Toward Collaborative LCA Ontology Development: a Scenario-Based Recommender System for Environmental Data Qualification

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***Abstract*—This paper describes a collaborative approach to ontology development for data qualification for life cycle assessment by taking into consideration the Life Cycle Inventory (LCI) and Data Quality Indicator (DQI). The developed ontology is integrated with rule-based knowledge, to provide user-defined policies for LCI based on DQI. An ontology application management framework is developed to provide a collaborative environment for knowledge engineers and domain experts to define the knowledge explication and recommendation rules based on usage scenario. LCI data from agricultural domain is collected, and mapped to the knowledge base. To demonstrate the advantage of transformed rules, a scenario-based recommender system is built on top of the ontology, and carries out data quality measurement.**

***Index Terms*—Semantic Web, Ontology, Collaboration, Life Cycle Assessment, Life Cycle Inventory, Data Quality Indicator**

I. Introduction

In terms of sustainability sciences [1], an understanding of the fundamental characteristics of interaction between nature and society is emerging in environmental management and preservation. In Sustainable Development (SD), current human needs of the Earth's limited resources is taken into account to balance technological advancement with the environmental survivability of future generations.

To measure the environmental impact, *Life Cycle Assessment (LCA)* is an environmental impact assessment (EIA) tool that identifies, quantifies energy and materials used and released to the environment, and evaluates and implements opportunities to influence environmental improvements. Following the SD paradigm in an interdisciplinary approach, LCA is then applied to assist other disciplines to understand environmental impacts in their field of interest as cross-disciplinary coordination. The standard guidelines (ISO 14040 [2], 14044 [3], and 14048 [4]) of LCA are employed to calculate the environmental impacts by several agencies, companies, and research fields that have different approach depending on their interpretation. Interpreted guidelines are utilized in many approaches such as a Life Cycle Inventory (LCI) database in information technology, Life Cycle Costing (LCC) in determining the most cost-effective option in an economic field, and knowledge structuring in semantic technology.

In the semantic approach, LCA knowledge is analyzed and formalized into a computable representation. This kind of representation is formally defined by Semantic Web [5] that enables computers and people to work side by side [6]. The Semantic Web provides a language to express datafields, concepts, concept relations, and rules for an inference system allowing us to conduct automated reasoning. Concepts of many LCA knowledge representations are interpreted and exported into the Web, called ontologies.

Although we have a variety of LCA ontologies to adopt in our research activities, acquisitions for a comprehensive knowledge of LCA require a very steep learning curve for novice users. Development and management of such knowledge are laborious and require a close collaboration among domain experts [7]. Therefore, knowledge transfer among the relevant stakeholder's community becomes a non-trivial task.

To shorten learning curve, this paper presents a collaborative approach to cope with an issue that two kinds of stakeholder (knowledge engineers and domain experts) participates in a contribution of the LCA knowledge curation. The challenge of knowledge extraction and a practical usage of knowledge base is solved by knowledge engineering.

We first describe the roles of LCA, semantic web technology management, and existing LCA knowledge bases in Section II. Two components of a knowledge framework for LCA ontology management are described in Section III. Ontology development, instantiation, defining rules, and semantic web applications are described and demonstrated subsequently. We discuss issues of practical usage and working challenges and give conclusion, respectively, in the last two sections.

II. Related work

A. LCA ontologies

This section reviews previous work on ontology development and implementation that is applied to LCA knowledge.

Table I
COMPARISON OF LCA ONTOLOGIES

Related work	Reference source of LCA knowledge		Semantic Web Technology		Reasoning	Software/ Application
	ISO14040, ISO14044 Principle and Framework	ISO14048 Data document format	Ontology development RDF/XML	Ontology based-on OWL/DL		
F. Cappellaro et al.[8]		✓		✓		✓
M. Braescher et al.[9]	✓		✓	✓		
B. Sayan [10]	✓	✓				
B. Bertin et al. [11]	✓	✓	✓			✓
E. Muñoz et al. [12]						
A. Takhom et al. [13], [14]	✓	✓		✓	✓	✓

Their characteristics are summarized and compared in Table I.

CASCADE Project. The first LCA ontology project is designed under Project CASCADE [8]. The project interprets LCA information in the standard data format guideline in ISO14048 [4]. The data format ontology aims to accommodate standard development in design and manufacturing with their requirements for LCA. The project achievements are delivered in LCA ontology OWL [5], a W3C recommended ontology language. The ontology was utilized in a standard conversion software, a web site, and a procedural guideline. For the collaborative aspect, LCA knowledge is interpreted by a domain expert and the ontology is constructed by a knowledge engineer.

LCAO Ontology. This LCAO ontology [9] is developed by the Brazilian Institute for Information in Science and Technology (IBICT). Their work concern the Follow-up of Life Cycle Assessment (FLCA) according to ISO 14040 [2] standard guideline. The project provides the LCA framework, aiming at organization and retrieval of information, and a contribution to consensual vision. Their work presents an effort to construct the LCA framework from interpretation of the standard guideline by knowledge engineers.

Bertin et al. [11]'s ontology modelling. As a case study of the U.S. energy impact data management, LCI data can also be semantically represented as manipulatable databases using relational algebra. This LCI ontology consists of economic activities considered as elementary processes linked together through interdependency relations. Their work presents a semantic approach to LCA knowledge that is applied to energy environmental impact data management. The data was analyzed and then interpreted. LCI can also be semantically represented as manipulatable databases using relational algebra. The ontology modeling by a mathematical technique for collaborative discussions among domain exports and knowledge engineers demonstrates the benefits of logical structures extraction.

Applied environmental ontology for enterprise resource management. The ontology for the environmental assessment of enterprise system [12] is applied to a case study of a supply chain network design and planning in optimization problems of process scheduling. In terms of interdisciplinary approach, conceptualization requires collaboration among stakeholders (e.g. discussion) to integrate existing environmental ontologies with knowledge of enterprise resource planning.

O-LCA Ontology. LCA knowledge is formalized by taking life cycle inventory and life cycle impact assessment into account and designing an ontology. The knowledge are converted the knowledge into a well-structured and exchangeable form which facilitates information sharing and discussion among domain experts. An LCA ontology is represented formally in terms of Description Logic (DL). For a collaborative aspect, the ontology was designed from interpretation of resources of knowledge including LCA standard guidelines and existing ontologies, and discussion with domain experts. The ontology requires knowledge formalization in conceptual design based on DL by knowledge engineering. For instance, constraints of concepts could be expressed effectively and also inference with available reasoning services.

For our work, the new ontology is designed by considering concepts and their relations in the existing ontologies. Necessary concepts from analyzing the the applied ontology [12] and O-LCA ontology ([14], [11]) are also integrated into the ontology.

However, our ontology differs from the others in that we focus on adaptative LCA ontology in LCI concepts for qualitative data measurement. Our LCI concepts are designed to comply with the Data Quality Indicator (DQI) measures, enabling us to formally describe LCA data properties in terms of DQI concepts. Moreover, our recommender system can inferences by deploying of defined rules, transforming of usage scenario from domain experts.

B. An approach for collaborative ontology development

Existing LCA ontologies were constructed for simulation and decision support systems. Our ontology development needs to ensure the quality of ontology, because the knowledge is curated and authored by different domain experts.

From Groza et al. [15]'s commentary in knowledge curation and creating of collaborative environment, our work deals with knowledge curation by refining LCA ontologies and employing a knowledge-based framework for enhancing a collaborative creation. Challenges for a collaborative approach, are in two aspects: 1) to design ontology by knowledge engineering, and 2) to capture knowledge by domain experts.

III. KNOWLEDGE FRAMEWORK

With the rationale of ontology stakeholder collaboration described in Section I, OAM Framework[1], an ontology-based application management system [16], is selected to simplify our activities in collaborative development and implementation

[1] http://text.hlt.nectec.or.th/ontology/

with a knowledge base as illustrated in Figure III. Collaborative activities are facilitated by our system as demonstrated in Section IV. We focus on acquisition and accessing of the knowledge base that are designed and organized both LCI and DQI concepts. The framework consists of two main components: 1) the knowledge base and 2) the recommender engine.

Knowledge Base. The knowledge base is a component built from resources of knowledge (e.g. existing ontologies, guideline document) analyzed and designed by domain experts. It consists of two subcomponents: 1) a domain ontology representing a knowledge structure to user by a visualization tool, 2) defined rules are created for inference in a decision model that use in generating recommendation results.

Recommender Engine. The recommender engine processes the ontology data in the W3C Web Ontology Language (OWL) [5] format in the knowledge base. The framework maps the database to ontology using the RDF model for ease of data manipulation. Thus, the rule-based knowledge can be applied by retrieving data from mapping of knowledge base and database. The Jena API is mainly used in manipulating the knowledge base data.

IV. Design and implementation

A. Ontology development

The LCA knowledge structure is explicated and visualized by using the Hozo ontology editor [17] as shown in Figure 3. The ontology is designed based on the ontology theory of Role-concept [18]. Basic terms are defined are distinguished by the domain context. The representation of basic concepts can identify the relation with other corresponding concepts.

As aforementioned in Section II, necessary concepts of the DQ-LCA ontology is analyzed and designed based on existing LCA ontologies. The ontology development involves defined concepts, concept hierarchies, concept properties and its constraints. The ontology contains 105 concepts, 21 object properties, 105 datatype properties, and 20 individuals. The LCA concepts are categorized into three groups of upper concepts (as depicted in Figure 2,): Life Cycle Inventory concepts in the yellow rectangle group, Environmental Impact Assessment Concepts in the blue rectangle group, and Data Quality Indicator concepts in the red rectangle group.

Although we organize the DQ-LCA ontology into three groups from necessary concepts of existing ontologies, one of our objectives is to present benefits of data quality measurement. Thus, we focus on two groups of concepts including 1) Life Cycle Inventory and 2) Data Quality Indicator.

Life Cycle Inventory Concept. The structure of the "*Life Cycle Inventory*" or LCI is the concept group of dataset inventory that formalizes data and its documentation describing the properties of the environmental process. As illustrated in Figure 3, the interpreted concepts are presented as follows:

1) "*Process*" concept, consisting of four main sub concepts, "*Process Description*", "*Administrative Information*", "*Process Modelling*", and "*Input and Output Process Flows*";
2) "*Assessed Process*" concept, an inheritance concept, consisting of "*Process*" and "*Assessment Method*";
3) The quantified concepts consisted of "*Quantity*" and "*Unit*".

Data Quality Indicator Concept. We construct this concept y encouraging participation of domain experts. As mentioned in the standard guideline (ISO14044), data quality requirements should be described to define the LCA scope clearly. The requirements specify the goal and scope, involving precision, completeness, representativeness, consistency, reproducibility, sources of the data, uncertainty of the information and also coverage of time-related, geography, technology. To make the requirements quantifiable, we consider Product Environmental Footprint (PEF), a measure of all environmental impacts. The measure helps us to compromise two main concepts; LCI and DQI. We consider a related document from European Commission that explain and give an example of PEF approach. An official journal of European Commission [19] is analyzed and interpreted as knowledge resource in a section of data quality requirements. The journal describes six criteria to adopt DQI knowledge based on PEF studies. Our ontology is designed to comply with Data Quality Indicator (DQI). The DQI concepts are associated with LCI concepts by indicating quality of a process described in its concept description. As illustrated in Figure 4, DQI concepts have two object property and one datatype properties as follows:

1) Concept "*Data Quality Criterion*" presents data quality used throughout the standard guideline [3], consisting of six kinds of criteria: 1) "*Technological Representativeness*"; 2) "*Geographical representativeness*"; 3) "*Time-related representativeness*"; 4) "*Completeness*"; 5) "*Parameter uncertainty*"; and 6) "*Methodological Appropriateness and Consistency*" .
2) Concept "*Data Quality Rating*" presents calculation of the achieved quality rating in six criteria of "*Data Quality Criteria*" concept, defining by five level of "*Data Quality Level*"

B. Instantiation

Despite visualization as ontology, a compatibility between concept and its related data needed to make domain experts familiar with domain contexts. To instantiate individuals of a concept, we look for open data to collect and then to check contextual compatibility for concept and data mapping. Therefore, the requirements from our experiment are as follows:

- Open data;
- Collected data that are interpreted from ISO standard guideline. (e.g. Ecospold dataset format or ELCD data format);
- Specified-field of interest as agriculture domain.

Note that we are interested in LCI data of an agricultural domain that will be useful in concept checking, because the terms of this domain are common understanding. We sample the domain data from LCA Digital Commons Project

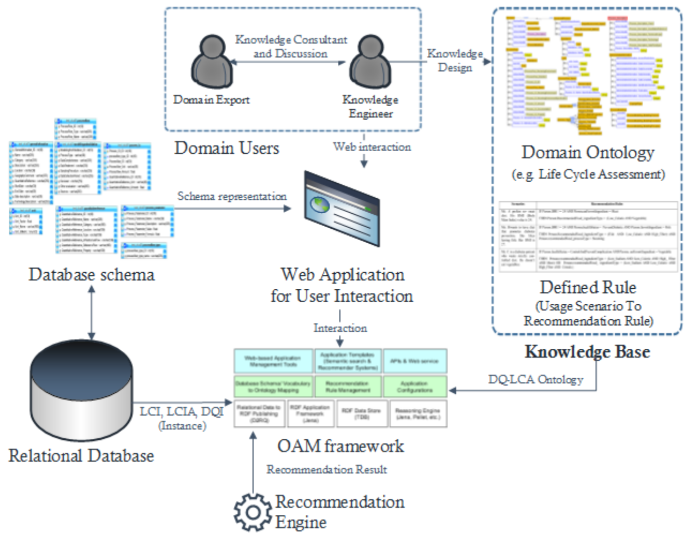

Figure 1. Collaborative interaction of domain stakeholders in knowledge-based framework [16] for a recommendation system

at the National Agricultural Library[2] [20] that provides open access to LCI datasets and an open source software. The data quality analysis methods are applied to describe qualitative information of the datasets as numeric scores. Their methods consider the data quality aspects specified by the ISO standards and in the differentiation of data quality. For an infrastructure of their LCI dataset management system, their open datasets are collected from practitioners in RDF/XML syntax, called EcoSpold data format. The datasets are transformed into ELCD Format, and then stored in LCI database.

After the dataset preparation, we construct the database of storage our collected datasets and map the concepts to the datafields. We consider a relationship between properties of related concepts and datafields of LCI datasets (e.g. "*Geographical representativeness*" and "*Valid-geography*"). As illustrated in Figure 4. Each concept has its properties including descriptive values and numerical values. We let two stakeholders (LCA domain experts and knowledge engineers) discuss in interrelation among properties of related concepts and a definition of related datafields. To encourage this collaborative process, the OAM framework provides an application system for mapping between OWL ontology and a relational database that can select concepts and map them with related datafields as depicted in Figure 5.

C. Defining rules

To point out the benefits of knowledge inference, each rule-based concept is defined based on data measurement as DQI concepts, and user-defined policy concepts. For instance, an industrial policy defines the standard policy to measure process quality, following DQI. The defined rules for recommender system is transforming usage scenarios defined by domain experts. The vocabularies in the usage scenarios control scope of describing scenario by a concept name its relation concepts

[2]LCA Digital Commons Project at the National Agricultural Library (http://www.lcacommons.gov) was used to collect data for instantiation

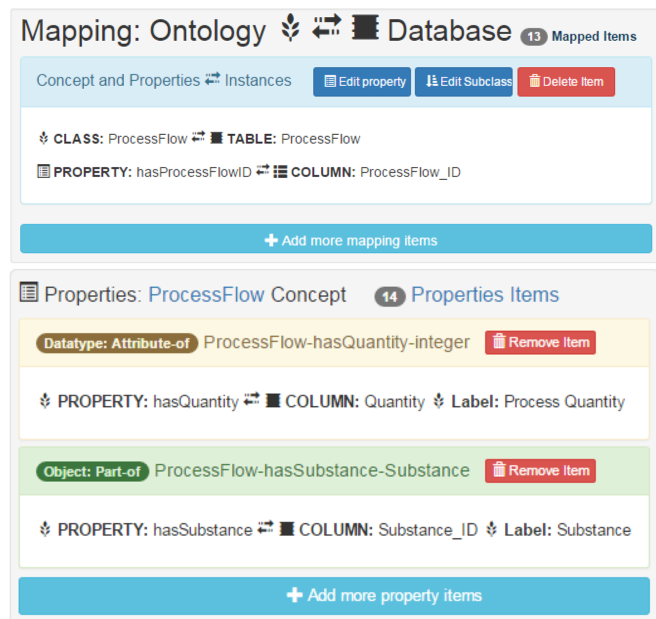

Figure 5. Mapping between ontology and database: concept properties are considered with corresponding data fields

in user defined policy. Therefore, the rules can be used in generating a quality process as the recommended result.

In our approach, LCA knowledge elicitation and visualization are used to encourage domain experts to participate in knowledge engineering. Domain experts and knowledge engineers transcribe the domain knowledge into concepts, concept relations, and individuals and then co-define inference rules, using the same semantics. This technique is called *vocabulary control*. We assume domain experts to have stipulate some assessment criteria for the qualified dataset. For instance, to claim the green label for their production, the quality criteria for process assessment are as following conditions:

- Overall DQR should be fairer (lower than 4.0);

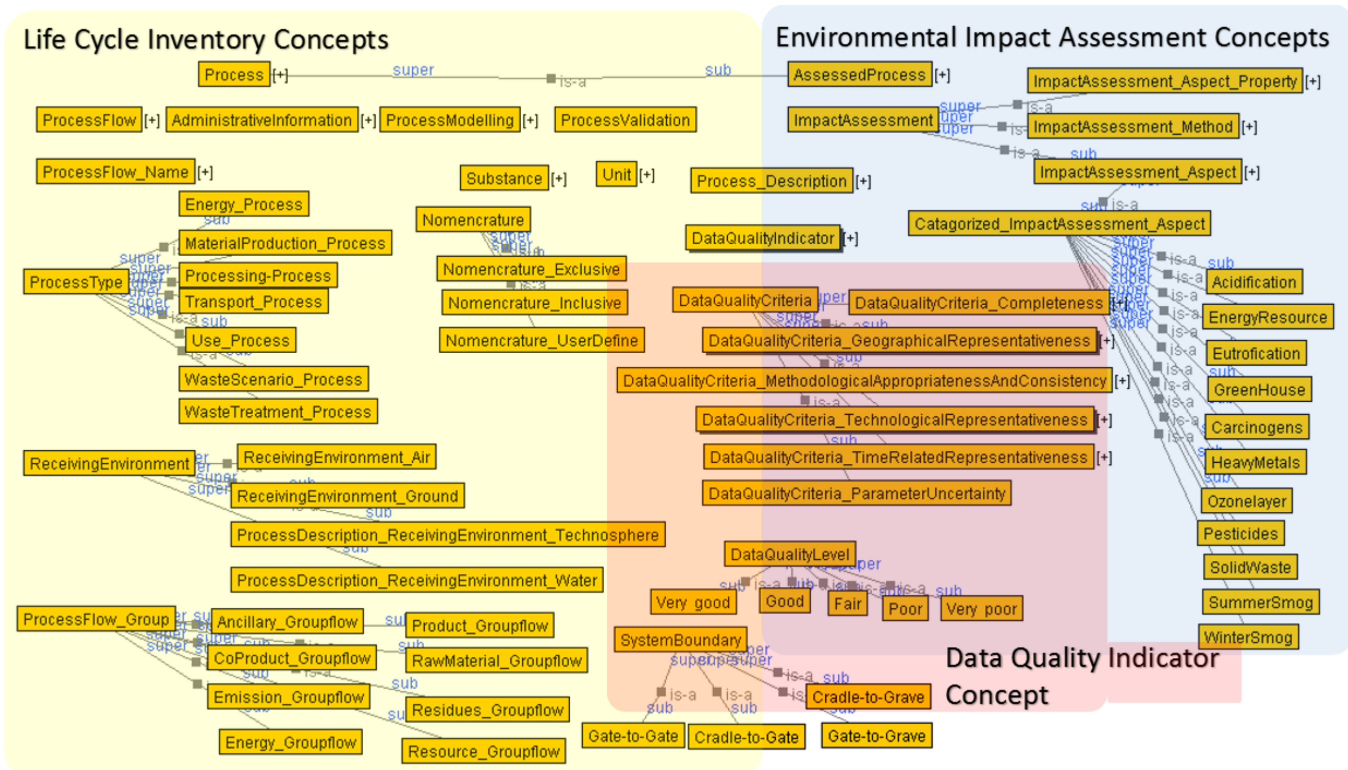

Figure 2. Three groups of upper concepts in our DQ-LCA ontology: 1) LCI concepts in a yellow group, 2) EIA concepts in blue group, and 3) DQI concepts in red group.

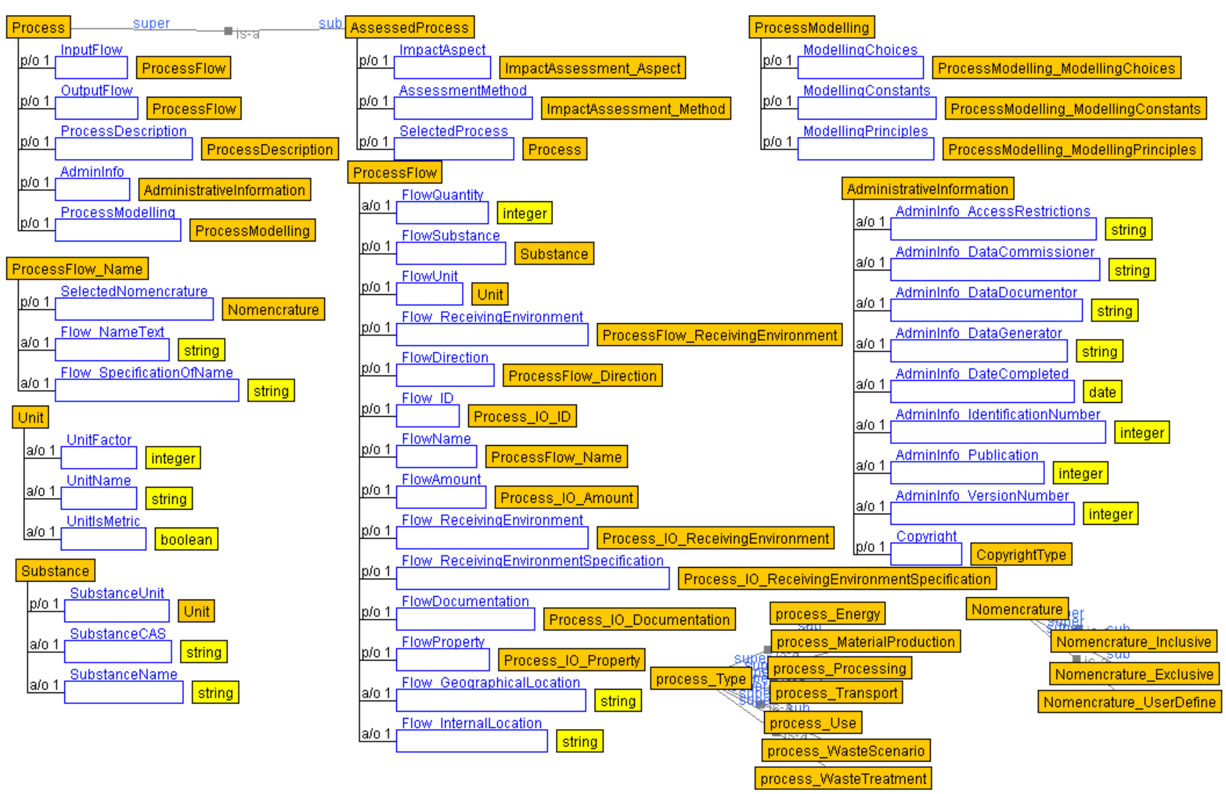

Figure 3. A group of Life Cycle Inventory concepts in the DQ-LCA ontology

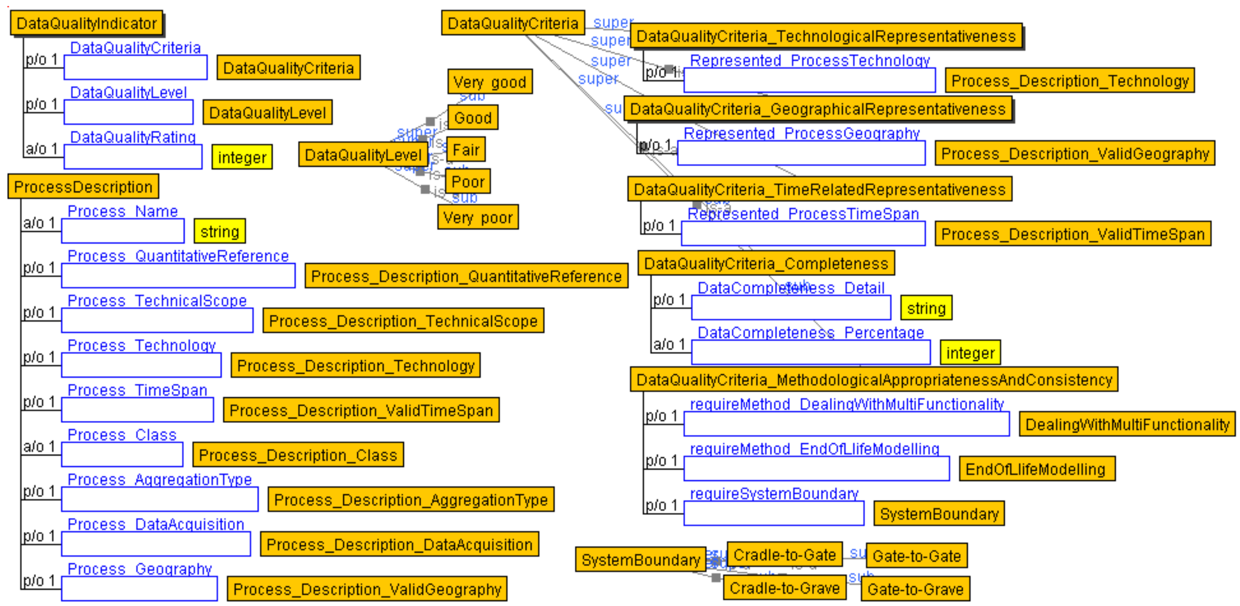

Figure 4. A group of Data Quality Indicator concepts in the DQ-LCA ontology

- Collected in Arkansas, United States only;
- Gathered from last five years from now (Fair);
- At least two method requirements of the PEF Guide: (System boundary should be the same, e.g. Cradle-to-Gate, Gate-to-Gate, and the end of life modeling requires an environmental burden).

Then, the usage scenario is analyzed and transformed into defined rules as shown in Table II.

D. Semantic search and data quality recommendation system

The OAM framework provides two application systems that simplify collaboration among LCA stakeholders: 1) semantic search and 2) recommendation rule management.

Semantic search. LCA stakeholders can search concept individuals by selecting a concept and defining conditions. The conditions can be defined by two types of property (i.e. object and data type). The properties are made for domain users familiar with object properties. The object property is transformed into "*part-of*" relations with concept constraints (e.g. hasSubstance), and the datatype property is transformed into "*attribute-of*" relations with concept constraints (e.g. hasQuantity). By doing so, domain experts can understand the underlying semantics by selecting the related properties. After defining the concept properties, LCA stakeholders define values of each condition for searching. Finally, the individuals are displayed as the result of selected concept and defined conditions as depicted in Figure 6.

Recommendation system. For deploying recommendation rule management, the defined rules for based on the scenario of data qualification are used in implementation of a recommender system. The usage scenario defines prerequisite criteria of "*LCI*" concept to inference individuals that associated with "*User-Defined Policy*" concept as depicted in Figure 7.

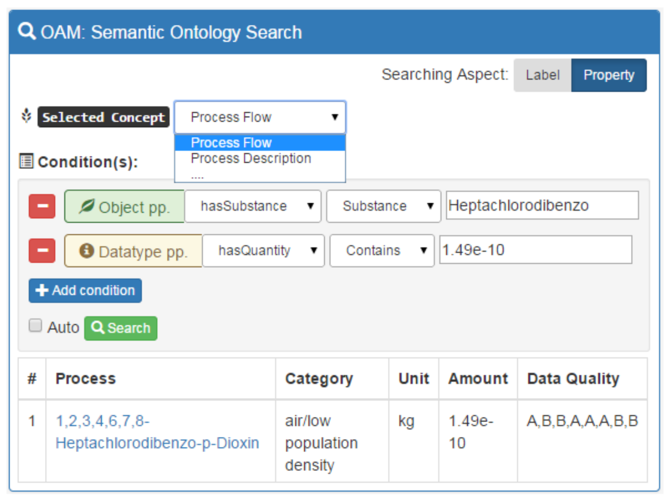

Figure 6. Semantic search for the integrated LCA ontology

V. Discussion

Although collaborative rule based approaches can be integrated into LCA systems or other LCS software directly, rule-based knowledge representations are limited to basic equations describing concepts [21]. While our approach to handle data quality evaluation, the prevalence of collaborative ontology approaches provide a level of generality by a richer semantic representation. For instance, expressivity of the OWL language can describe concept constraint such as "exists", "all", "at least", "at most", "exactly". The elements of the OWL language have at least two lower language layers: Resource Description Framework (RDF) and; RDF Schema.

Aiming at knowledge-based sustainability with the collaborative approach, we present LCA knowledge curation that make LCI concepts to be compatible with concept properties of data quality criteria in DQI concepts. The recommended

Table II
AN EXAMPLE SCENARIO FOR A RECOMMENDER SYSTEM FOR ENVIRONMENTAL DATA QUALIFICATION CONSISTING OF THE USER SCENARIOS AND THE RECOMMENDATION RULES THAT APPLIED.

Usage Scenario	**Recommendation Rules**
Goal: to claim the green label for rice product **Prerequisite criteria for qualify datasets:** - Overall DQR should be fairer (lower than 4.0) - Collected in Arkansas, United States only - Gathered from last five years from now (Fair) - At least two method requirements of the green labels guide: (1) System boundary should be the same, e.g. Cradle-to-Gate, Gate-to-Gate (2) The end of life modeling requires an environmental burden	IF *DataQualityIndicator.hasDataQualityRating* <= 4.0 AND *GeographicalRepresentativeness* = "Arkansas, UnitedStates" AND *TimeRelatedRepresentativeness* = *Fair* AND *MethodologicalAppropriatenessAndConsistency.requiredMethod* = (*SystemBoundary* = *CradleToGate* OR *SystemBoundary* = *GateToGate*) AND *MethodologicalAppropriatenessAndConsistency.requiredMethod* = (*EndOfLifeMidelling* = "EnvironmentalBurden") THEN *UserDefinedPolicy.hasRecommendedProcess* = (*ProcessDescriptionName* AND *ProcessDescriptionType*) AND *UserDefinedPolicy.hasRecommendedQualifiedProcess* = (*DataQulityRating* AND *DataQulityCriteria.isPresentedBy*= *TechnologicalRepresentativeness* AND *DataQulityCriteria.isPresentedBy*= *GeographicalRepresentativeness* AND *DataQulityCriteria.isPresentedBy*= *Completeness* AND *DataQulityCriteria.isPresentedBy*= *MethodologyAppropriatenessAndConsistency*)

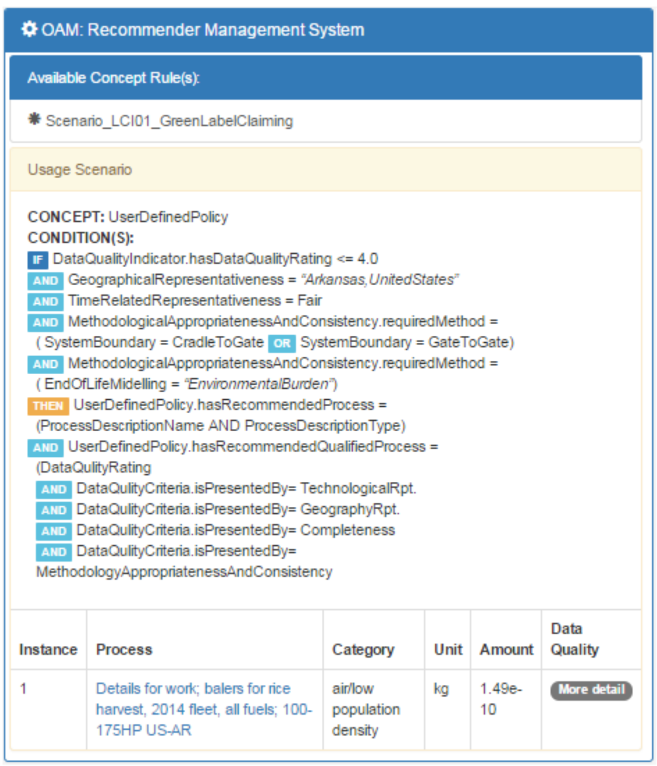

Figure 7. DQI, User-defined policy recommendation for the integrated LCA ontology

result from the ontology meet our research object that we can create the defining rules by partcipation of domain experts.

Although the DQ-LCA ontology is constructed from many knowledge sources (ISO standard guidelines, the official journal from European Commission, and existing ontologies) and designed by domain experts and knowledge engineers, the issue that some concepts in the knowledge structure, may contradict the logical constraint. In a traditional way, all stakeholders need to solve their contradictions by consensus. For instance, there are several ways to name datafields having the same functions, disallowing cross-platform compatibility and data conversion.

VI. CONCLUSION AND FUTURE WORK

We present a knowledge-based framework with a collaborative approach among domain experts and knowledge engineers. A challenge in LCA knowledge curation is demonstrated by design and implementation of a recommender system. The instruction in demonstration our collaborative approach is concluded as follows:

- First, we investigate existing LCA ontologies and adopt necessary concepts in the group of *Life Cycle Inventory (LCI)* concepts. *Data Quality Indicator (DQI)* concepts are analyzed and interpreted
- Next, we design and construct a database schema to store our collected LCI data from an open data provider.
- Then, we encourage domain experts to participate with our created knowledge base. Starting with mapping LCI concepts to the database, LCA stakeholders can select a concept to map with associated data field in a relational database. From the mapping result, domain experts can check compatibility of concepts and data with knowledge engineer in the same semantic.
- After that, we extract an approach of data quality measurement based on usage scenarios from domain experts and then transform them into defined rules. We use defined rules to build the recommender system for qualified LCI processes based on prerequisite criteria.

Future work remains as follows. We plan to analyze Reza's [22] methodology to maintenance a knowledge base by community-driven approach. However, we plan to consider another issue to improve both of a collaborative approach and ontology development. Knowledge curation and creating collaborative environment are many challenges to find out the most suitable solution our research approach.

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