# 1. Developing Ontologies for Representing Data about Key Performance Indicators


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## Abstract

Multiple indicators are of interest in smart cities at different scales and for different stakeholders. In open environments, such as The Web, or when indicator information has to be interchanged across systems, contextual information (e.g., unit of measurement, measurement method) should be transmitted together with the data and the lack of such information might cause undesirable effects. Describing the data by means of ontologies increases interoperability among datasets and applications. However, methodological guidance is crucial during ontology development in order to transform the art of modeling in an engineering activity. In the current paper, we present a methodological approach for modelling data about Key Performance Indicators and their context with an application example of such guidelines.



**Keywords**: ontology development, ontology development methodologies, key performance indicator


## Introduction

Multiple indicators are of interest in smart cities at different scales: devices, buildings, districts, cities, etc. The description of such indicators goes beyond giving a label to some value. In order to be successfully used or interchanged, indicator information must be related to other entities that contextualize the indicator and allow a meaningful use of it. Therefore, a concrete indicator: a) usually satisfies some information need that a certain stakeholder requires to make decisions; b) refers to a certain attribute of some entity; c) is specified in terms of a concrete measure, with a concrete scale (nominal, ordinal, interval, or ratio) and unit of measurement; and d) has a concrete value that has been obtained through some method in which certain technologies were used.

In closed measurement environments, there is no need to make explicit most of the entities that conform the context of an indicator. However, in open environments, or when indicator information has to be interchanged across systems, the lack of complete contextual information (e.g., unit of measurement, measurement method) may cause undesirable effects, for example, misunderstandings of the measurement units, that is, takes as kilometers what is indicated in miles.

Ontologies are formal, explicit specifications of shared conceptualizations and allow developers to reuse and share application domain knowledge using a common vocabulary across heterogeneous systems or environments. Therefore, ontologies do not only provide semantics and reasoning power to the data described in a given application but also increase the interoperability among datasets and applications.

The W3C has defined different specifications to represent ontologies and to represent data according to such ontologies. The ultimate goal is to allow software agents to use those ontologies and data, and the main use scenario is when ontologies and data are published in the Web and/or accessed using web protocols (e.g., HTTP). Furthermore, by following the Linked Data principles[1], data published online can be easily accessed and integrated with other data. This has caused that, in the last years, the amount of semantically structured data (i.e., Linked Data) available on the Web has witnessed a substantial growth.

In order to realize the notion of Linked Data, not only must data be available in a standard format, but also concepts and relationships among datasets must be defined by means of ontologies. New ontologies to model data to be exposed as Linked Data should be created and published when the existing and broadly-used ontologies do not cover all the data intended for publication. Practitioners should describe their data, on the one hand, by reusing as many terms as possible from those existing in the vocabularies already published and, on the other hand, by creating new terms when available vocabularies do not model all the data that must

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[1] http://www.w3.org/DesignIssues/LinkedData.html

be represented. During this apparently simple process of developing an ontology for a concrete use case, several questions may arise for a data publisher.

This paper aims at guiding through the process of developing an ontology to represent data about Key Performance Indicators (KPIs) and their context. To this end, it provides a lightweight method for developing ontologies with advice on design decisions related to the representation of indicators (e.g., how to represent measurements) along with an instantiation of such method in the development of an ontology for modeling energy consumption data.

The remainder of this paper is organized as follows. Section 1 reviews existing methodologies for ontology development. Section 2 presents the methodological guidelines proposed in this work. Section 3 shows how these guidelines are applied throughout an example in section 4. Next, section 5 shows an overview of the ontology developed before wrapping up this paper with some concluding remarks.

# 1. Related work

In terms of methods for modeling KPIs in the field of energy efficiency we can account for the work performed by Vogt and colleagues (Vogt et al., 2013), where a framework for defining and implementing KPIs is provided according to the S.M.A.R.T. principles (Specific, Measurable, Attainable, Relevant and Time-bound). In this work, the basic concepts in order to establish a common vocabulary to be supported using semantic web standards are proposed. However, no ontological development is provided.

Relevant approaches for ontology development for KPIs are developed in the area of business processes (del-Río-Ortega et al., 2010) and enterprises (Jussupova-Mariethoz and Probst, 2006). However, to the best of our knowledge no methodological process is followed, or described, during such ontological developments.

In the last years there has been a growing effort to collect indicators, to represent indicator-related data using ontologies, and to publish those data online as Linked Data; and we expect that these initiatives continue in the future. However, one issue that hinders this process is the lack of clear guidelines on how to build ontologies for representing such data, since this task is usually carried out by people that are not necessarily experts in semantic web technologies.

Existing ontological engineering methodologies should be reviewed and adapted to support ontology development in the Linked Data context (e.g., lightweight and semi-automatic processes, reusing terms already available in the Linked Data cloud, etc.). Some of them propose a heavyweight development process with time and resource consuming activities, such as METHONTOLOGY (Fernández-López et al., 1999), On-To-Knowledge (Staab et al., 2001) and DILIGENT (Pinto et al., 2004), or the NeOn Methodology (Suárez-Figueroa, 2010). Other approaches propose agile methodologies for ontology development but, as in the previous cases, do not fully account for the Linked Data reality, such as the eXtreme Method (Hristozova and Sterling, 2002), the XD Methodology (Presutti et al., 2009), or RapidOWL (Auer, 2006). Within the literature on Linked Data (Heath and Bizer, 2001), some high-level guidelines have been outlined to create vocabularies; however no concrete processes and detailed guidelines have been proposed to carry out such a development.

## 2. Methodological guidelines

By describing the concepts in a domain and the relationships between them, ontologies represent formal representations of knowledge about a certain domain and are the cornerstone of the Linked Data initiative since they are the formal models for representing data on the Web. Ontologies can be implemented in various languages; the most widely used and accepted language is that standardized by the W3C, the Web Ontology Language (OWL) (W3C, 2012).

Ontologies contain different components (e.g., classes, properties, instances and axioms). Ontologies denoted as lightweight contain only classes, properties, and instances. On the other hand, heavyweight ontologies are developed having in mind all the components.

Since ontologies in the energy domain might be developed to represent the data that is already available in a data source, along these guidelines a data-driven development is taking into account and it can be combined with the classical ontology development based on requirements elicitation.

Taking this into account, ontology development can be achieved in several consecutive steps (Poveda-Villalón, 2012). *Figure 1* shows a graphical workflow of the seven proposed activities that will be elaborated along this section.

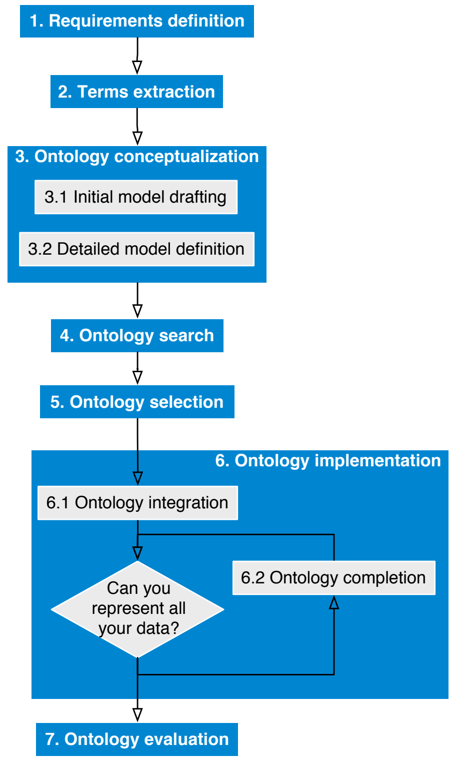


*Figure 1. Workflow of activities for ontology development.*

1. ***Requirements definition***

The goal of this activity is to define the requirements that have to be fulfilled by the ontology. These requirements can be related to the purpose of usage of the ontology, to the domain that the ontology is covering, or to technical details of the ontology, among others. We refer developers to (Suárez-Figueroa, 2010) for specific and detailed methodological support to carry out the requirements definition activity.

2. ***Terms extraction***

This activity consists of extracting the terms from the list of ontological requirements, more precisely from the competency questions, and/or the data source to be transformed into RDF from where basic concepts and the relationships between those concepts are extracted. In the case when the schema of the data source already exists or has been previously extracted, it can be used together with the data as a reference for terms in the data source. Furthermore, the extracted terms should consist of not only the terms from the data source, but also of the synonyms of those terms. In order to find the synonyms, some of available online services[2] can be used.

3. ***Ontology conceptualization***

This activity is carried out in two levels of detail. While it is recommended to develop the two steps presented below, the first one could be considered as optional. As an initial step developers might find helpful to divide the list of terms into terms for classes, terms for properties, and terms for instances, or it could be done during the specific conceptualization steps if such division is not clear at the beginning.

3.1. *Initial model drafting.* This step is intended to identify the main domains or top concepts to be represented in the ontology. Relations between such domains or concepts should also be annotated during this step. It should be noted that these concepts and relations do not need to represent actual elements in existing ontologies or the ontology being built; the aim of this step is having an initial conceptual map that will be refined in future steps.

3.2. *Detailed model definition*. Taking as input the draft model defined in the previous step, during this activity a more detailed conceptual model is elaborated. During this stage each domain or top concept should be split into specific concepts and hierarchies if needed. In addition, factual relations between the specific concepts might be defined as well as necessary attributes for each concept. Finally, rules and axioms (e.g., existential or universal definitions) could be attached to classes or domains and ranges could be defined for properties.

4. ***Ontology search***

Reusability is one of the main principles to follow when developing ontologies. The best practice is to reuse existing ontologies whenever possible and, therefore, it is necessary to first perform a search to find which existing ontologies best fit the previously-extracted terms. For doing so, developers should use ontology indexes and registries (e.g., the smart city ontology catalogue[3], LOV[4]) and search engines (e.g., Google).

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[2] For example online services as http://thesaurus.com/

[3] http://smartcity.linkeddata.es/

[4] http://lov.okfn.org/

Existing ontologies are searched based on keywords in such a way that previously extracted terms (including their synonyms) are searched using one or more tools in order to find ontologies in which classes and properties related to those terms are already defined.

In this step, search results often need to be filtered because they can consist of several hundred ontologies and it is not possible to inspect all of them.

In those cases when widely-used ontologies are already known and can be reused with certain classes or properties, terms from these ontologies can be selected for reuse and there is no need to perform the ontology search for the terms related to these classes or properties.

5. ***Ontology selection***

After the search for ontologies is performed, based on the search results and on the extracted terms, the appropriate ontologies that are going to be reused or particular ontology elements (concepts, relations or attributes) are selected.

For every extracted term, an ontology or ontology element is selected for reuse in such a way that:

- The class or property in the ontology relates to the context of the searched term, i.e., the semantics of the class or property in the ontology is related to the term.
- If the term relates to a class, the class in the ontology has as much properties that correlate to the term as possible.
- The ontology that describes the class or property related to the search term is widely accepted and used.

For detailed methodological guidelines to carry out this activity, we refer developers to (Suárez-Figueroa, 2010).

6. ***Ontology implementation***

In order to be used in software systems, the ontology has to be implemented according to an ontology implementation language and has to follow some strategy to name (i.e., assign URIs that stands for "Uniform Resource Identifiers") all the classes and properties. It is worth noting that even though one of the inputs for this activity is the conceptual model (defined in the activity 3), due to implementation and reuse reasons such initial model might be slightly modified during this activity. For carrying out this activity, developers should use an ontology editor for example Protégé[5], WebProtégé[6] or the NeOn Toolkit[7]

6.1. *Ontology integration*. Taking into account the ontologies to be reused, the integration of the concepts from the selected ontologies into an initial conceptualization could be done in two different ways: (1) importing[8] the ontology to be reused into the ontology being developed; and (2) referring to element URIs so that only those element references are included in the ontology being built (Poveda-Villalón et al., 2012a).

If all the needed classes and properties are available in existing ontologies, the next step to be performed is step 7. Usually, this is not the case and step 6.2 should be carried out.

6.2. *Ontology completion*. If existing ontologies do not provide all the information needed to represent the data, it is necessary to complete the ontology by introducing:

- *New classes*, which are introduced only in the case when existing ontologies do not describe the desired classes; new classes have to be related to the terms extracted in the first step.
- *New properties*, which can be introduced to newly introduced classes as well as to classes from other ontologies that are selected for reuse; these properties have to be related to terms extracted in the first step.

7. ***Ontology evaluation***

Once the ontology is implemented, it should be evaluated, that is, its technical quality should be checked against a frame of reference (Suárez-Figueroa et al., 2013). For doing so, several dimensions for ontology evaluation could be taken into account (Poveda-Villalón et al., 2012b), for example: logical consistency, modeling issues, human understanding, ontology implementation language compliance or the suitability for a given application. In order to carry out this

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5 http://protegewiki.stanford.edu/wiki/Protege4UserDocs

6 http://protegewiki.stanford.edu/wiki/WebProtege

7 http://neon-toolkit.org

8 http://www.w3.org/TR/owl-ref/#imports-def

activity, it is advisable to use OOPS! (Ontology Pitfall Scanner!)[9] in order to find potential modeling errors in the ontology (Poveda-Villalón et al., 2012b), among other types of errors, and a reasoner (e.g., Pellet, Fact), in order to find logical inconsistencies. Developers might use syntax validators (e.g., OWL validator[10]) in order to check whether the ontology is compliant with the implementation language. If the ontology is going to be integrated in a particular system, integration tests should be developed.

# 3. Modelling example

As an example of ontology development in the energy domain, we have decided to use data from the BECA project and to develop an ontology for representing these data. The BECA (Balanced European Conservation Approach) project[11] is a European ICT PSP project that aims to reduce energy consumption in European social housing. In order to achieve this goal, BECA has developed a set of innovative services for resource use awareness and resource management. The services developed in the project are being used and tested in several pilot sites, and the project has collected data about energy consumption in households from such pilots, which is stored in Excel format.

The benefits of using the presented methodology for the BECA example is that the methodology have been designed for ontology developments in which there is already some data available and it has to be annotated by means of a domain ontology describing such data. Therefore, the order and guidelines for each step can be applied with no need for adaptation.

The purpose of this example ontology is to capture the knowledge about energy resources related to the BECA example and to provide a model for the representation of data from such example. Next, we describe each ontology development step carried out in the BECA example. It should be noted that we do not detail all the steps and decisions for the whole ontology but only those significant for illustrating the application of the methodological guidelines.

The correspondences between prefixes and namespaces used through this section are shown in *Table 1*.

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[9] http://oeg-upm.net/oops

[10] http://mowl-power.cs.man.ac.uk:8080/validator/

[11] http://www.beca-project.eu/home/

| Ontology | Prefix | URI |
|---|---|---|
| **Beca** | beca | http://smartcity.linkeddata.es/BECA/ontology/Energy Consumption# |
| **BIO** | bio | https://www.auto.tuwien.ac.at/downloads/thinkhome/ ontology/gbBuildingOntology.owl# |
| **DOLCE+DnS Ultralite** | dul | http://www.loa-cnr.it/ontologies/DUL.owl# |
| **Units of Measure** | om | http://www.wurvoc.org/vocabularies/om-1.8/ |
| **Energy Resource Ontology** | ero | https://www.auto.tuwien.ac.at/downloads/thinkhome/ ontology/EnergyResourceOntology.owl# |
| **Schema** | schema | http://schema.org/ |
| **Semantic Sensor Network** | ssn | http://purl.oclc.org/NET/ssnx/ssn# |

*Table 1. Correspondences between the ontology URIs and their prefixes.*

1. ***Requirements definition.*** For the ontology to be developed for the BECA example, several requirements were specified:
    - The ontology will try to adopt concepts and design patterns in other ontologies where possible (for example, a range of a property can be changed, additional classes could be introduced, etc.).
    - The ontology should be implemented in OWL 2 DL (OWL DL is so named due to its correspondence with "description logics").
2. ***Terms extraction*.** As the schema of the BECA example is already available within the Excel spreadsheet, it was used (together with available data) as the reference for the terms and their synonyms, presented between brackets. For readability and space issues the following list shows uniquely the main terms considered during this example: dwelling (residence, habitat), city, building, evaluation group, tenancy (occupancy), pilot, heating degree days, hot water, cold water, heating (heat), energy, consumption (utilization), unit of measurement, month (time), Kilowatt hour (kWh), cubic meter (cbm), square meter (sqm), thermal unit, evaluation number, building identifier, building name (name), tenant identifier, tenant number, dwelling identifier, change of tenancy, vacancy of dwelling, number of persons living (number of persons), size of dwelling (size), night setback, ventilation system, value.
3. ***Ontology conceptualization.*** Based on the terms extracted in the previous step, we have defined both an initial and a complete ontology conceptualization as indicated in activities 3.1 (*Initial model drafting*) and 3.2 (*Detailed model definition*) respectively. *Figure 2* shows an overview of the ontology to be developed where only the main areas of knowledge or top concepts are

represented and related among them according to activity 3.1. More detailed concepts and relationships should be included according to activity 3.2; however, due to space restrictions the final model will be shown below instead of the detailed conceptualization.

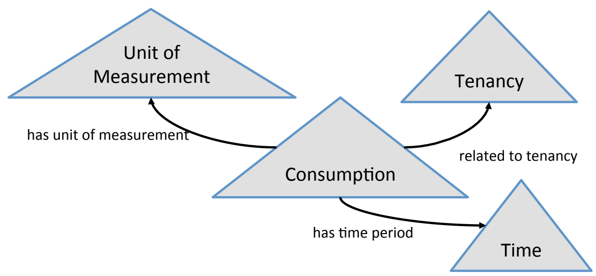


*Figure 2. Ontology overview (initial draft).*

4. ***Ontology search.*** In order to search for existing ontologies that describe the extracted terms, we used LOV, Google, and the smart cities ontology catalogue.

As an example, for the search of ontologies including the concept of *dwelling*, we have performed the following steps:

- We have first used the term *dwelling* with the previously mentioned tools to search for ontologies. The search results contained more than three hundred ontologies, and we have included only a number of those that are available (excluding links with errors and no content) and that can be used to represent the concept of dwelling.
- We have also performed the search using the synonyms of the term *dwelling* and using the same search tools as when searching for the term *dwelling*. In this case, the search results contained more than six hundred results.

*Table* ***2*** shows an excerpt of the results of the search for the concept "Dwelling". For the term "dwelling" and its synonyms "residence" and "habitat2, URIs of the ontology concepts that can be reused are listed.

| **Ontology** | **Term** |
|---|---|
| http://schema.org/ | Residence |
| http://www.semanticweb.org/ontologies/2012/2/OpenStreetMapFeatures.owl# | Isolated_Dwelling |
| http://www.semanticweb.org/ontologies/2011/5/Ontology1307456124031.owl# | RESDW |
| http://www.cyc.com/2003/04/01/cyc# | ModernHumanResidence |

*Table 2. Existing terms in ontologies for the concept "Dwelling".*

5. ***Ontology selection.*** Several ontologies were found in the previous step. The *schema.org* one provides a class for describing residences, which can be used for dwelling description, and includes a number of properties to describe it (e.g., address and geographical coordinates, among others). In this case, *schema.org* was selected to be used because it is widely-known and an accepted vocabulary. Another ontology reused for describing buildings is the *gbBuilding Information Ontology (BIO)*. BIO provides some additional classes and properties that can be used for building description.

   The general concept of energy was found in two ontologies, *Energy Resource Ontology (ERO)* and *schema.org*; however, since the *UsefulEnergy* class from ERO is semantically closer to the context of the BECA example, and since ERO also describes some instances of the mentioned class that are of interest for the BECA example (e.g., *Heat*), it was selected for reuse.

6. ***Ontology implementation.*** The ontology developed for the BECA example has been implemented in OWL using Protégé as ontology editor. The implemented ontology is available online[12]. Due to space issues all details about the final implementation are shown in *Figure **3*** (see section 5).

   6.1. *Ontology integration*. For the case of the BECA example, the integration of the reused elements has been done by referencing such terms, that is, including them in to the ontology, instead of importing the reused ontologies as a whole. For example, the class `ssn:FeatureOfInterest` has been included in the ontology and extended by means of the classes `schema:City` and `beca:Tenancy`.

   *6.2. Ontology completion*. Since the search for existing ontologies did not provide results for all extracted terms and their synonyms, it was necessary to complete the ontology. Therefore, several classes, properties, and instances were introduced. As an example, we can mention that the object property `beca:belongsToBuilding` is introduced in order to establish a relationship between the reused classes `schema:Residence` and `bio:Building`, which act as domain and range of the property respectively. As this model relates two reused elements it could also be consider part of ontology integration as well as completion.

[12] See http://smartcity.linkeddata.es/BECA/ontology/EnergyConsumption.owl for implementation details.

7. ***Ontology evaluation.*** The ontology developed for this example was evaluated using the OOPS! pitfall scanner. Several errors were found, both minor and important ones. Through several evaluation iterations, the important errors were corrected and only one minor warning remains in the current version of the ontology. This warning is related to classes and properties that lack annotations. In this case, these are the classes and properties that are reused and, therefore, these annotations were purposely omitted.

   During the evaluation process, in order to correct some important pitfalls, a set of axioms was added to the ontology. Because of this, the resulting ontology is heavyweight, which is not in line with the initial guideline requirements; however, this step of defining ontology axioms was performed in order to provide an ontology of higher quality.

   Furthermore, the syntax of the ontology was also validated and we have used the Pellet reasoner in order to evaluate the logical consistency of the ontology.

## 5. Ontology overview and discussion

This section provides some detailed information about how indicators have been represented in the final implementation of the ontology. In addition, a graphical description of the ontology is shown in *Figure **3***.

Several key indicators are measured in the BECA example: cold water, hot water, and heating. In order to capture these indicators and energy consumption in tenancies, we have reused the Semantic Sensor Network (SSN) ontology. The key class in this ontology is the `ssn:Observation` class. Time periods for the observation are represented with the `dul:TimeInterval` class from the DUL ontology, while the observed value of the consumption is modeled with the `ssn:SensorOutput` and `ssn:ObservationValue` classes. To capture the specific indicator for which the consumption is related to, the `ssn:Property` class from the SSN ontology and the `ero:UsefulEnergy` class from the Energy Resource Ontology are used, and several instances have been introduced (one for each indicator). For each indicator and measured value, the measurement unit is captured with the `mo:Unit_of_measure` class from Units of Measure ontology.

Consumption for every indicator is related to a particular tenancy, modeled with the `beca:Tenancy` class, which is connected to consumptions through the `ssn:FeatureOfInterest` class.

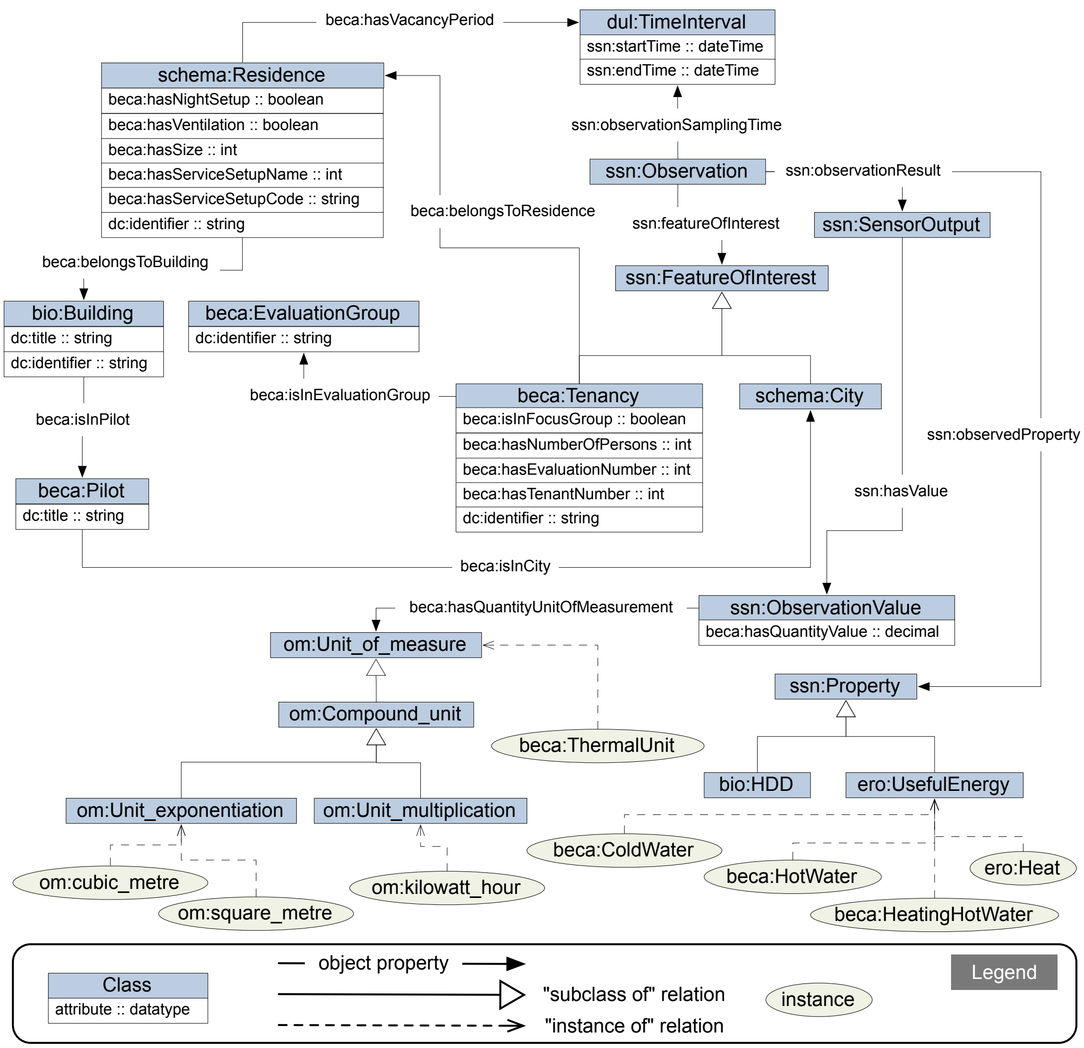


*Figure 3. The BECA ontology.*

An alternative to the SSN ontology for modeling indicator data is the W3C DataCube[13] ontology; the central class in this ontology that can be used to represent consumptions is the `qb:Observation` class. Unlike with the SSN ontology, the values for indicators are represented with properties related to the `qb:Observation` class, while indicators are represented as instances of the `qb:MeasureProperty` class. The time period of the observation is represented similarly as in the SSN case, while the connection of energy consumption and tenancies is modelled through the `beca:observedTenancy` property. Units of measure are modelled using the `om:Unit_of_measure` class, as in the case of the SSN, which in this case is directly

[13] http://purl.org/linked-data/cube# the "qb" prefix is used for this ontology.

connected to the `qb:Observation` and to `qb:AttributeProperty` classes. However, a more detailed description of DataCube alternative is out of the scope of this paper.

## Conclusions

When interchanging KPI data across systems, such data should be properly contextualized in order to allow a meaningful use of it. If this information is shared through the Linked Data cloud, ontologies must be used to increase the interoperability among datasets and applications as well as for providing semantics and reasoning power to the annotated data. During the process of developing an ontology for an specific use case, several questions may arise for a data publisher therefore methodological guidance is needed.

This paper proposes a methodological approach for the process of developing an ontology to represent data about Key Performance Indicators and their context. In addition, an example of such method in the development of an ontology for modeling energy consumption data is provided.

As future lines of work, we envisage to provide more details about modeling decisions and alternatives.

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