontology.tno.nl/federatedCatalogue/", "foaf": "http://xmlns.com/foaf/0.1/" }, "@id": "https://example.com/participant/1", "@type": "fedcat:Participant", "foaf:name": "Updated Organization", "foaf:mbox": { "@id": "mailto:info@example.com" } }

Response

The response is an HTTP status code indicating whether the operation was successful (Table 26).

Table 26: participant update response of the Federated Catalogue

Code	Example Response
200	

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2.4.3.5 Delete specific participant

This endpoint updates the RDF instance graph of the Participant object with the given participant_id (Table 27).

Table 27: participant delete method of the Federated Catalogue

Method	Path
DELETE	/participants/{participant_id}

Request parameters

participant_id (string, required): The ID of the Participant object to update.

Request body

None.

Response

The response is an HTTP status code indicating whether the operation was successful (Table 28).

Table 28: participant delete response of the Federated Catalogue

Code	Example Response
200	

2.5 Swim lane diagrams

This section describes the four interaction patterns in the Federated Catalogue that were defined in BD4NRG deliverable D4.3 – 'D4.3 Architecture document on the integration of selected existing methods, tools, platforms in the BD4NRG platform':

- Query-time federation
- Publish-time federation
- Consumer-initiated federation
- Provider-initiated federation

Swim-lane diagrams are used to explain the interaction patterns in the following paragraphs.

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2.5.1 Query-time federation

Query-time federation means that a consumer is provided a real-time aggregated query result from multiple catalogue instances. Figure 6 illustrates query-time federation across two configured Catalogues. First, a resource provider publishes resource descriptions to its local Catalogue (Figure 6, Federated Catalogue 1). Next, a consumer seeking a Resource queries its local Catalogue (Figure 6, Federated Catalogue 2). Federated Catalogue 2 federates the query to other Catalogues in the network, including Federated Catalogue 1, aggregates the responses and sends this aggregated response back to the Consumer. Finally, the aggregated response provides the Consumer with the required resources metadata to consume the resource[2].

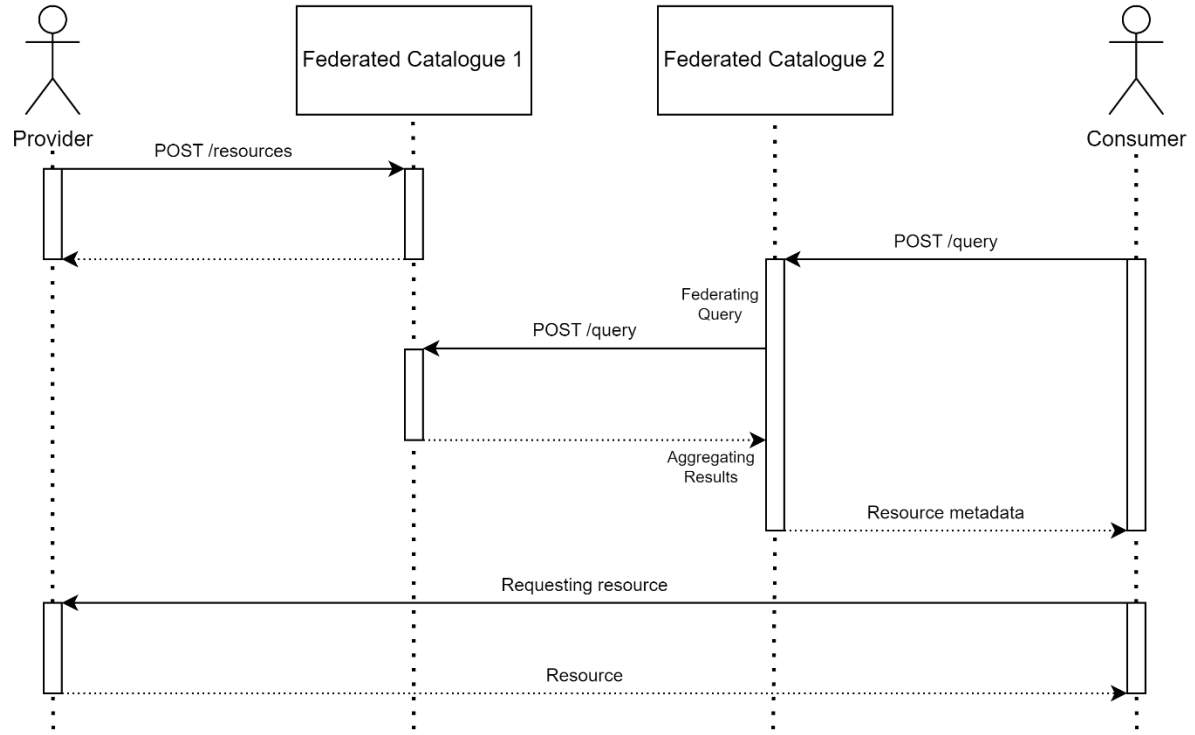

Figure 6: swim lane diagram for query-time federation across catalogues

2.5.2 Publish-time Federation

Publish-time Federation means that the Catalogues distribute resource descriptions to other Catalogues (either synchronously or asynchronously) after publication by a resource provider (Figure 7). Publish-time Federation enables eventual consistency in the network of Catalogues.

[2] Note that while we present the actual query to the /query endpoint, it may also be a similar GET /resources endpoint with specific filters.

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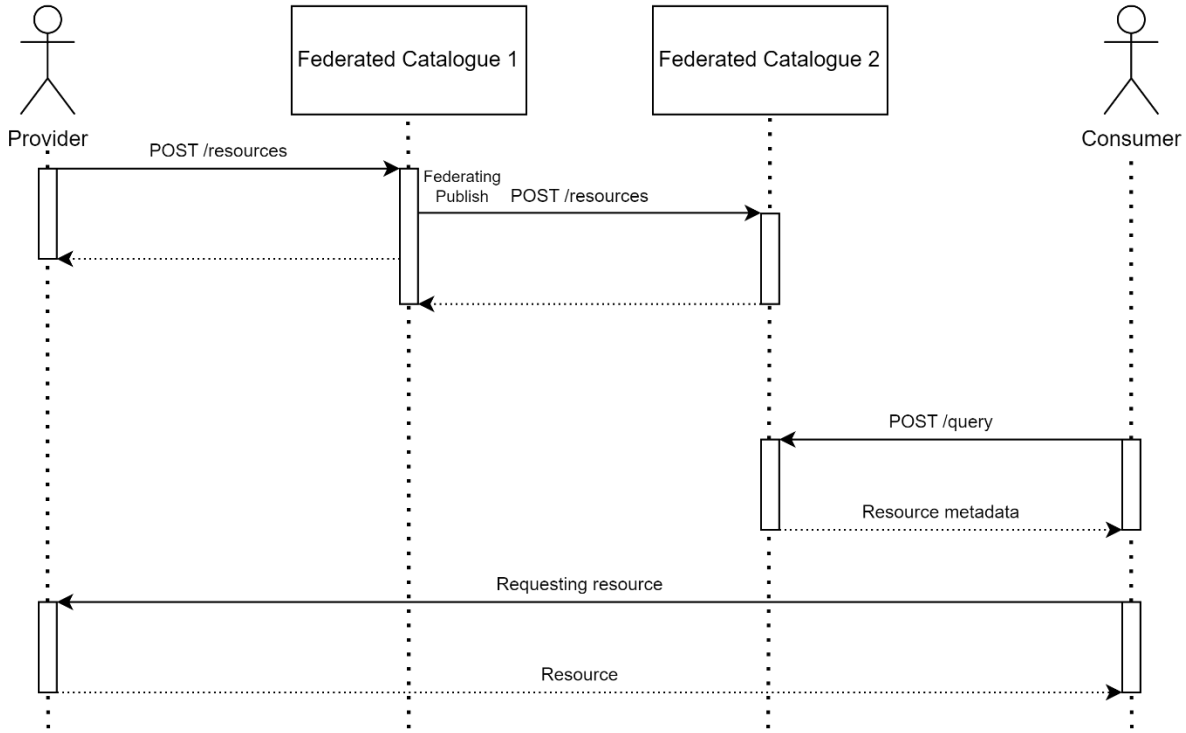

Figure 7: swim lane diagram for publish-time federation across catalogues

2.5.3 Consumer-initiated Federation

Consumer-initiated Federation is a form of Query-time Federation (section 2.5.1) that is initiated by a consumer (Figure 8). First, providers share their resources on their respective local Catalogues (Figure 8, Federated Catalogue 1). Next, consumers query their local Catalogue for resource descriptions of other Catalogues[3]. Finally, the consumer itself (instead of its local Catalogue) will query the different Catalogues and aggregate the results as it sees fit.

[3] Please note that a Catalogue can be considered a resource and as such has a resource description that can be registered in a Catalogue.

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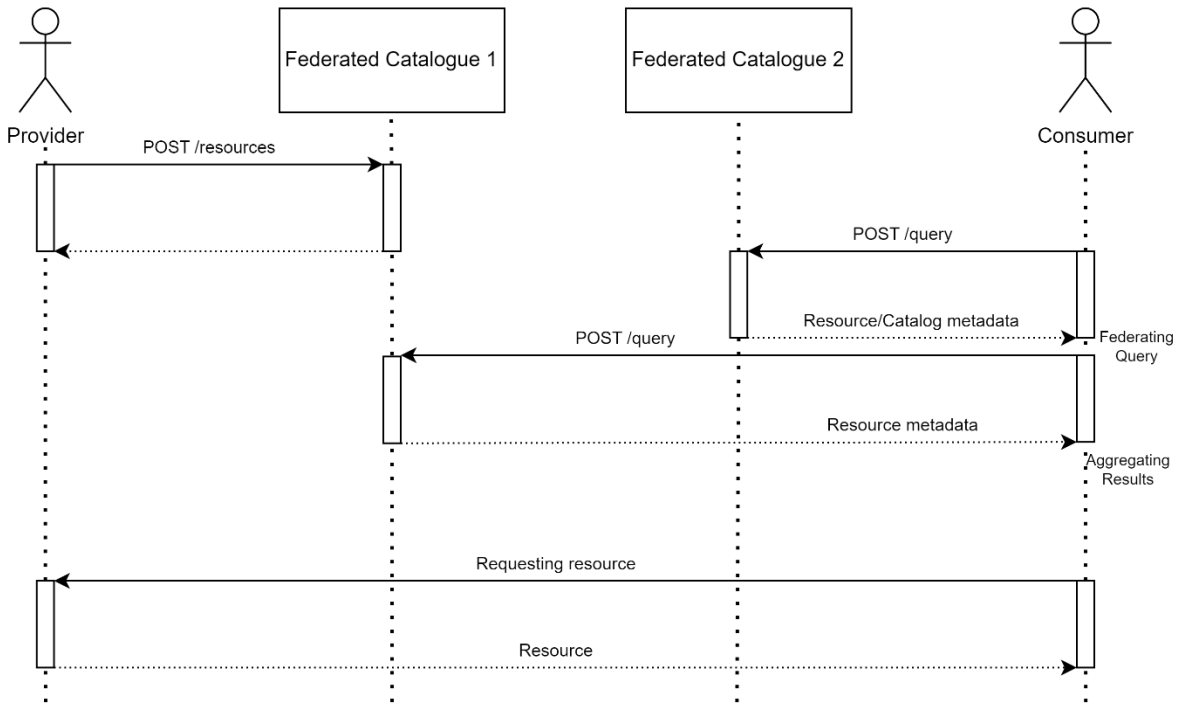

Figure 8: swim lane diagram for consumer-initiated Federation across Catalogues

2.5.4 Provider-initiated Federation

Provider-initiated Federation is a type of Publish-time Federation where resource providers register their resource descriptions in one or more Catalogues themselves (Figure 9). Here, it is assumed that a Provider has previously obtained resource descriptions about other catalogs, either via prior configuration or at query-time (similar to Consumer-initiated Federation, section 2.5.3). Next, the Provider publishes its resource descriptions to the Catalogues it wants to publish its resources to (Figure 9, Federated Catalogue 1 and Federated Catalogue 2). As with In this case, consumers can access metadata from their local Catalogues and directly request the required resources.

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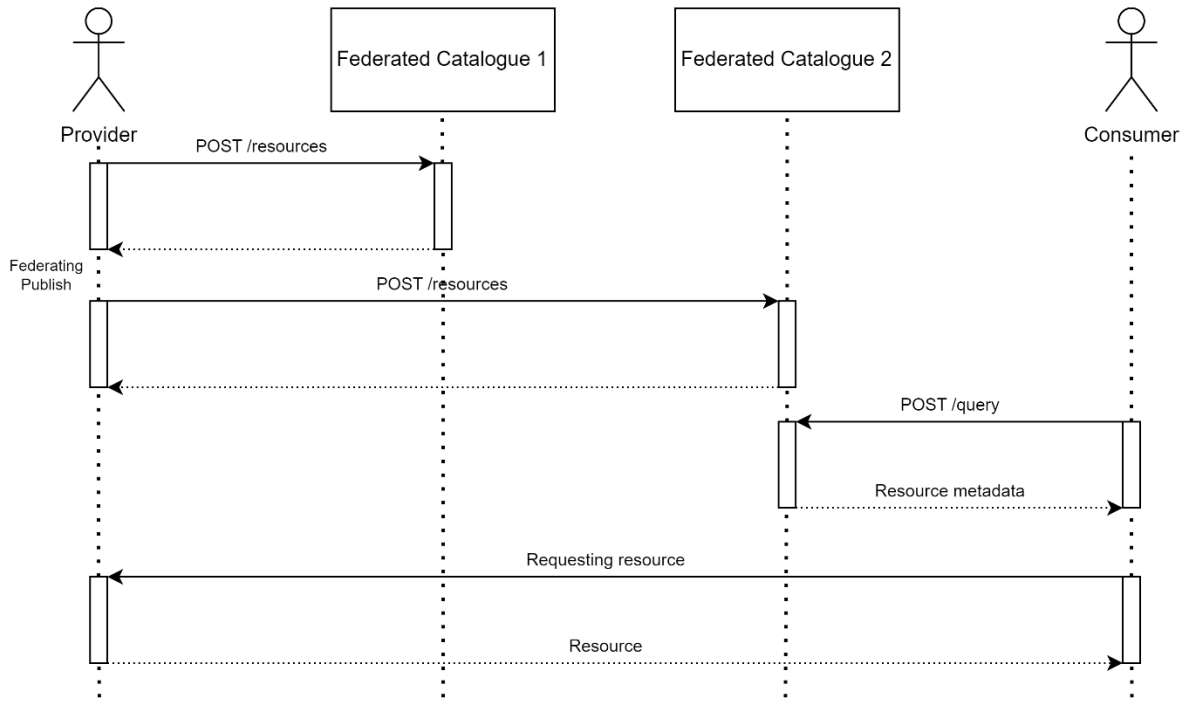

Figure 9: swim lane diagram for provider-initiated Federation across Catalogues

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3 Vocabulary Hub implementation

Here, we present the development achievements for the Vocabulary Hub in the BD4NRG project. Development focused on the Data Space Connector Configurator, an integrated part the BD4NRG Vocabulary Hub that was introduced in BD4NRG deliverable D4.3 – 'D4.3 Architecture document on the integration of selected existing methods, tools, platforms in the BD4NRG platform'.

The purpose of the Vocabulary Hub in general is to increase semantic interoperability by providing a toolset that facilitates the use of standardized vocabularies by data space participants (Figure 10). This is achieved via a sequence of steps where users:

1. identify the appropriate (standardized) vocabulary for their use case;
2. select the concepts/terms from that vocabulary (and maybe others) that are relevant for their use case (and nothing more);
3. choose a syntax format for the generated schema, e.g. XML or JSON.

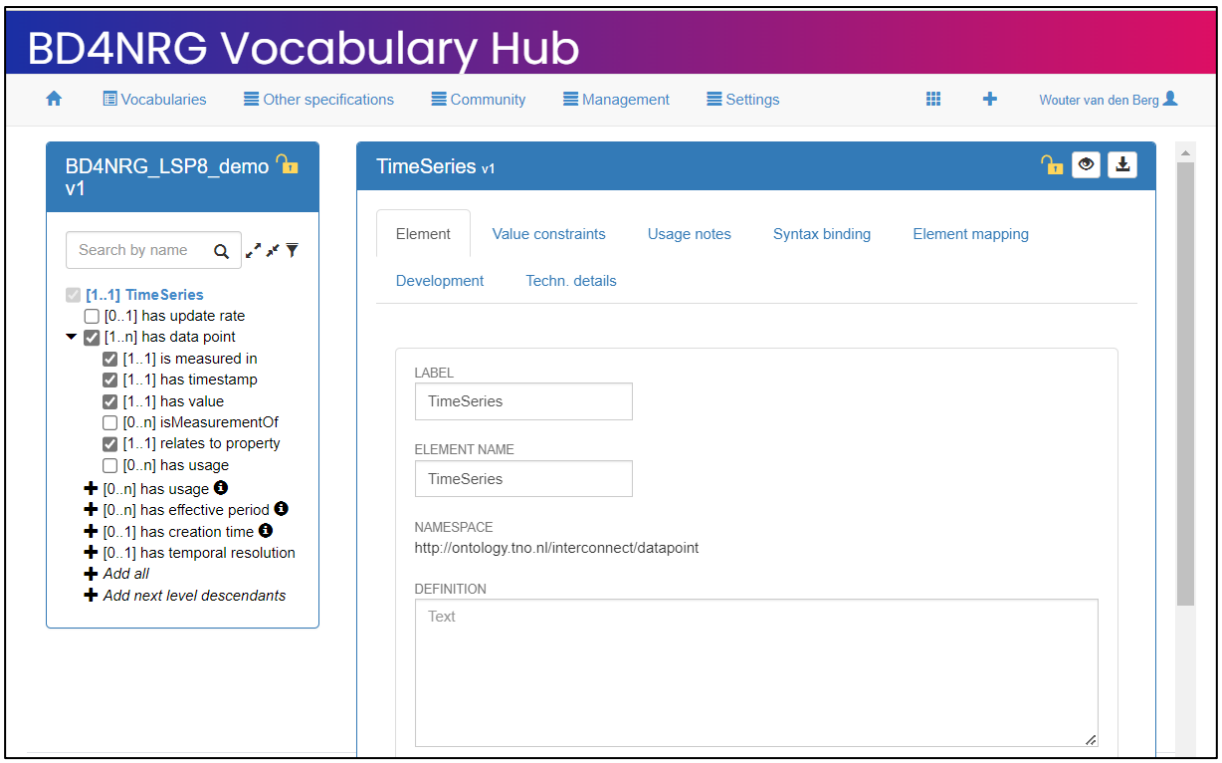

Figure 10: selecting terms from SAREF ontology in step 2 of the Data Space Connector Configurator

Most of the standardized vocabularies identified in BD4NRG deliverable D2.6 – 'BD4NRG Reference Architecture Final Version' have been OWL ontologies. In general, these are powerful but also complex semantic models that are sometimes hard to use. By following the above three steps of the Configurator, the user is provided the tools to create ontology-based schemata and mappings for their API specifications while reducing the complexity of working with the OWL ontologies, and without the need for deep ontology engineering expertise.

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The major Vocabulary Hub developments in BD4NRG are:

1. Added **Open API Specifications (OAS)** as an *output* for the Data Space Connector Configurator (i.e. 'the Configurator').
2. Added support for **SHACL vocabularies** as an *input* for the Configurator
3. Created **documentation** for the Vocabulary Hub
4. Published the Vocabulary Hub code base as **open source** software under Apache License 2.0

The above developments will be described further in the following paragraphs.

3.1 Semantic Treehouse platform as starting point

The BD4NRG Vocabulary Hub took the Semantic Treehouse application (developed by TNO) as a starting point.

For over a decade, TNO has developed and maintained semantic data models for a large variety of industries. Around 2015, while using many different tools, communication channels and knowledge sources, the idea arose that these should be unified into a single platform specifically designed to support open semantic standardization activities. These activities include governance, editing, maintenance, community management, collaboration, offering helpdesk and implementation support. In short, everything to boost the actual adoption of vocabularies by envisioned end-users. TNO's hands-on experience and best practices are the roots of the Semantic Treehouse design.

Since then, we have shown that the integrated functionalities for publication, community management and validation provide a strong foundation to facilitate organizations that struggle with the complex task of developing and maintaining common data models. At the time of writing, ten or so Semantic Treehouse deployments serve ~1000 unique business users every month.

One of the major design goals for Semantic Treehouse is to bridge the gap between the power of linked data and the practice of business operations. While linked data technologies are powerful, they also require expertise and infrastructure that is far from ubiquitous in the world of business. Semantic Treehouse aims to boost the use of powerful linked data vocabularies (i.e. ontologies) by increasing their ease of use.

The foundation that Semantic Treehouse provided allowed BD4NRG task T4.2 to more quickly implement the functionalities required by project partners.

3.2 Added support for OAS (output)

The added support for OAS has expanded the output options of the Configurator in step 3. Users can now create these specifications by selecting the relevant data properties from their vocabulary of choice. OAS is now the fourth type of output that the Configurator presents to the user in step 3:

1. JSON Schema
2. XML Schema
3. RDF/SHACL

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4. OAS

To generate the OAS, the Configurator takes the generated JSON Schema as a starting point. It adds meta-information and three API operations: Post, Get and Put. Figure 11 shows an overview of the generated OAS as visualized by the 'editor-next' of swagger.io. Users can copy the output of the Configurator wizard from the OAS tab and paste into the editor-next window.

OAS support in the Vocabulary Hub allows data sharing communities like BD4NRG to create a set of ontology-based standardized APIs.

Note that the current release of OAS support is a beta version (i.e. an experimental feature that requires additional user testing).

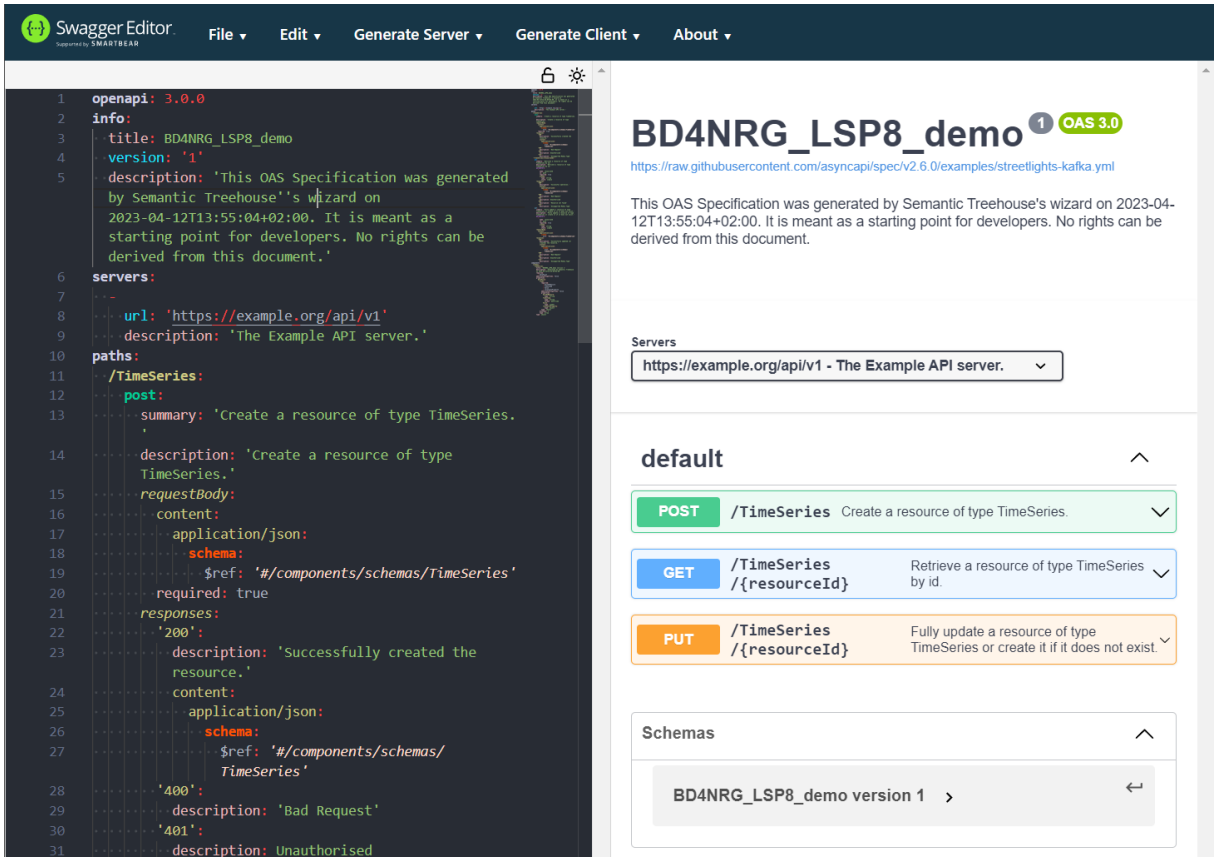

Figure 11: an overview of the generated OAS as visualized by the 'editor-next' of swagger.io

As illustrated in Figure 11, the three HTTP operations added automatically are *Post*, *Get* and *Put* request. These represent, respectively, creating a new resource, retrieving an existing resource, and fully updating a resource that already exists. For example, an organization can offer to create a new timeseries using the API, retrieve an existing timeseries, or fully update an existing timeseries, using this OpenAPI specification. Designers who take the outgoing OpenAPI specification can remove any of the actions that are not applicable for their use case.

All of these REST operations include the notion of an identifier, which is required for any given message. Usually in REST operations the maintainer of a certain resource gives out this identifier after

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receiving a new resource creation. That party delivers the identifier of the newly created resource, back to the party who made the original request for the resource to be created. So, the communications of this type of message can only happen when an agreed upon Identifier is shared between the parties. In the Vocabulary Hub, there currently is no special indicator of the chosen identifier for a type of message. Of course there are Identifiers in the schemas of most messages, but there is no special annotation for which of the identifiers is the chosen one to use in the REST operations. The OpenAPI designer has to choose the identifier and has to clearly indicate this in the description of the API.

3.3 Added support for SHACL (input)

SHACL specifications define the shape of an ontology model. They can be used to determine the structure, cardinalities (multiplicity) and other constraints for a given data exchange using RDF graphs. SHACL support was added to the configurator so that it can use vocabularies that contain SHACL specifications as input.

For vocabularies that contain both OWL and SHACL specifications, the Configurator first looks at the SHACL shapes of an ontology and then at the restrictions defined in OWL. Although there is no standard that demanded this choice from us during implementation of the Vocabulary Hub, many people consider RDFS + SHACL as more intuitive than full OWL restrictions.

As is the case with the OAS functionality, the support for SHACL requires further testing in order to discover use cases with new requirements.

Based on our tests, the most important SHACL property shapes that we identified and implemented were:

- SHACL *path*
- SHACL *minCount* / *maxCount* (cardinality)
- SHACL description
- SHACL datatype
- SHACL minExclusive, minInclusive, maxExclusive, maxInclusive (value constraints)
- SHACL *minLength*, *maxLength* (string constraints)

More information is available on the Vocabulary Hub documentation pages (section 3.4).

3.4 Created documentation

The documentation for the Vocabulary Hub was updated and extended for use in the BD4NRG project. The full documentation can be found here: https://www.semantic-treehouse.nl/docs/

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Added documentation on the functionality of the Vocabulary Hub were:

- Configurator steps: https://www.semantic-treehouse.nl/docs/wizard/
- Support for OAS: https://www.semantic-treehouse.nl/docs/wizard/openapi-output
- Support for SHACL input: https://www.semantic-treehouse.nl/docs/wizard/shacl-input

3.5 Open sourced code base

The open sourced code base and documentation of the Vocabulary Hub can be found in the BD4NRG Final Technology Release repository at:

https://gitlab.com/bd4nrg-technology-release/vocabulary-hub

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4 Application in Large Scale Pilots

4.1 Purpose

Development activities described in the previous chapter were carried out in parallel to testing with LSPs. This allowed us to more quickly validate that these functionalities serve to meet project requirements. The goal of the tests with LSP data was to show how vocabulary use by these LSPs can be facilitated using the tools provided by Task 4.2.

4.2 Selection of LSPs

BD4NRG demonstrates its tools and solutions to a diverse range of EPES value chains, focusing on three key pillars of LSPs (Large Scale Pilots):

- **"BD-4-NET"** LSPs focusing on predictive analytics that can forecast and increase the efficiency and reliability of the electricity network.
- **"BD-4-DER"** LSPs focusing on optimizing the management of assets connected to the grid.
- **"BD-4-ENEF"** LSPs focusing on increasing the efficiency and comfort of buildings, and de-risking investments in energy efficiency.

One LSP was selected from each of the three pillars to demonstrate the implementation of the Federated Catalogue and the Vocabulary Hub. The selection was based on the progress of each LSP in relation to the iterative cycles of work and the development cycles followed by BD4NRG[4]. The selection criteria for the specific use cases (UCs) of the LSP demonstrators were as follows:

- Preferably, an LSP should be selected from each BD4NRG pillar in order to showcase the Federated Catalogue and Vocabulary Hub implementations in different domains and applications within the EPES value chain. This would allow engaging different stakeholders with unique needs for their semantic data interoperability, as the UCs concern different applications, target stakeholders, analytics services and eventually data usage.
- According to the development cycles of BD4NRG and the Pilot Deployment Plan (D6.1), the different LSPs were at different stages of development when T4.2 activities started. This includes data availability, pilot preparation activities, business- and technical specifications (as part of WP2 activities and their progress within the project timeline) and finally BD4NRG deployment of technical components (from the respective WP3 and WP4 activities). LSPs had to have reached deployment maturity and -consequently- data sharing capabilities with BD4NRG technical solutions in order to be included in T4.2.

[4] Please refer to deliverable D6.1 – 'Pilot Operation, Engagement and M&V Plan' for the pilot validation process within the development cycles.

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- A key part of the activities in WP2 and WP3 was the BD4NRG Reference Architecture design and implementation. The first components of BD4NRG's technological enablers were prototyped and tested in a subset of pilot sites[5] as part of the BD4NRG RA development. The initial results and feedback that resulted from these prototypes were used for further development of the technological enablers and deployment in the pilot demonstrators. This process led to the development of key technological components for data sharing for the selected LSPs ahead of others, thus making them prime candidates for performing the Vocabulary Hub implementation.

Based on these criteria, the following three LSPs have been selected, with a summary of their UCs being presented in Table 29. For a more detailed description, please refer to BD4NRG deliverables D7.1 – "Baseline Analysis Report and 'BD-4-NET' Large Scale Pilots Preparation", D8.1 – "Baseline Analysis Report and 'BD-4-DER' Large Scale Pilots Preparation" and D9.1 – "Baseline Analysis Report and 'BD-4-ENEF' Large Scale Pilots Preparation".

Table 29: selected LSPs Summary

LSP	UC Motivation and Summary
LSP1	Asset management departments of TSOs are traditionally data intensive. Over the last years, with the ongoing optimization of power systems, the amount of data streams and data sources have significantly increased, showing the need for improved data analytics tools, in order to derive predictive models for assets maintenance. These models are intended to extend the lifetime of assets and optimize operational and maintenance assets costs, hence enabling sustainable risk management and, in a later stage, the integration of asset management with grid improved network operation. The first UC of LSP1 aims to assess the condition of Circuit Breakers (CBs) in order to provide answers to key challenges in asset management: incident characterization by analysis of COMTRADE files and incident feature extraction and subsequent implementation of optimal condition-based maintenance plans. Both are core elements of the electricity network and represent different challenges related to data processing, due to the different nature of the associated datasets. The second UC of LSP1 aims to provide new data-based services which can be used to foster predictive maintenance strategies for TSO OHL tower infrastructures. Because overhead lines represent a major asset in power systems, the pilot aims to use inspection data (such as data from LiDAR technologies) to generate a semi-automatic maintenance plan for right of ways of overhead lines. The first objective of the UC is to automatically classify transmission towers in the field from point cloud scan data. On later stages, this knowledge will be used to perform identification of tower status and derive automatic condition-based maintenance plans.
LSP8	Non-interconnected island electricity systems are largely dependent on the use of imported oil for electricity generation purposes. This increases production costs considerably, while

[5] Please refer to deliverable D6.2 – 'BD4NRG Pilots Synergies, Evaluation and Feedback – First Release'.

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LSP	UC Motivation and Summary
	also introducing technical limitations to the large-scale exploitation of RES power generation. At the same time, significant load variation noted over the course of the year further challenges increased RES penetration, with many island systems presenting increased shares of RES curtailments, especially during the winter (non-touristic) period. This reflects upon the need for the introduction of flexibility means including the components of storage, demand response, vector coupling and advanced energy management relying on big data analytics and modern forecasting techniques. Similar portfolios and bundles of solutions may unlock the potential for further RES exploitation, offering at the same time readily available tools for local community scale actors. The scope of LSP8 UC is to support peak shaving and load shifting decisions based on electricity demand and RES production forecasts.
LSP12	Energy efficiency projects are often fragmented, with high transaction costs, while with no evidence-based platform that would allow investors and financial institutions to assess the risk-, the financial performance of the investments, as well as the impact on energy efficiency. The capability offered by emerging near big data analytics to integrate cross-domain financial and energy consumption is the key for building the necessary market confidence in energy efficiency projects and making them an attractive investment asset class. The use of historical data pooled from major market segments can encourage more energy efficiency investments and de-risk investments. The scope of LSP12 UC is to create a predictive/declarative service to de-risk funding in energy efficiency investments in the building sector by analysing previous performance.

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4.3 Method

We collaborated with project partners involved in LSP1, LSP8 and LSP12 to test and validate the Vocabulary Hub implementation. Each LSP provided a data sample that we took as a starting point. Although there were some descriptions of the data, these were written in natural language. None of the data samples came with an explicit machine readable vocabulary to specify the semantics of the data or a vocabulary that reuses existing standard vocabularies. The test, then, was to validate how the Vocabulary Hub can improve the use of vocabularies for the relevant datasets. Here, the method is illustrated using the dataset from LSP 12 as an example.

The LSP 12 dataset was already published on the Mendely Data platform[6] at the time of writing, which made it easily accessible. The dataset consisted of three Microsoft Excel files:

i. Data on projects: 445 projects implemented under 11 tenders of the funded KPFI programme of the Republic of Latvia
ii. Data on project activities: including the description of the energy saving activities, the building on which the project was implemented, and the resulting CO2 reductions.
iii. Data on implementation details, including data on many variables on different sources of energy consumption, and monthly reporting of temperature and heating days.

The illustration of the method is limited to the first dataset (data on projects), of which a sample is included in

[6] See: https://data.mendeley.com/datasets/x6wyhmpj2v (accessed on March 29th 2023)

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Table 30.

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Table 30: sample of LSP 12 'Project Data' data set

Tender	Name of Tender	Project No.	Project planned CO2 reduction (in tons)	Start date of the project	End date of the project	Project duration in months	Total project costs	Grant financing	% of Grant
KPFI-1	Increase of energy efficiency in municipal buildings (I round)	KPFI-1/1	95,750	2009-11-19	2010-12-21	13,07	367.882,94 €	155.643,93 €	42,31%
KPFI-1	Increase of energy efficiency in municipal buildings (I round)	KPFI-1/10	261,425	2009-11-11	2010-12-29	13,60	1.226.770,81 €	1.041.574,24 €	84,90%
KPFI-1	Increase of energy efficiency in municipal buildings (I round)	KPFI-1/11	64,500	2009-11-16	2010-12-29	13,43	220.956,24 €	92.388,59 €	41,81%
KPFI-1	Increase of energy efficiency in municipal buildings (I round)	KPFI-1/12	44,200	2009-12-01	2010-06-10	6,30	273.418,26 €	203.322,82 €	74,36%
KPFI-1	Increase of energy efficiency in municipal buildings (I round)	KPFI-1/13	73,900	2009-12-27	2011-02-02	13,17	396.496,04 €	170.638,71 €	43,04%
KPFI-1	Increase of energy efficiency in municipal buildings (I round)	KPFI-1/14	48,120	2009-11-27	2010-08-11	8,47	325.296,71 €	119.693,40 €	36,80%
KPFI-1	Increase of energy efficiency in municipal buildings (I round)	KPFI-1/15	470,400	2009-12-04	2011-12-29	24,83	1.850.566,56 €	1.331.837,57 €	71,97%
KPFI-1	Increase of energy efficiency in municipal buildings (I round)	KPFI-1/16	423,700	2009-12-04	2012-03-28	27,80	1.638.058,31 €	1.178.442,85 €	71,94%
KPFI-1	Increase of energy efficiency in municipal buildings (I round)	KPFI-1/17	107,500	2009-11-27	2011-08-29	21,07	667.100,98 €	416.055,67 €	62,37%
KPFI-1	Increase of energy efficiency in municipal buildings (I round)	KPFI-1/18	73,400	2009-11-11	2010-11-24	12,43	264.685,92 €	127.148,86 €	48,04%
KPFI-1	Increase of energy efficiency in municipal buildings (I round)	KPFI-1/19	357,450	2009-12-02	2012-02-17	26,50	1.595.940,92 €	1.103.442,62 €	69,14%
KPFI-1	Increase of energy efficiency in municipal buildings (I round)	KPFI-1/22	55,200	2009-11-11	2010-12-28	13,57	170.469,26 €	72.992,44 €	42,82%
KPFI-7	Complex solutions for greenhouse gas emission reduction in municipal buildings (II round)	KPFI-7/97	181,080	2011-03-07	2012-12-01	20,80	940.039,78 €	634.894,49 €	67,54%
KPFI-7	Complex solutions for greenhouse gas emission reduction in municipal buildings (II round)	KPFI-7/99	96,440	2011-02-28	2012-04-02	13,07	334.261,83 €	284.122,56 €	85,00%

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4.3.1 Step 1: selecting vocabularies for reuse

Some of the vocabularies identified in BD4NRG deliverables D2.3 – 'BD4NRG Semantification & Interoperability' and D2.6 – 'BD4NRG Reference Architecture Final Version' included terms of which the meaning overlaps with the meaning of the terms in the dataset. For example, the meaning of the column 'Project planned CO2 reduction (in tons)' can be modelled by both the Smart Data Model 'KeyPerformanceIndicator' but also with the SAREF extension for Smart City ontology. As shown in Figure 12, the latter was chosen in this case since the current implementation of the Vocabulary Hub only supported RDF/OWL/SHACL vocabularies at the time of writing.

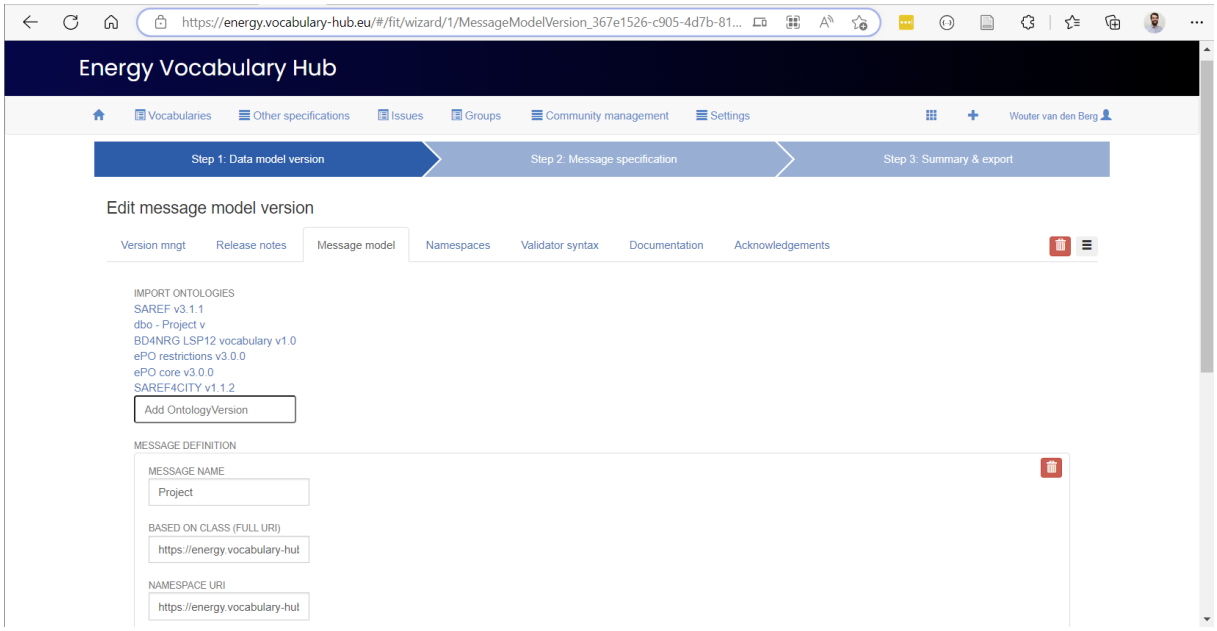

Figure 12: step 1 of the Vocabulary Hub Configurator for LSP 12 – selecting the ontologies to be reused

However, vocabularies that were not identified in BD4NRG deliverables D2.3 and D2.6 were also required to model the semantics of the dataset. Terms related to tenders and projects – e.g. 'Tender', 'Name of Tender' and 'Project No. – are not central concepts in the energy domain and some procurement vocabularies were required. The European eProcurement Ontology (ePO)[7] and a small part of the DBPedia[8] ontology for project-related concepts were used to model the remaining semantics in

[7] https://joinup.ec.europa.eu/collection/eprocurement/solution/eprocurement-ontology/about
[8] https://www.dbpedia.org/

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Table 30.

The final imported ontology in the list of Figure 12 was 'BD4NRG LSP 12 vocabulary v1.0', which is a small vocabulary created to tie the third-party vocabularies together. In other words, it serves the purpose of aligning the relevant terms from the third-party vocabularies in a way that fitted the LSP 12 dataset.

4.3.2 Step 2: create data model

The next step was to create the data model (or 'message specification') for the dataset. The data model was to serve data sharing by making very clear what kind of data structure can be expected. As shown in the left part of Figure 13, the user of the Configurator was able to check and uncheck the terms/properties they needed for their dataset. The screenshot shows the end result where all properties required for

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Table 30 have been checked. Figure 13 shows there were 16 more possible properties available. Please note that the Vocabulary Hub traverses the graphs of the imported ontologies from step 1 and presents all properties that it has found to the user in this step 2. This way the user is able to exactly decide which parts of the imported ontologies need to be reused and which can safely be ignored.

The middle part of the screen (Figure 13) is where the user can further customize the data model. For example, for this validation the multiplicity of every checked property was refined to be '[1..1]', i.e. all being mandatory properties. Thus, for a dataset to be compliant to this data model, every property has to have one value in the data. If for example *totalProjectCosts* were to be missing for a project in the dataset, that would be a violation of the data model since it is a mandatory property of projects. In that case, any data validation service would consider the data as invalid.

In order to facilitate the configuration of validation services, the vocabulary hub is able to automatically generate data model schemas in step 3 of the Configurator wizard.

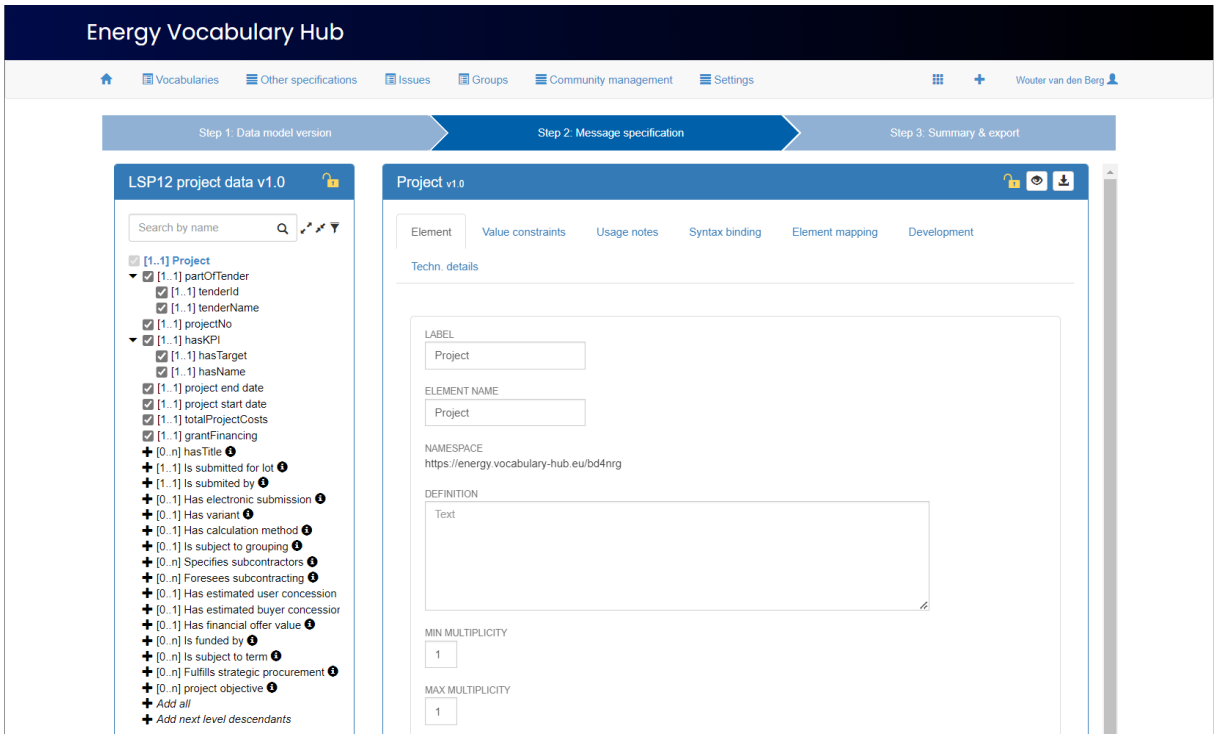

Figure 13: step 2 of the Vocabulary Hub wizard for LSP 12 – creating the data model

4.3.3 Step 3: export schemas

The final result of the Configurator wizard provides the user with schema's in preferred web languages: XML Schema (i.e. XSD), JSON schema, RDF/SHACL, CSV and even OpenAPI. These specifications are generated based on the user input from step 2 (see 4.3.2). As Figure 14 shows, the schema is on the left (or in this case the Open API specification that includes a schema), and an example message that conforms to said schema is on the right. (Note the identical property names in the message example

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compared to Figure 13.) Users that prefer some other syntax, e.g. XML, can find the XML schema under the XML syntax tab (Figure 14).

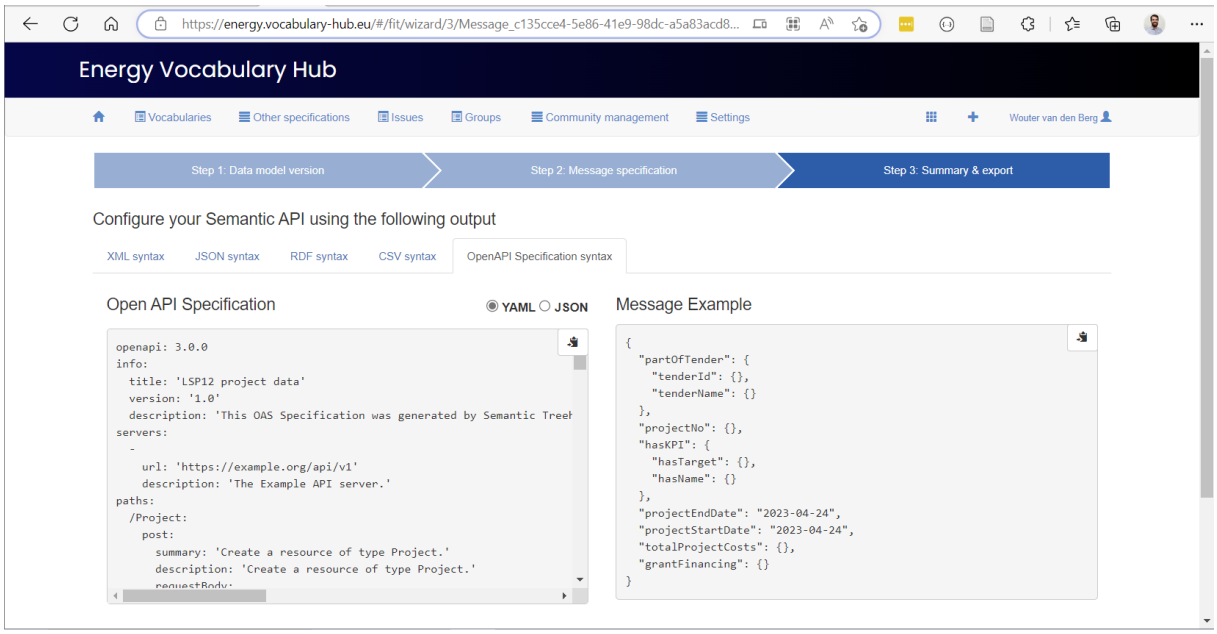

Figure 14: step 3 of the Vocabulary Hub wizard for LSP 12 – exporting schemas of your choice

The OAS option provides a basic API specification that can be implemented relatively easily, or can be used to confirm with a prospected data consumer whether the API would meet their requirements.

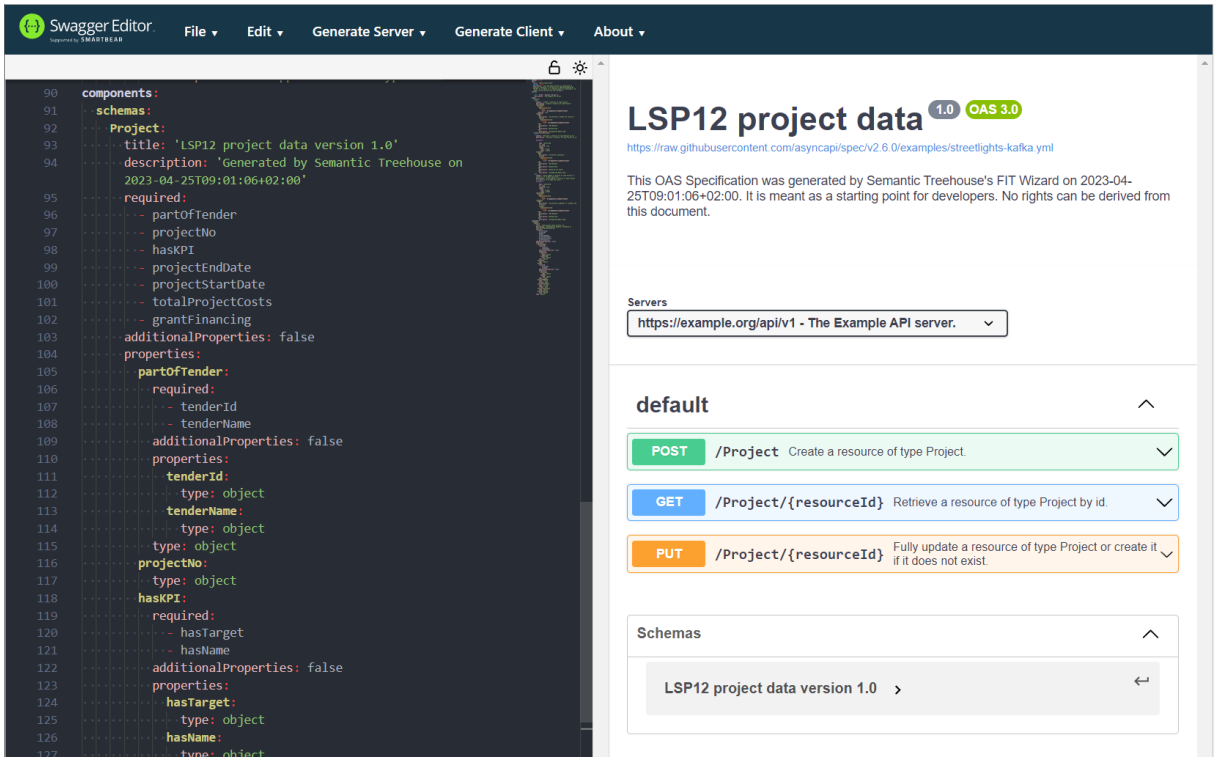

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Figure 15: step 3 of the Vocabulary Hub wizard for LSP 12 – exporting schemas of your choice

4.4 Results

This section presents the results of applying the method to LSP 1, LSP 8 and LSP 12. The results are available for viewing and download in the Vocabulary Hub (see 5.2). For each LSP, the results consist of:

- An abstract **data model** of the LSP dataset in the Vocabulary Hub
- The list of **used vocabularies** for that data model
- A **schema** document that specifies the structure of the particular dataset

Here, an abstract data model is a data model that is syntax independent. Since all the sample datasets were comma-separated value (CSV) files, the CSV for the Web (CSVW)[9] language was used to create the schema for each LSP. The current implementation of the Vocabulary hub does not yet support CSV, so the schemas were written manually.

[9] https://csvw.org/

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4.4.1 LSP1

The dataset provided by LSP 1 was a CSV file related to the first use case of their pilot, which was focused on enabling condition-based maintenance planning based on data about the health and performance of electrical equipment, in particular CBs. In the case of this CSV file, the data was simulated for confidentiality reasons. It included a timeseries of the oscillography for currents and voltages and one JSON file with metadata related to the event and to the asset concerned.

4.4.1.1 Data model

The current LSP 1 data model in the Vocabulary Hub has version number 1.0 and was published on April 28th 2023 (Figure 16, Figure 17). Acknowledged as authors are R&D Nester, TNO.

R&D Nester provided the initial data model that served as a starting point. TNO was editor of the final results presented here. NTUA contributed a LSPs coordinator.

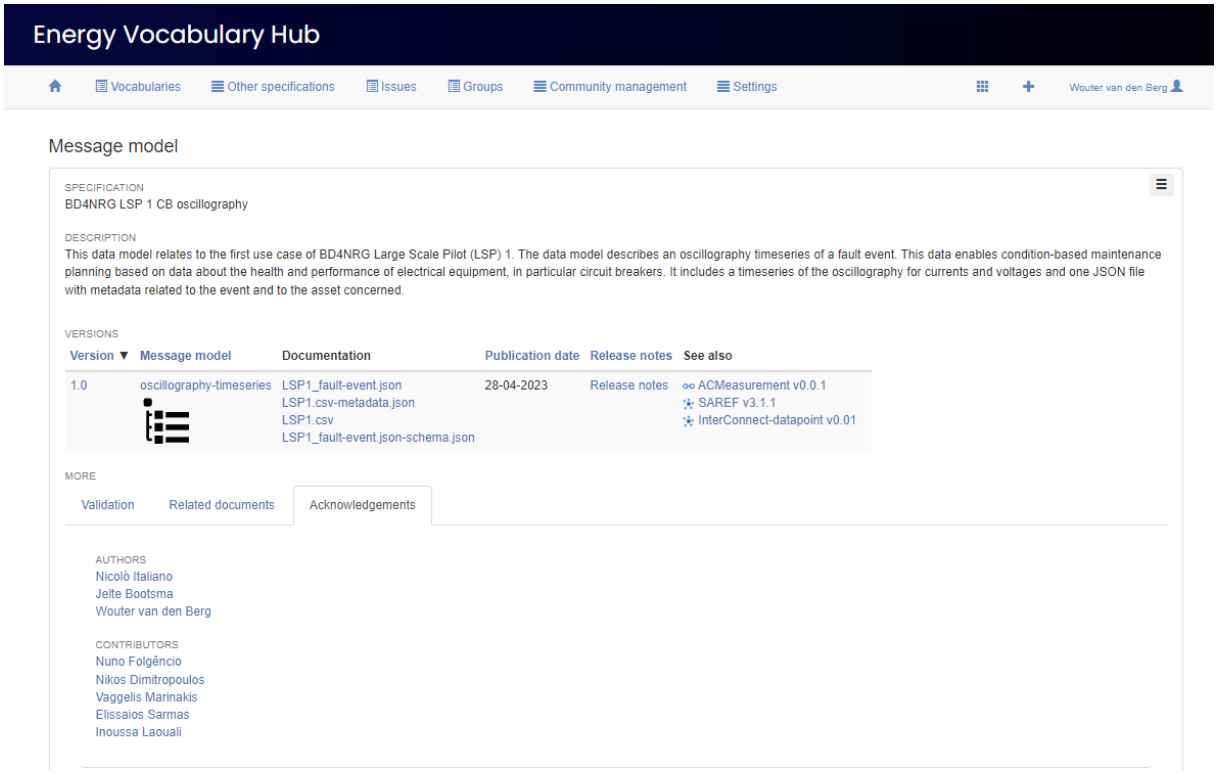

Figure 16: data model for LSP 1 including metadata and version management

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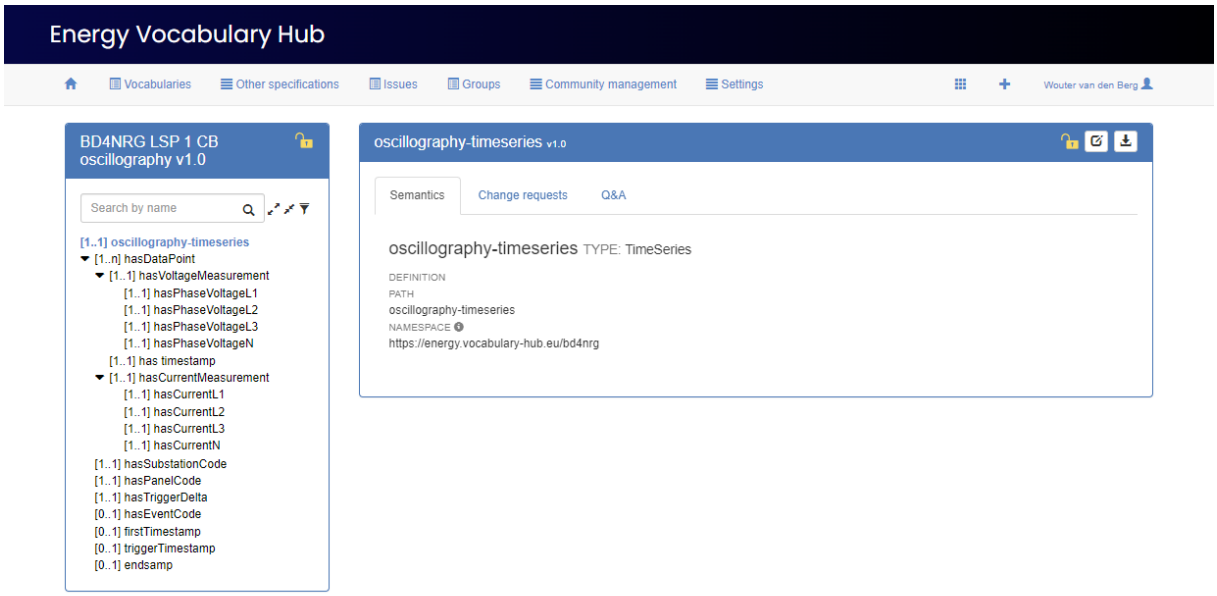

Figure 17: interactive view of the LSP 1 data model

4.4.1.2 Used vocabularies

The scope of the LSP 1 data corresponded with one of the Smart Data Models (SDM), namely the ACMeasurement model. According to the SDM GitHub page[10], this model was an adaption of the IEC standards (a Common Information Model (CIM)). However the Smart Data Models are JSON models and not ontologies. This meant that they could not be used in step 1 of the BD4NRG Vocabulary Hub implementation (see 4.3.1), since it lacked support for vocabularies other than ontologies at the time of writing.

To mitigate this, the following vocabularies were used:

- SAREF v3.1.1
- InterConnect-datapoint v0.01 (SAREF extension, ETSI standardization pending)
- BD4NRG LSP 1 vocabulary v1.0

The concepts of timeseries and datapoints was provided by the SAREF ontology combined with the Datapoint-extension developed in InterConnect. The main purpose of the custom BD4NRG LSP 1 vocabulary module was to provide an ontology variant of the ACMeasurement model from SDM. Below is the Turtle serialization of the model:

[10] https://github.com/smart-data-models/dataModel.Energy

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```
@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix xml: <http://www.w3.org/XML/1998/namespace> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix bd4nrg: <https://energy.vocabulary-hub.eu/bd4nrg#> .
@prefix ic-data: <http://ontology.tno.nl/interconnect/datapoint#> .
@prefix sdm-energy: <https://smartdatamodels.org/dataModel.Energy/> .

#################################################################
#    Object Properties
#################################################################

###  http://ontology.tno.nl/interconnect/datapoint#hasDataPoint
ic-data:hasDataPoint rdf:type owl:ObjectProperty .

###  https://energy.vocabulary-hub.eu/bd4nrg#hasCurrentMeasurement
bd4nrg:hasCurrentMeasurement rdf:type owl:ObjectProperty ;
                             rdfs:subPropertyOf sdm-energy:phaseVoltage ;
                             rdfs:domain bd4nrg:DataPoint ;
                             rdfs:range bd4nrg:CurrentMeasurement .

###  https://energy.vocabulary-hub.eu/bd4nrg#hasDataPoint
bd4nrg:hasDataPoint rdf:type owl:ObjectProperty ;
                    rdfs:subPropertyOf ic-data:hasDataPoint ;
                    rdfs:domain bd4nrg:TimeSeries ;
                    rdfs:range bd4nrg:DataPoint .

###  https://energy.vocabulary-hub.eu/bd4nrg#hasVoltageMeasurement
bd4nrg:hasVoltageMeasurement rdf:type owl:ObjectProperty ;
                             rdfs:subPropertyOf sdm-energy:phaseVoltage ;
                             rdfs:domain bd4nrg:DataPoint ;
                             rdfs:range bd4nrg:VoltageMeasurement .

#################################################################
#    Data properties
#################################################################

###  https://energy.vocabulary-hub.eu/bd4nrg#endsamp
bd4nrg:endsamp rdf:type owl:DatatypeProperty ;
               rdfs:subPropertyOf owl:topDataProperty ;
               rdfs:range xsd:decimal ;
               rdfs:comment "Time delta between the final and the first timestamp, in microseconds"^^xsd:string .

###  https://energy.vocabulary-hub.eu/bd4nrg#firstTimestamp
bd4nrg:firstTimestamp rdf:type owl:DatatypeProperty ;
                      rdfs:subPropertyOf sdm-energy:dateObservedFrom ;
                      rdfs:range xsd:dateTime .

###  https://energy.vocabulary-hub.eu/bd4nrg#hasCurrentL1
bd4nrg:hasCurrentL1 rdf:type owl:DatatypeProperty .

###  https://energy.vocabulary-hub.eu/bd4nrg#hasCurrentL2
bd4nrg:hasCurrentL2 rdf:type owl:DatatypeProperty .

###  https://energy.vocabulary-hub.eu/bd4nrg#hasCurrentL3
bd4nrg:hasCurrentL3 rdf:type owl:DatatypeProperty .

###  https://energy.vocabulary-hub.eu/bd4nrg#hasEventCode
bd4nrg:hasEventCode rdf:type owl:DatatypeProperty ;
                    rdfs:range xsd:normalizedString .

###  https://energy.vocabulary-hub.eu/bd4nrg#hasPanelCode
bd4nrg:hasPanelCode rdf:type owl:DatatypeProperty ;
                    rdfs:range xsd:normalizedString .

###  https://energy.vocabulary-hub.eu/bd4nrg#hasPhaseVoltageL1
bd4nrg:hasPhaseVoltageL1 rdf:type owl:DatatypeProperty .

###  https://energy.vocabulary-hub.eu/bd4nrg#hasPhaseVoltageL2
bd4nrg:hasPhaseVoltageL2 rdf:type owl:DatatypeProperty .

###  https://energy.vocabulary-hub.eu/bd4nrg#hasPhaseVoltageL3
bd4nrg:hasPhaseVoltageL3 rdf:type owl:DatatypeProperty .
```

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```
### https://energy.vocabulary-hub.eu/bd4nrg#hasPhaseVoltageN
bd4nrg:hasPhaseVoltageN rdf:type owl:DatatypeProperty .

### https://energy.vocabulary-hub.eu/bd4nrg#hasSubstationCode
bd4nrg:hasSubstationCode rdf:type owl:DatatypeProperty ;
                         rdfs:range xsd:normalizedString .

### https://energy.vocabulary-hub.eu/bd4nrg#hasTriggerDelta
bd4nrg:hasTriggerDelta rdf:type owl:DatatypeProperty ;
                       rdfs:range xsd:decimal .

### https://energy.vocabulary-hub.eu/bd4nrg#triggerTimestamp
bd4nrg:triggerTimestamp rdf:type owl:DatatypeProperty ;
                        rdfs:subPropertyOf owl:topDataProperty ;
                        rdfs:range xsd:dateTime .

### https://energy.vocabulary-hub.eu/bd4nrg#bd4nrg:hasCurrentN
bd4nrg:hasCurrentN rdf:type owl:DatatypeProperty .

### https://energy.vocabulary-hub.eu/bd4nrg#bd4nrg:hasPhaseType
bd4nrg:hasPhaseType rdf:type owl:DatatypeProperty ;
                    rdfs:subPropertyOf sdm-energy:phaseType ;
                    rdfs:domain bd4nrg:DataPoint ;
                    rdfs:range xsd:normalizedString .

#################################################################
#    Classes
#################################################################

### http://ontology.tno.nl/interconnect/datapoint#DataPoint
ic-data:DataPoint rdf:type owl:Class .

### http://ontology.tno.nl/interconnect/datapoint#TimeSeries
ic-data:TimeSeries rdf:type owl:Class .

### https://energy.vocabulary-hub.eu/bd4nrg#CurrentMeasurement
bd4nrg:CurrentMeasurement rdf:type owl:Class ;
                          rdfs:subClassOf owl:Thing ,
                                          [ rdf:type owl:Restriction ;
                                            owl:onProperty bd4nrg:hasCurrentL1 ;
                                            owl:someValuesFrom xsd:decimal
                                          ] ,
                                          [ rdf:type owl:Restriction ;
                                            owl:onProperty bd4nrg:hasCurrentL2 ;
                                            owl:someValuesFrom xsd:decimal
                                          ] ,
                                          [ rdf:type owl:Restriction ;
                                            owl:onProperty bd4nrg:hasCurrentL3 ;
                                            owl:someValuesFrom xsd:decimal
                                          ] ,
                                          [ rdf:type owl:Restriction ;
                                            owl:onProperty bd4nrg:hasCurrentN ;
                                            owl:someValuesFrom xsd:decimal
                                          ] .

### https://energy.vocabulary-hub.eu/bd4nrg#DataPoint
bd4nrg:DataPoint rdf:type owl:Class ;
                 rdfs:subClassOf ic-data:DataPoint ,
                                 [ rdf:type owl:Restriction ;
                                   owl:onProperty bd4nrg:hasCurrentMeasurement ;
                                   owl:someValuesFrom bd4nrg:CurrentMeasurement
                                 ] ,
                                 [ rdf:type owl:Restriction ;
                                   owl:onProperty bd4nrg:hasVoltageMeasurement ;
                                   owl:someValuesFrom bd4nrg:VoltageMeasurement
                                 ],
                                 sdm-energy:ACMeasurement .

### https://energy.vocabulary-hub.eu/bd4nrg#TimeSeries
bd4nrg:TimeSeries rdf:type owl:Class ;
                  rdfs:subClassOf ic-data:TimeSeries ,
                                  [ rdf:type owl:Restriction ;
                                    owl:onProperty bd4nrg:hasDataPoint ;
```

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```
                owl:someValuesFrom bd4nrg:DataPoint
              ] ,
              [ rdf:type owl:Restriction ;
                owl:onProperty bd4nrg:endsamp ;
                owl:someValuesFrom xsd:decimal
              ] ,
              [ rdf:type owl:Restriction ;
                owl:onProperty bd4nrg:firstTimestamp ;
                owl:someValuesFrom xsd:dateTime
              ] ,
              [ rdf:type owl:Restriction ;
                owl:onProperty bd4nrg:hasEventCode ;
                owl:someValuesFrom xsd:normalizedString
              ] ,
              [ rdf:type owl:Restriction ;
                owl:onProperty bd4nrg:hasPanelCode ;
                owl:someValuesFrom xsd:normalizedString
              ] ,
              [ rdf:type owl:Restriction ;
                owl:onProperty bd4nrg:hasSubstationCode ;
                owl:someValuesFrom xsd:normalizedString
              ] ,
              [ rdf:type owl:Restriction ;
                owl:onProperty bd4nrg:hasTriggerDelta ;
                owl:someValuesFrom xsd:decimal
              ] ,
              [ rdf:type owl:Restriction ;
                owl:onProperty bd4nrg:triggerTimestamp ;
                owl:someValuesFrom xsd:dateTime
              ] .

###  https://energy.vocabulary-hub.eu/bd4nrg#VoltageMeasurement
bd4nrg:VoltageMeasurement rdf:type owl:Class ;
                          rdfs:subClassOf [ rdf:type owl:Restriction ;
                                            owl:onProperty bd4nrg:hasPhaseVoltageL1 ;
                                            owl:someValuesFrom xsd:decimal
                                          ] ,
                                          [ rdf:type owl:Restriction ;
                                            owl:onProperty bd4nrg:hasPhaseVoltageL2 ;
                                            owl:someValuesFrom xsd:decimal
                                          ] ,
                                          [ rdf:type owl:Restriction ;
                                            owl:onProperty bd4nrg:hasPhaseVoltageL3 ;
                                            owl:someValuesFrom xsd:decimal
                                          ] ,
                                          [ rdf:type owl:Restriction ;
                                            owl:onProperty bd4nrg:hasPhaseVoltageN ;
                                            owl:someValuesFrom xsd:decimal
                                          ] .
```

4.4.1.3 Schema

The data sample provided by LSP 1 partners R&D Nester consisted of a CSV file with the time series of AC measurements and a JSON file with more info on the fault event. A schema was created for each.

Below is a schema for the CSV serialization of the LSP 1 dataset of a CB fault event consisting of an oscillography timeseries written in CSVW. The format of this schema document is JSON. Please note the references to existing vocabulary terms in the propertyUrl field.

4.4.1.3.1 CSV timeseries

```
{
  "@context": [
    "http://www.w3.org/ns/csvw",
    {
      "@language": "en"
```

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```
    }
],
"dialect": {
    "delimiter": ",",
    "encoding": "utf-8",
    "quoteChar": "\""
},
"dct:title": "LSP1.csv",
"dct:description": "Oscillography recorded for the fault event simulated on the 06/25/22, at 11:15:54.628",
"dcat:contactPoint": "Nicolò Italiano",
"dcat:keyword": [
    "circuit breaker",
    "fault",
    "electric current",
    "voltage"
],
"dct:publisher": {
    "foaf:name": "CENTRO DE INVESTIGAÇÃO EM ENERGIA REN - STATE GRID, S. A. (R&D NESTER)"
},
"url": null,
"tableSchema": {
    "columns": [
        {
            "name": "timestamp",
            "dc:description": "Timestamp of recorded event in microseconds",
            "datatype": "integer",
            "propertyUrl": "https://energy.vocabulary-hub.eu/bd4nrg#bd4nrg:hasTimeStamp",
            "required": true
        },
        {
            "name": "I1",
            "dc:description": "AC electric current of phase 1 in Ampere",
            "datatype": {
                "base": "decimal",
                "format": {
                    "decimalChar": "."
                }
            },
            "propertyUrl": "https://energy.vocabulary-hub.eu/bd4nrg#hasCurrentL1",
            "required": true
        },
        {
            "name": "I2",
            "dc:description": "AC electric current of phase 2 in Ampere",
            "datatype": {
                "base": "decimal",
                "format": {
                    "decimalChar": "."
                }
            },
            "propertyUrl": "https://energy.vocabulary-hub.eu/bd4nrg#hasCurrentL2",
            "required": true
        },
        {
            "name": "I3",
            "dc:description": "AC electric current of phase 3 in Ampere",
            "datatype": {
                "base": "decimal",
                "format": {
                    "decimalChar": "."
                }
            },
            "propertyUrl": "https://energy.vocabulary-hub.eu/bd4nrg#hasCurrentL3",
            "required": true
        },
        {
            "name": "IN",
            "dc:description": "AC electric current of neutral phase in Ampere",
            "datatype": {
                "base": "decimal",
                "format": {
                    "decimalChar": "."
                }
            },
```


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```
            "propertyUrl": "https://energy.vocabulary-hub.eu/bd4nrg#hasCurrentN",
            "required": true
         },
         {
            "name": "V1",
            "dc:description": "AC voltage of phase 1 in Volt",
            "datatype": {
               "base": "decimal",
               "format": {
                  "decimalChar": "."
               }
            },
            "propertyUrl": "https://energy.vocabulary-hub.eu/bd4nrg#hasPhaseVoltageL1",
            "required": true
         },
         {
            "name": "V2",
            "dc:description": "AC voltage of phase 2 in Volt",
            "datatype": {
               "base": "decimal",
               "format": {
                  "decimalChar": "."
               }
            },
            "propertyUrl": "https://energy.vocabulary-hub.eu/bd4nrg#hasPhaseVoltageL2",
            "required": true
         },
         {
            "name": "V3",
            "dc:description": "AC voltage of phase 3 in Volt",
            "datatype": {
               "base": "decimal",
               "format": {
                  "decimalChar": "."
               }
            },
            "propertyUrl": "https://energy.vocabulary-hub.eu/bd4nrg#hasPhaseVoltageL3",
            "required": true
         },
         {
            "name": "VN",
            "dc:description": "AC voltage of neutral phase in Volt",
            "datatype": {
               "base": "decimal",
               "format": {
                  "decimalChar": "."
               }
            },
            "propertyUrl": "https://energy.vocabulary-hub.eu/bd4nrg#hasPhaseVoltageN",
            "required": true
         }
      ]
   }
}
```


4.4.1.3.2 JSON fault event

Below is the JSON schema is for the fault-event JSON data in the LSP 1 data sample.


```
{
   "id": "https://energy.vocabulary-hub.eu/bd4nrg#oscillography-timeseries",
   "$schema": "https://json-schema.org/draft/2020-12/schema",
   "title": "BD4NRG LSP 1 CB oscillography version 1.0",
   "description": "Generated by Semantic Treehouse on 2023-05-01T14:49:51+02:00",
   "required": [
      "hasSubstationCode",
      "hasPanelCode",
      "hasTriggerDelta"
   ],
```


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```
  "additionalProperties": false,
  "properties": {
    "hasSubstationCode": {
      "type": "object"
    },
    "hasPanelCode": {
      "type": "object"
    },
    "hasTriggerDelta": {
      "type": "number"
    },
    "hasEventCode": {
      "type": "object"
    },
    "firstTimestamp": {
      "type": "string",
      "format": "date-time"
    },
    "triggerTimestamp": {
      "type": "string",
      "format": "date-time"
    },
    "endsamp": {
      "type": "number"
    }
  },
  "type": "object"
}
```

4.4.1.4 Self-description

Below is the self-description for the resource published to the Federated Catalogue for LSP1.

```
@prefix dcat: <http://www.w3.org/ns/dcat#> .
@prefix dcatap: <http://data.europa.eu/r5r/> .
@prefix dcterms: <http://purl.org/dc/terms/> .
@prefix fedcat: <http://ontology.tno.nl/federatedCatalogue/> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix ids: <https://w3id.org/idsa/core/> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .


<urn:circuitbreaker-data.localhost.demo:resources:5dde7815-fbb3-46dc-b21e-e4c509aa3fef> a
fedcat:Resource,
        ids:DataResource ;
    dcat:contactPoint "R&D Nester" ;
    dcat:description "A short sample of data about health and performance of circuit breakers" ;
    dcat:keyword "Condition-based maintenance"@en,
        "Circuit breakers"@en ;
    dcat:publisher <urn:ids:pyconnector:Owner> ; # The publisher of the resource (which may differ from
the sovereign)
    dcat:title "circuitbreaker-data" ;
    dcat:distribution <https://w3id.org/dcat/autogen/distribution/2a4c9f90-1222-4791-983a-6043175c9edb>
;
    ids:representation <https://w3id.org/idsa/autogen/dataRepresentation/c049d817-564f-47e6-9fff-
f79890013b8e> ;
    ids:sovereign <urn:publisher:ntua> ; # The 'owner', i.e. sovereign of the data.  # Unfortunately
not dangling URIRef to Participant owning the Connector


<https://w3id.org/idsa/autogen/artifact/f95cceff-0e95-49c9-8b5e-139b6b7f9f6c> a ids:Artifact ;
    ids:byteSize 372199 ;
```

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```
    ids:fileName "20230220_BD4NRG_LSP1_DATA_FP.csv" .


<https://w3id.org/dcat/autogen/distribution/2a4c9f90-1222-4791-983a-6043175c9edb> a dcat:Distribution ;
    dcat:accessURL "https://ntua.org/example/LSP1/541a556c-2816-4199-a6ce-
a70df2c179ba/20230220_BD4NRG_LSP1_DATA_FP.csv" .


<https://w3id.org/idsa/autogen/dataRepresentation/c049d817-564f-47e6-9fff-f79890013b8e> a
ids:DataRepresentation ;
    dcatap:availability "Experimental" ; # Unclear/non-finalized type
    dcterms:description "CSV about health and performance of circuit breakers" ;
    dcterms:license <https://tilos.waterpumpstations.example.com/terms-of-use/> ;
    ids:dataType <http://ontology.tno.nl/interconnect/datapoint#TimeSeries> ;
    ids:dataTypeSchema <http://bd4nrg.semantic-
treehouse.nl/LSP1/20230220_BD4NRG_LSP1_DATA_DESCRIPTION_FP.csv> ;
    ids:instance <https://w3id.org/idsa/autogen/artifact/f95cceff-0e95-49c9-8b5e-139b6b7f9f6c> ;
    ids:mediaType <https://w3id.org/idsa/autogen/iANAMediaType/8c8dff18-d9cb-4100-b0f6-fadb06f9243f> ;


<https://w3id.org/idsa/autogen/iANAMediaType/8c8dff18-d9cb-4100-b0f6-fadb06f9243f> a ids:IANAMediaType
;
    ids:filenameExtension "csv" .


# Federated Catalogue participant, also a normal organization, could be something different as well.
<urn:publisher:ntua> a fedcat:Participant,
        foaf:Organization ;
    foaf:name "National Technical University of Athens"@en .
```

Key aspects to be noted in the above self-description are:

- The publisher of the dataset – represented by the instance fedcat:Participant <urn:publisher:ntua>
- The type of the resource – represented by the instance fedcat:Resource <urn:circuitbreaker-data.localhost.demo:resources:5dde7815-fbb3-46dc-b21e-e4c509aa3fef>
- The datatype schema of the resource, explained in section 4.4.1.3.1 – represented by the property ids:dataTypeSchema “http://bd4nrg.semantic-treehouse.nl/LSP1/20230220_BD4NRG_LSP1_DATA_DESCRIPTION_FP.csv”
- The access URL to the resource, represented by the property dcat:accessURL “https://ntua.org/example/LSP1/541a556c-2816-4199-a6ce-a70df2c179ba/20230220_BD4NRG_LSP1_DATA_FP.csv”

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4.4.2 LSP8

4.4.2.1 Data model

The data sample from LSP 8 consisted of a CSV file with timeseries of energy use by different devices (e.g. pumps, ovens, fridges) and in different locations (e.g. homes, public buildings, stores). Figure 18 and Figure 19 show the data model and corresponding interactive view respectively.

TNO was the main author of the model with contribution from EUROSOL as LSP 8 partners NTUA as LSPs coordinator.

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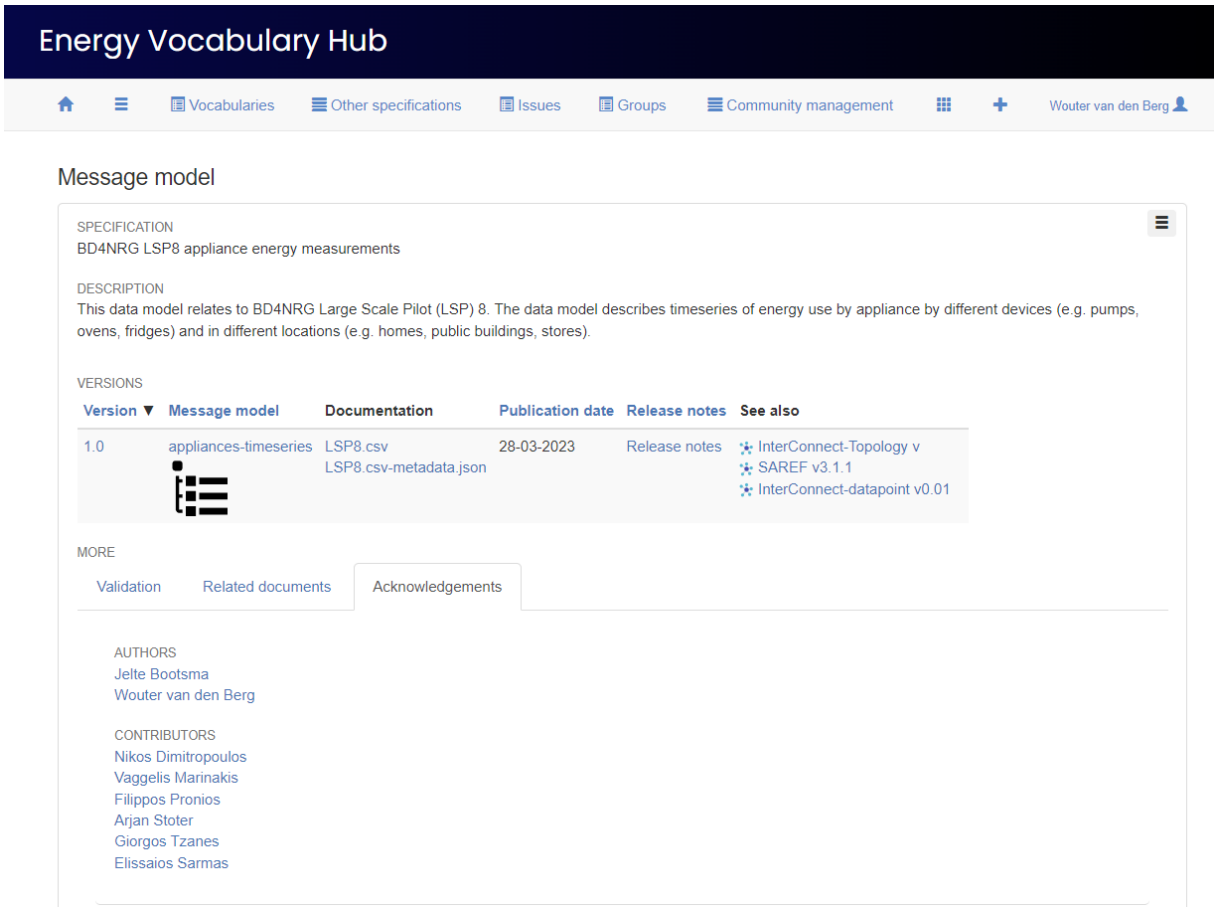

Figure 18: data model for LSP 8 including metadata and version management

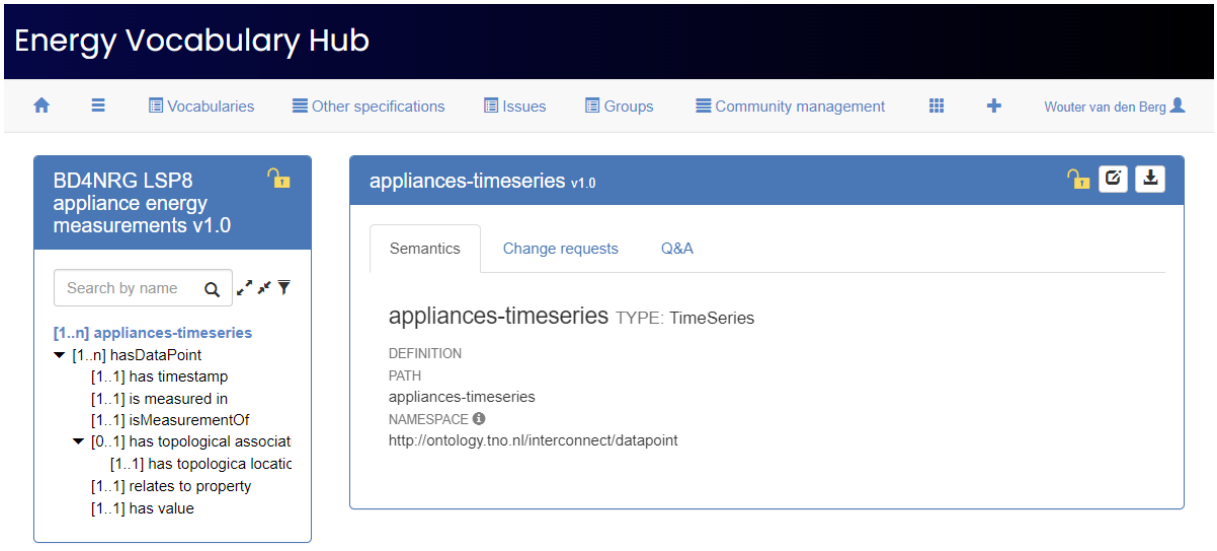

Figure 19: interactive view of the LSP 8 data model

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4.4.2.2 Used vocabularies

The vocabularies to construct the data model for LSP 8 were:

- InterConnect-Topology v1
- SAREF v3.1.1
- InterConnect-datapoint v0.01

No custom vocabulary was required to cover the semantics of the data in the data sample.

4.4.2.3 Schema

The schema for the CSV serialization of the LSP 8 dataset was written using the CSVW language in JSON format.


```
{
  "@context": [
    "http://www.w3.org/ns/csvw",
    {
      "@language": "en"
    }
  ],
  "dialect": {
    "delimiter": ",",
    "encoding": "utf-8",
    "quoteChar": "\"",
    "header": true
  },
  "dct:publisher": {
    "foaf:name": "University of West Attica"
  },
  "url": null,
  "tableSchema": {
    "columns": [
      {
        "name": "dt",
        "datatype": "date",
        "propertyUrl": "https://saref.etsi.org/core/hasTimestamp"
      },
      {
        "name": "house_1?boiler_power?W",
        "datatype": "decimal",
        "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/ActivePower/doc/spec.md",
        "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "house_1",
        "https://saref.etsi.org/core/isMeasurementOf": "boiler",
        "https://saref.etsi.org/core/relatesToProperty": "Power",
        "https://saref.etsi.org/core/isMeasuredIn": "Watt"
      },
      {
        "name": "house_1?fridge_power?W",
        "datatype": "decimal",
        "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/ActivePower/doc/spec.md",
        "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "house_1",
        "https://saref.etsi.org/core/relatesToProperty": "Power",
        "https://saref.etsi.org/core/isMeasurementOf": "fridge",
        "https://saref.etsi.org/core/isMeasuredIn": "Watt"
      },
      {
        "name": "house_1?outlet_power?W",
        "datatype": "decimal",
        "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/ActivePower/doc/spec.md",
        "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "house_1",
        "https://saref.etsi.org/core/isMeasurementOf": "outlet",
        "https://saref.etsi.org/core/relatesToProperty": "Power",
        "https://saref.etsi.org/core/isMeasuredIn": "Watt"
      },
```


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```
{
    "name": "house_1?oven_power?W",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/ActivePower/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "house_1",
    "https://saref.etsi.org/core/isMeasurementOf": "oven",
    "https://saref.etsi.org/core/relatesToProperty": "Power",
    "https://saref.etsi.org/core/isMeasuredIn": "Watt"
},
{
    "name": "house_1?total_power?W",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/ActivePower/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "house_1",
    "https://saref.etsi.org/core/isMeasurementOf": "house",
    "https://saref.etsi.org/core/relatesToProperty": "Power",
    "https://saref.etsi.org/core/isMeasuredIn": "Watt"
},
{
    "name": "house_1?total_power_factor?%",
    "datatype": "decimal",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "house_1",
    "https://saref.etsi.org/core/relatesToProperty": "Power factor",
    "https://saref.etsi.org/core/isMeasurementOf": "house",
    "https://saref.etsi.org/core/isMeasuredIn": "Percent"
},
{
    "name": "house_1?total_voltage?V",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/Voltage/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "house_1",
    "https://saref.etsi.org/core/isMeasurementOf": "house",
    "https://saref.etsi.org/core/relatesToProperty": "Total voltage",
    "https://saref.etsi.org/core/isMeasuredIn": "Volt"
},
{
    "name": "house_2?a_c_bedroom_power?W",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/ActivePower/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "house_2",
    "https://saref.etsi.org/core/isMeasurementOf": "bedroom",
    "https://saref.etsi.org/core/relatesToProperty": "Power",
    "https://saref.etsi.org/core/isMeasuredIn": "Watt"
},
{
    "name": "house_2?a_c_livingroom_power?W",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/ActivePower/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "house_2",
    "https://saref.etsi.org/core/isMeasurementOf": "boiler",
    "https://saref.etsi.org/core/relatesToProperty": "living room",
    "https://saref.etsi.org/core/isMeasuredIn": "Watt"
},
{
    "name": "house_2?boiler_power?W",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/ActivePower/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "house_2",
    "https://saref.etsi.org/core/isMeasurementOf": "boiler",
    "https://saref.etsi.org/core/relatesToProperty": "Power",
    "https://saref.etsi.org/core/isMeasuredIn": "Watt"
},
{
    "name": "house_2?outlet_power?W",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/ActivePower/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "house_2",
    "https://saref.etsi.org/core/isMeasurementOf": "outlet",
    "https://saref.etsi.org/core/relatesToProperty": "Power",
    "https://saref.etsi.org/core/isMeasuredIn": "Watt"
},
{
    "name": "house_2?total_power?W",
    "datatype": "decimal",
```


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```
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/ActivePower/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "house_2",
    "https://saref.etsi.org/core/isMeasurementOf": "house",
    "https://saref.etsi.org/core/relatesToProperty": "Total power",
    "https://saref.etsi.org/core/isMeasuredIn": "Watt"
},
{
    "name": "house_2?total_power_factor?%",
    "datatype": "decimal",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "house_2",
    "https://saref.etsi.org/core/isMeasurementOf": "house",
    "https://saref.etsi.org/core/relatesToProperty": "Power factor",
    "https://saref.etsi.org/core/isMeasuredIn": "Percent"
},
{
    "name": "house_2?total_voltage?V",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/Voltage/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "house_2",
    "https://saref.etsi.org/core/isMeasurementOf": "house",
    "https://saref.etsi.org/core/relatesToProperty": "Total voltage",
    "https://saref.etsi.org/core/isMeasuredIn": "Volt"
},
{
    "name": "public_building_1?channel_a_current?A",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/CurrentFlow/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "public_building_1",
    "https://saref.etsi.org/core/isMeasurementOf": "public building",
    "https://saref.etsi.org/core/relatesToProperty": "Current channel a",
    "https://saref.etsi.org/core/isMeasuredIn": "Ampere"
},
{
    "name": "public_building_1?channel_a_power?W",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/ActivePower/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "public_building_1",
    "https://saref.etsi.org/core/isMeasurementOf": "public building",
    "https://saref.etsi.org/core/relatesToProperty": "Power channel a",
    "https://saref.etsi.org/core/isMeasuredIn": "Watt"
},
{
    "name": "public_building_1?channel_a_power_factor?%",
    "datatype": "decimal",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "public_building_1",
    "https://saref.etsi.org/core/isMeasurementOf": "public building",
    "https://saref.etsi.org/core/relatesToProperty": "Power factor channel a",
    "https://saref.etsi.org/core/isMeasuredIn": "Percent"
},
{
    "name": "public_building_1?channel_a_voltage?V",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/Voltage/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "public_building_1",
    "https://saref.etsi.org/core/isMeasurementOf": "public building",
    "https://saref.etsi.org/core/relatesToProperty": "Voltage channel a",
    "https://saref.etsi.org/core/isMeasuredIn": "Volt"
},
{
    "name": "public_building_1?channel_b_current?A",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/CurrentFlow/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "public_building_1",
    "https://saref.etsi.org/core/isMeasurementOf": "public building",
    "https://saref.etsi.org/core/relatesToProperty": "Current channel b",
    "https://saref.etsi.org/core/isMeasuredIn": "Ampere"
},
{
    "name": "public_building_1?channel_b_power?W",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/ActivePower/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "public_building_1",
    "https://saref.etsi.org/core/isMeasurementOf": "public building",
    "https://saref.etsi.org/core/relatesToProperty": "Power channel b",
```


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```
    "https://saref.etsi.org/core/isMeasuredIn": "Watt"
},
{
    "name": "public_building_1?channel_b_power_factor?%",
    "datatype": "decimal",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "public_building_1",
    "https://saref.etsi.org/core/isMeasurementOf": "public building",
    "https://saref.etsi.org/core/relatesToProperty": "Power factor channel b",
    "https://saref.etsi.org/core/isMeasuredIn": "Percent"
},
{
    "name": "public_building_1?channel_b_voltage?V",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/Voltage/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "public_building_1",
    "https://saref.etsi.org/core/isMeasurementOf": "public building",
    "https://saref.etsi.org/core/relatesToProperty": "Voltage channel b",
    "https://saref.etsi.org/core/isMeasuredIn": "Volt"
},
{
    "name": "public_building_1?channel_c_current?A",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/CurrentFlow/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "public_building_1",
    "https://saref.etsi.org/core/isMeasurementOf": "public building",
    "https://saref.etsi.org/core/relatesToProperty": "Current channel c",
    "https://saref.etsi.org/core/isMeasuredIn": "Ampere"
},
{
    "name": "public_building_1?channel_c_power?W",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/ActivePower/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "public_building_1",
    "https://saref.etsi.org/core/isMeasurementOf": "public building",
    "https://saref.etsi.org/core/relatesToProperty": "Power channel c",
    "https://saref.etsi.org/core/isMeasuredIn": "Watt"
},
{
    "name": "public_building_1?channel_c_power_factor?%",
    "datatype": "decimal",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "public_building_1",
    "https://saref.etsi.org/core/isMeasurementOf": "public building",
    "https://saref.etsi.org/core/relatesToProperty": "Power factor channel c",
    "https://saref.etsi.org/core/isMeasuredIn": "Percent"
},
{
    "name": "public_building_1?channel_c_voltage?V",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/Voltage/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "public_building_1",
    "https://saref.etsi.org/core/isMeasurementOf": "public building",
    "https://saref.etsi.org/core/relatesToProperty": "Voltage channel c",
    "https://saref.etsi.org/core/isMeasuredIn": "Volt"
},
{
    "name": "public_building_1?total_current?A",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/CurrentFlow/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "public_building_1",
    "https://saref.etsi.org/core/isMeasurementOf": "public building",
    "https://saref.etsi.org/core/relatesToProperty": "total current",
    "https://saref.etsi.org/core/isMeasuredIn": "Ampere"
},
{
    "name": "public_building_1?total_power?W",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/ActivePower/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "public_building_1",
    "https://saref.etsi.org/core/isMeasurementOf": "public building",
    "https://saref.etsi.org/core/relatesToProperty": "total power",
    "https://saref.etsi.org/core/isMeasuredIn": "Watt"
},
{
    "name": "pump1?channel_a_current?A",
```


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```
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/CurrentFlow/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "pump1",
    "https://saref.etsi.org/core/isMeasurementOf": "pump",
    "https://saref.etsi.org/core/relatesToProperty": "Current channel a",
    "https://saref.etsi.org/core/isMeasuredIn": "Ampere"
},
{
    "name": "pump1?channel_a_power?W",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/ActivePower/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "pump1",
    "https://saref.etsi.org/core/isMeasurementOf": "pump",
    "https://saref.etsi.org/core/relatesToProperty": "Power channel a",
    "https://saref.etsi.org/core/isMeasuredIn": "Watt"
},
{
    "name": "pump1?channel_a_power_factor?%",
    "datatype": "decimal",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "pump1",
    "https://saref.etsi.org/core/isMeasurementOf": "pump",
    "https://saref.etsi.org/core/relatesToProperty": "Power factor channel a",
    "https://saref.etsi.org/core/isMeasuredIn": "Percent"
},
{
    "name": "pump1?channel_a_voltage?V",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/Voltage/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "pump1",
    "https://saref.etsi.org/core/isMeasurementOf": "pump",
    "https://saref.etsi.org/core/relatesToProperty": "Voltage channel a",
    "https://saref.etsi.org/core/isMeasuredIn": "Volt"
},
{
    "name": "pump1?channel_b_current?A",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/CurrentFlow/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "pump1",
    "https://saref.etsi.org/core/isMeasurementOf": "pump",
    "https://saref.etsi.org/core/relatesToProperty": "Current channel b",
    "https://saref.etsi.org/core/isMeasuredIn": "Ampere"
},
{
    "name": "pump1?channel_b_power?W",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/ActivePower/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "pump1",
    "https://saref.etsi.org/core/isMeasurementOf": "pump",
    "https://saref.etsi.org/core/relatesToProperty": "Power channel b",
    "https://saref.etsi.org/core/isMeasuredIn": "Watt"
},
{
    "name": "pump1?channel_b_power_factor?%",
    "datatype": "decimal",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "pump1",
    "https://saref.etsi.org/core/isMeasurementOf": "pump",
    "https://saref.etsi.org/core/relatesToProperty": "Power factor channel b",
    "https://saref.etsi.org/core/isMeasuredIn": "Percent"
},
{
    "name": "pump1?channel_b_voltage?V",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/Voltage/doc/spec.md",
    "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "pump1",
    "https://saref.etsi.org/core/isMeasurementOf": "pump",
    "https://saref.etsi.org/core/relatesToProperty": "Voltage channel b",
    "https://saref.etsi.org/core/isMeasuredIn": "Volt"
},
{
    "name": "pump1?channel_c_current?A",
    "datatype": "decimal",
    "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/CurrentFlow/doc/spec.md",
    "https://saref.etsi.org/core/relatesToProperty": "Current channel c",
    "https://saref.etsi.org/core/isMeasurementOf": "pump",
```


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```
            "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "pump1",
            "https://saref.etsi.org/core/isMeasuredIn": "Ampere"
        },
        {
            "name": "pump1?channel_c_power?W",
            "datatype": "decimal",
            "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/ActivePower/doc/spec.md",
            "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "pump1",
            "https://saref.etsi.org/core/isMeasurementOf": "pump",
            "https://saref.etsi.org/core/relatesToProperty": "Power channel c",
            "https://saref.etsi.org/core/isMeasuredIn": "Watt"
        },
        {
            "name": "pump1?channel_c_power_factor?%",
            "datatype": "decimal",
            "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "pump1",
            "https://saref.etsi.org/core/isMeasurementOf": "pump",
            "https://saref.etsi.org/core/relatesToProperty": "Power factor channel c",
            "https://saref.etsi.org/core/isMeasuredIn": "Percent"
        },
        {
            "name": "pump1?channel_c_voltage?V",
            "datatype": "decimal",
            "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/Voltage/doc/spec.md",
            "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "pump1",
            "https://saref.etsi.org/core/isMeasurementOf": "pump",
            "https://saref.etsi.org/core/relatesToProperty": "Voltage channel c",
            "https://saref.etsi.org/core/isMeasuredIn": "Volt"
        },
        {
            "name": "pump1?total_current?A",
            "datatype": "decimal",
            "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/CurrentFlow/doc/spec.md",
            "https://saref.etsi.org/core/relatesToProperty": "total current",
            "https://saref.etsi.org/core/isMeasurementOf": "pump",
            "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "pump1",
            "https://saref.etsi.org/core/isMeasuredIn": "Ampere"
        },
        {
            "name": "pump1?total_power?W",
            "datatype": "decimal",
            "propertyUrl": "https://github.com/smart-data-models/dataModel.EnergyCIM/blob/master/ActivePower/doc/spec.md",
            "http://ontology.tno.nl/interconnect/topology#hasTopologicalLocationDescription": "pump1",
            "https://saref.etsi.org/core/isMeasurementOf": "pump",
            "https://saref.etsi.org/core/relatesToProperty": "total power",
            "https://saref.etsi.org/core/isMeasuredIn": "Watt"
        }
    ]
  }
}
```


4.4.2.4 Self-description

Below is the self-description for the resource published to the Federated Catalogue for LSP8.

```
@prefix dcat: <http://www.w3.org/ns/dcat#> .
@prefix dcatap: <http://data.europa.eu/r5r/> .
@prefix dcterms: <http://purl.org/dc/terms/> .
@prefix fedcat: <http://ontology.tno.nl/federatedCatalogue/> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix ids: <https://w3id.org/idsa/core/> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

<urn:WaterPumpStation_Tilos.localhost.demo:resources:893a1667-e548-4060-84f3-595bfae3ba14> a
fedcat:Resource,
        ids:DataResource ;
```

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```
    dcterms:temporal <http://WaterPumpStation_Tilos.localhost.demo/resources/893a1667-e548-4060-84f3-595bfae3ba14/temporal> ;

    dcat:contactPoint "NTUA" ;

    dcat:description "A short sample of energy consumption for a water pump in Tilos" ;

    dcat:keyword "Power consumption"@en,

        "Water pump station"@en ;

    dcat:publisher <urn:ids:pyconnector:Owner> ; # The publisher of the resource (which may differ from the sovereign)

    dcat:title "WaterPumpStation_Tilos" ;

    dcat:distribution <https://w3id.org/dcat/autogen/distribution/59674ff3-9fe8-4b01-a4ab-3fcaa7d435d5> ;

    dcterms:spatial <https://www.geonames.org/8133941/>;

    ids:created "2021-10-08T16:37:55.012Z"^^xsd:dateTimeStamp ;

    ids:description "Test2"@en ;

    ids:representation <https://w3id.org/idsa/autogen/dataRepresentation/41db2440-b1e7-11ed-857c-00155d07c4d6> ;

    ids:sovereign <urn:publisher:ntua> ; # The 'owner', i.e. sovereign of the data.  # Unfortunately not dangling URIRef to Participant owning the Connector

    ids:title "Test2"@en .


<https://www.geonames.org/8133941/> a dcterms:Location .


<http://WaterPumpStation_Tilos.localhost.demo/resources/893a1667-e548-4060-84f3-595bfae3ba14/temporal> a dcterms:PeriodOfTime ;

    dcat:endDate "2019-12-31T23:00:00+02:00"^^xsd:dateTimeStamp ;

    dcat:startDate "2019-12-31T00:00:00+02:00"^^xsd:dateTimeStamp .


<https://w3id.org/idsa/autogen/artifact/aabea050-b29a-11ed-9491-00155d1542f0> a ids:Artifact ;

    ids:byteSize 372199 ;

    ids:fileName "20230220_BD4NRG_LSP8_DATA_FP.csv" .


<https://w3id.org/dcat/autogen/distribution/59674ff3-9fe8-4b01-a4ab-3fcaa7d435d5> a dcat:Distribution ;

    dcat:accessURL "https://ntua.org/example/LSP8/780f6bf1-fcb1-4daf-9175-ad08ecd7cedd/20230220_BD4NRG_LSP8_DATA_FP.csv" .


<https://w3id.org/idsa/autogen/dataRepresentation/41db2440-b1e7-11ed-857c-00155d07c4d6> a ids:DataRepresentation ;

    dcatap:availability "Experimental" ; # Unclear/non-finalized type

    dcterms:description "Excel sheet of energy consumption for a water pump in Tilos" ;

    dcterms:license <https://tilos.waterpumpstations.example.com/terms-of-use/> ;

    ids:dataType <http://ontology.tno.nl/interconnect/datapoint#TimeSeries> ;

    ids:dataTypeSchema <http://bd4nrg.semantic-treehouse.nl/LSP8/20230220_BD4NRG_LSP8_DATA_DESCRIPTION_FP.csv> ;

    ids:instance <https://w3id.org/idsa/autogen/artifact/aabea050-b29a-11ed-9491-00155d1542f0> ;

    ids:mediaType <https://w3id.org/idsa/autogen/iANAMediaType/41db2710-b1e7-11ed-857c-00155d07c4d6> ;

    ids:representationStandard <> ;

    ids:shapesGraph <> .
```

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```
<https://w3id.org/idsa/autogen/iANAMediaType/41db2710-b1e7-11ed-857c-00155d07c4d6> a ids:IANAMediaType
;
    ids:filenameExtension "csv" .


<urn:publisher:ntua> a fedcat:Participant, # Federated Catalogue participant, also a normal
organization, could be something different as well.
        foaf:Organization ;
    foaf:name "National Technical University of Athens"@en .
```

Key aspects to be noted in the above self-description are:

- The publisher of the dataset – represented by the instance fedcat:Participant <urn:publisher:ntua>
- The type of the resource – represented by the instance fedcat:Resource <urn:WaterPumpStation_Tilos.localhost.demo:resources:893a1667-e548-4060-84f3-595bfae3ba14>
- The datatype schema of the resource, explained in section 4.4.2.3 – represented by the property ids:dataTypeSchema “http://bd4nrg.semantic-treehouse.nl/LSP8/20230220_BD4NRG_LSP8_DATA_DESCRIPTION_FP.csv”
- The access URL to the resource, represented by the property dcat:accessURL “https://ntua.org/example/LSP8/780f6bf1-fcb1-4daf-9175-ad08ecd7cedd/20230220_BD4NRG_LSP8_DATA_FP.csv”

4.4.3 LSP12

The LSP 12 data model in the Vocabulary Hub was published on April 24th 2023 (

Figure 20, Figure 21). The data model description contains a direct link to the data set on the Mendeley Data platform.

TNO was the main author of the model with contributions from LEIF as LSP 12 partner NTUA as LSPs coordinator.

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4.4.3.1 Data model

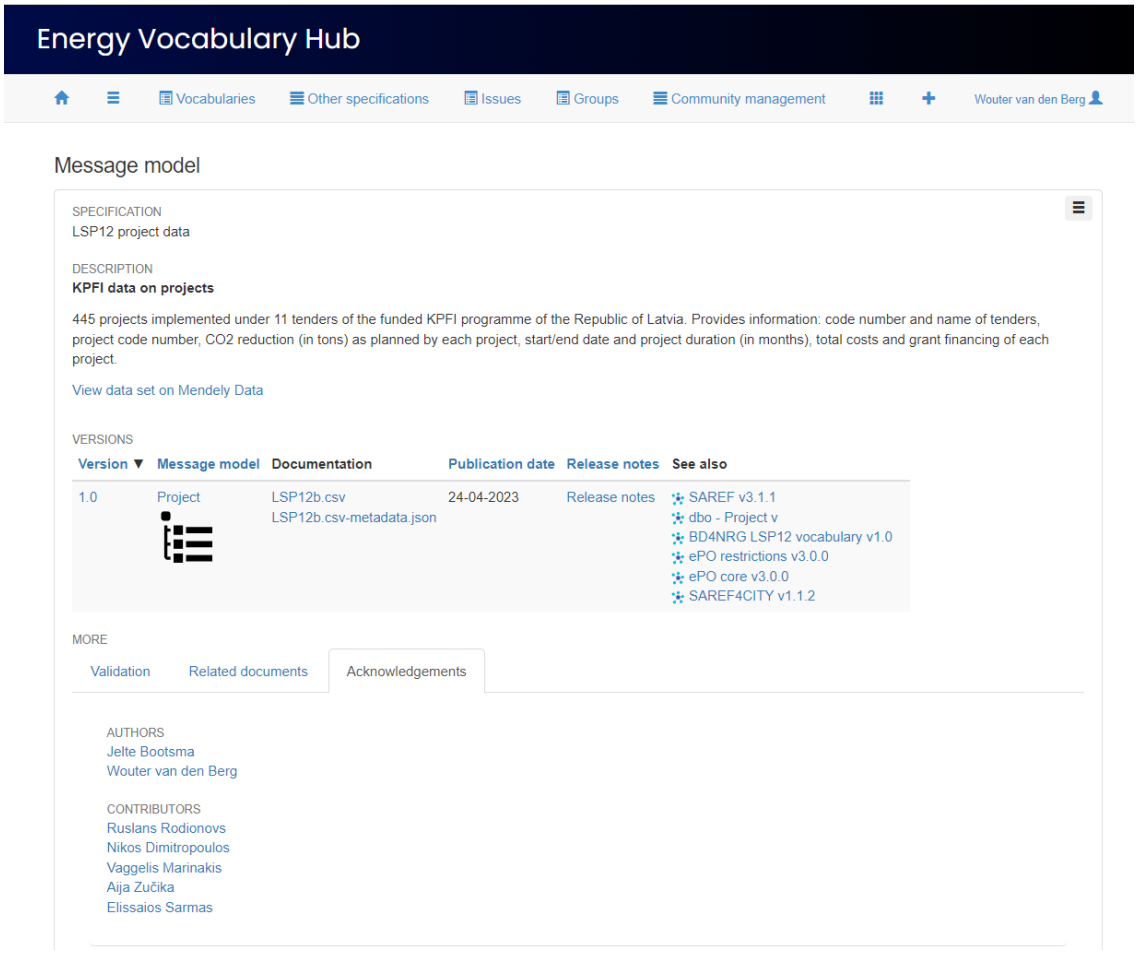

Figure 20: data model for LSP 12 including metadata and version management

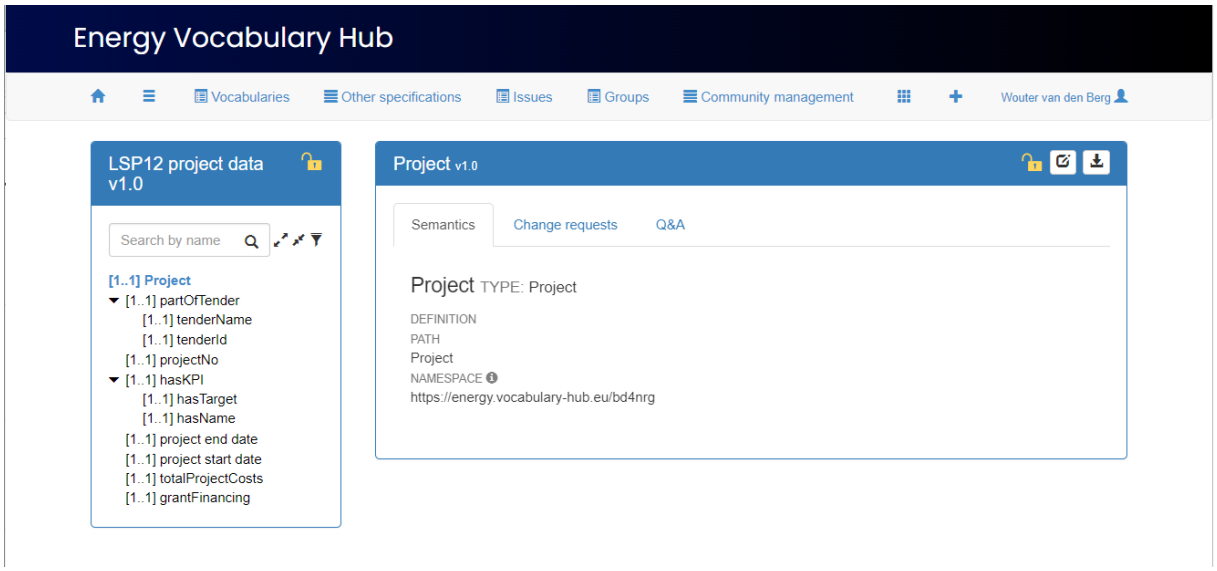

Figure 21: interactive view of the LSP 12 data model

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4.4.3.2 Used vocabularies

The used vocabularies to construct the data model for LSP 12 were:

- SAREF v3.1.1
- SAREF4CITY v1.1.2
- dbo - Project
- ePO restrictions v3.0.0
- ePO core v3.0.0
- BD4NRG LSP12 vocabulary v1.0

The last vocabulary on the above list is an alignment ontology module that was made specifically for LSP 12. It implemented 'indirect' vocabulary reuse through usage of the *rdfs:subClassOf* axiom. Below is the Turtle serialization of the whole model:

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```
@prefix dbo: <http://dbpedia.org/ontology/> .
@prefix epo: <http://data.europa.eu/a4g/ontology#> .
@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix xml: <http://www.w3.org/XML/1998/namespace> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix saref: <https://saref.etsi.org/core/> .
@prefix bd4nrg: <https://energy.vocabulary-hub.eu/bd4nrg#> .
@prefix s4city: <https://saref.etsi.org/saref4city/> .

#################################################################
#    Object Properties
#################################################################

###  https://energy.vocabulary-hub.eu/bd4nrg#hasKPI
bd4nrg:hasKPI rdf:type owl:ObjectProperty ;
              rdfs:subPropertyOf s4city:hasKPI ;
              rdfs:domain bd4nrg:Project ;
              rdfs:range bd4nrg:KPI ;
              rdfs:label "hasKPI"@en .

###  https://energy.vocabulary-hub.eu/bd4nrg#partOfTender
bd4nrg:partOfTender rdf:type owl:ObjectProperty ;
                    rdfs:domain bd4nrg:Project ;
                    rdfs:range bd4nrg:Tender ;
                    rdfs:label "partOfTender"@en .

###  https://saref.etsi.org/saref4city/hasKPI
s4city:hasKPI rdf:type owl:ObjectProperty ;
              rdfs:label "hasKPI"@en .

#################################################################
#    Data properties
#################################################################

###  https://energy.vocabulary-hub.eu/bd4nrg#TenderId
bd4nrg:TenderId rdf:type owl:DatatypeProperty .

###  https://energy.vocabulary-hub.eu/bd4nrg#grantFinancing
bd4nrg:grantFinancing rdf:type owl:DatatypeProperty ;
                      rdfs:label "grantFinancing"@en .

###  https://energy.vocabulary-hub.eu/bd4nrg#hasTarget
bd4nrg:hasTarget rdf:type owl:DatatypeProperty ;
                 rdfs:label "hasTarget"@en .

###  https://energy.vocabulary-hub.eu/bd4nrg#hasTitle
bd4nrg:hasTitle rdf:type owl:DatatypeProperty ;
                rdfs:domain bd4nrg:Project ;
                rdfs:range xsd:normalizedString .

###  https://energy.vocabulary-hub.eu/bd4nrg#tenderName
bd4nrg:tenderName rdf:type owl:DatatypeProperty ;
                  rdfs:label "tenderName"@en .

###  https://energy.vocabulary-hub.eu/bd4nrg#totalProjectCosts
bd4nrg:totalProjectCosts rdf:type owl:DatatypeProperty ;
                         rdfs:label "totalProjectCosts"@en .

#################################################################
#    Classes
#################################################################

###  http://data.europa.eu/a4g/ontology#Procedure
epo:Procedure rdf:type owl:Class ;
              rdfs:label "Procedure"@en .

###  http://data.europa.eu/a4g/ontology#Tender
epo:Tender rdf:type owl:Class ;
           rdfs:label "Tender"@en .

###  http://dbpedia.org/ontology/Project
dbo:Project rdf:type owl:Class ;
```

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```
        rdfs:label "Project"@en .

###  https://energy.vocabulary-hub.eu/bd4nrg#KPI
bd4nrg:KPI rdf:type owl:Class ;
        rdfs:subClassOf s4city:KeyPerformanceIndicator ,
                        [ rdf:type owl:Restriction ;
                          owl:onProperty bd4nrg:hasTarget ;
                          owl:someValuesFrom xsd:decimal
                        ] ;
        rdfs:label "KPI"@en .

###  https://energy.vocabulary-hub.eu/bd4nrg#Project
bd4nrg:Project rdf:type owl:Class ;
            rdfs:subClassOf epo:Tender ,
                            dbo:Project ,
                            [ rdf:type owl:Restriction ;
                              owl:onProperty bd4nrg:grantFinancing ;
                              owl:someValuesFrom xsd:decimal
                            ] ,
                            [ rdf:type owl:Restriction ;
                              owl:onProperty bd4nrg:totalProjectCosts ;
                              owl:someValuesFrom xsd:decimal
                            ] ;
            rdfs:label "Project"@en .

###  https://energy.vocabulary-hub.eu/bd4nrg#Tender
bd4nrg:Tender rdf:type owl:Class ;
            rdfs:subClassOf epo:Procedure ,
                            [ rdf:type owl:Restriction ;
                              owl:onProperty bd4nrg:TenderId ;
                              owl:someValuesFrom xsd:normalizedString
                            ] ,
                            [ rdf:type owl:Restriction ;
                              owl:onProperty bd4nrg:tenderName ;
                              owl:someValuesFrom xsd:normalizedString
                            ] ;
            rdfs:label "Tender"@en .

###  https://saref.etsi.org/saref4city/KeyPerformanceIndicator
s4city:KeyPerformanceIndicator rdf:type owl:Class ;
                            rdfs:label "KeyPerformanceIndicator"@en .
```

4.4.3.3 Schema

The following is a schema for the CSV serialization of the LSP 12 dataset of project data, written using the CSVW language. The format of this schema document is JSON. Note the references to existing vocabulary terms in the *propertyUrl* field.

```
{
  "@context": [
    "http://www.w3.org/ns/csvw"
  ],
  "url": "LSP12b.csv",
  "dialect": {
    "delimiter": ";",
    "encoding": "UTF-8-SIG",
    "quoteChar": "\""
  },
  "tableSchema": {
    "columns": [
      {
        "name": "Tender",
        "dc:description": "Tender code number",
        "datatype": "string",
        "propertyUrl": "https://energy.vocabulary-hub.eu/bd4nrg#TenderId"
      },
      {
        "name": "Name of Tender",
```

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```
        "datatype": "string",
        "propertyUrl": "https://energy.vocabulary-hub.eu/bd4nrg#tenderName"
      },
      {
        "name": "Project No.",
        "datatype": "string",
        "propertyUrl": "http://data.europa.eu/a4g/ontology#hasID"
      },
      {
        "name": "Project planned CO2 reduction (in tons)",
        "dc:description": "CO2 reduction (in tons) as planned by each project",
        "datatype": {
          "base": "decimal",
          "format": {
            "decimalChar": ","
          }
        },
        "propertyUrl": "https://energy.vocabulary-hub.eu/bd4nrg#hasTarget"
      },
      {
        "name": "Start date of the project",
        "datatype": "date",
        "propertyUrl": "http://dbpedia.org/ontology/projectStartDate"
      },
      {
        "name": "End date of the project",
        "datatype": "date",
        "propertyUrl": "http://dbpedia.org/ontology/projectEndDate"
      },
      {
        "name": "Project duration in months",
        "dc:description": "Project duration in months",
        "datatype": "string"
      },
      {
        "name": "Total project costs",
        "datatype": "string",
        "propertyUrl": "https://energy.vocabulary-hub.eu/bd4nrg#totalProjectCosts"
      },
      {
        "name": "Grant financing",
        "datatype": "string"
      },
      {
        "name": "% of Grant",
        "dc:description": "% of total project costs that is covered by Grant",
        "datatype": "string",
        "propertyUrl": "https://energy.vocabulary-hub.eu/bd4nrg#grantFinancing"
      }
    ]
  }
}
```


4.4.3.4 Self-description

Below is the self-description for the resource published to the Federated Catalogue for LSP12.


```
@prefix dcat: <http://www.w3.org/ns/dcat#> .
@prefix dcatap: <http://data.europa.eu/r5r/> .
@prefix dcterms: <http://purl.org/dc/terms/> .
@prefix fedcat: <http://ontology.tno.nl/federatedCatalogue/> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix ids: <https://w3id.org/idsa/core/> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

<urn:energy-efficiency.localhost.demo:resources:38be013d-7449-47de-bbd7-15136a633430>                a
fedcat:Resource,
```


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```
        ids:DataResource ;
    dcat:contactPoint "TNO" ;
    dcat:description "Historical data from KPFI regarding multiple energy efficiency projects" ;
    dcat:keyword "Historical data"@en,
        "Energy efficience projects"@en ;
    dcat:publisher <urn:ids:pyconnector:Owner> ; # The publisher of the resource (which may differ from
the sovereign)
    dcat:title "energy-efficiency" ;
    dcat:distribution <https://w3id.org/dcat/autogen/distribution/2054bf9a-d4bb-4bcd-9c3f-d05c22374069>
;
    ids:representation       <https://w3id.org/idsa/autogen/dataRepresentation/79a16eb1-4331-4f7b-936a-
0abd3248f08a> ;
    ids:sovereign <urn:publisher:ntua> ; # The 'owner', i.e. sovereign of the data.  # Unfortunately not
dangling URIRef to Participant owning the Connector

<https://w3id.org/idsa/autogen/artifact/c311c09a-c8f3-49b6-9bfc-24f6cd2dd24a> a ids:Artifact ;
    ids:byteSize 372199 ;
    ids:fileName "20230220_BD4NRG_LSP12_DATA_FP.csv" .

<https://w3id.org/dcat/autogen/distribution/2054bf9a-d4bb-4bcd-9c3f-d05c22374069> a dcat:Distribution ;
    dcat:accessURL                          "https://ntua.org/example/LSP12/87495451-edae-4bcd-a52d-
a1bdb54e633b/20230220_BD4NRG_LSP12_DATA_FP.csv" .

<https://w3id.org/idsa/autogen/dataRepresentation/79a16eb1-4331-4f7b-936a-0abd3248f08a>              a
ids:DataRepresentation ;
    dcatap:availability "Experimental" ; # Unclear/non-finalized type
    dcterms:description "Historical data from KPFI regarding multiple energy efficiency projects" ;
    dcterms:license <https://tilos.waterpumpstations.example.com/terms-of-use/> ;
    ids:dataType <http://ontology.tno.nl/interconnect/datapoint#TimeSeries> ;
    ids:dataTypeSchema                                                    <http://bd4nrg.semantic-
treehouse.nl/LSP12/20230220_BD4NRG_LSP12_DATA_DESCRIPTION_FP.csv> ;
    ids:instance <https://w3id.org/idsa/autogen/artifact/c311c09a-c8f3-49b6-9bfc-24f6cd2dd24a> ;
    ids:mediaType <https://w3id.org/idsa/autogen/iANAMediaType/a21e29fc-cd17-4400-863d-7484e0ad2c81> ;

<https://w3id.org/idsa/autogen/iANAMediaType/a21e29fc-cd17-4400-863d-7484e0ad2c81>  a  ids:IANAMediaType
;
    ids:filenameExtension "csv" .

# Federated Catalogue participant, also a normal organization, could be something different as well.
<urn:publisher:ntua> a fedcat:Participant,
        foaf:Organization ;
    foaf:name "National Technical University of Athens"@en .
```

Key aspects to be noted in the above self-description are:

- The publisher of the dataset – represented by the instance fedcat:Participant <urn:publisher:ntua>

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- The type of the resource – represented by the instance fedcat:Resource <urn:energy-efficiency.localhost.demo:resources:38be013d-7449-47de-bbd7-15136a633430>
- The datatype schema of the resource, explained in section 4.4.3.3 – represented by the property ids:dataTypeSchema <http://bd4nrg.semantic-treehouse.nl/LSP12/20230220_BD4NRG_LSP12_DATA_DESCRIPTION_FP.csv>
- The access URL to the resource, represented by the property dcat:accessURL "https://ntua.org/example/LSP12/87495451-edae-4bcd-a52d-a1bdb54e633b/20230220_BD4NRG_LSP12_DATA_FP.csv"

4.5 Lessons learned

At the start of the BD4NRG project it was assumed that the Vocabulary Hub would provide an easy means for the BD4NRG pilot partners to enrich their data with metadata by providing them the combination of a set of existing vocabularies and the Configurator functionality and that it would provide the sufficient tools to enable the pilot partners to create their metadata themselves. During the project, however, it was observed that there was unclarity among the pilot partners about the required content of the metadata, its purpose and why (in some cases) existing natural language descriptions in of their data were not enough.

The above experiences led to the conclusion that a clearer and simpler approach was required to engage data providers. The approach needed to emphasize the importance of vocabulary use by using specific examples that were preferably based on the data provider's own dataset.

The 5-star model of vocabulary usage [5] was used and served to simplify the challenge of reusing existing vocabularies by introducing a series of steps (or levels). Each star was earned with increasingly sophisticated use of vocabularies to describe the semantics of the data, starting with simply providing human-readable documentation (★☆☆☆☆). For the second star, data providers needed to provide some kind of machine-readable vocabulary. However, it did not involve the reuse of existing vocabularies and could be completely custom or unique to the specific context (★★☆☆☆). The third star involved reuse of vocabularies, demonstrated here using the Configurator wizard for LSPs 1, 8 and 12 (★★★☆☆). The Vocabulary Hub also provided the tools to manage vocabulary metadata, as shown in subsections 4.4.1.1, 4.4.2.1 and 4.4.3.1 (★★★★☆). The fifth star involves reuse of the created vocabularies by others. This is theoretically supported by the Vocabulary Hub, as data providers can reuse vocabularies that were created before and reuse them for their own data models (★★★★★). Note that the 5-star model is focused on vocabulary usage only and leaves out some other considerations such vocabulary quality requirements.

Several meetings with the selected pilot partners of LSPs 1, 8 and 12 were organized where the 5-star model was presented without mentioning the Vocabulary Hub or its technical functionalities. These meetings resulted in clear understanding of the goal and justification of vocabulary (re)use and the added value of using vocabularies to describe LSP data. Only then were metadata descriptions created in an interactive process using the Vocabulary Hub, together with the pilot partners.

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In sum, the 5-star model served as a successful framework to organize the use of vocabularies in a community such as the BD4NRG consortium. Applying these steps to the LSP data in an interactive process resulted in a higher engagement of the BD4NRG LSPs. The 5-star model proved to be an excellent tool for communication about concerns of semantic interoperability and how to achieve it. Together with the functionality of the Vocabulary Hub, this enabled the results described in the current document and so helped achieve alignment of the BD4NRG LSPs and task T4.2.

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5 Deployment and repositories

5.1 Federated Catalogue

The Federated Catalogue API and Vocabulary have been developed as part of the PyConnector, an implementation of the IDS Connector by TNO being implemented as a joint effort across multiple Horizon 2020 projects.

A preliminary version of the IDS Metadata Broker integrating both features of the Federated Catalogue is deployed and accessible at the following base URL:

https://catalog.python.dataspac.es/api/broker/

The components being released relevant to the Federated Catalogue are:

- A Postman collection with examples of interactions with the deployed Federated Catalogue
- The ontology extension for the Federated Catalogue with custom IDS extensions.
- An OpenAPI specification file for the Federated Catalogue interface

While the functionality has been successfully implemented, the supporting source code is not being released at this time due to the immature state of the component, and the state of active development. The link to the components is available at:

https://gitlab.com/bd4nrg-technology-release/federated-catalogue/release

5.2 Vocabulary Hub

Since February 2022, TNO has provided a deployment of the BD4NRG Vocabulary Hub at https://bd4nrg.semantic-treehouse.nl. This has since been replaced by a new deployment that includes other energy related EU-projects as well. This Energy Vocabulary Hub can be found at:

https://energy.vocabulary-hub.eu

By doing so we can combine the shared need for such a vocabulary hub functionality for both BD4NRG and other European energy data space projects, e.g. ENERSHARE, into a single deployment. That means that these projects can benefit from published vocabularies using shared models for pilots and use-cases. This also extends the service beyond the project lead time as the BD4NRG project is nearing its end while other projects are still beginning. We expect that other projects will join in years to come, enabling even more synergies on semantic interoperability across projects.

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The open sourced code base and documentation of the Vocabulary Hub can be found in the BD4NRG Final Technology Release repository at:

https://gitlab.com/bd4nrg-technology-release/vocabulary-hub

Work on the Vocabulary Hub is ongoing and expected to continue in the following years. There are numerous parties that have shown interest in using the Vocabulary Hub in its current state for their own purposes. This includes other Horizon Europe project consortia, as well as private companies. By making the source code available, others can join the effort to bring this component forward. The BD4NRG project will then have served as a springboard for the development of tools that support semantic interoperability in next generation data sharing ecosystems.

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