New environmental supplier selection criteria for circular supply chains: Lessons from a consequential LCA study on waste recovery

Ernst Johannes Prosman a, *, Romain Sacchi b

a Center for Industrial Production, Aalborg University, Aalborg, Denmark
b Department of Planning, Aalborg University, Aalborg, Denmark

Abstract

Although circular supply chains are widely perceived as a leap towards a more environmentally friendly economy, the environmental impact across circular supply chains differs. This article sets out to develop environmental supplier selection criteria for circular supply chains. The method draws upon a consequential life cycle assessment and the monetized environmental impact of four alternative fuel suppliers in the cement industry. The best supplier performs three times better than the worst supplier in terms of environmental impact, thereby exemplifying the need for this study. The findings also show how three supplier selection criteria explain most of the environmental impact of selecting a supplier in a circular supply chain. First, supplier selection might impact environmentally preferred waste handling activities. Second, sourcing from a supplier located on an under-supplied market may lead to indirect transport as the players on that market may source on other markets to compensate for the diverted products. Third, low usability of the discarded product compared to the substituted virgin material may lead to additional emissions. The three criteria must be considered simultaneously when selecting suppliers in circular supply chains since focusing on a single criterion may negatively affect the other criteria. The findings contribute to circular supply chain literature by proposing and demonstrating the need for environmental supplier selection criteria in circular supply chains. Moreover, this study is relevant for achieving cleaner production in the cases where firms increasingly rely on the use of discarded products as a virgin fuel or material substitute.

1. Introduction

While firms experience a pressing need to engage in the circular economy, the link between circular economy and sustainability remains blurred (Geissdoerfer et al., 2017). Concrete examples of the pressing need include the Circular Economy Production Law of the People's Republic of China (The Standing Committee of the National People's Congress China, 2008) and the European Circular Economy package (European Commission, 2015). Concurrently, Wolfenbarger and Phifer (2000) stress the complex and ambiguous nature of environmental impacts. Selecting suppliers based on environmental performance therefore becomes a complicated task (Bai and Sarkis, 2010; Matos and Hall, 2007). Hence, academics and practitioners alike consider supplier selection criteria (SSC) as a valuable means to select suppliers (Bai et al., 2012). While literature offers environmental SSC (E-SSC) for forward supply chains — see for example Freeman and Chen (2015) — literature lacks E-SSC for circular supply chains (Wells and Seitz, 2005).

Forward supply chains differ significantly from circular supply chains. Circular supply chains source on markets where the availability of a discarded product (e.g. used tin cans) is constrained by the demand for the primary product it originates from (e.g. canned food). Households and firms do not discard more products when the demand for discarded products increases. Besides, waste handling activities in circular supply chains are mutually exclusive. For example, the recycling of a discarded product excludes its incineration or landfilling. The combination of constrained supply and mutually exclusive waste handling activities leads to a situation where an increase in demand for a supplier of discarded products creates a supply shortage for other waste handling activities, including landfilling.

Creating shortages at other waste handling activities affects the environment. First, not all the waste handling activities are equally efficient at recovering value from discarded products (Mondragon...
Diverting discarded products from a less eco-efficient waste handling activity has a positive environmental impact; diverting discarded products from a more eco-efficient waste handling activity has a negative environmental impact. Second, transport-related emissions increase when waste handling activities start to import discarded products to compensate for the created shortage. In addition, the environmental impacts related to the processing of discarded products should be taken into account as well (Geng et al., 2012). This study therefore aims to develop generic E-SSC for circular supply chains by considering the constrained nature of the supply, the competition of waste handling activities for discarded products as well as the processing of the discarded products in the receiving production system.

To achieve this aim, a consequential life cycle assessment (CLCA) is conducted to assess the environmental impact of selecting different municipal solid waste (MSW) suppliers in the cement industry. CLCA is a particularly well-fitting tool for this study as it characterizes the changes in the economic system related to an increase in demand for a product. Hence, CLCAs can be modeled to consider the supplier’s reaction to demand and supply changes at the margin. This is crucial when the product under investigation is constrained in supply and system-wide impacts may occur — as is the case in circular supply chains. Therefore, E-SSC based on a CLCA adhere to the suggestions of Seuring and Müller (2008) to include environmental impacts beyond the immediate interfaces of the supply network.

Despite the interests of policy makers and firms into the circular economy (Geng and Doberstein, 2008; Ghisellini et al., 2015; Lieder and Rashid, 2016), how firms can environmentally optimize their circular supply chains remains unclear (Geissdoerfer et al., 2017). Therefore, this study contributes to literature by proposing E-SSC for circular supply chains. The proposed E-SSC offer guidelines that firms can follow to achieve cleaner production and increase the environmental performance of their circular supply chain activities. Moreover, the E-SSC support the design of policies by providing insights into preferred circular supply chain efforts. Finally, this study contributes to literature by demonstrating the need and relevance of the proposed E-SSC for the use of MSW in the cement industry.

This article is organized as follows. It begins with the review of the supply chain literature on E-SSC and subsequently explore E-SSC for circular supply chains. It then presents the methodology and demonstrates the need, applicability and underlying mechanisms for E-SSC based on a case study of the use of combustible fraction of MSW in the cement industry. It eventually concludes the article with a discussion of the results followed by a conclusion.

2. Literature review

The real world complexity related to supplier selection creates the need for simplified but thoughtful SSC (Govindan et al., 2015; Williamson, 2008). The complexity increases even more when adding environmental aspects (Bai and Sarkis, 2010). It is therefore not surprising that E-SSC have attracted growing interest in literature and practice (Bai et al., 2012).

Most E-SSC presented in literature set out to screen suppliers in the forward supply chain based on their organizational performance, e.g. complying with ISO standards or green product design. Table 1 provides an overview of the most frequently used E-SSC in literature. Although some E-SSC touch upon aspects of circular supply chains — e.g. product design for reuse — existing E-SSC do not consider the constrained supply of discarded products and the mutual exclusiveness of waste handling activities. The next paragraphs elaborate on why circular supply chains require different E-SSC.

2.1. The distinct context of circular supply chains

Circular supply chains include forward supply chains and reverse activities (Wells and Seitz, 2005). The reverse activities of circular supply chains include (Tibben-Lembke and Rogers, 2002):

- Collection of waste/end-of-life products, hereinafter referred to as discarded products.
- Reverse logistics.
- Quality assessment, and
- Recycling, remanufacturing and other forms of recovery or disposal.

This research focuses on the reverse activities because ample research already addresses E-SSC for forward supply chains (Govindan et al., 2015). Literature distinguishes two types of circular supply chains. First, closed-loop systems aim to return products to their point of origin. Examples include Xerox's copy machines and Kodak's cameras. Second, in open-loop systems, other parties rather than the original producers recover the value of the discarded products. Examples include recycling firms and the exchanges taking place within industrial symbiosis networks: where waste and by-products of one firm serve as feedstock for another firm (Chertow, 2000). The next sections elaborate on how the environmental performance of both types of circular supply chains hinge on two key characteristics, namely 1) the constrained supply- and demand-driven product flows and 2) the usability of discarded products.

2.1.1. Product flows in circular supply chains

Circular and forward supply chains have different product flows (Tibben-Lembke and Rogers, 2002). Forward supply chains extract virgin materials to respond to customer demand. When customer demand increases, virgin material extraction increases (Naylor et al., 1999). Hence, forward supply chains have demand-driven product flows and are unconstrained in supply as long as virgin materials are available. In contrast, circular supply chains fulfill customer demand by extracting the remaining value of discarded products and looping them back into the economy (de la Fuente et al., 2011; Schmidt et al., 2007).

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Frequently used E-SSC in literature (based on Bai and Sarkis, 2010; Freeman and Chen, 2015; Govindan et al., 2013; Handfield et al., 2002; Lu et al., 2007; Zhu and Sarkis, 2004).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Organizational aspects</strong></td>
<td><strong>Related attributes</strong></td>
</tr>
<tr>
<td>Product design</td>
<td>Product design for reuse, recycle and recovery of material; green packaging; excess package reduction; toxic and hazardous components.</td>
</tr>
<tr>
<td>Process design</td>
<td>Internal recycling at the supplier; use of recycled materials; waste water; solid waste; energy consumption; resource consumption; air pollutants; emission and release of harmful substances.</td>
</tr>
<tr>
<td>Environmental management systems</td>
<td>ISO 14001; end-of-pipe control; eco-labeling; continuous monitoring; regulatory compliance; green process planning; up-to-date air, water and pollution permits.</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>Management commitment; environmental performance of the suppliers’ supplier; staff training on environmental issues; ability to improve towards more environmental activities; social responsibility.</td>
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