Environmental Impact Assessment Review 56 (2016) 128–138

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

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

New Internet search volume-based weighting method for integrating various environmental impacts

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ARTICLE INFO

Article history:
Received 27 April 2015
Received in revised form 13 July 2015
Accepted 29 September 2015
Available online 21 October 2015

Keywords:
Life cycle assessment
Weighting
Integration
Public opinion
Internet search volume

ABSTRACT

Weighting is one of the steps in life cycle impact assessment that integrates various characterized environmental impacts as a single index. Weighting factors should be based on the society's preferences. However, most previous studies consider only the opinion of some people. Thus, this research proposes a new weighting method that determines the weighting factors of environmental impact categories by considering public opinion on environmental impacts using the Internet search volumes for relevant terms. To validate the new weighting method, the weighting factors for six environmental impacts calculated by the new weighting method were compared with the existing weighting factors. The resulting Pearson's correlation coefficient between the new and existing weighting factors was from 0.8743 to 0.9889. It turned out that the new weighting method presents reasonable weighting factors. It also requires less time and lower cost compared to existing methods and likewise meets the main requirements of weighting methods such as simplicity, transparency, and reproducibility. The new weighting method is expected to be a good alternative for determining the weighting factor.

1. Introduction

Over the last two decades, assessment methods based on life cycle assessment (LCA) have been developed and used for evaluating the potential environmental impacts of products (Bilec et al., 2006; Chang et al., 2013; Collinge et al., 2013; Condeixa et al., 2014; Guggemos and Horvath, 2006; Hong et al., 2012a, 2012b, 2014; Jang et al., 2015; Jeong et al., 2014; Ji et al., 2014a,b; Kofoworola and Gheewala, 2008; Lee et al., 2009; Li et al., 2010; Li, 2006; Lim and Park, 2009; Moon et al., 2014; Proietti et al., 2013; Seppälä et al., 2001; Sharrard et al., 2008; Thiel et al., 2013). A life cycle impact assessment (LCIA) consists of characterization, normalization, and weighting, where characterization is a mandatory element while the other two components are optional elements (ISO, 2006). However, most LCA methods have only included characterization among LCIA elements (Zhou and Schoenung, 2007). Since the characterized environmental impacts cannot be compared across the impact categories, it is difficult for LCA practitioners to define which one is the most environment-friendly alternative in a situation where there is no one dominant impact framework that performs best in all of the impact categories. Therefore, when using LCA to compare the different alternatives and find the most environment-friendly alternative, it would be better to present a comprehensive result. Decision makers would like to get a single index by synthesizing the environmental impacts for each impact category.

Weighting, one of the steps in LCIA, integrates the various environmental impacts by assigning the relative importance to each impact category (ISO, 2006). Therefore, the characterized environmental impacts of impact categories can be integrated into a single index throughout the weighting. Several weighting methods have been used for integrating various environmental impacts in LCA: the distance-to-target method, panel method, and monetization method (Ahlroth, 2014; Ahlroth et al., 2011; Finnveden et al., 2002, 2009; Pizzol et al., 2015). The distance-to-target method defines the weighting factor by dividing the actual environmental impact by the target value (Seppälä and Hämäläinen, 2001; Soares et al., 2006). Although several LCIA methodologies such as Eco-indicator 95 and Environmental Design of Industrial Products (EDIP) presented the weighting factors, which have been determined by using the distance-to-target method (Finnveden, 1999; Wenzel et al., 1997), the weighting factors calculated by the distance-to-target method could not reflect the relative importance between the different impact categories (Soares et al., 2006). For this reason, several researchers mentioned that the distance-to-target method alone cannot be used as a weighting method in LCA (Finnveden, 1996; Lee, 1999).

The panel method determines the weighting factors based on public opinion. However, as it is difficult to include all the populations, panels consisting of some experts or stakeholders are considered. The panels are asked to weight each impact category based on subjective value choice (Myllyviita et al., 2014). The weighting factors determined from the panel method can reflect the relative importance of each

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http://dx.doi.org/10.1016/j.eiar.2015.09.008
0195-9255/

impact category. For this reason, the panel method has been considered as a most promising approach in determining the weighting factors (Finnveden et al., 2002), and has been used in LCA (Gloria et al., 2007; Koffler et al., 2008; Oztas and Tanacan, 2014). However, the panel method depends on the subjective value choices of each individual member of the panel. Due to the subjective nature of value choices, the weighting factors may differ considerably between the individuals in a panel (Gloria et al., 2007; Koffler et al., 2008; Myllyviita et al., 2014; Oztas and Tanacan, 2014; Soares et al., 2006) although they are determined by complying with the elicitation techniques such as the analytical hierarchy process (AHP). In addition, the panel method has an inherent limitation in the sense that the panel size is not always enough to ensure the representativeness of the survey results (Itsubo et al., 2012).

Monetization methods value the environmental impacts in monetary terms (e.g., restoration costs, damage cost, abatement cost, and restoration costs). There are a number of monetization methods based on observed, revealed and stated preferences, market prices, and etc. (Ahlroth et al., 2011; Ahlroth, 2014; Huppes et al., 2012; Pizzol et al., 2015). Generally, monetization methods have been used for the cost–benefit analysis of public or private projects with economic, environmental, and social impacts (Boardman et al., 2006). Since monetization methods express the environmental impacts in monetary terms, the monetized environmental impacts can be directly compared to each other. However, the application of monetization methods has a challenge in LCA since the environmental impacts have a high level of abstraction. The stated-preference method can be applied in principle at a higher level of abstraction (Pizzol et al., 2015). Thus, LCIA methodologies such as LIME, ReCiPe, and EPS have been developed based on the stated preferences (Itsubo et al., 2004; Itsubo et al., 2012; Goedkoop et al., 2013; Steen, 1999). However, since the stated preference method may be a panel method focused on eliciting monetary values, the weighting factors determined by the stated preference method may also differ depending on the individuals in a panel.

Democracy cannot thrive without government accountability over the public's wishes (Lax and Phillips, 2009). In a democracy, public opinion is also very critical to policy making in relation to environmental problems. Therefore, it is possible to determine the weighting factors reflecting public opinion on environmental problems instead of relying on the experts' knowledge. In recent years, Internet search volume has been considered a tool for determining public opinion and interest on some issues. Many researchers have used Internet search volume for determining public opinion and interest in various research fields such as medicine, policy, environment, economy (Ayers et al., 2011; Bank et al., 2011; Baram-Tsabari and Segev, 2009; Bragazzi, 2014; Carneiro and Mylonakis, 2009; Do et al., 2015; Dugas et al., 2012; Ficetola, 2013; Funk and Rusowsky, 2014; Ginsberg et al., 2009; Graefe and Armstrong, 2012; Gunn and Lester, 2013; Ortiz mail et al., 2011; Kim et al., 2014; Linkov et al., 2010; Margetts, 2009; McCallum and Bury, 2013, 2014; Mellon, 2013; Bromley-Trujillo et al., 2014; Reilly et al., 2012; Willard and Nguyen, 2013; Yang et al., 2011). In particular, since more than 80% of the population in developed countries are heavy Internet users (World Bank, 2014), Internet search volume can reflect the opinion and interests of the whole population. Therefore, this research aims to propose a new weighting method that determines the weighting factors reflecting public opinion on the environmental impact categories by using Internet search volume.

2. Previous research for determining public opinion and interest using Internet search volume

The World Wide Web contains extensive informational resources. Millions of people use Internet search engines such as *Google* to seek and share information related to various subjects. In 2000, 6.8% of the world's population were Internet users, but Internet users have increased by 38.1% in 2013. In addition, this increasing trend is still continuing. In particular, more than 80% of the population in developed countries are heavy Internet users (World Bank, 2014).

Search engines like Google presents Internet search volume data, which represent data from tracking online information seeker's behavior, for the search terms. Since social behaviors such as Internet searching reflect the public's interests and attitudes on issues, Internet search volume presented by search engines can be considered as an important source of information with regard to public opinion and interests. In particular, Internet search volume data have clear advantages over survey data in terms of cost, availability, and frequency. These advantages have led many researchers in various research fields to use Internet search volume.

First of all, Internet search volume has been used in monitoring and predicting the spread of infectious disease outbreaks (Carneiro and Mylonakis, 2009; Dugas et al., 2012; Ginsberg et al., 2009; Ortiz mail et al., 2011). The spread of infectious disease outbreaks was monitored and predicted by determining Internet search volume for the terms related to the infectious disease such as influenza. Willard and Nguyen (2013) used Internet search volume for the terms related to kidney stone disease to estimate kidney stone occurrence and understand the priorities of patients with kidney stones. According to Willard and Nguyen (2013), Internet search volume accurately reflected the geographic and temporal variability in kidney stone disease.

In recent years, Internet search volume data have been used in various fields including economics, sociology, biology, and ecology (Bank et al., 2011; Bragazzi, 2014; Do et al., 2015; Ficetola, 2013; Funk and Rusowsky, 2014; Gunn and Lester, 2013; Kim et al., 2014; Linkov et al., 2010; McCallum and Bury, 2013, 2014; Yang et al., 2011). Gunn and Lester (2013) and Yang et al. (2011) analyzed the relationship between Internet search volume for suicide-related terms (e.g., "how to suicide", "major depression", "stress", "suicide prevention") and suicide rate for monitoring and predicting suicidal behavior. Several researchers analyzed Internet search volume for environment-related terms for understanding public interest on environment (Funk and Rusowsky, 2014; McCallum and Bury, 2013, 2014). In addition, political scientists have determined public opinion based on the issues in major newspapers (e.g., *New York Times*) or responses to Gallup's survey. However, in recent years, many political scientists have begun to use Internet search volume as a new tool for identifying the public opinion and issue salience (Graefe and Armstrong, 2012; Lax and Phillips, 2009; Margetts, 2009; Mellon, 2013; Bromley-Trujillo et al., 2014; Reilly et al., 2012). In particular, Mellon (2013) suggested the potential of Internet search volume data as a tool for determining public opinion by comparing Internet search volume against the Gallup's "most important problem" question. Thus, Internet search volume has been used in various research fields, but it has never been used in LCA.

According to the results of previous research, the use of Internet search volume is valid in determining public interest and opinion on a variety of issues. In addition, the fields of application for Internet search volume are becoming increasingly wide-spread. Since Internet search volume can be used to determine public opinion and interest, it is possible to determine such with regard to environmental problems that have been considered in LCA by using Internet search volume. Therefore, this research aims to propose the new weighting method based on the hypotheses that Internet search volume for terms related to environmental impact categories can reflect public interests on the environmental impact categories, and that the level of interests can indicate the level of opinion.

3. Materials and methods

3.1. Source for the Internet search volume

Google Inc. measures the search volume for terms entered in Google, and represents the weekly relative search volume (RSV), which is normalized on a scale from zero to 100 in the selected time period,