Ontological Metamodel of Sustainable Development

Boryana Deliyska
https://orcid.org/0000-0002-7791-4623
University of Forestry, Bulgaria

Adelina Ivanova
University of Forestry, Bulgaria

INTRODUCTION

In recent years, one of the most important research areas is that of Sustainable Development (SD). In its various aspects, SD is a multifaceted, complex and contradictory concept, interpreted in numerous studies. According to the most known and commonly accepted definition, "SD is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987, p.37). SD studies are inseparable from their modeling implemented by interdisciplinary researchers in a wide range of natural, engineering, mathematical, social, and economic sciences. Recently, a new scientific direction has emerged, called *sustainability science*. As in any science, in the core of the sustainability science is its conceptualization, i.e. clarifying and establishing a set of concepts that characterize it. One of the most effective approaches for this purpose is the ontology building. The notion *ontology* has two aspects. On the one hand, the ontology, as a branch of philosophy, studies, classifies and explains the entities and the nature of human beings. On the other hand, in informatics and computer science, an ontology is a computational data model representing concepts of given knowledge domain and their relationships. The main advantage of the computational ontology (referred briefly ontology from here below) compared to other domain conceptualization frameworks is that it represents widely available, shareable and reusable by human and computers domain knowledge and enable automated reasoning about data. Currently, the ontological modeling often precedes concrete researches and projects in different areas seeing the need for the non-ambiguous interpretation of the area's inherent terminology. Moreover, an ontology is a means for formal knowledge representation and machine-understandable knowledge generation based mainly on artificial intelligence (AI) theory, web technologies, data science and informatics methods and algorithms. For example, the background knowledge available in ontologies can be used to expand or enrich features in machine learning and to constrain the search for solutions to an optimization problem (Kulmanov, Smaili, Xin, & Hoehndorf, 2021). In other words, the ontology engineering is an AI technology for knowledge structuring, interchange and presentation. For these reasons, in the last 30 years ontologies have been actively developed.

Due to the interdisciplinarity of the SD field, in this work a conceptual model of SD in the form of set of interrelated ontologies (ontological metamodel) is developed. In view of the rapid SD evolution, a continuous generalization, clarification and refinement of its knowledge is necessary and the need of full SD ontological modeling arises. The generally shared view is that SD has three interdependent dimensions (pillars or constituents): ecological, social and economic. A coevolutionary approach is ap-

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plied as a framework for analyzing the mutual causal influences between the natural (environmental) and human (social and economic) dimensions.

The current work is intended for a wide range of specialists involved in the data science theory and practice including ontological data modeling and extracting knowledge in the various fields related to the SD. The goal of the work is to present a SD ontological metamodel which systematizes and brings together SD terminology, activities and documents as well as to provide the possibility for knowledge extraction. The metamodel includes two layers – conceptual and physical. At the conceptual layer, a hierarchical structure of three levels is built including: Common Ontology of SD (COSD) as a top ontology; related to it domain ontologies of SD in economy, society and nature; and application ontologies concerning specific SD object and processes. As example, an application ontology of firm sustainability is developed. The physical layer consists of instance databases (databases containing instances of the ontology concepts). As whole, for each ontology of the metamodel links to other external ontologies are established.

The remainder of this article contains the following. The next background is a review of SD ontological modeling. Then, a methodology of SD ontological metamodel development is exposed followed by description of reasoning and verification of the created ontologies. The metamodel publication and the problems of ontology knowledge extraction are presented. On the base of the results, solutions and recommendations are discussed. In the end, future research directions and conclusion are proposed.

BACKGROUND

A review of the achievements in ontological SD modeling discovers several ontologies that can be considered as parts of a common SD ontology:

- The Sustainable Development Goals Interface Ontology (SDGIO), elaborated by United Nations (UN) Inter-Agency Expert Group on Sustainable Development Goals (IAEG-SDG) in 2016-2017 (Jensen, 2016). SDGIO is the most developed ontology in the SD area and its last version from 08.10.2018 includes 906 terms (OLS, n.d.).
- The Ontology of Sustainable Development Indicators called SDI-Economics (Brilhante, Ferreira, Marinho, & Pereira, 2006). This ontology does not support all Sustainable Development Goal (SDG) indicators.
- The Ontology of Sustainability Assessment (SA) (Konys, 2018) and the Ontology for Sustainability Indicator Sets (OSIS) (Ghahremanloo, Thom, & Magee, 2012) containing mainly methodological issues about sustainability measurement and assessment.

These ontologies have some overlapping concepts but they are not related each other.

Claiming that a lack of knowledge systematization in the SD field exists, Deliyska, Todorov, & Ivanova (2020) have presented an elementary schema of SD ontological metamodel including a top SD common ontology and planned development of corresponding domain ontologies. In other works (Ivanova, Deliyska, & Todorov, 2018; Ivanova, Deliyska, & Todorov, 2021; Ivanova, & Deliyska, 2020), domain ontologies of SD in economy (called OSDE), in society (OSSD) and in environment (OESD) were presented. Besides OSDE, OESD and OSSD, other domain SD ontologies were not found, excluding Ontology for Bioeconomy (BiOnto) (Bicchielli, Biancone, Ferri, & Grifoni, 2021), which is associated with the economic and the environmental SD pillars.