Journal of Cleaner Production 126 (2016) 337–351

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Value creation with life cycle assessment: an approach to contextualize the application of life cycle assessment in chemical companies to create sustainable value

B.M. Krishna Manda [a, *], Henk Bosch [b], Sreepadaraj Karanam [c], Heidi Beers [d], Harrie Bosman [d], Eelco Rietveld [e], Ernst Worrell [a], Martin K. Patel [f]

[a] Utrecht University, Copernicus Institute of Sustainable Development, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands
[b] DSM, Corporate Operations & Responsible Care, Het Overloon 1, P.O. Box 6500, 6401 JH Heerlen, The Netherlands
[c] SABIC, Innovative Plastics Business Unit, P.O. Box 5151, 6130 PD Sittard, The Netherlands
[d] Teijin Aramid, Eco-Efficiency Services, Marketing and Sales Department, Velperweg 76, P.O. Box 5153, 6802 ED Arnhem, The Netherlands
[e] DPI Value Centre, John. F. Kennedylaan 2, 5612 AB Eindhoven, The Netherlands
[f] University of Geneva, Institute for Environmental Sciences and Forel Institute, Energy Group, Route de Drize 7, 1227 Carouge/Geneva, Switzerland

ARTICLE INFO

Article history:
Received 15 August 2014
Received in revised form
15 February 2016
Accepted 4 March 2016
Available online 16 March 2016

Keywords:
Sustainable value creation
Life cycle assessment
Integrating environmental sustainability
Business functions
Business decisions
Systems tool

ABSTRACT

Businesses have a responsibility to shareholders and other stakeholders. By establishing a direct link between sustainability and shareholder value, businesses can successfully include sustainability considerations in managerial decisions and create sustainable value. The value creation opportunities include cost reduction, risk reduction, product differentiation, and new products to address unsatisfied needs. However, the relevance of various aspects of sustainability changes from company to company depending on the context; this can involve the type of product systems, geographical scope, and related social and environmental drivers. This requires a framework and tool that can capture the complexity, yet provide holistic understanding of the interdependence of industrial systems and, more importantly, furnish sound metrics to include sustainability considerations in business decisions. This paper shows how value can be created by integrating environmental sustainability through Life Cycle Assessment in business, especially in the chemical industry and provides an implementation procedure for business value creation based on life cycle assessment. The application of life cycle assessment was contextualized to various drivers and situations of chemical companies with the help of sustainable value framework. Case studies from three companies were used to illustrate value creation by integrating environmental sustainability through life cycle assessment. A procedure was presented to translate life cycle assessment insights into value creation opportunities. This article provides a better understanding of employing life cycle assessment by business managers in day-to-day business decisions to create value.

1. Introduction

Businesses cater for societal or customer needs, which is a primary value of business. While doing so, they create shareholder value, which is a secondary value of business (Braudel, 1979; Polman, 2014). The industrial revolution has reversed this order and shareholder value has taken center stage. Meanwhile, environmental, resource and social challenges such as climate change, resource depletion and inhumane working conditions have become rampant in many societies. Companies are struggling with the apparent inconsistency between being sustainable and creating shareholder value. This leads to tensions with shareholders and other stakeholders, but also to internal frictions. Companies need a framework to understand how sustainability and shareholder value are interrelated, and a procedure to reconcile the two. With this article we intend to provide these.

Reconciling these two aspects is difficult and there is no one size fits all solution. The relevance of various aspects of sustainability

* Corresponding author. Tel.: +31 30 2533145; fax: +31 30 2537601.
E-mail addresses: b.m.k.manda@uu.nl (B.M.K. Manda), Henk.Bosch@dsm.com (H. Bosch), sreepadaraj.karanam@sabic-ip.com (S. Karanam), heidi.beers@teijinaramid.com (H. Beers), harrie.bosman@teijinaramid.com (H. Bosman), e.rietveld@dpivaluecentre.nl (E. Rietveld), e.worrell@uu.nl (E. Worrell), martin.patel@unige.ch (M.K. Patel).

http://dx.doi.org/10.1016/j.jclepro.2016.03.020
0959-6526/

changes from company to company depending on the context, such as the type of product systems, the geographical scope, and the social and environmental drivers. Thus, the integration of sustainability in business is inherently complex. It requires a holistic understanding of the interdependence of industrial systems with sound tools that can capture the complexity and provide metrics to embed sustainability in different business decisions. Systems thinking helps to understand the different parts within the system and their relation to other systems. Life Cycle Assessment (LCA) is a systems tool that can assess and help improve the environmental performance (one of the three pillars of sustainability) of products by providing powerful insights into the whole value chain[1] (ISO, 2006a, 2006b; ILCD, 2010). By doing this, LCA avoids shifting of impacts from one process step/industry to another, from one impact category to another and from one place to another. LCA supports businesses in making various decisions such as the selection of processes, materials, and supply chains. By supporting these business decisions and actions LCA offers various value creation opportunities to business and improves shareholder and stakeholder value simultaneously.

International standards and publications on LCA (ISO 2006a, 2006b; ILCD, 2010; EC, 2011; Remmen et al., 2007; Jensen and Remmen, 2006; Fava, 2004; UNEP/SETAC, 2009; UNEP/TU Delft, 2007), mention potential applications and some value of LCA in business and governments. However, these do not provide guidance on how to contextualize the application of LCA to suit the varying contexts and drivers of companies and on how to integrate LCA-based insights into the core business for creating value for a specific industry. Therefore, the main objective of this paper is to show *how value can be created by integrating environmental sustainability through LCA in business, especially in the chemical industry*. The secondary objective is to provide an *implementation procedure for business value creation based on LCA*. These objectives are addressed by synthesizing various perspectives and insights into a coherent picture to help sustainability practitioners who face various practical challenges. This article mainly focuses on environmental sustainability, due to the lack of matured systems tools for social sustainability. However, we mention social sustainability aspects wherever relevant, such as elements in the framework, only to show their existence and importance for value creation opportunities but not with social-LCA in the case studies.

Section 2 presents the research design, methods used and data collection. Section 3 discusses the literature review and the framework to understand the important aspects that show the interrelationship between various aspects of sustainability and value creation. In Section 4, the framework is operationalized with LCA examples and shows how LCA can contribute to sustainable value creation. In Section 5, three real-life case studies are presented to illustrate how insights from LCA contributed to value creation and how sustainability is integrated into business functions. Consequently, we propose an implementation procedure for translating LCA based insights into value creation opportunities. Limitations of LCA, framework and case studies are also presented. Finally, in Section 6 conclusions and recommendations are provided.

[1] Value chain of a product refers to all of the upstream and downstream activities associated with the operations of the reporting company, including the use of sold products by consumers and the end-of-life treatment of sold products after consumer use (WRI/WBCSD, 2011). Porter (1985) defined value chain of a company as the whole series of activities that create and build value at every step. A value chain is made up of primary activities and supporting activities which are delivered by different business function. Primary activities are inbound logistics (getting the material in for adding value by processing it), operations (which are all the processes within the manufacturing), outbound (which involves distribution to the points of sale), marketing and sales (which go sell it, brand it and promote it) and service (which maintains the functionality of the product, post sales).

2. Methods

Fig. 1 shows the research design applied in this paper. A case study approach is recommended to investigate the value creation with environmental sustainability (Reed, 2001). Thus, the descriptive case study approach (Scapens, 1990; Jupp, 2006) was employed with three chemical companies in Netherlands. This enabled us to investigate the phenomenon of value creation with environmental sustainability, especially LCA, in real-life contexts. The main elements of the case studies are the drivers, approaches for data collection and analysis, communication, embedding sustainability in business decisions, and value creation. Each case study focused on a specific example to study the similarities and differences of approaches between different companies with different examples. This multiple case approach also confirms the reproducibility of the proposed iterative procedure (theory) and its practical implementation in real life cases with sound data. Therefore, a multiple case study approach can provide more robust evidence than a one case study with regard to creation of value with LCA and its implementation in companies (Eisenhardt and Graebner, 2007).

2.1. Literature review and selection of framework

We reviewed the literature on value creation and corporate sustainability. Based on the literature, we specified criteria which need to be fulfilled by the framework. Section 3 describes this process and the framework.

2.2. Data collection and analysis

To illustrate the relation between broader sustainability, LCA and value creation in Section 4, we collected examples from publicly available sources such as company websites and sustainability reports. Case studies were presented from the collection of primary data and own experience of authors in three respective chemical companies. These cases are illustrative examples and not intended to demonstrate detailed LCA studies. A multi-stakeholder seminar was conducted by the authors with the Dutch Polymer Institute (DPI) Value Center to identify the barriers and challenges in the creation of value from LCA. The participants of this seminar represented different business functions and also covered various companies involved in different stages of the value chain such as chemical companies, brands, and retailers. The sustainable value framework provided guidance for describing and analyzing the case studies.

3. Literature review and framework

In this section, various perspectives on corporate sustainability and value creation are presented to derive criteria for selecting a suitable framework. Later, a description of the framework is presented.

3.1. Corporate sustainability literature review for selecting a suitable framework

In a global survey of CEOs, conducted by United Nations Global Compact and Accenture (UNGC 2013), it was found that the major barrier to embedding sustainability in business is a perceived lack of a direct link between sustainability and business value. Despite having systems tools such as LCA that can provide sound metrics

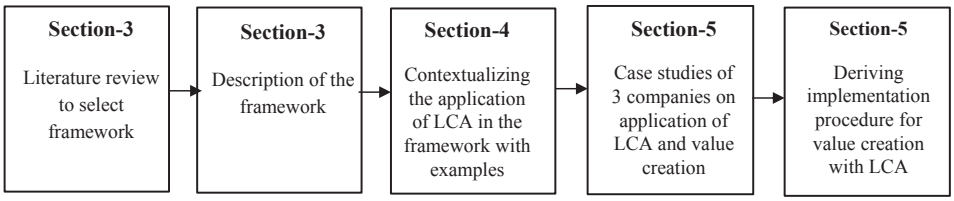

Fig. 1. Schematic diagram of the research design.

to assist business decisions, we still need a framework that makes clear the relevance of LCA in various business contexts and directly links sustainability (and its metrics derived from LCAs) with business value creation. Similarly, by looking at the insights provided by various experts we can derive criteria for selecting a framework. Eccles et al. (2012) showed that companies with "high" sustainability culture, having a corporate governance for sustainability, stakeholder engagement practices that involve product LCAs and that take a long term perspective have outperformed their competitors with higher shareholder value and return on investment. Senge et al. (2008) delineated the importance of systems thinking and suggested that the integration of sustainability in core business should start with primary business functions such as R&D and innovation, operations, procurement/sourcing, marketing and sales (Kumar and Christodoulopoulou, 2013). Conversely, the usual expectation from businesses is to increase profits alone; "*there is one and only one social responsibility of business to use its resources and engage in activities designed to increase its profits*" (Friedman, 1970). However, with the advent of social media, civil society stakeholders can profoundly impact the profit earning capability of corporations. For instance, a consumer disappointed by the poor product quality or unethical practices of a company can write a blog about them and may cause loss of market share of the product (Vermeulen, 2013). This suggests the blurring of boundaries and integral nature between shareholder value and stakeholder value (Polman, 2014). A business strategy approach (Hart and Milstein, 2003; Porter and Kramer, 2006; Laszlo and Zhexembayeva, 2011) that enables a company to pursue profit while embedding sustainability in its core business is more appropriate for companies. It also creates opportunities and competitive advantage. Based on the above discussion, we have enlisted a criteria to select and develop a framework. It:

i) should be able to capture the current and future trends and drivers of sustainability
ii) inherently considers wider stakeholder views and other concerns for the short and long term
iii) has a wider meaning of value creation that includes economic, environmental and social aspects
iv) demonstrates a direct link between strategies and sustainable value creation
v) identifies the roles and involvement of main business functions to create sustainable value
vi) should account for the life cycle perspective of technologies/processes, products and services offered by businesses

A review was conducted to select a suitable framework that fulfills the criteria. Frameworks developed by various authors have covered several aspects with a specific focus on sustainable supply chain management (Seuring and Muller, 2008), financial analysis of sustainability (Castro and Chousa, 2006), corporate social performance (Siltaoja, 2013), various social and environmental sustainability aspects (Labuschagne et al., 2005; Veleva and Ellenbecker, 2001) and strategic guidelines and tools for implementing sustainability in organizations (Robèrt et al., 2002). These frameworks did not either explicitly link sustainability with value creation or cover value creation from different business functions, current sustainability trends, various stakeholders and systems thinking approaches such as LCA. The sustainable value framework by Hart and Milstein (2003) covers many aspects of the criteria. First, it clearly discerns the link between sustainability drivers, possible strategies and business value. Second, it distinguishes different dimensions of sustainability integration in business. We could further adapt this framework to criterion (v) (role and involvement of main business functions) and criterion (vi) (relevance of LCA in various business contexts (see Section 4)) which make sustainability an integral and day-to-day activity of business.

3.2. Description of sustainable value framework for the chemical industry

In order to integrate sustainability in the core business, functional managers, top management and investors need to be convinced of value creation from sustainability. The sustainable value framework, see Fig. 2, helps to link sustainability and value creation. We have adapted the framework developed by Hart and Milstein (2003) to suit to the chemical industry situation and also added the interaction of business functions in various quadrants.

To succeed in the long term, businesses should approach value creation by encompassing social (people), environmental (planet), and economic (prosperity) aspects (Elkington, 1997; EC, 2002). To clarify the concept of value creation, we present an adapted definition of sustainable value creation (Hart and Milstein, 2003): Creation of sustainable value is the identification of strategies and practices that contribute to a more sustainable world by viewing global challenges associated with sustainability through an appropriate set of business perspectives, and the utilization of these strategies and practices to drive shareholder value. There are various levers which contribute to shareholder value while addressing sustainability issues. Thus, they are also recognized as business value (Hart and Milstein, 2003). Some examples of the business value are cost and risk reduction, legitimacy of existence, reputation, product differentiation, innovation and business growth (Laszlo and Zhexembayeva, 2011; Hart and Milstein, 2003; Nidumolu et al., 2009; UNEP/SETAC, 2009). Innovation covers different aspects such as technologies, management practices and business models. Business growth can be achieved by expanding to new markets and providing new products to address unsatisfied needs.

Fig. 2 shows the multidimensional construct of the sustainable value framework that blends two dimensions. The vertical axis is about balancing the short term results such as financial improvements while making progress for the long term business growth and success in a competitive and disruptive technology landscape. The horizontal axis shows the firms' need to manage and grow internal organizational skills and capabilities while capturing the

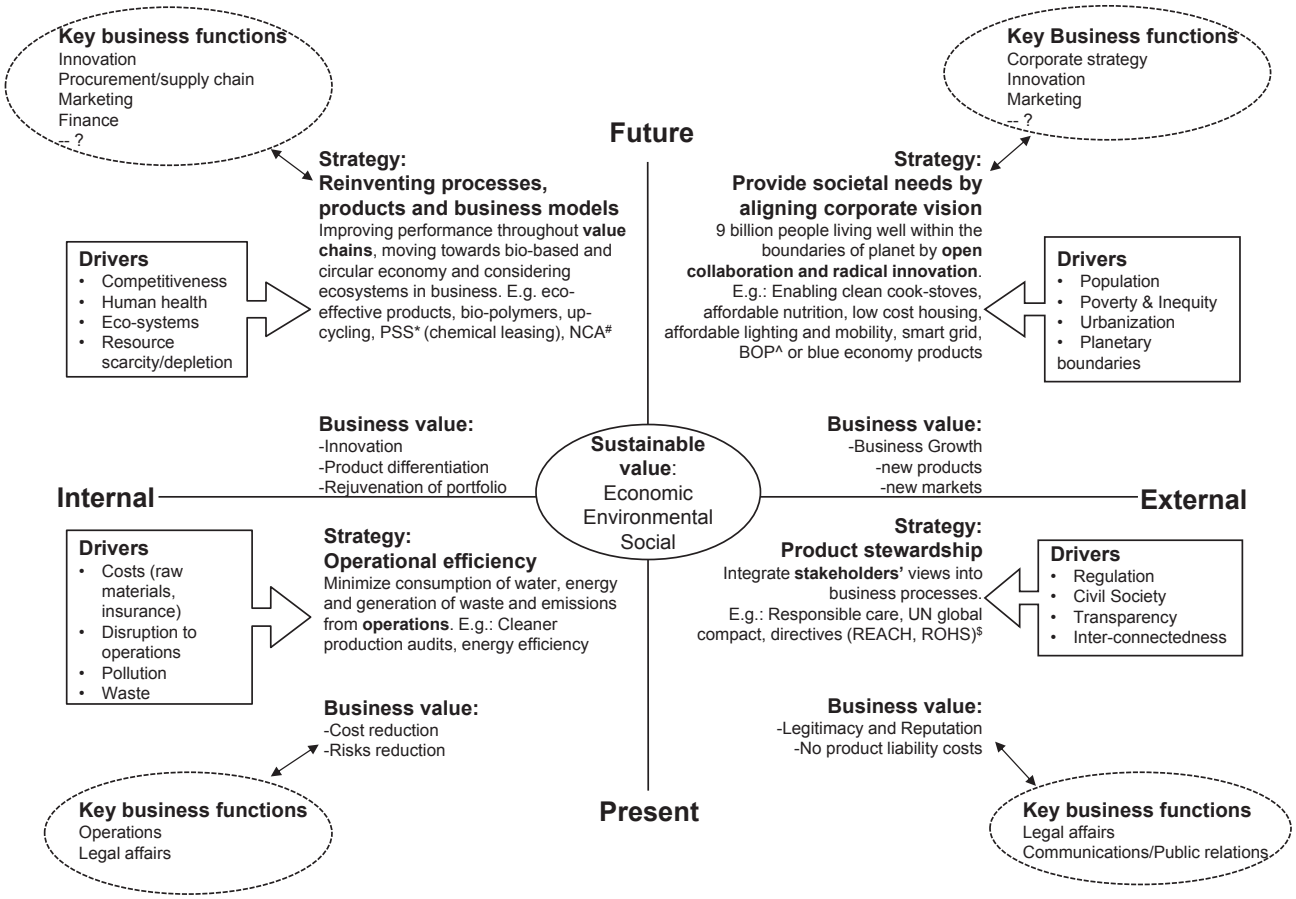

Fig. 2. Sustainable value framework for chemical industry (adapted from Hart and Milstein, 2003). (*PSS is Product Service Systems, #NCA is Natural Capital. Accounting, ^BOP is Base Of the Pyramid, $REACH is Registration, Evaluation, Authorization of Chemicals and ROHS is Restriction of Hazardous Substances).

new perspectives, knowledge, and challenges posed by external stakeholders.[2] Strategies on the left side are within the purview of a corporation, and the strategies on the right side are mostly driven by other stakeholders or changing environmental, social, and market circumstances. There are four sets of sustainability drivers that are also found in literature (Lozano, 2013; Epstein and Roy, 2001; UNEP/TU Delft, 2007). The first set of drivers (lower-left quadrant) is pollution and waste, the second set of drivers (lower-right) is transparency and regulations, the third set of drivers (top-left) is growing environmental footprint and resource depletion, the fourth set of drivers (top-right) is megatrends such as population, inequality and planetary boundaries. Addressing these drivers with a proper strategy could lead to business value. For example, an operational efficiency strategy can address drivers such as raw material costs and pollution and can create business value such as reducing costs and avoiding risks.

Though the environmental drivers in top-left and top-right appear similar, their influence on businesses is different. In the top-left quadrant, businesses deal with the resource constraints and product impacts with a piecemeal approach. Whereas in the top-right quadrant businesses are aware of the limited capacity of our planet and its influence on their long term existence and, thus, openly collaborate with others to radically transform whole systems for planetary sustainability. Implementing strategies in each dimension needs the involvement of specific corporate functions in order to reap the business value. In order to be successful in the short and long term, companies need to devise strategies in all quadrants to create sustainable value. For a detailed description of the framework see Supplementary electronic material.

The ovals in Fig. 2 show various business functions that either take part in the implementation or benefit from the corresponding strategies. Depending on the structure of the company there might be differences in involvement by specific business functions in each quadrant. The environmental management or sustainability departments are not separately shown because they either implement the projects or they are involved in all quadrants depending on the type of project; they can also be part of operations, innovation or marketing in many companies. The role of various business functions is illustrated with real life case studies in Section 5.

4. Contextualizing the application of LCA in business with sustainable value framework

In order to devise strategies and assess the impact of business decisions, we need comprehensive, scientifically robust, and widely

[2] According to Freeman and Reed (1983) internal stakeholders have economic power i.e. ability to influence market place decisions, such as employees, suppliers, other value chain partners, investors, customers (B2B) and consumers (B2C). External stakeholders are those who have political power such as civil society, governments, local community, trade unions, and consumers. We consider other industries as external stakeholders to a specific industry. Consumers can exercise both economic (through purchase) and political power (through social-media activism).

accepted tools for evaluating, benchmarking and communicating across business functions, value chains, and between businesses and stakeholders. Life cycle management tools can operationalize the framework for implementing strategies through assessment of impacts of the whole product life cycle, thereby supporting business decisions. Environmental life cycle assessment is specific to environmental sustainability. Similarly, Life Cycle Costing (LCC) and Social Life Cycle Assessment (Social-LCA) can be used to understand the economic costs (externalities can also be included) and social impacts (both positive and negative) throughout product life cycles. We focus on environmental LCA and combine other tools wherever possible. We describe various applications of LCA that address different drivers and correspondingly create sustainable value in different quadrants.

4.1. LCA and operational efficiency (lower left quadrant)

LCA can be used to find not only environmental impacts throughout product life cycles but also to determine environmental hotspots and inefficiencies in different stages such as product design, manufacturing or upstream and downstream value chains. This analysis helps to reduce inputs of raw materials, energy and water and the generation of emissions, waste and wastewater. In most cases these reductions also reduce cost and ensure compliance with legislation. By understanding the release of emissions from a specific process or excessive use of resources such as water, and their effects, LCA makes it possible to devise strategies to reduce these, avoiding operational risks such as disruption of business operations. Many forward-looking companies have achieved substantial financial benefits with implementation of eco-efficiency measures. We present one example among many to show the potential cost savings. Unilever reduced costs and improved profits through eco-efficiency. According to John Maguire, Unilever's group manufacturing sustainability director "*Eco-efficiency is not just about reducing the environmental footprint it also makes good business sense. Since 2008 Unilever's eco-efficiency programs have avoided more than $395 million of costs. Almost $132 million in energy; $245 million in materials; $22 million in water; and $13 million in waste disposal. The benefits are clear in a world where energy prices are increasing*". Unilever has announced that since 2008 the company has achieved a CO_2 emission reduction of more than one million tons from its manufacturing and logistics operations. This was achieved while growing sales by 24% from $54.4 billion in 2008 to $67.6 billion in 2012 (EarthShift, 2013). LCA can empower the key business functions, operations and legal affairs, by providing information on where the biggest impacts originate, and help these functions to focus investment and efforts to minimize cost, as well as to reduce the risks and environmental impacts of operations.

Conventionally, life cycle thinking is limited to consideration of environmental aspects and impacts like energy use, climate change or waste. LCA is the tool to measure environmental impacts using life cycle thinking. It considers all the relevant environmental impacts throughout the life cycle of the product. LCA shows the hotspots in a product life cycle and the direction for improvements. In order to make real life improvements, practices and techniques like cleaner production, green chemistry, energy management, eco-design, engineering disciplines etc. are needed. Eco-efficiency combines the environmental and economic aspects over a product life cycle and can be benchmarked against alternative competing products in the market. This helps in strategic decision making such as product development and marketing communication. However, the analysis should be based on LCA standards and guidelines provided by authoritative sources like the ISO, the UNEP-SETAC, the EU etc.

4.2. LCA and product stewardship (lower right quadrant)

Intrinsically, LCA considers the entire value chain including distribution, consumer use and disposal of products at the end of life (EOL). The implied philosophy of product stewardship, i.e. taking responsibility for a product throughout its life cycle, helps to integrate product performance in the use/service phase such as energy consumption and possibilities to recover and recycle waste products. For the chemical industry, regulations such as Registration, Evaluation, and Authorization and Restriction of Chemicals (REACH, 2015) are important not only for compliance but also for product stewardship reasons. By understanding the interrelationship between processes throughout the product life cycle, concerns of stakeholders regarding chemicals and toxicity can be effectively addressed. For instance, an LCA was conducted to understand the influence of using brominated flame retardants (BFR) in the laptop life cycle (Jonker et al., 2013). It was found that the end of life disposal has the most significant toxicity impact in the whole laptop life cycle, attributable to the use of BFR. This LCA has helped companies in the whole value chain to understand the impact (or role) of one intermediate chemical i.e. BFR and helped the intermediate chemical company (FR producer) to find suitable alternatives for substitution. This type of analysis also helps companies to understand the potential issues that might attract attention of policy makers in the future and prepare companies for impending regulation, avoiding regulatory risk. Initiatives such as the Grenelle law (AFNOR, 2011) by the French government and the European Union Product Environmental Footprint (EU PEF, 2013) are ushering the way towards transparent reporting of the environmental performance of end products along with their price based on a common LCA methodology per product category (known as Product Category Rules (PCR)). Extending the responsibility throughout the whole product life cycle helps business functions, legal affairs and communications/public relations, to consider the life cycle issues for regulatory affairs planning as well as to transparently communicate the environmental footprint. Thus, LCA helps to create value for the company by enhanced transparency and reputation, and ensuring license to operate (legitimacy) due to its pro-active and responsible approach.

Product stewardship is less obvious for chemical companies making intermediates ending up in complex goods but some examples do exist and the trend towards a product service economy (EMF, 2013) will make it more important in the future. For example, in order to extend the lifetime of end products, materials manufacturers might need to collaborate with their customers and share required information and expertise as part of their product stewardship commitment.

4.3. LCA and re-inventing processes, products and business models (top left quadrant)

LCA provides the environmental footprint of products and services and helps to understand which raw materials and processes make the most significant contributions. This understanding can be used to inspire innovations that create new products, new services, and new business models, as well as change the way the value proposition is offered to customers and attract a premium on environmentally superior products. Innovation could also include management practices such as supplier selection policy, accounting for externalities (natural capital management), and innovating value chains by new business models. LCA combined with LCC (additionally, including the cost of externalities) would offer new perspectives to business to analyze and re-position offerings to customers and collaborate with key value chain actors to reduce costs, footprint and dependence on natural resources. This

combined analysis can improve the opportunities to reduce the footprint and disrupt current technologies. This innovation process could also help to improve competencies of employees and contribute to the development of the core competencies of the organization that ensure future success. Through LCA, Proctor and Gamble has found that consumer hot water use in cloth washing is the most impact causing step in a detergent's life cycle. In order to reduce the energy bill of consumers and environmental impacts of detergents, P&G has developed a detergent with which cold water can be used for washing. This innovation has helped to expand the market share of P&G and reduced impacts of laundry detergents substantially (Werbach, 2009). Similarly, NatureWorks (Vink et al., 2010) and DuPont (2015) have used LCA to understand and improve the environmental performance of their new bio-based products, PLA and Sorona, respectively, in their innovation phase as well as to communicate the environmental benefits to customers. These products are competing with conventional fossil based plastics. PUMA has used inventory data of their products and combined with economic costs of externalities to understand the main impacts of their business on ecosystem services. According to PUMA (2011), this way of accounting helped to develop new products such as the biodegradable PUMA InCycle shoe and T-shirt which have 31% lower environmental impacts than conventional products (PUMA, 2012).

Product service systems (PSS) help create new business models with new value propositions and improve competitiveness of companies (Tucker and Tischner, 2006). By understanding the impact of carpets throughout their life cycle, Interface Inc. has designed and developed a PSS where carpeting is provided as a service rather than a product. According to Interface, PSS has helped to change their role from carpet manufacturer to flooring service provider which integrates downstream processes that not only close the material loops (by making clean collection and separation possible), but also reduce the total life cycle costs of carpeting service to customers and enhance the customer's experience by offering one accountable source of contact for all flooring needs (installation, maintenance and disposal). Extending the material life (redirecting from landfilling) by the development of advanced recycling technology and reusing it for next life has significantly reduced full life cycle carbon footprint from 16 kg CO_2 eq./m^2 to around 7 kg CO_2 eq./m^2 (Hensler, 2013). The key business functions that get insights from LCA at this stage are innovation which improves products design or processes, procurement/supply chain that chooses the right suppliers and materials, marketing that communicates product differentiation aspects or brings customer demands and finance that sets the cost structure of these products and measures the economic success. Thus, the value for the company through LCA is improved competitiveness in existing business through differentiation, customer loyalty, creation of new product offerings and new business models through innovation and rejuvenation of product portfolio.

4.4. LCA and providing societal needs by aligning corporate vision (top right quadrant)

To ensure that 9 billion people can live well within the limits of planet we need open collaboration that enables radical innovation across different industries for creating future products. The examples are bottom of the pyramid (BOP) products (Prahalad, 2006) and blue economy products and services which can reduce impacts from current inefficient products used by developed and developing countries (Pauli, 2010). For instance, development of affordable lighting solutions such as efficient LED systems is such a cross-industry effort. An LCA conducted for this innovative technology has found that the highest impacts come from energy consumption in the use phase and raw material production, especially for the large aluminum heat sink used in current LED lighting system (Scholand and Dillon, 2012). This may offer business opportunities for the chemical industry, working with the lighting industry, to find alternative materials for making small heat sinks with better heat conductivity and dissipation that improve the material efficiency and reduce the cost of LED lighting systems, increasing affordability. This type of innovation has the potential to reduce the carbon footprint of today's incandescent lighting systems from 50 kg CO_2 eq. to 5 kg CO_2 eq. per mega lumen-hour of LED technology in 2017 (Scholand and Dillon, 2012). Thus, affordable lighting and higher end use efficiency (lower electricity bill) motivate replacing billions of incandescent light bulbs while simultaneously addressing resource scarcity and respecting planetary boundaries.[3] Similarly, technologies like smart grids, electric mobility, affordable nutrition, low cost housing and cooking stoves can benefit from open collaboration to make the solutions affordable for the majority of the world's population.

Combination of LCA with engineering tools such as Computer Aided Design (CAD), Computer Aided Manufacturing (CAM) and chemical process design with ASPEN in the conceptual and detailed design phases (Eerhart et al., 2012) can help process and product designers and architects to understand the impacts of different designs/scenarios and find related opportunities to limit the environmental impacts of products. This type of analysis has the potential to help establish targets for material producers to develop new materials with the required attributes or component manufacturers for limiting the total impact profile of end products at a desired level. There are uncertainties involved in this exercise and there is a need for intensive collaboration between value chain actors. However, this process can conjure up the imagination of designers, systems architects and material developers. For example, there are projects to integrate LCA with design tools such as product life cycle management (PLM) (Ciroth et al., 2013). Thus, LCA as a strategic design tool helps to create product or service scenarios within constraints such as planetary boundaries, and provide direction to companies in devising new solutions and new ways of thinking within those constraints. The key business functions such as corporate strategy, innovation and marketing can use key insights from LCA to conceive new products and make collaborations with other industries for fueling business growth. Thus, the value for the company is new business opportunities and market growth while living well within the planetary boundaries.

A strategy might create value from one or multiple quadrants though it might primarily belong to a specific quadrant due to its relation to the main drivers it is responding to and the consequent value it creates. Hence, a strategy belonging to one quadrant can still create value in other quadrants which suggests the non-exclusive nature of value creation in different quadrants. Companies usually make progress in the order of bottom left-bottom right-top left-top right quadrants.

[3] We use planetary boundaries as a guiding principle for designing products and services by companies. In reality, the planetary boundary approach needs to consider the macro-flows of materials and energy, leading to environmental assessment for larger systems (e.g. regions) and thereby deriving allocation limits (in terms of different boundaries) to each industry or intended function. Based on this guidance, end producers and their value chain partners need to innovate products in such a way that the global production and consumption for that function will be limited within the allocated impact. This is a top down approach. World Business Council for Sustainable Development (WBCSD) uses living well within the limits of the planet as a principle and lays out the challenges, pathway and options that business can use to create opportunistic strategies towards a sustainable world by 2050 (WBCSD, 2010).

4.5. Common barriers and challenges to value creation with LCA in business

Companies may face several barriers and challenges to creating value from LCA; the participants of the seminar shared several of these important barriers and challenges (Table 1). Giunipero et al. (2012), Schneider and Wallenburg (2012), Ras and Vermeulen (2006) found some of these barriers and challenges while working with supply chain sustainability. Many participants faced challenges in more than one focus area. This is due to the interrelation between challenges which act in concert. Some approaches to address these challenges at a company level were discussed in case studies in Section 5.

5. Findings and discussion: case studies from chemical companies

In this section, the case examples (see Fig. 3) are described with three main aspects. First, we provide the context of companies in terms of different sustainability challenges, drivers (shown in the framework) and market situation such as customer needs and demands. Second, we show how LCAs are conducted in chemical companies, with respect to approaches for data collection, communication of key results and their integration in business decisions. Third, we delineate how these results and business decisions are translated into value creation for the company while addressing some of the challenges presented in Table 1. The three case studies belong to top-left quadrant i.e. reinventing processes, products and business models. The LCA case studies shown here are illustrative examples with important impact categories such as GHG emissions and energy use which is an indicative driver for several impact categories (Huijbregts et al., 2006). However, the original studies are detailed LCAs and include several impact categories and consider the trade-offs while interpreting the results. We also present an implementation procedure to translate LCA insights into value creation opportunities for business and discuss the limitations of LCA.

5.1. DSM case study

Royal DSM is a global science-based company active in health, nutrition and materials. Sustainability is now a strategic business driver for DSM and it is pursued in order to differentiate the company from the competition in the years ahead as a new global generation with a different set of values and priorities, comes to the fore. The fact that 94% of DSM's innovation pipeline is made from ECO + products (DSM, 2013); or that DSM has reduced its own energy consumption by 13% since 2008, shows how seriously it takes sustainability. DSM epitomizes its commitment by asking this fundamental question “What's the point in being successful in a world that fails?”

Bio-based materials are a key area where DSM expects new business opportunities to emerge, because of the necessity to limit climate change, resource depletion and other impacts. However, not every bio-based material is actually beneficial to the environment. Therefore, some customers request a life cycle assessment to prove the overall benefit. Once an LCA is performed, various possibilities can be explored to reduce the footprint further.

EcoPaXX is DSM's brand name for PA410, a polyamide produced from diamino butane and sebacic acid. Sebacic acid is produced from castor oil. The castor bean grows in dry warm climates, e.g. India. 70% of the carbon in the EcoPaXX comes from sebacic acid and is therefore bio-based. EcoPaXX also has outstanding properties, such as a high melting point, which allow application at high temperatures near the engine of a car. DSM expected EcoPaXX to reduce climate change compared to fossil based plastics, but to be able to say so it had to carry out a cradle to gate LCA, starting with agriculture, and ending with the polymerization, resulting in the product. It was found that a small weight reduction is possible by replacing alternative plastic with EcoPaXX. However, this needs to be proven when the complete design is available. In the absence of this information, the use phase was excluded in this study. The amount of material used and the way it is compounded and shaped depend very much on the application. To make the study broadly applicable, the functional unit was taken as 1 kg of base polymer. The LCA team at DSM collected data from literature and also sent DSM employees and consultants on field trips to collect more information about upstream processes, such as castor bean farming in India, and sebacic acid production in China. DSM produces the other monomer and the polymer in Europe, so for these processes primary data could be used. DSM asked an external expert to review the study because it wanted to use this information commercially. Initially they followed the ISO standard and used system expansion to account for co-products. At the request of the reviewer they added a sensitivity study in which they also assessed the impact of using economic allocation instead. It turns out that the emissions of greenhouse gases in all processes are compensated by the CO_2 absorbed in the plants; making the cradle to gate carbon footprint zero.

EcoPaXX is an example from the top left quadrant of our framework. Procurement was involved in identifying the best sources of sebacic acid and analyzing the upstream part of the value chain. Innovation was involved in developing the polymerization and compounding technology and developing applications. Marketing was involved in finding applications and customers that can benefit from the new material. The insights gained from LCA

Table 1
Summary of key common barriers and challenges in creating value from sustainability through LCA.

Focus areas	Common barriers and challenges
A. Value chain and collaboration	1) Understanding the interrelation between processes of the value chain companies and, consequently, offering innovative solutions to be more sustainable. 2) Creating a business case and collaborative environment in a complex supply chain while covering environmental, social and economic benefits for various stakeholders.
B. Communication	3) Clearly communicating sustainability performance to different business functions, such as marketing and sales, within own company and in the value chain. 4) Moving from one impact category communication (e.g.: CO_2 emissions) to all aspects of sustainability to customers and consumers.
C. Financial aspects	5) Translating sustainability into financial value with current accounting standards, which does not account for externalities. 6) Ensuring that the benefits of an improvement can be reaped by parties who have invested (principal and agent problem). 7) Short-term financial focus of businesses and investors and thus no reward for sustainable performance of products and processes which consider the total cost of ownership (relevant for all actors in the value chain as well as consumers).
D. Methodology	8) Creating and communicating LCAs without proper methodology and measurements. 9) Competing on a level playing field with a harmonized methodology and availability of credible and cheaper data.

Fig. 3. a) Engine cover made from EcoPaXX polymer of DSM for Mercedes Benz A class cars, b) Low-weight (LoW8) gas cylinder made with Twaron reinforcement, c) Utensils and EV charger made from up-cycled resins of SABIC.

provided guidance and helped initiate dialogue between different colleagues and contributed to the decision making of these business functions at various dimensions. Thus, LCA served as a platform to interlink various issues, between different business functions such as innovation, marketing & sales, and procurement within the company as well as in the organizations of suppliers and customers. Thus, DSM provides an approach to address the challenges A and B of Table 1.

The fact that the material is bio-based and carbon neutral motivates people to be innovative and persistent to find solutions to problems on the way. EcoPaXX is applied in the engine cover of the new Mercedes A-class. Even in high end automotive applications such as this one, cost is an important factor. Engineers from both companies joined forces to utilize the properties of the material to create a cost effective solution and capture the environmental benefits. This collaboration resulted in the introduction of a new technology for coloring the engine covers. By understanding the concerns and demands of customers and stakeholders, DSM used co-creation to devise solutions for the companies in the value chain (addressing the challenges A and B of Table 1). This is a case where sustainability and LCA has supported the decision to use the bio-based material and has ultimately led to sales. For some customers LCA is not a priority and the material properties are the main driver for material selection. However, in some other applications, bio-based origin and the proof of lower environmental impacts (with an LCA) is a requirement of the customer, without which the material would not sell.

To conclude, the use of LCA has helped the development of an innovative bio-based polymer and to differentiate in the market with carbon neutrality alongside better functionality at high temperatures. This innovation has rejuvenated the product portfolio of DSM Engineering Plastics business group and strengthened its collaborative efforts with key customers.

5.2. SABIC case study

SABIC is the world's largest petrochemicals manufacturer. SABIC produces Chemicals, Polymers, Performance Chemicals, Fertilizers, Metals and Innovative Plastics. In the past decade, the demand for plastics with recycled content has increased significantly. The aim of E-waste and end-of-life vehicle regulations, industry standards and other initiatives is to increase resource efficiency, to close material loops and to encourage the market expansion of recycled materials. Corporate sustainability programs have also led many manufacturing companies to set targets for the use of recycled materials in their products. In addition, consumers have become more aware of sustainability issues, and oil prices have steadily increased due to concerns about resource scarcity – all of which have made recycling technologies more competitive and attractive. One way that SABIC has addressed these market needs is by developing a broad portfolio of recycled resins using mechanical and chemical recycling technologies. One such series is iQ resins, for example Valox iQ™ and Xenoy iQ™ resins.

Valox iQ™ resins are polybutylene terephthalate (PBT)-based resins, which are produced by using up to 60 percent post-consumer polyethylene terephthalate (PET). PET from waste bottles is upcycled into high performance PBT, which has better engineering properties than the original bottle-grade PET. Xenoy iQ resin is obtained through blending recycled PBT with polycarbonate. In order to validate and communicate environmental

benefits of recycled products, SABIC developed a sustainability solutions qualification process. This process uses two key tools.

1) LCA methods, based on the ISO 14040 and 14044 standards, to estimate the carbon, energy and other impacts of the products or applications across the life cycle. All life cycle impact categories are assessed and considered in the qualification process.
2) Sustainable chemistry principles (OECD, 2014) to assess the chemical composition of the product, including impurities, byproducts, and catalysts, against well-established toxicological, regulatory, and industry-standard criteria.

The functional unit used in this LCA study is 1 kg of resin pellets (conventional Valox or Valox iQ resin) at the factory gate. Both conventional Valox and Valox iQ resins are used in similar applications and physical properties are essentially the same at the plant gate, therefore the post-gate stages (final product manufacturing, use and disposal) are identical and were not considered in this base resin comparative assessment. Valox or standard PBT is manufactured at Indiana, America. Valox iQ PBT resin is made in India. PET bottle/bale acquisition was estimated as 50–60% from USA, 25–20% in India, and rest from Europe. All the relevant transportation for collection of PET bottles was included. For allocation of recycled PET both cut-off and open loop recycling approaches were considered in the analysis.

An ISO compliant critically reviewed LCA concluded that Valox iQ resin technology causes 49% smaller GHG and 61% smaller energy footprints (SABIC, 2011), compared to the production of traditional DMT-based PBT, without the traditional trade-off in performance usually found in mechanically recycled resins. The properties of Valox iQ resin are nearly equivalent to those of the virgin Valox PBT resin used in electrical connectors, electronic devices, fibers, and consumer goods, such as oral care and food utensils. Xenoy iQ resin has been used in power-tool housings, transportation exteriors, outdoor products, and other components requiring resistance to high impact and chemicals, such as healthcare applications. Today, SABIC's iQ resin portfolio includes approximately 20 commercial grades.

The success of the Valox iQ resin product helped SABIC to develop the experience, confidence, and LCA competency required to lay additional emphasis on creating new sustainability solutions for the market, which has become one of the major themes of SABIC's sustainability program. This includes commercialization of 3 additional post-consumer recycled resin series with ~15 grades to complement the Valox iQ resin, implementation of a sustainability product standard and qualification to monitor progress, and further expansion of the role of LCA in making business decisions and in communication of results. Valox iQ resin series belong to the top-left quadrant of the framework. It is a clear example of upcycling which leads to innovation of recycling technology while addressing drivers such as resource depletion.

With the development of Valox iQ and Xenoy iQ resins, SABIC has addressed customer needs for new recycled resins. It formed new business collaborations across the value chain to drive the concept of closing the material loops while simultaneously generating additional sales by these recycled resins and provided access to new customers. During the development of these resins, SABIC has gained substantial experience in the capability of innovation of recycling and separation technologies.

5.3. Teijin Aramid case study

Teijin Aramid, a subsidiary of the Teijin Group, is a producer of aramid products. Customers are increasingly demanding financially beneficial (competitive) ecological solutions which consume fewer resources, energy, and can be recyclable. Twaron® is strong, heat resistant, long lasting and needs low maintenance. Owing to these characteristics it can offer wide ranging innovative solutions such as conveyor belts in mines and low weight gas cylinders. Teijin Aramid believes that Twaron® based solutions, which simultaneously address environmental and economic issues, lead to business growth and new markets.

In general, lightweight and long-lasting solutions can lead to resource and financial savings, lower CO_2 emissions and a smaller ecological footprint along the whole value chain. In many applications this can be achieved by the use and reuse of Twaron® – a para-aramid fiber produced by Teijin Aramid. To analyze and quantify the performance of Twaron®, Teijin Aramid developed a TUV (Technical Inspection Association in Germany) certified Customer Benefit Model (CBM) based on the principles of Eco-Efficiency Analysis (Uhlman and Saling, 2010). The model quantifies financial and ecological value for every actor throughout the value chain. This identifies potential competitive advantages of Twaron®-based solutions for every partner.

The CBM is used to support business cases by comparing mainstream products with Twaron®-based solutions (products) for the same functional unit. The CBM starts with a qualitative assessment, which can lead to a quantitative model with three main components:

1) Environmental assessment based on Life Cycle Assessment (LCA), which comprises basic environmental inventory data: energy and CO_2 emissions throughout the whole product life cycle.
2) Financial assessment based on the Total Cost of Ownership (TCO) approach. By using the TCO, the cost structure of the product life cycle is analyzed and the payback time, the Net Present Value (NPV) and Internal Rate of Return (IRR) are calculated.
3) Current and future scenarios can be quantified by changing values of variables.

Teijin Aramid's engineering partner Advanced Lightweight Engineering Delft (ALE Delft) has developed a method to manufacture Twaron® reinforced low-weight (LoW8) gas cylinders (LoW8, 2014). The advantages of lightweight cylinders compared to steel cylinders over the total value chain were quantified by the cooperation between Teijin Aramid and Ecomatters consultancy. By comparing both solutions over their lifetime, it became clear that for tropical regions maintenance is an extra driver. A steel cylinder needs to be repainted several times during the lifetime, whilst for the Twaron®-based composite gas cylinder this is not necessary.

A big advantage in the use phase is the lower weight of the cylinder; 4.3 kg for Twaron®-based composite cylinders compared to 16.4 kg for steel (Fig. 4). The positive effects of low weight during transportation over the total lifetime are customer specific i.e. the effect depends on the amount of kilometers the cylinders are transported. The functional unit is to provide 14 kg of gas in a cylinder (UN 1965 Propane) to consumers for a period of 25 years. Twaron production takes place in the Netherlands. Cylinder manufacturing and use are currently in the Netherlands but they can take place in many regions in the future such as Asia and South America. CBM can analyze various scenarios from cradle to grave system boundaries. The example in Fig. 4 shows high transport scenario of a customer located in the Netherlands.

Fig. 4 shows the advantages of LoW8 cylinders for one customer. The LoW8 cylinder caused 22% lower life cycle CO_2 emissions than the steel cylinder due to the lower fuel use for transportation of LoW8 cylinders in the lifetime. Another advantage of the LoW8 cylinders is that the occupational health risks of employees are

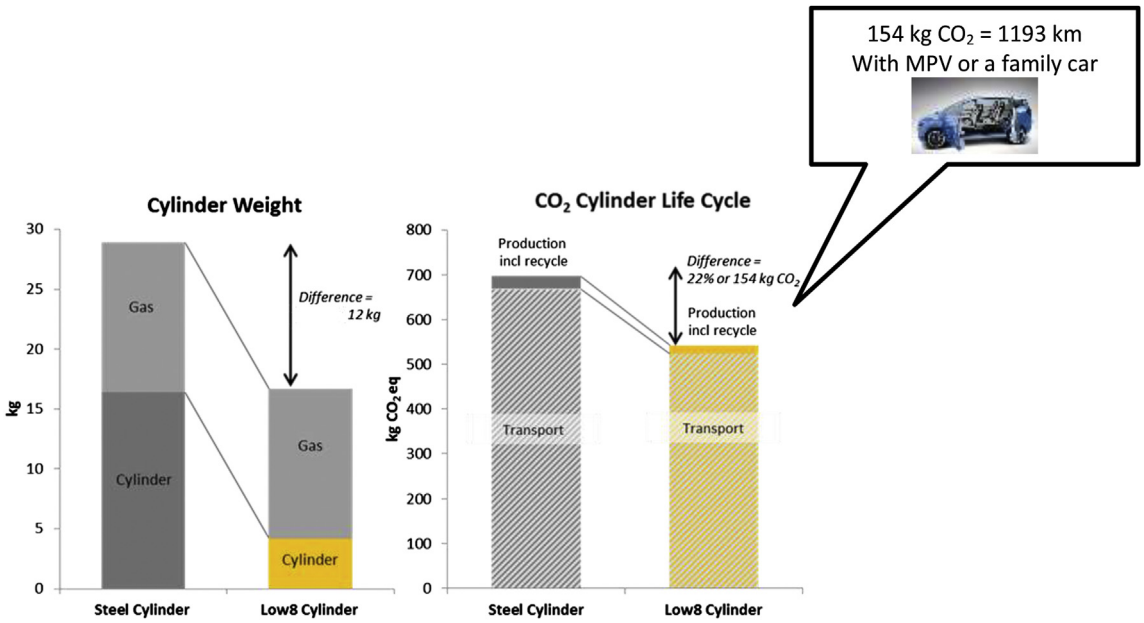

Fig. 4. Left part: weight comparison of steel and LoW8 gas cylinder. Right part: example of a customer specific result regarding CO_2 emission savings.

reduced. This results from the fact that gas cylinders are manually carried from a truck to the point of use at the place of end consumers, i.e. households in developing countries.

There are different variables in the CBM model based on the type of Twaron® application and geographical region of customers such as the type and price of fuel for transport, price and source of energy (e.g. coal, wind etc.), and carbon pricing, if applicable. By using variables, a tailor-made calculation of the energy and CO_2 emission savings and the yearly financial benefit in terms of payback period and internal rate of return (IRR) can be provided for every customer.

Owing to the lower transportation energy consumption and the lower maintenance costs, Twaron® can be differentiated in the market from competing materials for gas cylinders and it also offers operational cost reduction for gas distributors. The CBM model has helped Teijin Aramid to build business cases in collaboration with value chain partners via an interactive and iterative process that analyses the benefits and trade-offs of sustainable solutions. The outcomes of the process are shared and accepted by all participants because of the transparency of the process and also due to the discussion of scenarios. The LCA insights were incorporated in commercial presentations of sales and marketing functions for offering sustainable solutions to customers. By this means, engagement with value chain partners and end customers was enhanced. Teijin Aramid offers an approach to address challenges related to focus areas A and B in Table 1.

All three case studies also show that third party reviews were used to improve their methodology and to address credibility issues with communication of sustainability and thus provide a solution to the challenges mentioned in focus area D in Table 1. We acknowledge that for B2B applications third party reviews are not necessary but it depends on the customer's demands. The examples described from the three companies primarily fit in the top left quadrant due to the main drivers competitiveness which is motivated by customer demand, lower impacts and resource depletion. The value creation opportunities reaped are differentiation, rejuvenation of product portfolio and innovation. All three companies apply LCA also for continuous improvement of their processes (bottom left quadrant) and other quadrants for different products.

5.4. Implementation procedure for business value creation based on LCA in companies

UNEP/SETAC has proposed the application of Life Cycle Management (LCM) capability maturity model for developing the capacity of small and medium sized companies to achieve their sustainability goals (UNEP/SETAC, 2009). We propose an implementation procedure for business value creation based on the insights gained from LCA studies and its integration in business functions. Owing to this integration and emphasis on value, our procedure goes further than procedures available in the literature (UNEP/TU Delft, 2007; UNEP/SETAC, 2009). This is an iterative procedure of various steps as shown in Fig. 5.

The steps of the procedure are:

1. Understand the context of the product by collecting information on various drivers and stakeholder views/concerns: Drivers mostly depend on aspects of the product such as its function, industry, geographical scope of the value chain and the consumer market situation. Hence a company with a broad portfolio of products can be subjected to a wide range of drivers. Understanding drivers is a crucial step since it provides the essential motivation for conducting an LCA and to which strategy/quadrant it belongs, what needs to be achieved by the study and which value creation opportunities are most relevant to the product. This process also provides basic understanding about which business functions need to be engaged in various stages.
2. Involve the relevant business functions within the company: The business functions that need to utilize the insights provided by the LCA and also those that can contribute knowledge to the process should be involved from the start. The outcomes of the product context and drivers (step 1) should be discussed openly and their opinion should be elicited. This ensures shared understanding, provides critical knowledge and helps the co-creation and collaboration throughout the whole process. For instance, through understanding of fabric dyeing impacts in the downstream value chain of textile garments and concerns raised by global NGOs, helped a fiber producer to understand the business opportunity for spun-dyed (dope-dyed) fibers that

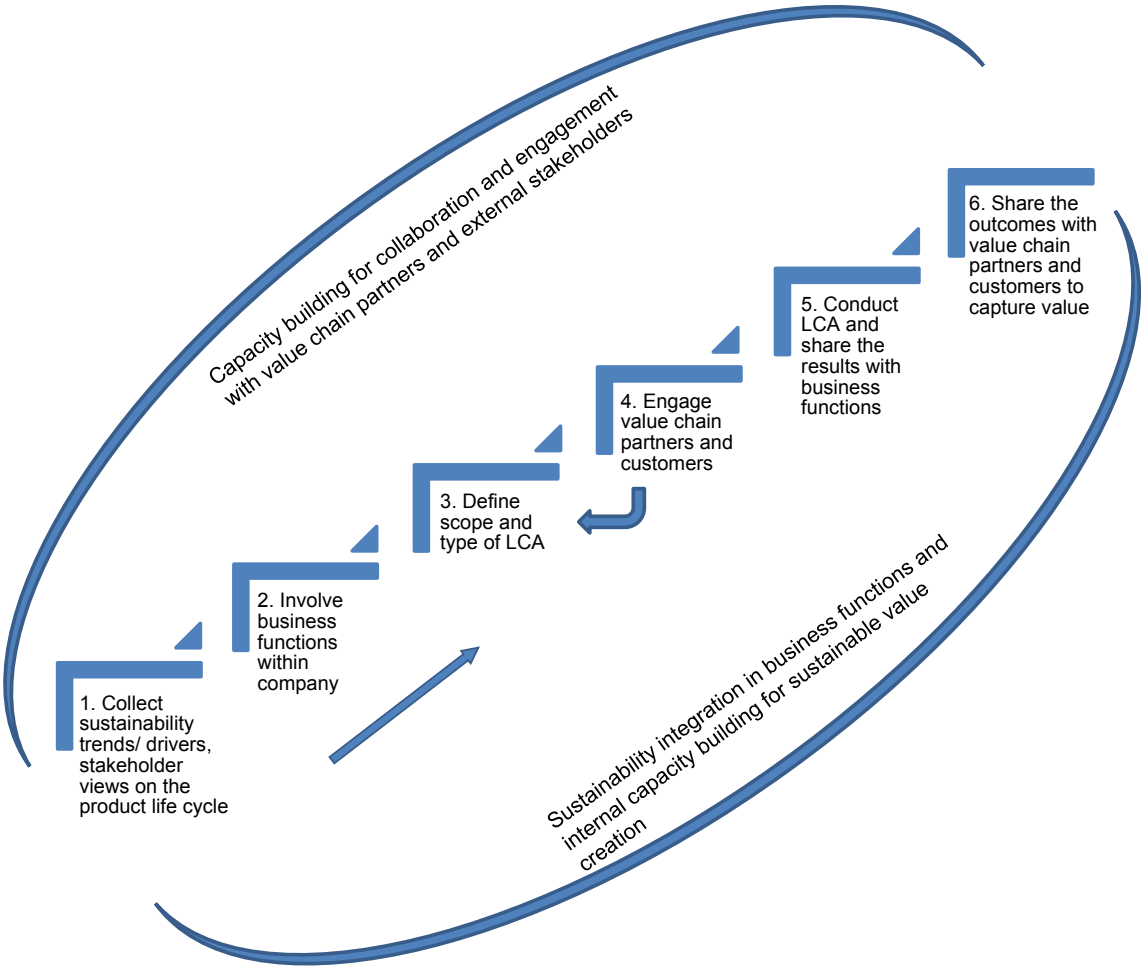

Fig. 5. Iterative procedure for translating insights from the LCA into value creation.

consume little resources and avoid conventional dyeing and related water pollution (Terinte et al., 2014). At the start they identified the innovation and marketing departments as the key business functions that need to be involved in the LCA. The innovation department was engaged since it provided the necessary information to conduct and guide the LCA. The marketing department was engaged to understand the concerns of brands and retailers and also to communicate to customers about new product attributes and to differentiate their products at a later phase.

3. Define the goal, scope and type of LCA: With inputs from steps 1 and 2 formulate the goal and scope and decide what type of LCA is required to address them. Depending on the context, a screening LCA could be sufficient. A detailed LCA is needed for a holistic understanding, to address a wide range of drivers and to credibly communicate the results. In this step, it is possible to decide whether the LCA should be peer reviewed by independent experts to achieve the goal.
4. Engage the value chain companies and customers: Clearly communicate the main reasons for conducting the LCA and understand their key concerns and perspectives. It is important to offer the specific advantages of this process to them. This approach can help to collect data and to get process and site specific insights. In order to innovate collaboratively, the value chain should be engaged thoroughly. If necessary, some agreements need to be made depending on the situation either before (such as confidentiality and IP rights) or after the process (in some cases, when the study results are available and the producer is certain that substantial improvements can be achieved at this company, then the value chain partner need to be assured of long term business relation through contracts etc.). Inputs from this step might help to refine the scope of the LCA in step 3.
5. Conducting the LCA and discussing results internally: Present the results in an easy to understand format to the relevant business functions and discuss the actions that can be undertaken. In order to effectively capture the value such as mitigating risks, product differentiation, entering new markets etc. various business functions need to be convinced of the insights provided by the LCA study. Sensitivity, scenario and uncertainty analyses can provide insights covering various possible situations that businesses might face and prepare the business functions in advance to respond to those situations. Owing to their earlier involvement (step 2), they would be aware of the drivers, insights provided by value chain members and of the LCA results. By involving business functions at the start of the process there is a greater possibility of them embracing the outcomes and implementing any actions/recommendations.
6. Share the outcomes of the process with value chain companies and customers to capture value: Present the results of the LCA and the potential actions suggested by different business functions within the company to value chain partners. Discuss the various possibilities for collaboration and involvement with value chain companies to capture the value.

During this implementation process, companies build internal capability to integrate sustainability in different business functions. Companies also develop capabilities for external collaboration and engagement with various value chain partners, other industries and even competitors.

5.4.1. Possible difficulties encountered in the implementation procedure

There may be several difficulties in implementing the six steps explained above. These originate from the awareness and knowledge level of the people involved, their perceptions and mental models, company and market situation in different geographies, and skills of people implementing the whole process such as engaging stakeholders, synthesizing insights from seemingly different aspects to provide a coherent picture, conducting dialogues etc. It will hardly ever be possible to find a single person having all the necessary skills; hence team work and collaboration are paramount. Despite these challenges, the three companies described in the examples above are making progress in acquiring these skills through the process of learning by doing, recruitment of people with different skills and experience and seeking help from external experts.

There are other challenges related to organizational constraints. In many companies, there are no line managers specifically responsible for the sustainability assessment of their product portfolios. Thus, there will be no substantial progress with respect to sustainability assessments unless there are strong and repeated requests from key customers. In the studied companies, there is a designated line manager for each business group responsible for coordinating LCA activities with a specific target per year. There are also programs to assess supplier sustainability with dedicated personnel and targets. In some cases, compensation and bonus of the managing board and line managers are also linked to the sustainability performance assessment of products (e.g. DSM). In some cases, the sustainability team is part of marketing and sales and supports it with the benefits offered by sustainability assessments in acquiring new customers (e.g. Teijin Aramid, SABIC).

In many situations, value chain partners do not like to share the process data and information because of intellectual property rights, the fear of price negotiations based on information on the use of resources and utilities and for other reasons. This is one of the most common challenges of conducting LCAs in industry. Some ways to address this are ensuring confidentiality through agreements, having long term co-operation or contractual agreements, sharing of benefits etc. For example, a multi-national footwear brand promised its supplier if they co-operate and share data, then the brand will not claim any economic benefit from the sustainability improvements (e.g. from reduced resource use). The supplier had substantial raw material waste during the manufacturing of the shoe soles, while the cost of total raw material was borne by the brand, the sale of material waste was a continuous monetary stream for the supplier. Since the brand ensured no price negotiation based on the sharing of process data, the supplier shared the details of the process and together improved the manufacturing process (better process and product design) which reduced raw material consumption substantially.

5.5. Limitations of the framework, LCA and case studies

For a detailed description of other possible interpretations of the framework see supplementary electronic material. There are many other social and financial benefits (value) of the strategies implemented in various quadrants next to the already explained value, such as attracting and retaining talent, being a preferred supplier for key customers, influencing policy makers based on commitment and credibility, and attracting investors. These business value aspects can be realized by strategies in different quadrants.

We acknowledge the limitations of the LCA approach in terms of the state of development of methods for impacts such as biodiversity and toxicity, lack of inventory, uncertainties in data and methods, limited guidance on allocation for different product categories etc. (Finnveden et al., 2009). Lack of location-specific life cycle inventory databases is one of the most important limitations. Resource requirements are also acting as limitation for implementing LCA. Despite this, businesses should implement life cycle tools because they can help businesses to make better decisions and create value. This provides impetus for removing current limitations of LCA.

Companies can also create value with customer experience, products with superior aesthetics, feel etc. These aspects might not be captured by LCA, if its unit of analysis i.e. functional unit cannot take into account these aspects. LCA is not easily able to capture the perception and preferences of people, taste, and emotional value attached to products, hence it cannot help companies in terms of these aspects for creating value. LCA also does not inherently indicate regulatory limits with respect to type of resource use or quantity of emissions rather it provides guidance for making decisions in various stages of product life cycle.

In this article, we have limited our scope to show value creation opportunities with the integration of environmental sustainability through LCA. Combining social aspects, such as working conditions and rights of workers, throughout the value chain provides more drivers and associated opportunities for value creation in different quadrants. Further research is needed for the development of a mature social-LCA method and its integration in the framework.

This article focuses mainly on the chemical industry, one of the largest consumers of resources. The energy consumption of the EU chemical industry is around 20% of the total use of EU manufacturing industry (CEFIC, 2013). Though it needs to improve its own environmental performance, it can enable other industries to deliver sustainable products such as food, textiles and electronics and help us to live within the limits of planetary boundaries (Rockström et al., 2009; WBCSD, 2010). Hence, it has the potential to create value for businesses by providing new products, services and business models which are environmentally, socially and economically better than existing ones. A solution would be considered successful when it is profitable and makes a sound business case (covering business value aspects) for all the companies involved in the value chain including suppliers, brands/retailers and consumers. Further research needs to be conducted with different value chain partners and other industries to understand the applicability of the framework and value creation with LCA approach.

In Section 4, we present a preliminary list of barriers and challenges to value creation with LCA in business from 45 responses of seminar participants. A larger survey is needed to capture other aspects as well as to corroborate this list. We have described three cases as illustrative examples of LCA thus cover only a few impact categories. Further research needs to be conducted to show detailed LCA studies that cover all relevant impact categories and value creation. Owing to a limited number of case studies, we do not generalize our approach to other chemical companies and industries. However, it may be possible to reap the benefits of applying our approach to any company since LCA can create value for many industries as shown in this article. Our approach is limited in showing the possible value creation opportunities resulting from environmental sustainability strategies employing LCA. Hence, the role and importance of organizational culture in implementing strategies (Baumgartner, 2009), to create value, was not discussed.

No attempt was made to quantify the value with various valuation techniques identified in the literature (Reed, 2001). These issues should be dealt with by further research.

6. Conclusions and recommendations

The relevance of various aspects of environmental sustainability, such as water scarcity, resource depletion, and climate change, changes from product to product depending on the type of product and supply chain locations. To grasp this complexity, business managers need concrete tools and sound metrics to integrate environmental sustainability into their core business. Life cycle assessment (LCA) is a widely acknowledged systems modeling tool that can provide metrics to help improve the environmental sustainability of processes, products and services. However, many companies are not implementing LCA in their day-to-day business due to its resource-intensive nature, complexity and difficulty of contextualizing the relevance of LCA in various circumstances. Moreover, corporate sustainability of most companies, except for a few pioneers, is revolving around quick wins rather than changing the core business, i.e. improving the sustainability of its products and services. In this context, the main contribution of this article is twofold. First, it contextualizes the different applications of LCA with the help of the sustainable value framework by relating LCA with appropriate drivers, strategies and resulting business value to the ground reality or context of companies. Therefore, the business managers can justify the application of LCA in companies by aligning it with business priorities. By this means, dedicated resources such as manpower and budget can be allocated to LCA and, ultimately, its practice can be institutionalized. Second, this article shows how LCA can be used as a strategic decision support tool in the field of corporate sustainability and to different functional managers and, thus, establishes the position of LCA in the corporate toolbox. For simplicity, case studies in this article describe how understanding a few impact categories such as climate change and energy use have helped the business functions to create value for a company. Other relevant environmental impact categories should be included in the LCAs to address environmental sustainability and to identify numerous opportunities to create sustainable value.

LCA provides support to the decision-making process of managers from different business functions such as innovation and marketing and, consequently, helps translation of the LCA-based insights into sustainable value creation opportunities. The improved environmental and social performance of companies can have a positive impact on the financial performance through reduced costs, improved revenues, avoidance of risks and new business opportunities. There are several risks that can be avoided by sustainability performance improvements. Increased scarcity of resources such as water can lead to disruption of operations, i.e. lost production activity, which will impact the revenue earning capacity. Companies have to increasingly pay higher fines for violations, they need to compensate for wrongdoings, and need to earn the license to operate from the local communities by avoiding law suits of communities challenging business activities. These are called regulatory and legal risks. There are possibilities for damaging corporate reputation, i.e. reputational risks, from media and NGO campaigns for not meeting stakeholder expectations such as workers' health and safety and labor practices. Market and product risks can also occur when customers move to other products with better sustainability performance or when governments and organizations impose sustainable procurement policies. On the other hand, there are several value creation opportunities for companies with superior sustainability performance for each risk category mentioned above. It is possible to obtain additional revenues from environmentally and socially superior products through an eco-premium. Moreover, high sustainability performance of companies can positively influence the desire of customers to buy their products (brand image), the desire of employees to work for them (preferred employer) and the desire of investors to provide long-term capital (blue chip status or good rank in indexes such as Dow Jones sustainability index). Companies with superior sustainability performance can differentiate their products in the market against competitors to attract new customers and create a competitive advantage. Business to Business (B2B) companies can help their customers, i.e. end producers, to meet their sustainability goals by supplying superior intermediate products. In essence we can say that the existence of a company or its profit making capacity can be affected in several ways described above through various risks and opportunities.

The case studies showed how three companies used LCA to create value in their day-to-day business by developing bio-based materials (DSM), closing the material loops by developing recycled resins and associated technology (SABIC), and offering eco-effective solutions to customers (Teijin Aramid). Also, we proposed an implementation procedure for conducting LCAs with the involvement of various business functions and ultimately creating sustainable business value.

To capture the numerous value creation opportunities, businesses should concentrate on raising awareness about and developing skills for using life cycle approaches, such as thinking in systems and orchestrating dialogues for collaboration. There are three levels of collaboration. First, cross-functional collaboration should be fostered within the companies. Despite this internal collaboration, a company alone cannot embed sustainability. Therefore, second, companies should collaborate with peer companies and competitors in devising common approaches and tools which can solve the problems of engaging and collecting data from value chain members that support more than one customer. This can reduce cost of implementation and help to devise strategies to address common problems economically. Third, the chemical industry needs to openly collaborate with other industries, such as agriculture and transport, to radically innovate products and services with ultra-low footprints or net positive benefits. Furthermore, companies should engage all affected stakeholders to understand their concerns and take advantage of the creative potential of different people. LCA as a strategic decision support tool can help organizations in leveraging all of these interactions. Further research is needed to include social life cycle assessment in the framework, which can offer opportunities for value creation from social aspects.

Disclaimer

The opinions expressed in this paper by the authors are their personal views alone and do not represent the views of the organizations they work for.

Acknowledgment

Authors would like to thank DPI Value Centre for hosting the LCA knowledge platform and coordinating all the meetings and value creation with the LCA seminar. We would like to thank Neena C, Ananda Sekar for their contribution to the SABIC case study and Marjan Kamer for her contribution to the Teijin Aramid case study. We would like to thank Dr. Rodrigo Lozano, Sjors Witjes, Dr. Walter Vermuelen and Ioannis Tsiropoulos for suggesting improvements as well as article structure. We would like to thank Mr. Dave Morris, DSM for editing and improving the language of the article.

Appendix A. Supplementary material

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jclepro.2016.03.020.

References

AFNOR, 2011. BP X 30-323-0: General Principles for an Environmental Communication on Mass Market Products; Part 0: General Principles and Methodological Framework.

Baumgartner, R.J., 2009. Organizational culture and leadership: preconditions for the development of a sustainable corporation. Sustain. Dev. 17, 102–113.

Braudel, F., 1979. The Wheels of Commerce: Civilization & Capitalism 15th–18th Century. Harper & Row, New York.

Castro, N.R., Chousa, J.P., 2006. An integrated framework for the financial analysis of sustainability. Bus. Strat. Environ. 15, 322–333. http://dx.doi.org/10.1002/bse.539.

CEFIC, 2013. The Chemical Industry in Europe: towards Sustainability 2011/12 Report. http://www.cefic.org/Documents/Learn%20and%20Share/Cefic_Sutainability_Report2011-2012.pdf (accessed 06.03.14).

Ciroth, A., Theret, J.P., Fliegner, M., Srocka, M., Bläsig Duyan, V., 2013. Integrating Life Cycle Assessment Tools and Information with Product Life Cycle Management/Product Data Management. http://www.greendelta.com/uploads/media/GCSM2013_Sept22_Integrating_LCA_with_Design_tools_final_2.pdf (accessed 05.03.14).

DSM, 2013. Royal DSM Integrated Annual Report 2012. http://www.dsm.com/content/dam/dsm/cworld/en_US/documents/integrated-annual-report-2012.pdf?fileaction=openFile (accessed 10.03.14).

DuPont, 2015. Sorona® Environmental Data Sheet. http://www2.dupont.com/Sorona_Consumer/en_US/assets/downloads/PS-1_Sorona_Environmental_Data.pdf (accessed 25.02.15).

EarthShift, 2013. Potential for Cost Savings through Eco-efficiency and LCA. http://web.earthshift.com/blog/bid/305032/Potential-For-Cost-Savings-Through-Eco-Efficiency-and-LCA?goback=%2Egde_1940348_member_259148112 (accessed 20.08.13).

EC, 2002. The World Summit on Sustainable Development: People, Planet, Prosperity. Office for Official Publications of the European Communities, Luxembourg.

EC, 2011. A Resource-efficient Europe – Flagship Initiative under the Europe 2020 Strategy.

Eccles, R.G., Ioannou, I., Serafeim, G., 2012. The Impact of a Corporate Culture of Sustainability on Corporate Behavior and Performance (Working paper, 12-035, May 9, 2012). Harvard Business School.

Eerhart, A.J.J.E., Faaij, A.P.C., Patel, M.K., 2012. Replacing fossil based PET with biobased PEF; process analysis, energy and GHG balance. Energy Environ. Sci. 5 (4), 6407–6422. http://dx.doi.org/10.1039/C2EE02480B.

Eisenhardt, K.M., Graebner, M.E., 2007. Theory building from cases: opportunities and challenges. Acad. Manag. J. 50, 25–32.

Elkington, J., 1997. Cannibals with Forks: the Triple Bottom Line of 21st Century Business. Capstone Publishing, Oxford.

EMF, 2013. Towards the Circular Economy-1: Economic and Business Rationale for an Accelerated Transition – Part-1. Ellen Macarthur Foundation.

Epstein, M.J., Roy, M.J., 2001. Sustainability in action: identifying and measuring the key performance drivers. Long. Range Plan. 34 (5), 585–604. http://dx.doi.org/10.1016/S0024-301(01)00084-X.

EU PEF, 2013. Commission Recommendation: on the Use of Common Methods to Measure and Communicate the Life Cycle Environmental Performance of Products and Organisations. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:124:FULL:EN:PDF (accessed 02.02.14).

Fava, J., 2004. Why Take a Life Cycle Approach? UNEP-SETAC Life Cycle Initiative, Paris. http://www.unep.fr/scp/publications/details.asp?id=DTI/0585/PA.

Finnveden, G., Hauschild, M.Z., Ekvall, T., Guine, J., Heijungs, R., Hellweg, S., Koehler, A., Pennington, D., Suh, S., 2009. Recent developments in life cycle assessment. J. Environ. Manag. 91, 1–21.

Freeman, R.E., Reed, D.L., 1983. Stockholders and stakeholders: a new perspective on corporate governance. Calif. Manag. Rev. 25 (3), 88–106.

Friedman, M., 1970. The social responsibility of business is to increase its profits. N. Y. Times Mag. (September 13, 1970).

Giunipero, L.C., Hooker, R.E., Denslow, D., 2012. Purchasing and supply management sustainability: drivers and barriers. J. Purch. Supply Manag. 18, 258–269.

Hart, Milstein, 2003. Creating sustainable value. Acad. Manag. Exec. 17 (2).

Hensler, C., 2013. One Step Forward, Two Steps Back: Recycling, an Evolving Process with Changing Environmental Impacts.

Huijbregts, M., Rombouts, L.M., Hellweg, S., Frischknecht, R., Hendriks, A.J., Van de meent, D., Ragas, A.M.J., Reijnders, L., Struijs, J., 2006. Is cumulative fossil energy demand a useful indicator for the environmental performance of products? Environ. Sci. Technol. 40 (3), 641–648.

ILCD, 2010. International Reference Life Cycle Data System (ILCD) Handbook – General Guide for Life Cycle Assessment – Detailed Guidance. European Commission – Joint Research Centre – Institute for Environment and Sustainability, first ed. Publications Office of the European Union, Luxembourg. March 2010.

ISO 14040, 2006a. Environmental Management – Life Cycle Assessment – Principles and Framework. International Standardisation Organisation.

ISO 14044, 2006b. Environmental Management – Life Cycle Assessment – Requirements and Guidelines. International Standardisation Organisation.

Jensen, A.A., Remmen, A., 2006. Background Report for a UNEP Guide to Life Cycle Management – A Bridge to Sustainable Products. UNEP-SETAC Life Cycle Initiative, Paris. http://www.lifecycleinitiative.org/wp-content/uploads/2013/09/UNEP_Background_document_LCM_2006_Febr.pdf.

Jonker, N., Brugman, L., Krop, H., 2013. Flame Retardants, from Mining to Recycling: the Life Cycle Assessment Approach (E. U. FP7 project ENVIRO). http://www.enfiro.eu/.

Jupp, V. (Ed.), 2006. The SAGE Dictionary of Social Research Methods. Sage Publications, London.

Kumar, V., Christodoulopoulou, A., 2013. Sustainability and branding: an integrated perspective. Ind. Mark. Manag. http://dx.doi.org/10.1016/j.indmarman.2013.06.008.

Labuschagne, C., Brent, A.C., van Erck, R.P.G., 2005. Assessing the sustainability performances of industries. J. Clean. Prod. 13 (4), 373–385. http://dx.doi.org/10.1016/j.jclepro.2003.10.007.

Laszlo, C., Zhexembayeva, N., 2011. Embedded Sustainability: the Next Big Competitive Advantage. Stanford University Press, Stanford, California.

LoW8, 2014. Low Weight Gas Cylinders. http://www.low8.com/ (accessed 01.07.14).

Lozano, R., 2013. A holistic perspective on corporate sustainability drivers. Corp. Soc. Responsib. Environ. Manag. http://dx.doi.org/10.1002/csr.1325.

Nidumolu, R., Prahalad, C.K., Rangaswami, M.R., 2009. Why sustainability is now the key driver of innovation. Harv. Bus. Rev. September 2009.

OECD, 2014. What is Sustainable Chemistry? http://www.oecd.org/env_sustainablechemistry_platform/ (accessed 10.03.14).

Pauli, G., 2010. The Blue Economy: 10 Years, 100 Innovations, 100 Million Jobs. Paradigm Publications, US.

Polman, P., 2014. Business, society, and the future of capitalism. McKinsey Quart. http://www.mckinsey.com/Insights/Sustainability/Business_society_and_the_future_of_capitalism?cid=other-eml-alt-mkq-mck-oth-1405 May 2014 (accessed 19.05.14).

Porter, M.E., 1985. Competitive Advantage: Creating and Sustaining Superior Performance. The Free Press, New York.

Porter, M.E., Kramer, M.R., 2006. Strategy and society: the link between competitive advantage and corporate social responsibility. Harvard Bus. Rev. (December 2006).

Prahalad, C.K., 2006. Fortune at the Bottom of the Pyramid: Eradicating Poverty through Profits Hardcover. Dorling Kindersley Pvt Ltd Publishing.

PUMA, 2011. PUMA Completes First Environmental Profit and Loss Account Which Values Impacts at € 145 Million. http://about.puma.com/puma-completes-first-environmental-profit-and-loss-account-which-values-impacts-at-e-145-million/.

PUMA, 2012. New PUMA Shoe and T-shirt Impact the Environment by a Third Less than Conventional Products. http://about.puma.com/new-puma-shoe-and-t-shirt-impact-the-environment-by-a-third-less-than-conventional-products/ (accessed 28.09.13).

Ras, P.J., Vermeulen, W., 2006. The challenge of greening global product chains: meeting both ends. Sustain. Dev. 14, 245–256.

REACH, 2015. REACH – Registration, Evaluation, Authorisation and Restriction of Chemicals. http://ec.europa.eu/enterprise/sectors/chemicals/reach/index_en.htm (accessed 21.01.15).

Reed, D.J., 2001. Stalking the Elusive Business Case for Corporate Sustainability. Sustainable Enterprise Perspectives. World Resources Institute.

Remmen, A., Jensen, A.A., Frydendal, J., 2007. Life Cycle Management: a Business Guide to Sustainability. UNEP-SETAC Life Cycle Initiative, Paris. http://www.unep.fr/shared/publications/pdf/DTIx0889xPA-LifeCycleManagement.pdf.

Robèrt, K.H., Schmidt-Bleck, B., Aloisi de Laderel, J., Basile, G., Jansen, J.L., Kuehr, R., Price Thomas, P., Suzuki, M., Hawken, P., Wackernagel, M., 2002. Strategic sustainable development – selection, design and synergies of applied tools. J. Clean. Prod. 10 (3), 197–214.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F. Stuart, Lambin, E., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., Foley, J., 2009. Planetary boundaries: exploring the safe operating space for humanity. Ecol. Soc. 14 (2), 32 (online) URL: http://www.ecologyandsociety.org/vol14/iss2/art32/.

SABIC, 2011. In: Proceedings from the LCA XI International Conference, October 4–6, 2011, Chicago, IL, United States, pp. 126–134.

Scapens, R.,W., 1990. Researching management accounting practice: the role of case study methods. Br. Acc. Rev. 22, 259–281.

Schneider, L., Wallenburg, C.M., 2012. Implementing sustainable sourcing—does purchasing need to change? J. Purch. Supply Manag. 18, 243–257.

Scholand, M.J., Dillon, H.E., 2012. Life-cycle Assessment of Energy and Environmental Impacts of LED Lighting Products, Part 2: LED Manufacturing and Performance. Solid-state Lighting Program, Building Technologies Program. Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy.

Senge, P., Smith, B., Kruschwitz, N., Schley, S., 2008. The Necessary Revolution: How Individuals and Organizations Are Working Together to Create a Sustainable World. Nicholas Brealey Publishing, London.

Seuring, S., Muller, M., 2008. From a literature review to a conceptual framework for sustainable supply chain management. J. Clean. Prod. 16, 1699–1710.

Siltaoja, M.S., 2013. Revising the corporate social performance model – towards knowledge creation for sustainable development. Bus. Strat. Env. http://dx.doi.org/10.1002/bse.1783.

Terinte, N., Manda, B.M.K., Taylor, J., Schuster, K.C., Patel, M.K., 2014. Environmental assessment of coloured fabrics and opportunities for value creation: spun-dyeing versus conventional dyeing of modal fabrics. J. Clean. Prod. 72, 127–138. http://dx.doi.org/10.1016/j.jclepro.2014.02.002.

Tucker, A., Tischner, U., 2006. New Business for Old Europe: Product–Service Development, Competitiveness and Sustainability. Greenleaf Publishing, Sheffield, UK.

Uhlman, B.W., Saling, P., 2010. Measuring and communicating sustainability through eco-efficiency analysis. Chem. Eng. Prog. December 2010.

UNEP/SETAC, 2009. Life Cycle Management: How Business Uses it to Decrease Footprint, Create Opportunities and Make Value Chains More Sustainable. UNEP/SETAC, 2009.

UNEP/TU Delft, 2007. Design for Sustainability: a Practical Approach for Developing Economies.

UNGC, 2013. Global Compact. http://www.unglobalcompact.org/ (accessed 14.07.13).

United Nations Global Compact and Accenture, 2013. The UN Global Compact-Accenture CEO Study on Sustainability 2013. Architects of a Better World: CEOs on accelerating the journey from plateau to peak on sustainability. September 2013.

Veleva, V., Ellenbecker, M., 2001. Indicators of sustainable production: framework and methodology. J. Clean. Prod. 9 (6), 519–549. http://dx.doi.org/10.1016/S0959-6526(01)00010-5.

Vermeulen, W., 2013. Self-governance for sustainable global Supply chains: can it deliver the impacts needed? Bus. Strat. Environ. http://dx.doi.org/10.1002/bse.

Vink, E.T.H., Davies, S., Kolstad, J.J., 2010. The eco-profile for current Ingeo® polylactide production. Ind. Biotechnol. 6 (4), 212–224. http://dx.doi.org/10.1089/ind.2010.6.212.

WBCSD, 2010. Vision 2050: the New Agenda for Business. http://www.wbcsd.org/pages/edocument/edocumentdetails.aspx?id=219&nosearchcontextkey=true (accessed 15.05.13).

Werbach, A., 2009. Strategy for Sustainability. Harvard Business Press. July 2009.

WRI/WBCSD, 2011. World Resources Institute/World Business Council for Sustainable Development, GHG Protocol: Corporate Value Chain (Scope 3) Accounting and Reporting Standard. 2011.