Using Ontology Design Patterns to Represent Sustainability Indicator Sets

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Abstract. Sustainability indicators are increasingly being used to measure the economic, environmental and social properties of complex systems across different temporal and spatial scales. This motivates their inclusion in open distributed knowledge systems such as the Semantic Web. The diversity of such indicator sets provides considerable choice but also poses problems for those who need to measure and report. To address the modelling problems of indicator sets, we propose the use of Value Partition pattern to construct two design candidates: *generic* and *specific*. The generic design is more abstract, with fewer classes and properties, than the specific design. Documents describing two indicator systems – the Global Reporting Initiative and the Organisation for Economic Co-operation and Development – are used in the design of both candidate ontologies. We show the use of existing structural ontology design patterns can help to solve problems of ontology representations for modelling sustainability indicator sets.

Keywords: Sustainability Indicator Sets · Sustainability Reporting · Ontology Design Patterns · Value Partition

1 Introduction

Sustainability indicators estimate the past, current and future states of complex systems, such as cities, organisations, community groups and natural habitats. In a measurement context, a "system" is the entity that is the focus of various tasks that include identifying properties, devising scales, testing and measuring, and reporting on progress towards defined sustainability goals. In response to the demands of measuring and maintaining sustainability for diverse systems, many indicator sets have been developed and are in use today [4,16,19].

The diversity of such indicator sets provides considerable choice but also poses problems for those who need to measure and report. Often, relevant indicators need to be selected from multiple sets, with any gaps in specific measurement goals filled by the development of new indicators. Ontologies provide one

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means for consolidating these multiple sets in a single representation, but leave open the problem of exactly how this representation is designed. In many cases, it remains an advantage for such a representation to be human-readable as well as machine-readable. This facilitates interpretation of how different sets compare and contrast. To support human usability in the sustainability domain, any such representation should aim to support the easy *reading* of existing indicators compiled from heterogeneous sources, and the easy *writing* of new indicators and annotations to the ontology through common authoring tools such as *Protégé Desktop*[1].

We argue *ontology design patterns* can help to address both problems in a way that is systematic and builds upon the experience of others. Our focus in this paper is on the first of these problems: **How to represent indicators from multiple indicator sets in an ontology?** This problem includes a further semantic challenge, since multiple sets may overlap at the level of individual concepts but may also overlap between broader conceptual clusters. We argue this challenge in turn has at least two levels: (i) indicators may be *named differently*, due to different languages, disciplinary jargon, or designer preferences; and (ii) indicators may also be *conceptually organised differently*, due to the knowledge paradigms and priorities motivating indicator selection. In both cases, merging two or more indicator sets into a single, combined ontology can assist in identifying which specific indicators might be most relevant to the measurement task at hand.

Well-known standardised frameworks for sustainability reporting include the Global Reporting Initiative (GRI) indicators and guidelines[2], the Organization for Economic Co-operation and Development (OECD)[3] and the United Nations Statistics Division (UN Social Indicators)[4]. Each of these frameworks group sustainability indicators into hierarchical structures that include categories and sub-categories of indicators. Extracts of GRI and OECD indicator sets are shown in Fig. 1, which illustrates (i) categories (or aspects), (ii) sub-categories (themes) and (iii) indicators. This shows, at least at a structural level, that there is some basis for comparison between these two widely used sets of sustainability indicators.

To date, there have been few efforts to represent *multiple* sustainability indicator sets in a systematic semantic way. Advantages of representing indicators in a formal *ontology* include developing a consistent definition of what an indicator is, how it can be applied, and how it relates to higher order grouping constructs used in theories and definitions of sustainability. An ontology representation also builds upon the many tools now available for ontology reasoning, alignment and visualisation, allowing organisations to browse and review different kinds of indicators for different measurement applications. Most importantly, by utilising pre-defined matches between non-identical but related indicators, measurements

1 http://protege.stanford.edu/.
2 http://www.globalreporting.org/.
3 http://www.oecd.org/.
4 http://www.un.org/esa.

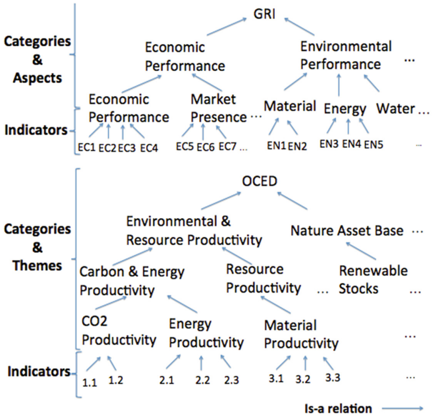

Fig. 1. Extracts of GRI and OECD indicator sets

and reports developed by different organisations and contexts can be more easily compared.

A key concern in ontology engineering is to design and organise groups of related concepts that capture the relevant information of the domain being modelled as an ontology. *Ontology Design Patterns* (ODPs) have been proposed to encourage compatibility, efficiency and recognisability of ontology designs [14,17]. In the formal sense provided by those listed[5], patterns make explicit relations that would otherwise remain implicit, or at best only documented. As one example, the *Role* pattern[6] makes clear that two ontology classes are not simply related through user-defined properties, but are related specifically as *task actions* and *role objects*.

In this paper we discuss two ontology design candidates, which we term *generic* and *specific*, developed to represent sustainability indicator sets. We have termed the target end ontology OSIS (Ontology for Sustainability Indicator Sets), and the two design candidates GOSIS and SOSIS. The details of ontology engineering steps are described in earlier work [13]. This paper instead discusses the varied use of an ODP called *Value Partition* in the construction of the two candidates, and presents conclusions on the relevant merits of each variation.

2 Related Work

To prepare our discussion of the two ontologies, we review briefly literature relating to (i) sustainability indicator sets and (ii) ontology design patterns.

5 http://ontologydesignpatterns.org.
6 http://ontologydesignpatterns.org/wiki/Submissions:Role_task.

2.1 Ontologies and Taxonomies Used in Sustainability Indicator Sets

There have been several attempts to develop domain and application ontologies in the context of sustainability and sustainability reporting. Brilhante et al. [4] present an ontology that aims to represent economic indicators of sustainable development. Similarly, Madlberger et al. [18] develop an ontology for the domain of corporate sustainability, heavily influenced by the design of the Global Reporting Initiative's *XBRL* specification. Kumazawa et al. [16] outline an ontological approach to capture a very broad problem-based definition of sustainability science, developed around five key concepts of *Problem*, *Goal*, *Evaluation*, *Countermeasure* and *Domain Concept*. Han and Stoffel [15] apply text extraction and analysis techniques to environmental sustainability case studies to generate machine and humanly-readable ontologies. An ontology-based approach has also been used by Pinheiro et al. [19] to assist selection of relevant sustainability indicators. Finally, Fox [7] has developed an ontology to represent ISO37120 Global City Indicators, a standard that defines measures for urban sustainability.

This prior work has not sought to combine more than one representation of sustainability indicators into a single ontology design. To help address this problem, we next examine ontology design patterns.

2.2 Ontology Design Patterns

Ontology design patterns borrow heavily from the related concept of *Software Design Patterns* (SDPs) [8] in software engineering. Using object oriented SDPs provides software class models with well-understood properties and behaviours that solve common engineering challenges in generic, abstract and reusable ways. As a result, such patterns improve software development efficiency and generate high-quality and more maintainable software artefacts [3]. In an equivalent way, an ontology can be composed of different related ODPs, which resemble building blocks that make up the ontology structure. Recognising generic or abstract ontology components is an integral part of specifying appropriate ODPs. This process is often domain-dependent, and thus requires deep understanding of the key concepts of the domain problem. Similar to SDPs, ODPs are abstract, flexible and reusable solutions that address common problems and use cases in the field of ontology engineering [1,2]. However, given that ontology engineering is a less mature field compared with software engineering, the definition, representation and application of ODPs lack the same level of consensus as software engineering design patterns.

The ODP literature can be divided into studies that discuss general ideas about ODPs and those that discuss concrete ODPs for tackling specific design problems in developing ontologies. As examples of the former, Reich [21] first introduced the notion of ODPs in the context of molecular biology. Shortly after, Staab et al. [23] discussed the idea of Semantic Patterns and Knowledge Patterns as reusable components for building knowledge bases. Their work was later

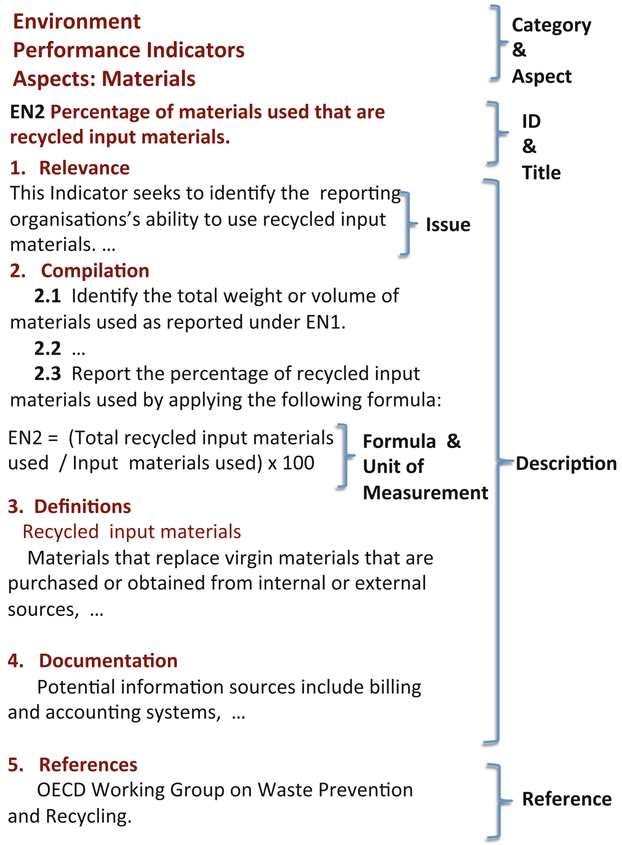

Fig. 2. An extract of a GRI indicator

followed by the work of Gangemi [9] and Gangemi et al. [11] that distinguished between Logical, Conceptual and Content Ontology Design Patterns. Finally, Gangemi and Presutti [10] classify a number of commonly-used ontology patterns into six major categories including: Structural, Correspondence, Content, Reasoning, Presentation, and Lexico-Syntactic ODPs. This classification system continues to influence their organisation on the widely-used pattern repository[7].

[7] http://ontologydesignpatterns.org.

3 Sustainability Indicator Sets Ontology Development

In this section we discuss the development process of our ontology design.

3.1 Extracting Foundational Concepts

After reviewing GRI and OECD indicator sets, and interviewing sustainability domain experts, we first identify several common foundational concepts of sustainability indicators. Highlighted in Fig. 2, these concepts include: *Indicator*, *IndicatorSet*, *Category*, *SubCategory (Group, Theme, Aspect)*, *Issue*, *Description (Relevance, Compilation, Definitions, Documentation)*, *Reference (Sources, Information).*

3.2 Modelling Problems

Second, given the identified key concepts within the domain-dependent taxonomies, we further identify relations between these concepts and the relevant entities within those taxonomies. These may have quite different representations. In particular, we have noticed that specific GRI and OECD indicator systems can be specified in relation to abstract concepts of `IndicatorSet` and `Indicator` in different ways. The question here is of **how to determine whether such relations be represented as disjoint class hierarchies, as subclasses of a common parent class, or as instances of a given class**, and represents a refinement of the overall research question of how to represent indicators from multiple sets in an ontology. In concrete terms, as we discuss in the next subsection, the design problem involves the association of the `Indicator` concept with the `IndicatorSet` concept. This also affects the relations of other concepts such as `Category`, `Description` and `Reference`. Addressing these modelling problems ideally should reflect the requirements of the final ontology design, leading us to choose appropriate patterns that satisfy both computational properties and the human interpretation of ontologies. These ontology requirements for sustainability indicator sets are discussed in our earlier work [12].

3.3 Ontology Design Patterns Solution

Third, to address the aforementioned modelling problems, we decided upon the use of the Value Partition (VP) pattern. The VP ontology pattern was first introduced by Rector [20] and further reviewed and developed by Aranguren [1] for the biomedical domain. The VP pattern represents specified collections of "values" – also known as a "feature space" – using hierarchical modelling. Generally speaking, in any domain, such characteristics are used to describe different concepts in the ontology. For example, given the description of the "IndicatorSet" concept in the sustainability domain, in the presented ontology model, there are two VP patterns as follows.

As Rector [20] notes, the VP pattern can be implemented in different ways: as a collection of individuals, as disjoint classes, or as datatypes. As the values we are modelling form themselves complex taxonomic structures, datatypes are not adequate. Accordingly we present two approaches to OSIS that represent multiple indicator sets, respectively, as collections of interrelated individuals and as disjoint classes. In doing so, we also acknowledge subsequent clarifications of complex uses of the Value Partition ODP in, for example, Rodriguez-Castro et al. [22], who relate VP to two other ODPs: Normalisation and Class as a Property Value (or CPV). In line with their findings, both of our VP implementations simultaneously constitute implementations of Normalisation and what they term strict-CPV ODPs.

- **Pattern 1 - GOSIS design:** This design assumes indicator sets and indicators are instances of classes. Both GRI and OECD taxonomic structures are represented as individuals of the `IndicatorSet` class. Specific measures, such as GRI's "Percentage of total employees covered by collective bargaining agreements" (Disclosure 102-41) and OECD's "share of the population connected to sewerage with primary, secondary, tertiary treatment", are represented as instances of the `Indicator` class. The `Indicator` class is further linked by a particular property, `belongsToIndicatorSet`, to the `IndicatorSet` class. This view is broader to cover sustainability indicators' key information with no reference to any particular organisations and is called *Generic Ontology for Sustainability Indicator Set* or GOSIS.
  In our discussions with domain experts, the particular affordance of this design is its *reusability* and *extensibility*. People who are not ontology designers can add new indicator sets and indicators without modifying the classes and properties of the ontology.
- **Pattern 2 - SOSIS design:** This design treats indicator sets and their indicators as disjoint class hierarchies. For example, `GRIIndicatorSet` is a subclass of the `IndicatorSet` superclass, while indicators are instances of classes that model properties specific to each indicator system. This allows for a more direct representation of the underlying conceptualisation of those systems. The `GRI Relevance` class has no equivalent concept in the OECD taxonomy, and this difference is evident in the class design of the ontology alone. Since this view includes direct references to specific indicator sets, it is called *Specific Ontology for Sustainability Indicator Sets* or SOSIS.
  Domain experts considered this design more helpful in terms of *explicitness*, as it is clear what information is available about indicators in each of the distinct indicator sets. However new indicator sets require additional modelling of the ontology's classes and properties, which impacts its *reusability*.

4 Discussion

Following the ontology engineering process of METHONTOLOGY [6] described in earlier works [12,13] and using the Value Partition pattern – described in the

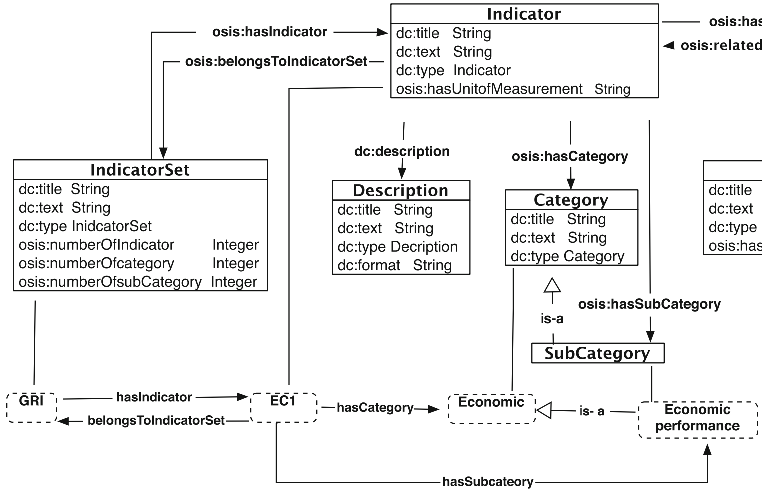

Fig. 3. UML diagram of GOSIS design using Value Partition pattern 1

series of WC3 practices[8] and discussed in Sect. 3.3 – we have developed two ontology design candidates, labelled respectively GOSIS and SOSIS. These differ largely in terms of abstraction, as discussed below.

The GOSIS design defines broadly a suitable structure and reflects the generic key concepts of sustainability indicators. As a result, and in line with pattern 1, this design applies an object-oriented approach that encapsulates the generic features of all indicator sets into a series of base or foundational classes. The SOSIS design, on the other hand, emphasises the role of the organisations that develop sustainability indicators. In designing SOSIS, we use VP pattern 2, that includes the key concepts of these organisations with their own indicator classifications. As a result, this design uses a range of classes and relations that are specifically added for each sustainability indicator set.

The UML diagrams, built upon the aforementioned Patterns of VP, are shown in Figs. 3 and 4 and the OWL representation of both ontology designs can be found here[9].

The GOSIS design treats each indicator set as well as their indicators as individuals, and each set instantiates properties and relations of the `IndicatorSet` class (Fig. 3). It contains fewer classes, and is less intuitive for domain experts to read – at least in an ontology editing tool such as *Protégé Desktop*, understanding the structure of the ontology requires frequent traversal of 'Class' and 'Individual' tabs, for instance. Accordingly, we consider this a more abstracted view of the underlying domain of multiple sustainability indicator systems.

By contrast, the SOSIS design treats each indicator set as a class. Accordingly, they inherit rather than instantiate properties and relations of the `IndicatorSet`

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[8] http://www.w3.org/2001/sw/BestPractices/OEP/SpecifiedValues-20050223/.
[9] http://www.circlesofsustainability.org/wp-content/uploads/2016/12/.

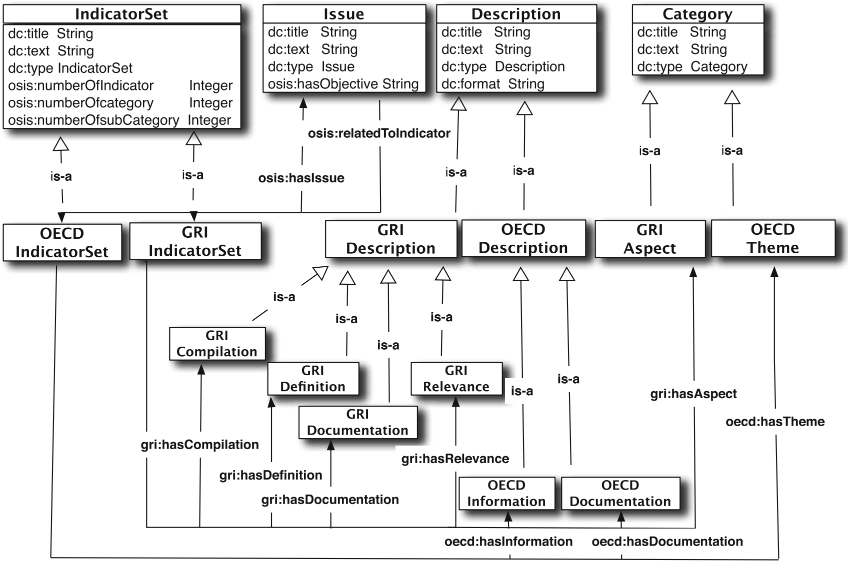

Fig. 4. UML diagram of SOSIS design using Value Partition pattern 2

class. This produces a much larger ontology that maps directly to the specific frames of reference that it is derived from, and we term this the *concrete* variation of the Value Partition ontology design pattern (Fig. 4).

5 Conclusion and Future Work

In this work, we have discussed how the use of existing ontology design patterns can help resolve modelling issues in developing and constructing an ontology for sustainability indicators.

Our focus in designing GOSIS and SOSIS was to employ the Value Partition ODP to develop generic and specific models for sustainability indicators that covers broad key concepts of the domain as well as specific indicator sets. The findings from the previous section indicate the relative merits of our ontology designs. From a human readability perspective, we determine the two candidates, the generic design GOSIS and the specific design SOSIS, differ largely in terms of their relative abstractness or concreteness. The generic design contains less classes, and is less readable; the specific design has more classes, but is more difficult to modify or extend.

We have previously evaluated these ontology design candidates in earlier work [13]. Based on the findings presented here, we conclude that the specific design is preferable where the domain requirements require a high degree of fidelity to existing and known frames of reference, while the generic design offers greater reuse in contexts where unseen and unknown sets of indicators need to be added to the ontology in an *ad hoc* fashion. Accordingly, we also suggest that both ontology design models have their distinct merits, satisfying different requirements for representing indicator systems. Such requirements are generality and reusability in the case of GOSIS, and precision and intuitiveness in the case of SOSIS.

Our conclusion is aligned with one of the limitations of the VP ontology design pattern, which was developed based on OWL 1 in 2005 [20]. The constraints with OWL 1 was that a class in ontology must not be the value of a property. According to Rodriguez-Castro et al. [22], this constraint is resolved in OWL 2, where a class can have a property or instance values at the same time for DL reasoner. In addition, recent studies [5, 24] propose mapping structural design patterns in OWL as new solutions for such constraints.

Further work can be undertaken to incorporate additional sustainability indicators systems, and to further refine the candidate OSIS ontologies presented in this research. One approach for incorporating new systems is through the automation facilities provided by ontology matching algorithms[10]. Though discouraged by Rector [20], we also anticipate the possibility of blending the generic and specific designs in future, possibly using Simple Knowledge Organization System (SKOS)[11] as a means for representing complex sets of values that align to the `IndicatorSet` and `Indicator` classes of the generic and more abstract design. Recent work by Dudáš et al. [5] has also proposed PURO, a partially automated approach to generating alternative OWL encodings. Future work aims to examine how the respective merits of both designs can be preserved, and the ontology extended to other indicators systems, using combinations of ontology matching, SKOS representations and PURO software. Once complete, we also aim to conduct an axiom-based comparison of the two designs, to evaluate formally their respective similarities, differences and merits.

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References

1. Aranguren, M.E.: Ontology design patterns for the formalisation of biological ontologies. Master's thesis, University of Manchester (2005)
2. Aranguren, M.E.: Role and Application of Ontology Design Patterns in Bio-Ontologies. PhD thesis, University of Manchester (2009). http://mikeleganaaranguren.files.wordpress.com/2010/01/thesis.pdf
3. Booch, G.: Object-Oriented Analysis and Design with Applications. Benjamin-Cummings, Redwood City (1994)
4. Brilhante, V., Ferreira, A., Marinho, J., Pereira, J.S.: Information integration through ontology and metadata for sustainability analysis. In: The International Environmental Modelling and Software Society (iEMSs) 3rd Biennial Meeting (2006)

[10] http://ontologymatching.org/projects.html.
[11] https://www.w3.org/2004/02/skos/.

5. Dudáš, M., Hanzal, T., Svátek, V., Zamazal, O.: OBOWLMorph: Starting ontology development from PURO background models. In: Tamma, V., Dragoni, M., Gonçalves, R., Ławrynowicz, A. (eds.) OWLED 2015. LNCS, vol. 9557, pp. 14–20. Springer, Cham (2016). doi:10.1007/978-3-319-33245-1_2
6. Fernandez, M., Gomez-Perez, A., Juristo, N.: METHONTOLOGY: From ontological art towards ontological engineering. In: Proceedings of the AAAI97 Spring Symposium Series on Ontological Engineering, pp. 33–40. AAAI Press (1997)
7. Fox, M.S.: A foundation ontology for global city indicators. Department of Mechanical and Industrial Engineering University of Toronto, Global Cities Institute Working Paper No. 3 (2014)
8. Gamma, E., Helm, R., Johnson, R., Vlissides, J.: Design Patterns: Elements of Reusable Object-oriented Software. Pearson Education, Upper Saddle River (1994)
9. Gangemi, A.: Ontology design patterns for semantic web content. In: Gil, Y., Motta, E., Benjamins, V.R., Musen, M.A. (eds.) ISWC 2005. LNCS, vol. 3729, pp. 262–276. Springer, Heidelberg (2005). doi:10.1007/11574620_21
10. Gangemi, A., Presutti, V.: Ontology design patterns. In: Staab, S., Studer, R. (eds.) Handbook on Ontologies. International Handbooks on Information Systems, pp. 221–243. Springer, Heidelberg (2009). doi:10.1007/978-3-540-92673-3_10
11. Gangemi, A., Gómez-Pérez, A., Presutti, V., Suárez-Figueroa, M.C.: Towards a catalog of OWL-based ontology design patterns. In: CAEPIA. Neon Project Publications (2007)
12. Ghahremanloo, L.: An integrated knowledge base for sustainability indicators. In: Australasian Computing Doctoral Consortium. RMIT Melbourne (2012). http://www.cs.rmit.edu.au/acdc2012/
13. Ghahremanloo, L., Thom, J.A., Magee, L.: An ontology derived from heterogeneous sustainability indicator set documents. In: Proceedings of the Seventeenth Australasian Document Computing Symposium, pp. 72–79. ACM (2012)
14. Guarino, N., Welty, C.: Evaluating ontological decisions with OntoClean. Commun. ACM **45**(2), 61–65 (2002). doi:10.1145/503124.503150
15. Han, D., Stoffel, K.: Ontology based qualitative case studies for sustainability research. In: Proceedings of the AI for an Intelligent Planet. ACM (2011). Article 6
16. Kumazawa, T., Saito, O., Kozaki, K., Matsui, T., Mizoguchi, R.: Toward knowledge structuring of sustainability science based on ontology engineering. Sustain. Sci. **4**(1), 99–116 (2009). doi:10.1007/s11625-008-0063-z
17. Lozano-Tello, A., Gómez-Pérez, A.: ONTOMETRIC: a method to choose the appropriate ontology. J. Database Manage. **15**(2), 1–18 (2004). http://oa.upm.es/6467/
18. Madlberger, L., Thöni, A., Wetz, P., Schatten, A., Tjoa, A.M.: Ontology-based data integration for corporate sustainability information systems. In: Proceedings of International Conference on Information Integration and Web-Based Applications & Services, pp. 353–357. ACM (2013)
19. Pinheiro, W.A., Barros, R., De Souza, J.M., Xexeo, G.B., Strauch, J., Barros, P., Campos, M.: Adaptative methodology of sustainability indicators management by ontology. Int. J. Glob. Environ. Issues **9**(4), 338–355 (2009). http://EconPapers.repec.org/RePEc:ids:ijgenv:v:9:y:2009:i:4:p:338-355
20. Rector, A. (ed.) Representing specified values in OWL: "value partitions" and "value sets". W3C working group note, 17 May 2005

21. Reich, J.R.: Ontological design patterns: metadata of molecular biological ontologies, information and knowledge. In: Ibrahim, M., Küng, J., Revell, N. (eds.) DEXA 2000. LNCS, vol. 1873, pp. 698–709. Springer, Heidelberg (2000). doi:10.1007/3-540-44469-6_65
22. Rodriguez-Castro, B., Ge, M., Hepp, M.: Alignment of ontology design patterns: class as property value, value partition and normalisation. In: Meersman, R., et al. (eds.) OTM 2012. LNCS, vol. 7566, pp. 682–699. Springer, Heidelberg (2012). doi:10.1007/978-3-642-33615-7_16
23. Staab, S., Erdmann, M., Maedche, A.: Engineering ontologies using semantic patterns. In: Proceedings of the IJCAI 2001 Workshop on E-Business & the Intelligent Web, pp. 174–185 (2001)
24. Svátek, V., Homola, M., Kluka, J., Vacura, M.: Mapping structural design patterns in owl to ontological background models. In: Proceedings of the Seventh International Conference on Knowledge Capture, pp. 117–120. ACM (2013)