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Survey concerning enablers for material efficiency activities in manufacturing, their supply chains and the transformation towards circular economy

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Abstract

In order to decouple economic growth from global material consumption it is necessary to implement material efficiency strategies at the level of single enterprises and their supply chains, and to implement circular economy aspects. Manufacturing firms face multiple implementation challenges like cost limitations, competition, innovation and stakeholder pressure, and supplier and customer relationships, among others. An extended evaluation of triggers and barriers to improve material efficiency in manufacturing companies, along the sup-ply chain and concerning circular economy considerations is provided. This paper delivers an extended literature review, a critical discussion of the current situation and resulting challenges concerning material efficiency approaches in manufacturing supply chains. Finally, a conclusion and outlook on further research direction is given.

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Abbreviations

GDP	Global gross domestic product
SME	Small and medium sized enterprises
MFCA	Material flow cost accounting
PDCA	plan-do-check-act
LCA	Life cycle assessment

1. Introduction

What would a world look like in which there was no more waste? How could everyday products be designed to be reused several times? What if in future, manufacturers had to return the entirety of each product to the value-added cycle after the end of its life cycle?

The purpose of this paper is to review the scientific literature concerning drivers and barriers to implementation of material efficiency activities in the manufacturing industry throughout their upstream and downstream supply chains, including circular economy aspects.

The global population increased fourfold in the 20th century while the economically used raw material extraction increased by a factor of eight during the same period (Liedtke et al., 2014, p. 545) exerting pressure on the environmental resource extraction. However, global gross domestic product (GDP) and income levels have risen faster than the global material use since the 1950s, indicating an increase in resource productivity (Campanale & Femia, 2013, p. 614; Krausmann et al., 2009; Schaffartzik, Wiedenhofer, & Fischer-Kowalski, 2016, p. 201). Most of this productivity improvement can be attributed to the decline of biomass intensity in the last century (Krausmann et al., 2009). However, since 2000 global material productivity has stagnated (Campanale & Femia, 2013, p. 614). Absolute levels of material use increased on a global scale, mainly driven by population growth (Schaffartzik et al., 2016, p. 202).

In particular, small and medium sized enterprises (SMEs) and entrepreneurs play a key role in economies worldwide and represent the majority of the business population (OECD, 2017, p. 15). For instance, in the EU 28 SMEs comprise 99.8% of all enterprises (European Commission, 2016, p. 1 and 3) Even though SMEs contribute more to the service sector worldwide (approximately 65 %) (OECD, 2017, p. 15), within the EU28 manufacturing represented 44 % of total value added by SMEs in 2015 (European Commission, 2016, p. 4ff). In particular, the SME sector is globally perceived to be underperforming in terms of environmental friendliness (Lewis & Cassells, 2010). Environmental targets are often considered to conflict with economic objectives and improvement proposals suggested for material efficiency become secondary concerns (Kokubu & Kitada, 2015, p. 1282).

Most manufacturing related material efficiency approaches concentrate on level of the individual company. Leigh & Li (2015, p. 632) state that limited research has been conducted exploring the roles of industrial ecology in relation to the environmentally sustainable development of supply chains. Ahi & Searcy (2015) analysed the metrics published in the literature on green supply chain management and sustainable supply chain management until the end of 2012 and found no “material” specific metric. Schoer, Wood, Arto, & Weinzettel (2013) examined the calculation of the raw material equivalent, which is based on assumptions partially

due to limited data availability. The raw material equivalent indicates the “material footprint” of the product - how much of a particular material is extracted through a product’s entire production chain (Schoer, Weinzettel, Kovanda, Giegrich, & Lauwigi, 2012, p. 8903). Depending on which domestic technology model assumptions are based on and which materials are assessed, the differences for the raw material equivalent vary significantly (Schoer et al., 2013, p. 14288). Nikolopoulou & Ierapetritou (2012) identified different challenges for greening supply chains. These include numerical difficulties for simulation and optimisation, the development of stochastic patterns for environmental impacts, and the definition of performance indicators (Garretson, Mani, Leong, Lyons, & Haapala, 2016, p. 989). Lai, Harjati, McGinnis, Zhou, & Guldberg (2008) proposed an economic and environmental framework for the analysis of globally sourced auto parts packaging system. Bierer, Götze, Meynerts, & Sygulla (2015) investigated the extension of material flow cost accounting (MFCA) along supply chains. Initial ideas for ‘supply chain MFCA’ aspects can be found in Nakajima, M., Kimura, A., Oka, S. (2013) and Schrack (2014). The draft of a new International Organization for Standardization (ISO) standard for a supply chain MFCA has been published recently (Deutsches Institut für Normung, 2017). It is rooted on the plan-do-check-act (PDCA) cycle approach as known from other environmental standards and adhered to at a very rudimentary level. The mathematical structures of life cycle assessment (LCA) tools are poorly designed for extensive scenario analyses in supply chains (Steubing, Mutel, Suter, & Hellweg, 2016, p. 511). The need for and the potential benefits of routine generation for long-term, future-oriented information to support decision-making has been identified with regard to supply chain management (Seuring & Müller, 2008). However, no further developments in the area could be identified for the last decade (Schaltegger & Zvezdov, 2015, p. 1338).

In recent years, the circular economy approach has gained increasing attention worldwide, but the origins of the concept date back far into the last century. These emanate from several schools of thought and theories that challenge the established economic system, based on overconsumption due to the finiteness of natural resources (Rizos, V., Tuokko, K, Behrens, A., 2017). One of the first authors considered to have influenced the development of the circular economy concept is Boulding (1966). He envisaged a “spaceman economy” that would operate by reproducing the initial limited stock of inputs and recycling waste outputs. According to Braungart, McDonough, & Bollinger (2007), the cradle-to-cradle design demonstrates the need to maintain and even enhance the value, quality and productivity of resources in order to have a net positive environmental impact.

In the scientific literature the circular economy is defined as an industrial economy that relies on the “restorative capacity of natural resources” (Bastein, Roelofs, E. Rietveld, E., & Hoogendoorn, 2013). It focusses on the elimination or reduction of waste, utilisation of renewable sources of energy and the phasing out of the use of harmful substances. One of the most

frequently cited definitions that incorporate elements from various different disciplines has been provided by the Ellen MacArthur Foundation, which describes the circular economy as “an industrial system that is restorative or regenerative by intention and design” (Ellen MacArthur Foundation, 2013a). Therefore, the current ‘end-of-life’ concept shifts towards the use of renewable energy, eliminates the use of toxic chemicals, encourages reuse and strives for the elimination of waste by rethinking the product design. A design for environment of materials, products, systems allows a merge of economic potential benefits with ecological advantages and enables new business models along the whole supply chain.

According to Pagell & Wu (2009), reverse logistics and closed-loop supply chains have not been sufficiently addressed by the green supply chain management literature. Gunasekaran & Spalanzani (2012) stress the importance of reverse logistics, remanufacturing and recycling in green supply chain management. Mitra (2014, p. 41) states that there are many issues to be considered in reverse logistics, for example the degree of centralisation of collection, inspection and recovery facilities, integrating material recovery into production operations or outsourcing of recovery activities.

The state of the art regarding material efficiency in supply chains as well as circular economy aspects appears fragmented. It seems that there is a lack of solutions of sufficiently low complexity to encourage manufacturing enterprises to implement material efficiency measures within their own borders and along their supply chains. Most approaches require complete datasets, putting too much strain on the firms’ limited resources. Further, disruption concerning product design and production technologies requires the redesign of existing supply chain setups. Circular economy aspects require the development of operating networks which are financially attractive for business partners over the long term.

The remainder of this literature review is structured as follows: as a starting point the paper outlines the material and energy efficiency optimisation potentials in the manufacturing industry. In this context, supply chain and circular economy aspects are highlighted, followed by socio-economic considerations. Subsequently general market, company, society and legislative drivers and barriers comprise the larger portion of the paper. Circular economic specific drivers and barriers are addressed individually. All findings are discussed in detail and the conclusion and outlook finalises the paper.

2. Materials and methods

For the investigations of the state of the art concerning material efficiency in manufacturing and along the supply chain, an extended literature research for the period between 2006 and January 2017 has been undertaken. Databases included: Academic Search Premier, Business Source Complete, China Online Journals, Complementary Index, Directory of Open Access Journals, EBSCO, Emerald Insight, IEEE Xplore Digital Library, JSTOR, OaFindr, Science Direct, SpringerLink, Supplemental Index, Taylor and Francis, TEMA and Wiley. Appropriate keyword combinations have been used, ranging from but not limited to: ‘assessment’, ‘barriers’, ‘circular’, ‘cleaner production’, ‘consumption’, ‘drivers, ‘Eco efficiency’, ‘ecology’, ‘efficiency’, ‘modeling’, ‘framework’, ‘intensity’, ‘lean management’, ‘manufacturing’, ‘material’, ‘flow cost accounting’, ‘primary’, ‘productivity’, ‘remanufacturing’, ‘resource’, ‘socioeconomics’, ‘supply chain management’, ‘sustainability’, and ‘waste flow’. The academic references have been scanned and selected concerning the relation of their title and abstract content to the research matter and rated by a minimum of two authors. The papers identified were enhanced with publications covering material and environmental concerns from the ISO. Citations which proved irretrievable or were deemed to be weakly linked have been discarded. The collected information facilitated a substantial understanding of the topic across different disciplines, and serves as a foundational resource gaining an impression of the state of the art and identifying research gaps.

3. Result of the literature review

3.1 Material and energy efficiency

There are a number of country-specific investigations concerning material efficiency questions in the manufacturing sector. For example, Ibenholt (2003) estimated the generation of waste in the manufacturing sector in Norway. The production of intermediate inputs and capital goods in Norway generated 43% of the total residual. This result corresponds well with an investigation concerning the US automobile industry, which showed that from resource extraction to final disposal 40 % of total input into a mid-sized automobile produced in 1990 was converted to residual waste (Ibenholt, 2003, pp. 238–239). Resource efficiencies measured in a number of Australian companies ranged between 27 and 98 % (Schliephake, Stevens, & Clay, 2009, p. 1257). A different picture is drawn from the chemical industry, where on average 100 kg of

input is converted into 38 kg of products per single process step. Material efficiencies range from a minimum of 20% (pharma) to a maximum of 73 % (base chemicals). The product yields of complete process chains are significantly lower than the single process steps. In pharmaceutical production for instance, yields range between 0.1 and 4.3 % (Steinbach, Winkenbach, & Ehmsen, 2011, p. 304). Allwood, Ashby, Gutowski, & Worrell (2011) report that in sheet metal production up to 50 % of waste is created during manufacturing. In the aerospace industry significant material and energy savings in the order of 75 % have been realised. This was achieved by transitioning from traditional milling, which had formerly converted 90% of input material to scrap (Boyer, 2010), to state-of-the-art precision casting for titanium aerospace components (VDI Zentrum Ressourceneffizienz, 2014).

These few examples indicate firstly the range of material and energy efficiency rates in different manufacturing branches, while also demonstrating that significant improvements are feasible. Further, energy and material efficiency improvements need to encompass whole supply chains, including circular economy aspects, in order to reduce material extraction from the biosphere and achieve the ultimate goal of decoupling material consumption from economic growth. Loiseau et al. (2016) emphasise that efficiency improvement measures are more commonly linked to weak sustainability, while circular economy or product service systems may result in stronger improvements. However, these concepts require societal transformations (Loiseau et al., 2016, p. 368).

3.2 Supply chain and circular economy considerations

In order to maximise the resource efficiency in value-added systems, linear supply chains need to be reconsidered. The circular economy represents an alternative to the current ´take-make-use-dispose´ economic model. The transition to a circular value creation requires evaluation of materials and products in closed-loop systems, which includes some other disciplines such as eco-innovation, environmental design, life cycle management, reverse logistics, clean production and energy technology among others. In an established circular economy, waste would become obsolete; everything could be used as an input for a new value-creation cycle. This perspective is inspired by biological cycles, emphasising the optimisation of natural resource use in the life cycle (Di Maio & Rem, 2015; Ellen MacArthur Foundation, 2013a; World Economic Forum, 2014).

Circular economy is a multidisciplinary discipline with the aim to encourage a shift towards a more sustainable society. In general, it relies on three principles (Ellen MacArthur Foundation, 2013a; Motta, Prado P., & Issberner, 2015):

1. preserving and enhancing natural capital by controlling finite stocks and balancing renewable resource flows;
2. optimising resource yields by circulating products, components and materials at the highest utility and value at all times within technical and biological cycles and
3. enhance system effectiveness by revealing and designing out negative externalities.

The core processes of a circular economy involve the use of fewer primary resources through recycling, efficient use of resources, utilisation of renewable energy sources, and maintenance of high value materials and products through product life extension and refurbishment, remanufacturing and reuse of products and components. An additional part of circular economy thinking involves changing utilisation patterns through product as a service, sharing models and shift in consumption patterns as new business model innovations are implemented (Rizos, V., Tuokko, K, Behrens, A., 2017).

The transition to a circular economy will require disruption to the current approach to production and consumption. In the opinion of the authors, a promising way forward is to ensure that all stakeholders along the value creation network work together and have the same understanding of a circular economy.

3.3 The socio-economic framework

The analysis of material efficiency must consider different dimensions. In general, the way goods and services are produced in an economy is the outcome of individual decision-making at the firm level, which is simultaneously embedded in a multi-dimensional socio-economic framework. The latter aspect is predominantly based on a society's idea of the process necessary to coordinate needs and the ability to efficiently satisfy these needs. The two ideal and typical coordination mechanisms are

1. a free market and
2. central planning.

However, there are many differences between these two concepts, the key difference is seen in the role of the government. While in a free market economy, the government should focus on setting the legal framework for free and competitive markets, it is the dominant player in a central planning economy. Thus, market-oriented societies rely more on market forces guiding entrepreneurial decisions towards technological change than societies with a tradition of centralised decision-making where the responsibility for innovations and progress is assigned to the government (see e.g. (Hayek, 1944; Mises, 1951, New Haven/1981).

The economic decline of socialist economies experienced in the late 1980s and a lack of innovation were two of the key drivers for their orientation toward more liberal and capitalistic

structures. Simultaneously, the awareness of market failure with regard to ecological and environmental aspects grew in market economies. The concept of a social market economy that limits a free market economy by considering social aspects was broadened to become a social and ecological market economy including ecological goals. The concept of a circular economy is an outflow of this change in mindset (Treaty of Lisbon amending the Treaty on European Union and the Treaty establishing the European Community, signed at Lisbon, 2007). The general understanding is that a social market economy means as little regulation of the market as possible with as much social policy intervention as necessary. It follows that the ecological dimension of a social and ecological market economy additionally implies as much ecological policy intervention as necessary. The open question is how much ecological policy intervention is necessary. Here, the utility function of the respective society is relevant and should be reflected in the political decision-making process.

However, in any market economy consumers and producers should not shift all responsibility for achieving the social and ecological goals to the government and administration, but must also reveal their preferences for ecologically produced goods. The willingness to pay reflects the preferences of the consumers. Thus, they must demand these products. Only then, profit-oriented firms will supply them. In general, the relative price of a product is one of the key determinants of demand. If prices of ecological products are perceived to be too high when compared to conventional products, they will lack sufficient demand. Another important variable is the income level. Consumers must be able to afford such products. Therefore, the ability and the willingness to buy are decisive factors influencing ecological change.

Prices also depend on supply side conditions. In particular, technology and input prices are influential. Technological progress implies growing productivity, leading to lower costs and prices. In the case of a highly price-elastic demand function, demand will increase disproportionately. This might imply an absolute growth of inputs. Such developments, known as rebound effects (direct, indirect or macroeconomic) depend mainly on the cost structure, on the efficiency gain and the response of factor markets (Broberg, Berg, & Samakovlis, 2015; Jevons, 1865; Pfaff & Sartorius, 2015; Wu, Wu, Huang, Fu, & Chen, 2016). Consequently, it is unknown whether a decoupling of economic growth and material input is possible. Changes in relative prices could lead to a structural change in favour of increasingly material-intensive products. Thereby, output growth overcompensates for efficiency gains due to technical progress (Lorek & Spangenberg, 2014; Talmon-Gros, 2014).

New means of production are the outcome of research and development (R&D). They could be seen as a new combination, as suggested by Kurz (2012). In general, technical progress could be induced by costs or by demand. On the one side, firms have an interest in lowering the costs of production. In the case of implicit and explicit costs, a reduction of material input

will c.p. lower the unit costs. R&D will focus on an increased efficiency of material input if it promises profit growth. Conversely, profits are also determined by sales that depend on buyer demand. Consequently, consumers must prefer efficient means of production so that firms are provided with the incentive to invest in respective production processes. Finally, the openness for technical change and the technical dynamism of a society are crucial for further development (Dosi & Nelson, 2010).

However, uncertainty is one of the most relevant characteristics of market economies. No firm can be certain whether an investment will be successful and its production matched by demand. Particularly when faced with a change in the technological paradigm, firms must address this challenge or accept an increased risk to fail. While mainstream economics see competitive markets as the best way to find new technological solutions and innovations, firms show an interest in legal settings and guidance from government to reduce uncertainty. This implies a trade-off between market efficiency and uncertainty reduction. A society must decide which goal is of greater importance.

Moreover, R&D as well as the diffusion of new technologies are time consuming. Although markets can detect and select the most efficient technologies, time can be too short for this process. For example, a phenomenon such as climate change might require quick, effective yet expensive solutions at the firm level. The positive effects of avoiding climate change are external to the firms and are therefore unlikely to be included in decision making regarding production. Here, government must intervene and provide incentives to internalise such externalities. If markets are too slow to achieve necessary changes, legal mechanisms should be preferred over market-oriented tools such as certificates and taxes (Gleich & Gößling-Reisemann, 2008).

These reflections reveal that the concept of a social ecological market economy is an important component of a successful technological change which lowers the use of material inputs in production. The following sections will emphasise the implications of this framework for the firms and their activities to increase material efficiency.

3.4 Market, company, society and legislative drivers and barriers

Multiple objectives must be satisfied to move forward in the context of sustainable supply chains. This requires the inclusion of economic, environmental, social and time dimensions. Therefore, key drivers and barriers in manufacturing enterprise, their supply chains and in circular economy systems must be understood (Blok et al., 2015, p. 28). (Mittal, Sangwan, Herrmann, Egede, & Wulbusch, 2012) presented a driver and barrier framework for

environmentally-conscious manufacturing, which is applicable for material efficiency purposes. This framework for companies builds on four pillars:

1. economy and market;
2. the company culture;
3. society demands; and
4. legislative policies.

For the purpose of this paper, this framework is also applied to

5. supply chain aspects.

In the following sections drivers and barriers are described concerning these pillars and additional supply chain aspects. Drivers and barriers that particularly affect material efficiency improvements in supply chains are represented in Table 1.

Company and supply chain drivers	**Company and supply chain barriers**
Customer demand	Coordination efforts
Corporate environmental policy	Increased complexity
Top management commitment	Insufficient communication
Monitoring, reporting and evaluation	Lack of power
Environmental management system	Lack of customer demand
Economic benefits	Higher cost
Training and education	Economic uncertainties
Joint efforts and cooperation	Customer acceptance
Visibility, image	Excessive quality requirements
Stakeholder incentives	No commitment from business partners
Sanctions	Willingness to supply data
External pressure	Ability to supply data
Legislation	Lack of manpower and time
Administrative support	Training demand

Table 1: *Drivers and barriers for material efficiency improvements in supply chains*

Regarding economy and market, the most important motivators for the introduction of resource efficiency are improved customer satisfaction and cost savings (Fernández-Viñé, Gómez-Navarro, & Capuz-Rizo, 2013; Hrovatin, Dolšak, & Zorić, 2016, p. 485; Wecus, Weber, & Willeke, 2017, p. 4). On the other side, implementation costs and the influence of environmental improvements on the cash flow can represent a significant barrier for manufacturing companies (Lewis & Cassells, 2010, p. 10; Wecus et al., 2017, p. 29), especially impacting their supply chain. Further, their share of material and energy costs, market share, export orientation (Hrovatin et al., 2016, p. 475), past environmental activities, their importance for customers and the firms' performance influence environmental investment in a positive way (Murovec, Erker, & Prodan, 2012, p. 265). Economic uncertainties, its climate (Blok et al., 2015, p. 25; Lewis & Cassells, 2010, p. 18; Mittal & Sangwan, 2013, p. 590), lack of customer demand (Mittal et al., 2012, p. 101) and a market that is not ready for eco-efficient products and services (Fernández-Viñé et al., 2013, p. 268) represent very strong barriers. Customer demand for excessive quality requirements and inflexible delivery deadlines result in inefficiencies. Sometimes it is difficult to implement environmental improvements in practice because of a lack of power (Nakano & Hirao, 2011, p. 1190). Lewis & Cassells (2010) found that customers had the strongest influence on decisions of firms regarding implementing environmental practices. Direct support from stakeholders and a favourable market environment are more important than financial incentives or social pressure (Xia, Chen, & Zheng, 2015, p. 494).

Concerning company culture, the importance of organisational and behavioural factors differs depending on the country-specific environment. For instance, committed managers seem to be a dominant driver in Slovenia (Hrovatin et al., 2016, p. 477) and are considered of higher importance in India than in Germany (Mittal et al., 2012, p. 101). New Zealand manufacturing SMEs ranked 'personal commitment' as one of their top drivers of environmental improvement (Lewis & Cassells, 2010, p. 16). Independent of country-specific environment, top management support and committed managers seem to be one of the most important internal prerequisites enabling the implementation of material efficiency measures in companies, and in particular supply chains. Bey, Hauschild, & McAloone (2013) recommended addressing the barriers to information flow and resource allocation by establishing a clear management structure and procedure; a person in the organisation is designated a clear role in precisely defining environmental terms and issues, and implement quantitatively suitable key performance indicators (KPIs) (Bey et al., 2013, p. 46; Nakano & Hirao, 2011, p. 1191). Data management, trust and communication are critical enablers (Taylor, Gully, Sánchez, Rode, & Agarwal, 2016, p. 3), while data availability is a barrier (Angelakoglou & Gaidajis, 2015, p. 737). These factors align with the results of an investigation into German manufacturing companies, which regarded management systems as a major instrument for the improvement of material efficiency (Wecus et al., 2017, p. 28). Corporations with management systems in

place use on average more instruments and methods for analysis, record a larger amount of resource-related performance figures, and implement more actions concerning resource efficiency than companies without management systems (Wecus et al., 2017, p. 3). On the other side, companies regard as a major barrier the complication of simple processes due to the requirement for documentation (Wecus et al., 2017, p. 4). Barriers often cited are a lack of manpower and time (Bey et al., 2013, p. 44; Lewis & Cassells, 2010, p. 10), training requirements that put too much strain on SMEs' limited resources (Lewis & Cassells, 2010, p. 10), a lack of awareness, information deficits (Mittal et al., 2012, p. 101) and data availability (Angelakoglou & Gaidajis, 2015, p. 737). Employee training and empowerment, teamwork and reward systems are important key drivers (Carbone, 2012, p.30). Trial projects focusing on areas of greatest potential benefit increase the likelihood for diffusion of material efficiency strategies (Christ & Burritt, 2016, p. 5).

The society demand factor seems to play a different role in different cultural environments. In India for instance, ethical values like commitment of leadership are regarded as crucial for improved environmental development (Mittal et al., 2012, p. 101). Public pressure on the other side has a low driving influence in India and Germany, while public image is considered of much higher importance in India than in Germany (Mittal et al., 2012, p. 101). The best performing manufacturing companies in Turkey are driven by brand value and reputation, and by aiming to become pioneers in the field of sustainability (Küçüksayraç, 2015). In New Zealand, the majority of SME owner-managers recognised 'responsibility to the community' as one of their top drivers of environmental improvement for their firm, while 'image/reputation/brand' were identified as important drivers (Lewis & Cassells, 2010, p. 16). Community pressure is seen in China as a driver to balance economic and ecological aspects (Zhu & Sarkis, 2004, p. 266). The size of firms, their visibility and branch-membership are also significant influencing factors (Garretson et al., 2016, p. 988).

Legislative policies are ranked highly as motivating factors in Europe generally (Fernández-Viñé et al., 2013, p. 271), Germany and India (Mittal et al., 2012, p. 101), the USA (Taylor et al., 2016, p. 3) and in China (Zhu & Sarkis, 2004, p. 266). Incentive-based policy mechanisms like subsidies, voluntary agreements and green procurement consistent with ecological modernisation are suggested in order to encourage the industry to engage in environmental improvement processes. Repressive measures like legislation and taxes may prove to be powerful drivers for change (Ashford & Hall, 2011; Bruvoll, 1998; Dellink & Kandelaars, 2000; Dobers & Wolff, 1999; Fernández-Viñé et al., 2013, p. 271; Ibenholt, 2003, p. 243; Murovec et al., 2012; Smith & Crotty, 2008, p. 347). The anticipated future environmental regulation and pre-legislative dialogues are regarded as important drivers in both developed and developing countries (Bey et al., 2013, p. 46; Luken & van Rompaey, 2008, S75). Governmental pressure, either in the form of current or future regulations, is a much more important driver than

community pressures (Luken & van Rompaey, 2008, S75). However, (Garretson et al., 2016, p. 988) argue that policies resulting in incremental improvements will be insufficient to force or motivate sectors into the very best environmental performance that is both economically efficient and technically feasible. (Fernández-Viñé et al., 2013) have identified public administration as an important promoter with greater capacity for eco-efficiency among SMEs. They propose the installation of an office of the public administration primarily in order to advise and support SMEs, while also promoting alliances between market stakeholders (Fernández-Viñé et al., 2013, p. 271). Evaluations of 550 cases revealed that governmental and institutional support for SMEs in Germany resulted in an average of 2% annual turnover savings (Schmidt & Schneider, 2010). Such measures help to foster transition processes towards resource efficiency and are a key element for successful diffusion strategies (Hennicke, Kristof, & Götz, 2012).

Seuring & Müller (2008) performed a detailed literature review concerning the implementation of sustainable supply chains and related issues. (Carbone, 2012) built on this foundation and developed three different diffusion models. Seuring & Müller (2008) state that sustainable development in supply chains is unfortunately often restricted to one environmental improvement dimension. They called for an integrated perspective, where social issues in particular and the interrelation of the three dimensions of sustainability are considered. Most stringent barriers identified for implementing sustainable supply chains are higher costs, coordination efforts, increased complexity and insufficient or missing communication. The most important drivers clearly impact these barriers. These are communication, monitoring, evaluation, reporting, sanctions and costs. These need to be supported by joint efforts of all supply chain partners. Economic benefits for the supply chain partners play a key role in adopting and diffusing sustainable practices, and strong commitment of top management clearly is one of the main drivers for the implementation of sustainable supply chain management (Carbone, 2012, p. 30). Environmental management systems, the integration of sustainable supply chain practices into corporate policy, training and education also represent supporting factors (Seuring & Müller, 2008, p. 1704). Organisations implementing an environmental management system require the cooperation of suppliers along their supply chains to achieve better results (Agarwal & Thiel, 2012) which in turn facilitates the development of an externally orientated environmental management system (Darnall, Jolley, & Handfield, 2008; Grekova, Bremmers, Trienekens, Kemp, & Omta, 2014; Leigh & Li, 2015, p. 633). Triggers for sustainable supply chain management are external pressure, cooperation (Bala, Muñoz, Rieradevall, & Ysern, 2008; Sharfman, Shaft, & Anex, 2009; Vachon & Klassen, 2006) and incentives set by different stakeholders. On the one hand, customers are of great importance, as operating the supply chain is only justified if the products and services are finally ‘‘accepted’’ by customers. On the other hand, all modes of governmental control ranging from local municipalities to national and

multi-national governments are of great relevance. When a so-called focal company becomes pressured, it usually passes this pressure on to suppliers (Seuring & Müller, 2008, p. 1703). Focal companies according to Seuring & Müller (2008) are those companies that usually

1. rule or govern the supply chain,
2. provide the direct contact to the customer, and
3. design the product or service offered.

Even though regulation positively influences the implementation of sustainable practices in supply chains, companies' attitudes toward regulations vary greatly, ranging from a cautious position, readiness for change (Brito, Carbone, & Blanquart, 2008) and a proactive stance aimed at gaining a competitive advantage (Carbone, 2012, p. 29; Martinet & Reynaud, 2004). Lack of commitment from business partners is a major challenge to collaboration between actors in the supply chain, while it is also difficult to collect relevant information from business partners without the advantage of a strong bargaining position (Nakano & Hirao, 2011, p. 1190). Not every actor in the supply chain may be able to provide data with the desired standard of detail and quality, or data acquisition may prove too expensive (Bierer et al., 2015, p. 1299).

3.5 Circular economy specifics

The following section focusses on specific enablers and barriers for a circular economy. To consider material efficiency and other sustainability issues, the concept of the circular economy has become an important field of academic research with a rapid increase in the frequency of articles and journals addressing this topic in the last decade. It is rooted in several different schools of thought and theories that critique the prevailing linear economic systems, which assume that resources are infinite (Allwood, 2014; Ellen MacArthur Foundation, 2013b; Preston, 2012; Rizos et al., 2016). The circular economy concept has developed such that today policy-makers, academics and the business community are increasingly recognising the need to transition to this new economic model, whereby materials and energy from discarded products are reintroduced repeatedly into the economic cycle at the same value-added level (Lehmann, Leeuw, Fehr, & Wong, 2014). Existing supply chain networks for linear consumption need to be reconfigured for a shift towards the circular economy. This change in mindset is associated with several barriers, with particular relevance for manufacturing enterprises. Rizos et al. (2016) conducted a detailed literature review to identify potential barriers preventing enterprises from adopting infinite circular economy business models. The identified barriers are also relevant for the development of a procedure which enables material efficiency-strategies for manufacturing firms. In the case of such enterprises, the lack of support along the supply chain is a significant barrier. This barrier exists primarily in the

dependency on supplier and customer engagement in material efficiency activities. The successful implementation of a circular economy approach in practical application necessitates the collaboration of all partners across the supply chain (Dervojeda, Verzijl, Rouwmaat, Probst, & Frideres, 2014). In practice, suppliers and service provider may be reluctant to become involved in circular economy processes owing to perceived risks to their competitive advantage or due to a mindset that does not prioritise a material efficiency strategy (Luthra, Kumar, Kumar, & Haleem, 2011). In addition, insufficient customer awareness of the benefits of material efficiency in manufacturing processes discourages change in consumption patterns, and usually there is no substantial pressure from the demand side on enterprises to meet material efficiency criteria or develop a circular economy business model (Meqdadi, Johnsen, & Johnsen, 2012; Wooi & Zailani, 2010). The transformation toward a circular economy requires a shift in consumer lifestyle and behaviour. Other important barriers for enterprises implementing a circular economy business are a lack of capital and government support, administrative burden and lack of technical expertise and information (Martinet & Reynaud, 2004).

Nevertheless, there are also enabling factors for the move toward a circular economy business model for enterprises. An important enabler is an environmental culture of staff and management and a local or regional network with other enterprises and supporting multipliers for enhancement of information sharing and awareness creation (Martinet & Reynaud, 2004). Methods and procedures for improving material efficiency must be financially attractive. Possessing no alternative process technology and the lack of tradition and skills constitute important barriers (Luken & van Rompaey, 2008, p. S75) in addition to technology risks (Mittal & Sangwan, 2013, p. 590) and lack of expert knowledge (Bey et al., 2013, p. 44)

Table 2 summarises the most important barriers and drivers for the implementation of circular economy business models according to (Rizos, published at 2017).

Table 2: *Barriers and drivers for the implementation of circular economy business models*

Barriers	**Drivers**
Lack of support supply and demand network	Company environmental culture
Lack of capital	Networking
Lack of governmental support	Support from the demand network
Administrative burden	Financially attractive
Lack of technical skills	Recognition
Company environmental culture	Personal knowledge
Other barriers	Governmental support

The awareness of the aforementioned barriers and enablers are fundamental for the design of a practical procedural model using the circular economy concept, therefore enabling a material efficiency strategy tailored to manufacturing enterprises.

4. Discussion

In the following discussion the results of the literature review are interpreted and critically discussed.

The literature reviews reveals significant potential which however varies across different manufacturing sectors and countries. In contrast to material efficiency improvements within single firms - the focus of most existing attempts - there seems to be more significant improvement potential within supply chains and the shift towards a circular economy. Before discussing such challenging and disruptive aspects, the social economic framework and different drivers and barriers need to be considered. In this context, a balance between free market mechanisms and governmental control must be achieved. Governmental control does not seem to be the strongest driving force for material efficiency purposes along supply chains. Consumer and focal companies may have a stronger influence on sustainable material use. Openness and acceptance of technology change and dynamic development are important prerequisites for such a development. Nevertheless, rebound effects will reduce the maximum potential of material efficiency activities across supply chains.

Several objectives must be satisfied to advance the development of sustainable supply chains. Multiple drivers and barriers for the manufacturing sector require prioritisation. However, a general prioritisation approach does not yet exist. Drivers and barriers for material efficiency attempts are quite company specific. Under the current conditions of low material prices, short-term strategy, low price mentality, lack of transparency along the supply chains, and customer pressure, the strongest drivers for material efficiency seem to be cash-flow transparency for material efficiency measures and disruptive business model-innovations.

Especially in the context of the circular economy, the literature review highlights the lack of transparency of material-saving potentials along the supply chain and through reverse logistics. Furthermore, circular networks and attractive long-term economic perspectives need to be established in order to approach such innovative concepts. Companies and consumers must drive behaviour change in such a way that it is possible to reintroduce materials several times on the same value level into the economic cycle.

Economic investigations particularly addressing cash flow and sales volume considerations are important for the actors of the supply chain. Material efficiency improvements of one actor,

for instance the focal company, will improve the cash flow of this actor. However, the suppliers of this actor will ultimately lose sales volume, and it remains to be seen if and how these suppliers can be motivated to take material efficiency actions in a linear economy set up. Such actors could or even should look for technology and business model alternatives, which would in turn disrupt existing supply chains in favour of circular economy constructs. An investigation from Müller & Schneidewind (2008) of a textile supply chain concluded that implementing a completely new setup of the supply chain under the management of the focal company was the only chance to improve material and energy efficiency significantly.

As previously outlined in section 3.3., market-oriented tools such as taxes and certificates can feasibly influence relevant behaviour change within firms. Taxes as well as certificates lead to higher costs of production and provides an incentive to decrease inputs, thus helping to achieve ecological goals. A government cannot be certain that, for example, levying a tax on the material input will change quantities in the short term. If taxes are too low when compared to the costs of transition, firms lack the incentive to invest in new processes. Regarding ecological impact, issuing certificates seems to be a more promising mechanism, since the government regulates the permitted quantity of an input. If a government values achievement of ecological goals as a higher priority than that of economic and social goals, it will apply legal mechanisms that are more successful in changing behaviour but less efficient with regard to costs.

5. Conclusion and outlook

The literature review suggests that in the case of manufacturing enterprises, any isolated improvement of material efficiency will only lead to a minor contribution to overall efficiency in the supply chain. Their individual market power may be too small to significantly influence the behaviour of their suppliers. This is particularly so when the suppliers do not depend on the demand of the respective firm. Thus, the market form and the related power to set prices and conditions requires consideration in future research.

A promising approach may be a new orientation towards material efficiency in the target functions of firms and consumers, resulting in a comprehensive structural change of production processes and supply chains, as well as business models. If not, partial improvements will not be sustainable. The orientation towards a mindset based on the principles of circular economy promises to be an important step into this direction.

The circular economy has achieved broad appeal among academic, policy and business audiences, but its interpretation and application have varied considerably. The available

studies adopt diverse approaches to the assessment of circular economy impacts, limiting the comparison of results from different sources.

There is a need to understand indirect effects on the economy (e.g. impacts on the value chain and/or changes in consumption spending patterns) in order to estimate overall impacts at global or national levels. While acknowledging that, for example, the EU supports material efficiency initiatives in particular for SMEs through funding, training and other activities, this paper suggests that a wider range of enablers are required to enhance the attractiveness of material efficiency-strategies, especially in the SME sector. Therefore it is recommended that European and national policies intensify their focus on consumer environmental awareness along the supply chain and the culture of enterprises, and support the development of innovative forms of business by SMEs – for example, circular economy business models.

In order to obtain quantitative data concerning material savings within company borders, their supply chains and through circular economy activities, the authors will investigate an example focal company. Furthermore, to overcome the lack of transparency and inherent uncertainties, digitalisation tools have to be developed which particularly enable SMEs to transition from current business practices to sustainable circular business models.

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