Ecological Indicators 72 (2017) 803–820

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Text mining-based categorization and user perspective analysis of environmental sustainability indicators for manufacturing and service systems

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ARTICLE INFO

Article history:
Received 12 July 2015
Received in revised form 8 August 2016
Accepted 16 August 2016
Available online 20 September 2016

Keywords:
Environmental sustainability indicators
Categorization
Text mining
Indicator utilization
Indicator utility

ABSTRACT

In response to increasing global consciousness about the environmental impact of companies, a wide variety of environmental sustainability indicators and frameworks have been developed. Despite the variety of available environmental sustainability indicators, the absence of a commonly accepted categorization framework often creates confusion and inhibits indicator deployment in practice. This paper addresses this issue with a bottom-up approach that categorizes environmental sustainability indicators using their text-based objective information, and investigates industrial perceptions on indicator use. As the foundation for this work, 55 environmental sustainability indicators were extracted from extant literature. Then, companies from manufacturing and service domain were surveyed to reveal perceptions on utilization status (i.e. used in practice and future implementation) and utility (i.e. usefulness and practicality) of each indicator. For indicator categorization, the text descriptions of the collected indicators were modeled using a text mining technique, the correlated topic model, to extract their latent topics as a basis to categorize the indicators. As a result, five categories and their relevant indicators were defined. Further, the utilization status and utility levels of the indicators within the derived categories were analyzed. Possible relationships between indicator utility levels and company characteristics were also identified through logistic regression. Utility levels of specific indicators were found to change subject to market location and industry sector. Findings from this study can complement top-down conceptual categorization and inform implementation of indicators.

1. Introduction

Environmental sustainability is a broad concept that involves all scales of activities and efforts to maintain the appropriate quality of environmental infrastructure for short-term and long-term human well-being (Goodland, 1995; Moldan et al., 2012). Environmental sustainability has become an important issue for companies as their activities have been linked to a significant portion of global environment problems; for example, total global greenhouse gas emissions for industry and waste/wastewater increased by nearly 50% between 1990 and 2010, and 47% of wastewater produced in industrial sectors is untreated (IPCC, 2014). Given increasing global awareness towards environmental issues, companies are now urged to minimize their negative environmental impacts caused throughout the whole life-cycles of manufacturing processes, products, and services (Gunasekaran and Spalanzani, 2012; Klassen and McLaughlin, 1996; Yang et al., 2011). Moreover, business environments with limited natural resource capacity, energy cost fluctuation, environmental regulations, stakeholders' requirements, and cleaner technologies drive firms to integrate environmental sustainability in their core business strategies (Albino et al., 2009; Albino et al., 2012); thus, environmental sustainability is increasingly recognized as a new path of corporate competiveness (Dangelico and Pujari, 2010; Leonidou et al., 2015; Rao and Holt, 2005; Sonntag, 2000). Indeed, successful environmental management in firms leads to positive financial performance (Klassen and McLaughlin, 1996; Leonidou et al., 2015; Wong et al., 2012); and companies can attract environment-friendly customers through proactive efforts to satisfy environmental regulations and to reduce their environmental impacts (Bacallan, 2000; Martín-Peña et al., 2014).

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http://dx.doi.org/10.1016/j.ecolind.2016.08.027
1470-160X/

As a response to the emergence of environmental sustainability as a core business strategy and societal responsibility, a large number of indicators, indices, and accompanying assessment frameworks have been developed to assess progress and shortcomings towards environmental sustainability (Jasch, 2000; Joung et al., 2013; Singh et al., 2012). Indicators for environmental sustainability, as basic assessors of environmental impacts, have served a vital role. They utilize terms and values to effectively represent the multifaceted nature of environmental sustainability that can otherwise seem complex and ambiguous (Niemeijer and de Groot, 2008; Pannell and Glenn, 2000). Environmental sustainability indicators can be distinguished from metrics. Indicators effectively characterize various states of observed systems for decision makers to target and monitor environmental performance in firms (Jasch, 2000), whereas metrics are often used as means and measurements in calculating indicators (Veleva and Ellenbecker, 2001). Various indicators have been selectively grouped as indicator sets or aggregated as indices to provide assessment frameworks to comprehensively cover different aspects of environmental sustainability (Singh et al., 2012).

Despite the availability of various environmental sustainability indicators and assessment frameworks, it is still difficult for companies to use environmental sustainability indicators in practice. Companies face challenges in selecting a specific operational subset of indicators for their products and processes (Joung et al., 2013). Companies need to understand the relevance and potential benefits of numerous indicators to their objectives on environmental sustainability management in order to monitor their progress appropriately. They also should be able to properly organize applicable indicators in multiple environmental areas for a comprehensive interpretation of environmental impacts. Although evaluation frameworks with indicator sets or indices in extant literature support indicator selection, they often rely on ad hoc categorization and selection of indicators that may cause insufficient or excessive coverage across indicator categories. Moreover, the lack of information with regards to the utility of indicators and the technical and theoretical orientation of indicators hamper their implementation in practice.

Noting the necessity of indicator categorization and selection through an objective process that reflects users' perspectives, this paper focuses on environmental sustainability indicators for manufacturing and service systems to provide: 1) a logical decision process for categorizing indicators, 2) indicator utilization status and perceived utility levels in companies, and 3) an analysis of indicator utility subject to company characteristics. The remainder of this paper is organized into five sections. Section 2 reviews previous research on categorization and selection of environmental sustainability indicators. Section 3 introduces the preliminary work on the identification of available environmental sustainability indicators and the company surveys conducted to discern their utilization status and perceived utility levels. Section 4 presents an approach to categorize the collected environmental sustainability indicators through text mining along with its results. Section 5 presents the indicator survey results for the derived categories and analyzes the indicator utility levels and company characteristics through logistic regressions to reveal associations. Section 6 summarizes this work and proposes a compact set of useful and practical indicators for industrial use.

2. Previous research on categorization and selection of sustainability indicators

Indicator sets and indices combining various sustainability dimensions or areas help companies to measure their sustainability efforts on a much larger scale in comparison to the use of individual indicators (Joung et al., 2013). Indicator sets and indices can be used to conduct an unbiased evaluation of sustainability performance to easily identify deficit areas requiring further improvement. Responding to the necessity of sustainability evaluation from a holistic view, many studies have proposed indicator sets and indices that cover multifaceted sustainability dimensions from product/process, organizational, and regional perspectives. They include many indicators that can be employed to measure companies' sustainability efforts.

Earlier studies mainly focused on the development of indicator sets and indices relevant to environmental sustainability. Krotscheck and Narodoslawsky (1996) proposed the Sustainable Process Index (SPI), which consists of indicators to measure the areas required to provide raw materials and energy demands, to accommodate processes for products and by-products in a sustainable way. Shane and Graedel (2000) determined 10 categories of urban environmental sustainability for the essential components of cities and a representative indicator for each category to evaluate the sustainability levels of cities. Esty et al. (2005) of the Yale Center for Environmental Law and Policy developed the Environmental Sustainability Index (ESI) to assess environmental sustainability in regions and countries. ESI consists of 21 environmental sustainability indicators and categorizes these indicators into five core components derived from a broad theoretical basis in the ecological sciences and environmental policy.

Several of the frameworks featured categories of indicators covering environmental, social, and economic sustainability aspects. For example, Veleva and Ellenbecker (2001) proposed a framework with 22 core indicators for six indicator categories to facilitate measuring progress towards sustainable production in companies; this framework considers environmental, social, and economic aspects of an organization's activities. Schmidt and Taylor (2006) proposed the Product Sustainability Index (PSI), consisting of eight sustainability indicators in the environmental, social, and economic categories, to perform a life-cycle assessment in automotive products development. The United Nations' Department of Economic and Social Affairs (UN, 2007) provided 96 indicators grouped by 14 economic, social, and environmental health themes to measure the level of sustainable development in countries and regions.

Some frameworks were designed to be more relevant to various functional areas or foci in companies. The Organisation for Economic Co-operation and Development (OECD, 2011) introduced 18 key sustainable manufacturing indicators categorized by inputs, operations, and products to provide a sustainable manufacturing tool-kit for the evaluation of environmental performance in manufacturing companies. Erol et al. (2011) developed a sustainability assessment framework enabling multi-criteria sustainability evaluation for supply chains and determined a set of 37 indicators within environmental, social, and economic sustainability for retail companies. Efroymson and Dale (2015) provided an indicator set for analyzing the sustainability of algal biofuels, which consists of 16 environmental indicators in six categories to represent environmental sustainability areas for bioenergy.

A logical and clear process for categorizing and selecting indicators is required to ensure effectiveness and reliability of indicator use. Accordingly, methodological approaches to establish guidelines for proper indicator categorization and selection have been also discussed in the literature. Pannell and Glenn (2000) developed a conceptual framework based on Bayesian decision theory for the economic valuation and prioritization of sustainability indicators in agriculture to facilitate indicator selection under uncertain decision making environments. Krajnc and Glavič (2005) proposed a decision framework to create a composite sustainable development index for measuring and comparing performance of companies in all dimensions of sustainability, which can select, group, and aggregate indicators with different units and measurement char-