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WP4 – Digitalization of operational processes, smart sensors configuration and DSS implementation

T 4.1 – DSS semantic model

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ABSTRACT

The current document reports the development of a semantic model, which will serve as a common reference model in the frame of the DSS engine, taking into account the need for representation of information related to production management. Due to this end, the design of the model depends upon the technical and business requirements provided in WP1, and especially the concepts and entities that derive from the *D1.2: Business models circularity assessment, in the context of the circular economy principles*. Based upon this approach, both the core concepts and the interrelations among them are specified with the aim of creating a coherent semantic model, which will be fed by heterogeneous data sources stemming from pilot plants. Hence, an ontology-driven approach is followed by acting as a communication channel for the various concepts identified from the domains of the circular economy and resource management. The ontology that is the main output of the described approach is also documented in the present document.

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Abbreviations and Acronyms:	
BOL	Beginning of Life
CBM	Circular Business Model
CE	Circular Economy
CPA	Circularity Product Assessment
CPI	Circularity Performance Index
DSS	Decision Support System
EOL	End of Life
MOL	Middle of Life
RDF	Resource Description Framework

OWL	Ontology Web Language

INTRODUCTION

Deliverable 4.1: DSS Semantic Model documents the implementation of the semantic model, which will be used in the context of DSS engine implementation in order to ensure the conceptual encapsulation of the various potential actors involved in circular economy based on the selected methodology presented at *D1.2*, as well as of the available resource management concepts of each pilot plant. To this end, the identification of such entities will be established so that the main conceptual aspects will be formulated and subsequently defined with the aim of composing a coherent ontological schema that will represent the DSS semantic model. Firstly, a state-of-the-art analysis presenting relevant approaches in the frame of semantic models and linked data will be performed. Subsequently, the main concepts will be defined by taking into account both the proposed methodology of *D1.2* and the conceptual models that proposed at the literature. Moreover, a unifying conceptual model, which will allow diverse data sources and specifications to be annotated, interlinked and aligned will be presented and it will constitute the resulting ontology. With the aim of covering the aforementioned topics, the present report is structured as follows. Section 1 aims to provide a comprehensive overview of the available data models and approaches with respect to circular economy, as well as approaches on how data from various sources can be linked among each other under a unified ontological specification, while Section 2 presents the identified concepts of the proposed methodology of *D1.2*. and Section 3 demonstrates the resulting ontology in which the interconnections among the main entities will be defined.

1. STATE OF THE ART ON SEMANTIC DATA MODELS AND ONTOLOGIES AROUND CIRCULAR ECONOMY

The current section aims to provide a state-of-the-art analysis by presenting semantic models and approaches that are related to circular economy. Moreover, how the various actors of circular economy, as well as other conceptual entities in the context of CPA methodology can be linked among each other is also presented by means of existing approaches and tools. This interconnection will be the cornerstone of a coherent semantic data model, which will effectively support the implementation of the DSS engine in the frame of the pilot plants. To this end, the analysis will be focused on context modelling for industry domain and how the circular economy can be linked to this domain, while other domains that affect circular economy like location, products, resources and IoT will also be examined.

Currently, there are several approaches and research efforts on context modelling of circular economy in industry domain and in the current section some of them will be presented. Subsequently, a summarize of key aspects that will be taken into account in the context of FENIX will be specified, and they will conform a significant input for the semantic data model implementation.

1.1. Semantic data model

The semantic data model[1] is a method of structuring data for logical representation with the aim of describing a data set in terms of the kinds of entities that exist in specific application environment, the classifications and groupings of those entities, and the structural interconnections among them. In order to create the relationships between all parts of an application environment, a semantic data model should be created, which is a conceptual diagram of the data as it relates to the real world for this specific environment. Therefore, the need to define data from a conceptual view[2] has led to the development of semantic data modelling techniques, such as the development of ontologies[3] and linked data[4].

1.2. Ontology Specification and Methodology

Ontology specification aims to facilitate the conceptualization phase of a specific data set by allowing the development of a common terminological environment and at the same time by providing a flexible and easily extensible way of data modelling. More specifically, an ontology specification can formalize the description of knowledge as a set of concepts within a domain and the relationships that exist among them. To enable such a description, the specification of the main parts of the domain in terms of instances of objects, classes, attributes and relations as well as restrictions, rules and axioms must be defined. To this end, there are several methodologies for developing an ontology, which provide a set of guidelines about how to carry out the activities identified in the ontology development process and what kind of techniques are most appropriate in each activity. Some of these methodologies can be summarized as follows:

- **ONIONS**: Gangemi et al[5] introduce ONIONS methodology for integrating ontologically-heterogeneous taxonomic knowledge and its current application to medical domain.
- **On-To-Knowledge**: Sure et al[6] present the On-To-Knowledge Methodology (OTKM) for introducing and maintaining ontology based knowledge management applications into enterprises with a focus on Knowledge Processes and Knowledge Meta Processes
- **TOVE**: Gruninger et al[7] introduce the goal of TOVE to deduce answers to queries that require relative shallow knowledge of the domain. The approach is based on engineering ontologies using the problems that arise from enterprises and subsequently proceed with the definition of the ontology's requirements in the form of questions that an ontology must be able to answer. Then the terminology definition takes place (e.g. objects, properties and relations). Finally, the constraints on the terminology are specified.
- **MENTHONTOLOGY**: Fernández-López et al[8] demonstrate a methodology for creating ontologies and starts by identifying the following activities involved in the development of an ontology:
  - **Purpose and Scope Specifications**: Identification of the purpose of the ontology, including the intended users, usage scenarios, the required level of phrasing, etc., and the scope of the ontology, including all ontologies, terms that they must represent, their characteristics and the required detail. The result of this phase is a document of native language ontology specifications.
  - **Knowledge Acquisition**: This phase begins by gathering all available knowledge resources describing the domain of the ontology. These resources can be a collection of terms, a hierarchical structure, dataset repositories, tools and algorithms and technical documentations.
  - **Conceptualization**: domain terms are defined as concepts, instances, relationships or properties, and each is represented using a workable informal representation.
  - **Integration**: To achieve some uniformity in ontologies, definitions from other ontologies should be integrated.
  - **Implementation**: the ontology is officially represented in a language.
  - **Evaluation**: great emphasis is given at this stage on how to look for imperfections, inconsistencies and redundancies.
  - **Documentation**: classification of documents resulting from the other activities.

The life cycle of an ontology is based on an improvement in one prototype. An ontology goes through the following statements (corresponding to some of the activities identified above): specification, conceptualization, standardization, integration, execution. Finally, ontology enters the maintenance state. Knowledge, acquisition, evaluation and documentation are processes that take place throughout the ontology lifecycle. Moreover, Saad et al[9] consider MENTHOTOLOGY as the most comprehensive one, as evidenced by its development phases compared to others. Taking these aspects under consideration which imply that MENTHOTOLOGY is a very comprehensive methodology, it will be mainly used for the development of the ontology in the context of FENIX.

1.3. Linked data & RDF

Current approaches of construction coherent data sets using ontological patterns are RDF repositories[10]. Integration of multiple data sources becomes easier using Linked Data[11] by developing mechanisms that facilitate the reusability of common vocabularies, and this is an approach that will be taken into account during the construction of the DSS semantic model in the frame of FENIX. These mechanisms allow the quick alignment of resources - which are snapshots of entities - after they are created. Also, several extractors have been developed that can be applied for extracting knowledge encoded in multiple formats and publishing as linked data. These tools range from solutions that require extensive configuration but provide more control over the final outcomes (intuitive data structure), to more automated solutions which do not need configuration, but don't enable the user to control the structure of the data representation. The general approach of the ontology-driven mapping of structured and unstructured data into RDF[12] format and the subsequent use of that data by a Semantic Web application via a SPARQL endpoint[13] is shown below (Figure 1).

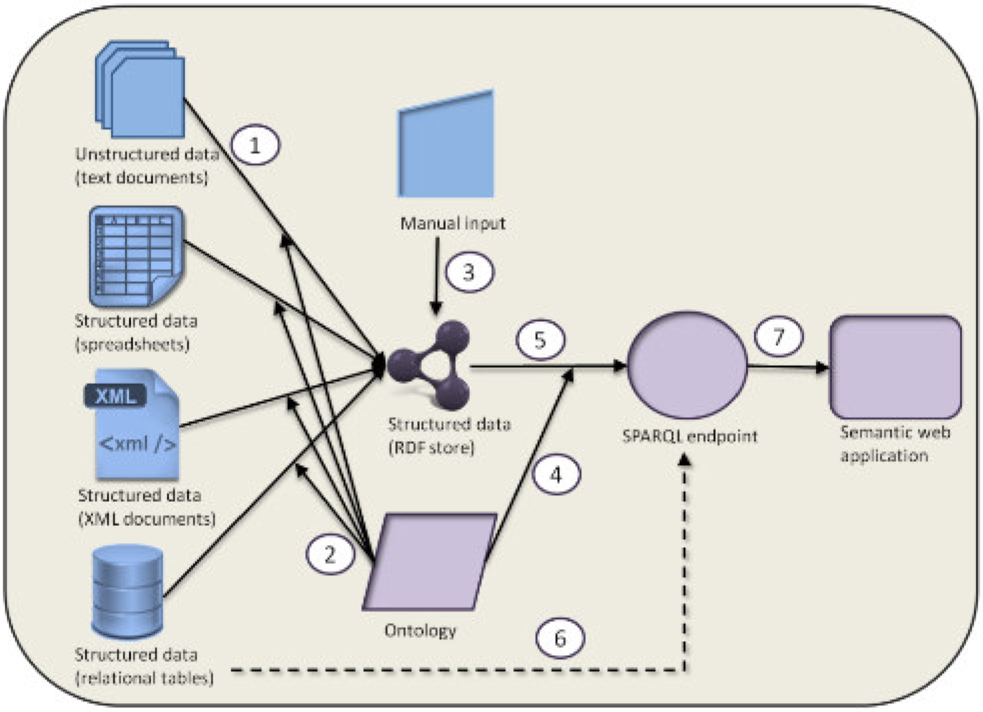

Figure 1:Publishing Data as Linked Data

The procedure presented in Figure 1 includes the following steps:

1. Access the selected data sources
2. Identify if the concepts can be described by existing ontologies and define the persistent URLs (PURLs). A mapping file is created (mostly automatically) which describes the

mappings from the structured data into an RDF view that can be used to transform data for SPARQL queries
3. The mapping file may be modified by the user
4. The concepts in the new RDF mapping are linked to concepts in other RDF data sources relying as much as possible on URIs from ontologies
5. The RDF data are published as Linked Data accessed through a SPARQL
6. If data are in a relational format (i.e. they belong in a relational database) RDBMS-to-RDF tools can be used to enable SPARQL queries over the relational schema
7. Semantic Web applications are created using the published data.

1.4. Semantic tools for RDF storage

Having described how RDF repositories can facilitate the reusability of common vocabularies, a couple of semantic tools that will store and distribute the data will be described in the current section. Karma[14] is such an integration tool that enables users to quickly and easily integrate data from a variety of data sources including databases, spreadsheets, delimited text files, XML, JSON, KML and Web APIs. Users integrate information by modelling it according to an ontology of their choice using a graphical user interface that automates much of the process. Karma learns to recognize the mapping of data to ontology classes and then uses the ontology to propose a model that ties together these classes. Users then interact with the system to adjust the automatically generated model. During this process, users can transform the data as needed to normalize data expressed in different formats and to restructure it. Once the model is complete, users can publish the integrated data as RDF or store it in a database.

Another tool that can offer significant integration results is Virtuoso Universal Server[15] (opensource edition), which is a middleware and database engine hybrid that combines the functionality of a traditional Relational database management system (RDBMS), Object-relational database (ORDBMS), virtual database, RDF, XML, free-text, web application server and file server functionality in a single system.

Some of its core features can be summarized as follows:

1) **Linked Data Publishing**: Virtuoso provides descriptor resources for every entity (data object) in the Native or Virtual Quad Stores
2) **RDF Data Management**: RDF Data Sets are managed by a dedicated module within the Virtuoso ORDBMS core. This functionality is exposed to client applications through implementations of the SPARQL Query Language and Protocol.
3) **RDF Middleware**: It contains a middleware component, which generates Linked Data (in the form of RDF) from a variety of data sources and supports a wide range of data representation and serialization formats.
4) **SPARQL Query Language**: Virtuoso supports a query service implementation which provides multiple output-formats.

1.5. Existing approaches of semantic models around circular economy

Currently, several approaches and methods have been demonstrated in the context of the semantic representation of circular economy in industry domain. These research efforts are mainly focus on several aspects around the implementation of circular economy in industry world. More specifically, Sauter et al[16] investigate the potential of Linked Spatial Data to facilitate collaboration in a Circular Economy by proposing an ontology that can integrate Circular Economy actors based on location and their material inputs and outputs. Various ontologies from different domains are introduced such as GoodRelations ontology[17] for extending the proposed ontology with extra entities such as the BusinessEntity (equivalent to actor) and ProductOrService (equivalent to product) classes and GeoSPARQL ontology[18] for annotating of resources in terms of spatial information. Martín et al[19] develop an ontological framework for information and knowledge models to share the circularity of resources through industrial ecosystems, based on ecological, economic, and social criteria. The ontology developed in the frame of the aforementioned framework is modelled using Ontology Web Language (OWL)[20]. Ali et al[21] present an approach for integrating data across systems in manufacturing domain, by demonstrating an ontological representation of products and its life cycle. Based upon this approach, the developed ontologies aim to promote interoperability among data systems deriving from various sources. Cao et al[22] introduce ontology-based context model for industry which facilitates context representation and reasoning by providing structures for context-related concepts, rules and their semantics.

The DSS semantic model of FENIX will take into account the aforementioned approaches and especially the principles around how the core concepts like products, resources, materials and circular economy actors are semantically modelled and linked among each other. The result of this interconnection will be the backbone of the DSS engine.

2. CORE ENTITIES AND DSS CONCEPTUALIZATION

Since one of the main objectives of the current deliverable is to conceptualize the circular model and methodology defined in D1.2, some key aspects of this proposed methodology are identified and will be the groundwork of the specification of the main entities in the frame of the ontology construction. Having said that, and based upon the approach presented in the current state of the art methodologies in section 1.2 with respect to the knowledge acquisition, the key parts of the respective circular methodology can be summarized as follows:

- Production lines may contain multiple systems, where each one of them consists of one or more products or functional units;
- For the creation of the products specific resources are used:
    - Energy flows (electricity and thermal energy);
    - Material flows: materials that make up the product;
    - Other resources flows used for product formation like water, cooling fluids, chemical additives, consumables, etc.).
- The main objective of CPA methodology is to quantify the circularity of each type of resource within the product life cycle;
- Considering a given resource of any kind in a generic phase of a product, a percentage of this input will end up in the output resource of a performed activity, a percentage will be discarded, and – if there are any circularities – another percentage will be reused within the same system or product, or even in a different one;
- In terms of circular calculation, for each system phase, all the resource flows (energy, materials and complementary resources) used within product lifecycle will be analysed in such a way to be able to calculate the different types of circularity;

- Energy and material resource flows hold several variables which have to be quantified in the respective phases for further circular model calculations (e.g. Kwh of Electric Energy consumed in a specific phase);
- Weights and indexes used in CPA will be calculated in order to analyse the resources present in the product life cycle based on their characteristics. (e.g. Weight (percentage) of energy consumed in the phase p on the total energy of the system).

After specifying the key aspects of the CPA methodology, the main entities which will be the cornerstone of the DSS semantic model will be the following:

- **System**: This entity represents the system of every product in which the circularity of its resources is quantified;
- **Product**: The current entity represents the actual products or functional units under analysis;
- **Phase**: This concept represents the specific phase where a specific activity related to a product occurs;
- **Resource**: This is any kind of resource that is used for every activity during a product's lifecycle (e.g. Materials, Thermal Energy etc.);
- **Flow**: This entity represents the types of flows which are related to any kind of resource and they will be quantified and allocated in the respective phases;
- **Activity**: It represents any kind of activity during a product's lifecycle (e.g. Manufacturing, Repair, Recycle etc.);
- **Circularity**: This concept represents the circularity indexes for the different types of resources which are calculated. In particular, the circular shares are weights for each resource flow present in each system phase grouped into a single index, the Circularity Product Indicator (CPI).

Apart from the definition of the main concepts, the interconnection among them will also be described. As shown in the high level class diagram of Figure 2, a system consists of products, which are the actual functional units of a production line and in which several material and resource flows are used through specific activities and in specific phase in order to ensure the circularity of each type of resource. To this end, a product consists of flows and activities that are performed and allocated in specific phase of the product life cycle. Furthermore, flows are related to different types of resources, which are used so that several activities may be performed.

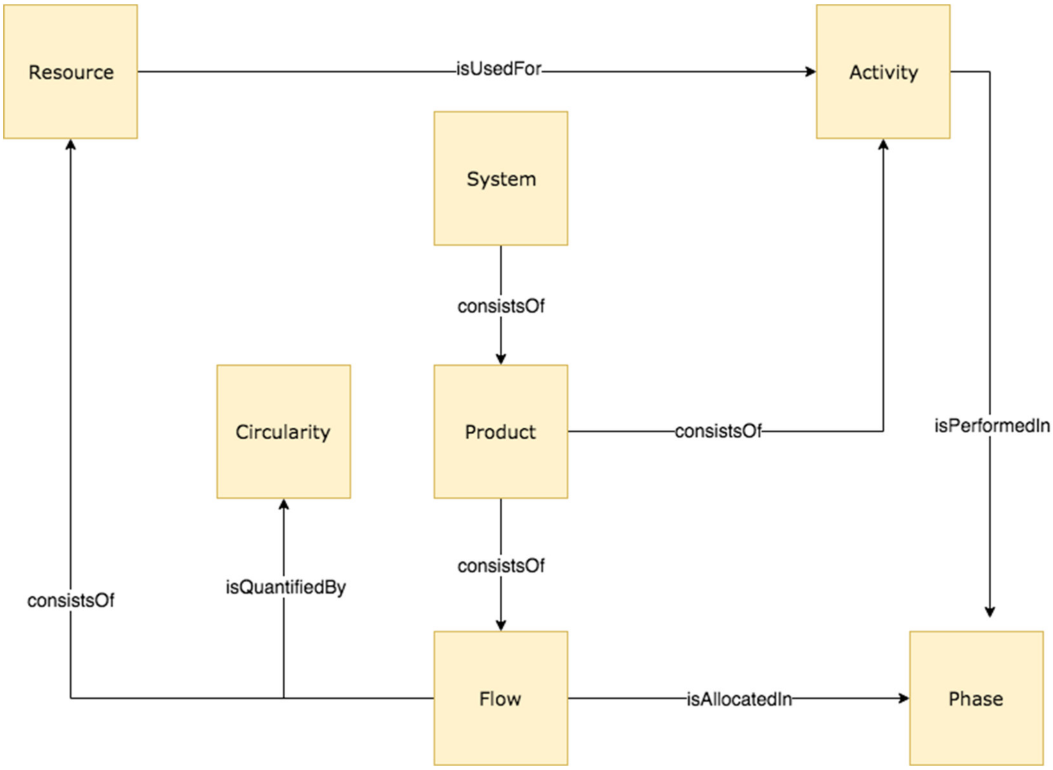

Figure 2: Semantic Model Entity Representation

3. SEMATIC DATA MODEL SPECIFICATION

In continuation to identification of key aspects and main entities of circular methodology, which was performed in section 2, the current section aims to provide a more comprehensive definition of the sematic model representation. To this end, the ontology specification will take place by taking into account the main entities and their interconnections. Moreover, some additional classes and properties will be defined so that a coherent ontology will be presented. In the frame of ontology construction, the W3C Web Ontology Language (OWL)[20] will be used, which is a Semantic Web language designed to represent rich and complex knowledge about things, groups of things, and relations between things. In the context of FENIX, things or classes are considered the identified entities stemming from the proposed circular methodology and the relations among their individuals are defined through object properties. Apart from the object properties, some datatype properties are also defined in the proposed ontology, which aim to link individuals of classes to data values. Based upon this approach, the following subsections will describe the vocabularies used for the ontology implementation, as well as the further ontology specification in terms of the definition of the classes and properties that compose the proposed ontology.

3.1. Vocabularies and Ontologies

With respect to the implementation phase of the ontology, one of the objectives is the reusability of other well-known vocabularies and ontologies that can cover the conceptualization part. In cases that existing models are insufficient or new domains had to be described, new concepts are defined. The most important ontology that is considered is the GoodRelations[17] ontology, which is a standardized vocabulary for publishing all of the details of products and services. In the context of Fenix, GoodRelations vocabulary is used for the description of products and functional units, which are involved in the circular model. It should be noticed that due to the fact that the data acquisition from each pilot plant is currently an ongoing process, the proposed ontology may be altered during the lifetime of WP4.

3.2. OWL model

In this section the classes, the object and datatype properties of the proposed ontology are presented and described along with the specification of namespaces of ontologies that are used. The following table presents them along with their prefixes and the Ontology or the Vocabulary they belongs to.

Prefix	**URI**	**Ontology**
gr	http://purl.org/goodrelations/v1#	GoodRelations
fenix	http://www.fenix-project.eu#	FENIX

Table 1: Namespace Specification

Classes

- fenix:Activity: This class represents any kind of activity during a product's lifecycle (e.g. Manufacturing, Repair, Recycle etc.)
- fenix:Flow: This class represents the types of flows which are related to any kind of resource and they will be quantified and allocated in the respective phases.
- fenix:Phase: This concept represents the specific phase where a specific activity related to a product occurs.
- gr:ProductOrService: The current entity represents the actual products or functional units under analysis.
- fenix:Resource: This is any kind of resource that is used for every activity during a product's lifecycle (e.g. Materials, Thermal Energy etc.)
- fenix:System: This entity represents the system of every product in which the circularity of its resources is quantified.
- fenix:Circularity: This class represents the circularity indexes for the different types of resources which are calculated for each resource flow.

Object Properties

- fenix:hasActivity: This property denotes the interconnection of any type of Activity with the respective Product.
- fenix:hasFlow: This specifies the Flow used within a Product lifecycle.
- fenix:hasProduct: This property specifies the Product that belongs to a System.
- fenix:hasResource: This property links the Flow with the related Resource.
- fenix:isAllocatedIn: This property denotes the Phase that a Flow is allocated into.
- fenix:isPerformedIn: This property links the Activity with the respective Phase it occurs.
- fenix:isUsedFor: This property links the Resource with the Activity in which it is used.
- fenix:quantifies: This property links a resource flow to the respective Circularity.
- fenix:isQuantifiedBy: This property is the inverse of "fenix:quantifies".

Datatype Properties

- fenix:consumedElectric: Kwh of Electric Energy consumed in specific Phase.
- fenix:consumedElectricRenewable: Electric kwh from renewable sources consumed in specific Phase.
- fenix:consumedThermal: Kwh of Thermal Energy consumed in specific Phase.
- fenix:consumedThermalRenewable: Thermal kwh from renewable sources consumed in specific Phase.
- fenix:discardedMass: Discarded mass of material in specific Phase.
- fenix:inputMass: Input mass of material in specific Phase.
- fenix:recycledMass: Recycled mass of material in specific Phase.
- fenix:reusableMass: Reusable mass of material in specific Phase.
- fenix:reusedMassOrVolume: Mass of resource rejected by specific phase and reused in the same or in another system.
- fenix:rejectedMassOrVolume: Mass of resource rejected by specific phase and it's not reused.
- fenix:inputMassOrVolume: Input mass or volume of resource in specific phase.
- gr:description: A short textual description of the Product.
- gr:name: A short text describing the respective Product.
- gr:condition: A textual description of the condition of the Product.

Having described the classes and properties that constitutes the ontology specification, in Figure 3 an OWL graph is presented, which represents the current status of the ontology from the conceptual perspective. As can be observed, the main entities of the circular methodology presented in section 2 are also introduced by the proposed ontology.

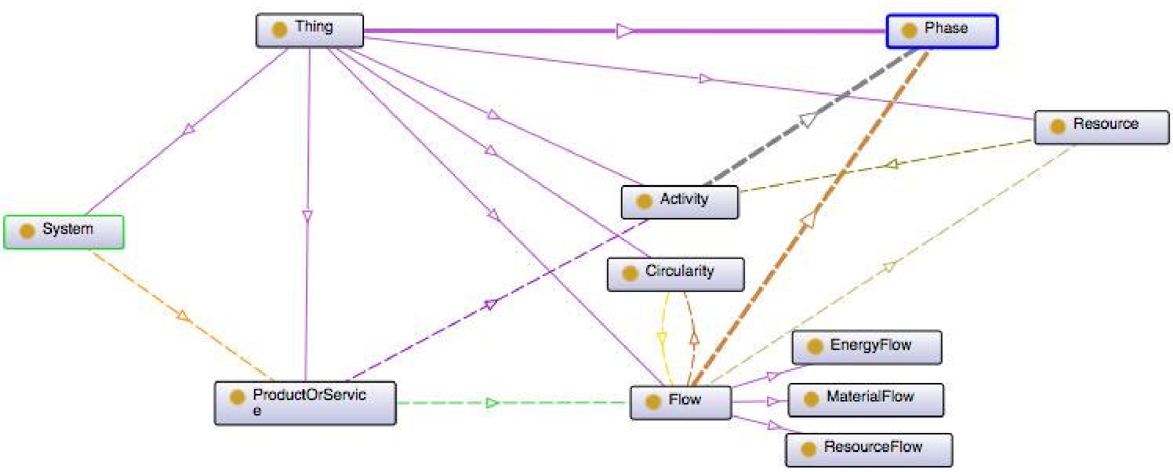

Figure 3: Ontology Specification

4. CONCLUSION

Taking into account that the main objective of this report is to define and document the semantic model, which will ensure the semantic consistency in the frame of the DSS engine, several semantic models and approaches were examined and they are the base of the ontology specification presented in the current deliverable. The ontology specification followed a methodology comprising of several activities like knowledge acquisition, conceptualization, integration and implementation, which are also specified in the section 1.2, where the state of the art methodologies for ontology development are presented. Towards the evaluation activity, further workshops with the pilots will take place with the aim of enhancing the current status of the ontology.

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