Journal of Cleaner Production 181 (2018) 17–32

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Material efficiency measurements in manufacturing: Swedish case studies

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A R T I C L E I N F O

Article history:
Received 2 May 2017
Received in revised form
12 January 2018
Accepted 25 January 2018

Keywords:
Material efficiency
Key performance indicators
Sustainable production

A B S T R A C T

A major factor in the continued deterioration of the global environment is unsustainable management of resources that includes the type and quantity of resources consumed and manufactured as well as the subsequent generation and treatment of wasted materials. Improved material efficiency (ME) in manufacturing is key to reducing resource consumption levels and improving waste management initiatives. However, ME must be measured, and related goals must be broken down into performance indicators for manufacturing companies. This paper aims to improve ME in manufacturing using a structured model for ME performance measurements. We present a set of ME key performance indicators (ME-KPIs) at the individual company and lower operational levels based on empirical studies and a structured literature review. Our empirical findings are based on data collected on the performance indicators and material and waste flows of nine manufacturing companies located in Sweden. The proposed model categorizes ME-KPIs into the following categories: productive input materials, auxiliary input materials, output products, and residual output materials. These categories must be measured equally to facilitate the measurement, assessment, improvement and reporting of material consumption and waste generation in a manufacturing context. Required qualities for ME-KPI suggested in literature are also discussed, and missing indicators are identified. Most of the identified ME-KPIs measure quality- and cost-related factors, while end-of-life scenarios, waste segregation and the environmental effects of waste generation and material consumption are not equally measured. Additionally, ME-KPIs must also be connected to pre-determined goals and that defining or revising ME-KPIs requires communication with various external and internal actors to increase employees' awareness and engagement.

1. Introduction

Since the introduction of the *sustainable development* concept (Brundtland, 1987), many companies have recognized the importance of applying sustainability practices and have taken steps to incorporate different aspects of sustainability into their production processes, products, short- and long-term decision-making, performance measurement systems and reporting systems. Such forms of integration provide companies a competitive advantage in the global market as well as reputational advantages, which are manifested as enhanced staff pride and loyalty and improved share prices; better internal data collection; improved reporting systems; social and environmental performance improvements (Adams and Frost, 2008); higher levels of financial performance; better investment opportunities; and greater value for stakeholders (Dočekalová and Kocmanová, 2016). *Manufacturing sustainability* (Garetti and Taisch, 2011) consists of achieving distinct sustainability goals. These goals must be consistent with global sustainable development targets (Hauschild, 2015) and should be incorporated into manufacturing strategies (Johansson and Winroth, 2010) and converted into operational implementation activities (Maas et al., 2016). Sustainability performance should be assessed (Bjørn et al., 2015; Tajbakhsh and Hassini, 2015) and values and progress toward goals should be monitored systematically (van Marrewijk,

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https://doi.org/10.1016/j.jclepro.2018.01.215
0959-6526/

2003; Veleva et al., 2001b) through the development of capabilities and sustainability key performance indicators (KPIs) measured over time (Singh et al., 2012). Despite previous efforts and many necessary (but not sufficient) steps taken toward manufacturing sustainability, several challenges remain, such as moving from eco-efficiency to eco-effectiveness (Hauschild, 2015), integrating sustainability into practice (Morioka and de Carvalho, 2016), applying improved sustainable development concepts into industrial businesses (Veleva et al., 2001b) and incorporating sustainability performance measurements (Cucek et al., 2012). Sustainable performance measurement capabilities must be integrated into reporting procedures and management decisions and be adopted at the lowest operational level (shop floor); otherwise, these capabilities will not contribute to sustainable development and value creation in society (Maas et al., 2016; Ragas et al., 1995). Sustainability performance measurements reveal weaknesses that could pose threats in the future (e.g., with upcoming legal frameworks, regulations and customer demands) as well as strengths that a company may pursue as opportunities (Dočekalová and Kocmanová, 2016).

Sustainability management, measurement and reporting has been supported using many guidelines and sustainability performance indicators. However, such guidelines and indicators do not provide sufficient insights into how corporations should define, revise and apply performance indicators to more accurately implement sustainability measurements (Veleva, 2010). These frameworks do not effectively cover performance assessment practices at the operational level (Lee and Farzipoor Saen, 2012) or sufficiently address the production aspects of an organization when the main focus remains on products (Azapagic and Perdan, 2000; Boks and McAloone, 2009). Therefore, the proposed guidelines and indicators do not adequately help industrial management teams (decision makers) assess their operations in terms of sustainability.

Unsustainable patterns of resource management in manufacturing are a major contributor to the continuous deterioration of the global environment (Chee Tahir and Darton, 2010). These patterns include the types and quantities of resources consumed, the levels of waste generated, the treatment and management of waste, and the lack of product life cycle perspectives (Krajnc and Glavič, 2003). The consumption of resources and materials has increased over time, and despite the establishment of waste minimization and increased efficiency targets in corporate waste management initiatives, industrial waste generation has also increased. With increases in land use and pressure on virgin raw materials as well as higher transportation costs and the likelihood of more rigid disposal standards in the future, diverting waste from the disposal process and increasing material recycling and reuse are extremely beneficial for the environment and create additional revenue streams for companies. This is consistent with waste hierarchy, stating that landfill and energy recovery from waste must be avoided and recycling efforts should instead be directed toward reusing, reducing and preventing waste generation. Material efficiency (ME) refers to the amount of materials required to manufacture a product and while using less material per product and/or generating less waste per product (Shahbazi et al., 2016). ME is an increasingly vital environmental and economic indicator that must be broken down to lower operational levels within a manufacturing company in terms of performance indicators, which are essential to achieving efficiency (Ragas et al., 1995).

Among other activities, including regulation adoption, minor technological improvements, selection of proper business models, management commitments to environmental goals, continuous process improvements, widespread life cycle thinking, and substitution of hazardous materials to environmentally friendly materials to achieve ME (Shahbazi, 2015), we believe that achieving ME in manufacturing can be facilitated by applying the correct set of material efficiency-related key performance indicators (ME-KPIs). However, most research has focused on sustainability issues at a corporate level (Winroth et al., 2016); mainly due to the links between corporate sustainability and global sustainability and legislation on corporate sustainability reporting. Hence, the links between global sustainability and lower operational levels within companies remain ambiguous (Klassen, 2001). In addition, sustainability efforts frequently focus on products rather than manufacturing (Azapagic and Perdan, 2000), and sustainability indicators are not typically included in the performance measurement systems of daily manufacturing controls but rather as separate organizational functions, such as corporate social responsibility or health, safety and environment functions for annual reporting to external authorities. In general, few empirical studies have been conducted on performance indicators (De Toni and Tonchia, 2001; Landström et al., 2016) and sustainability integration in operations (Labuschagne et al., 2005; Veleva et al., 2001b; Zackrissona et al., 2017). Moreover, few studies have specifically measured ME performance in a manufacturing company or examined the application of ME improvement concepts in an industrial business. Most have assessed ME in a broad sense related to a national context (e.g., Lilja (2009); Pajunen et al. (2012) or a sectorial or supply chain context (e.g., Allwood et al. (2013); Milford et al. (2011). Following the levels of sustainability proposed by Winroth et al. (2016), this paper focuses on the micro-level (individual company level) and lower operational levels within a factory, i.e., the shop floor, and we address the current lack of awareness of ME and relevant ME-KPIs at the shop floor level.

This paper aims to improve ME in manufacturing via a structured model for performance measurements. The paper highlights the need to develop a common understanding of what ME in manufacturing entails and link existing performance measurements to this common understanding through material efficient material operations. Therefore, the following research questions are posed: (a) What KPIs in manufacturing are linked to the ME of a manufacturing company? And (b) How can ME be improved via relevant KPIs? ME is typically more focused on the economic and environmental aspects of sustainability, although resource and raw material consumption and waste generation are also related to the social dimensions of sustainability in a broader sense. This paper contributes to the literature and industrial practices in several ways: (a) by introducing a general set of common *performance* and *industry-generic* indicators (Sikdar, 2003) for ME to inspire further theoretical and empirical research studies; (b) by identifying a set of KPIs with the potential to reduce the assessment and reporting requirements placed on manufacturing companies; (c) by helping companies cut costs associated with complying with upcoming material- and waste-related legal frameworks; and (d) by adding value to the literature on manufacturing sustainability and ME through a database of ME-KPIs.

Inspired by Allwood et al. (2011), Fig. 1 illustrates the various ME options available throughout the life cycle of a product. The focus of this paper, however, remains at the manufacturing stage, at which point productive (value-adding) and auxiliary materials (non-value-adding or non-productive) are consumed and residual materials (waste or rest material) are generated. Thus, issues related to product design, post-consumer recycling, and raw material and finished product transportation are excluded. Material acquisition involves similar ME options at the manufacturing stage, and package and transport options mainly mirror those of the design phase, such as the use of lightweight materials. Reuse options during the end-of-life stage include the reuse of materials and components with another purpose (i.e., new life cycle), while