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Approach to enable a Material Efficiency-Strategy for Small and Medium Sized Manufacturing Enterprises

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Abstract

It has not yet been possible to achieve the desired aim of decoupling economic growth from global material demand. Small and medium sized enterprises (SMEs) represent the backbone of most industrialized economies. Although material efficiency is of vital importance for many SMEs, few of them actually treat it as their top priority. There is a cornucopia of tools and methods available, which can be used for material efficiency purposes. These, however, have gained little ground in the SME-field. This work deals with the enabling factors for material efficiency improvements in manufacturing SMEs and projections towards aspects of supply chain and circular economy. A multi-disciplinary decoupling approach for manufacturing SMEs and an implementation roadmap for further practical development are proposed. The approach combines appropriate complexity of technology and socio-economic considerations. It enables a connection to existing methods and the implementation of established information technologies.

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Keywords: Productivity; Material; Manufacturing; Decision support tool

1. Introduction

From the 1950s onwards, global gross domestic product (GDP) grew more strongly than global material use, indicating an increase in resource productivity [1,2]. However, since the year 2000, global material productivity has been in a state of stagnation [1]. The absolute levels of material use increased on a global scale, mainly driven by population growth [2].

Small and medium-sized companies (SMEs) constitute the backbone of national economies around the world [3]. The SME sector is globally perceived to be underperforming in terms of environmental friendliness [4] and often fails to take advantage of efforts designed to improve material efficiency (ME), which are often considered to conflict with economic objectives. Currently, past-oriented information which can be collected from production and cost accounting is mainly used for decision making because future-oriented information which enables better judgement requires more efforts to collect [5].

The central research question of this paper is how a suitable approach for the implementation of ME activities in manufacturing SMEs could look. The paper is divided into (1) a brief state of the art description concerning methods and tools, motivators and drawback factors, (2) the conception of a low complex and convincing ME improvement approach for manufacturing SMEs, connectable to existing assessment methods, supply chains (SC) and circular economy (CE) demands, (3) the verification based on simulation methods and (4) a presentation of a possible roadmap for an implementation of ME concepts in SCs.

In order to investigate the state of the art concerning the research question, an extended literature research for the time between 2006 and January 2017 has been undertaken. The collected information allowed a substantial understanding of the topic across different disciplines and served as a profound basis for the development of the approach.

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2. State of the art

2.1. Material efficiency in manufacturing

Global material consumption rose from approx. 6.7 Gt in 1900 [6] to 71 Gt in 2010 [2]. Studies in Europe concerning waste generation in manufacturing correspond with investigations for the US automobile industry which showed that from mining to final disposal approx. 40 % of total input into a mid-sized automobile result in residual material [7]. In sheet metal production up to 50 % of cast metal is discarded in the process of scalping, rolling and blankings; in the aerospace industry machining titanium components can result in almost 90 % scrap [8]. Resource efficiencies measured in a number of Australian companies ranged between 27 and 98 % (average 74 %) [9].

The product yields of complete process chains are significant lower than the single process steps. Taking a series of processes in a row, the total efficiency can be derived by multiplying the efficiencies of each single process step. Assuming a process chain consisting of four steps, on average as much as 80 % ME per process step needs to be achieved in order to receive a total efficiency of 40 %. These examples highlight the magnitude of the challenge and indicate that there is significant room for improvement from a physical point of view.

2.2. Socio-economic considerations

When discussing ME, socio-economic dimensions have to be considered as well. First, rebound effects (direct, indirect and macroeconomic) have to be considered. Due to lower costs and therefore lower good prices, more effective ways to produce could lead to an increase in the demand for final products and thereby in the absolute demand for material inputs. Key determinants for these effects include the size of the efficiency gain, the cost structure and the response of factor markets [10–12]. Second, this phenomenon is related to the question of whether a decoupling of material input and economic growth can be achieved. If e.g. a change in relative input prices implied structural change towards material intensive products, economic growth could be characterized by a growing use of material [13,14]. Thus, technological progress must overcompensate this development. Third, the role of the government must be taken into account. The improvement of ME requires innovative processes and products. In general, mainstream economists consider free competitive markets as the best way to achieve innovations. However, since research and development are subject to uncertainty, enterprises are interested in legal settings and guidance by the government (see also 2.5). Consequently, a trade-off between efficiency of markets and uncertainty exists and society has to decide which goal is more important. The increased popularity of the CE approach (see 2.3) is a result of such a debate.

2.3. Supply chain and circular economy aspects

ME has to start at the single enterprise level first. However, in order to achieve decoupling of resource consumption from economic growth, SC and CE aspects also have to be taken into account. CE activities aim to supply materials and products several times at the same value level to the economic cycle in order to improve the resource productivity. CE activities combine economic and environmental benefits for companies.

Lewis and Cassells [4] state that firm-to-firm relationships and networks are key factors for implementing environmental practices in SCs. Informal pressure on SC partners seems to be particularly effective due to the existing trust in the connection. In other cases, supplier development and a much deeper information flow along the SC are required before sustainable practices can be implemented [15]. Gosl [16] proposed a concept in which so-called focal companies take over the leadership in greening SCs. Proactive initiatives are expected to diffuse more easily upstream of the SC than downstream in terms of customer and CE aspects [17].

The CE concept is rooted in several different schools of thought and theories that question the prevailing linear economic system [18]. This concept has since evolved to such an extent that today policy-makers, academics and the business community increasingly recognize the need to move towards a new economic model in which materials and energy from discarded products are reintroduced repeatedly into the SC at the same value added level [19]. Existing SC networks for linear consumption have to be rethought for a development towards the CE.

2.4. Methods, tools, standards and guidelines

In a currently ongoing analysis the authors have investigated existing methods, tools and standards that deal with material and energy efficiency matters concerning their metrics (physical, economic, social), scale (macro, meso, micro), usability (process level, enterprise, SC, CE) and entrance barrier for SMEs. Most of the investigated tools and methods represent a medium or high implementation barrier for SMEs because they are too involved, scientific, specialized, time consuming, need external know-how or are of a conceptual nature and fail to serve as a decision making tool [20].

Only the conceptual Energy and Material Flow Analysis (EMFA) tool presented by [21] constitutes according to [20] a low and the Cleaner Production (CP) guideline of [22] a medium entrance barrier for manufacturing SMEs. However, they tend not to use the latter, unless supported by external consultants. Reuter [23] proposed the development of simple-to-use low complex methods providing reliable results relevant for business that are able to operationalize the principles of sustainability.

SMEs are not able or are not willing to supply comprehensive internal data. For this reason, a suitable approach for manufacturing SMEs must abandon the idea of complete data acquisition and must unfold reliable results with incomplete data sets [20].

2.5. Motivators and drawback factors

Multiple beneficial outcomes in ME, covering economic, environmental, social and time dimensions are required. Therefore a better understanding of key motivators and drawbacks, the appropriate balancing of drivers and the use of methods from disciplines such as behavioral science is necessary [24]. The drivers and barriers framework for environmentally conscious manufacturing proposed by Mittal et al. [25] consisting of (1) economy and market, (2) policy, (3) company and (4) society related factors is used here but needs to be extended by (5) SC elements (see Figure 1).

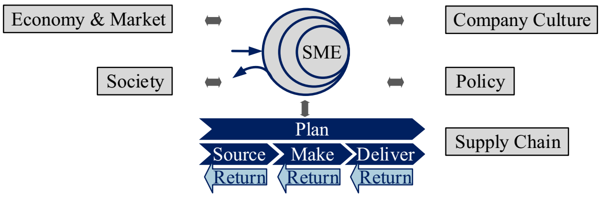

Fig. 1. Extended drivers and barriers framework

The most stimulating economy and market factors for the introduction of ME are improved customer satisfaction and cost savings [26,27]. Manufacturing SMEs weigh up carefully short and long term implementation costs [4,27]. Economic uncertainties and high short-term implementation costs represent strong barriers [25]. Opportunities for innovation are seen as an important incentive for eco-efficiency [28,29]. Lack of expert knowledge [30], alternative process technology, tradition and skills represent important barriers [31] as well as technology risks [32].

Concerning policy factors, consensus exists in the literature that compliance with legislation is one important driver for manufacturing SMEs in terms of the uptake of environmentally oriented initiatives [4,31,25,29]. The anticipated future environmental regulation and pre-legislative dialogues are seen as important drivers [30].

Voluntary action taken by companies brings about the greatest improvement [33]. Thus, top management support, long term strategy, committed managers [26], empowerment, employee training, teamwork and reward systems are important key drivers [17]. Further, it is important to address the internal barriers to information flow and resource allocation by establishing a clear management structure and procedure, to position a person in charge in the organization, to define exactly the terms and issues and to implement suitable key performance indicators (KPIs) [30,34]. Data management, trust and communication are seen as critical enablers [29], data availability as a barrier [35]. Most consistently cited barriers to engaging with environmental management are lack of manpower, time demand [30,4] and effort [35]. Complication of simple processes due to required documentation [27] and training requirements that put too much strain on SMEs' limited resources [4] are regarded as significant barriers.

Firm size, visibility, and branch-affiliation are significant society factors [33].

The economic and company specific enabling factors mentioned above, like costs, customer demand, policy demand, visibility, etc. are transferrable fully to greening SCs [17,15]. Especially for manufacturing SMEs, the lack of support along the SC is a significant barrier. This barrier refers mainly to the dependency of manufacturing SMEs on their suppliers and customers' engagement in ME activities. The successful implementation of a CE in practical application necessitates the collaboration of all partners across the supply chain [36]. Usually there is no substantial pressure from the demand side on SMEs to meet ME criteria or to develop a CE business model [37,38]. Other important barriers to manufacturing SMEs engaging in CE are lack of capital, government support, technical know-how and information. An important enabler is an environmental culture among the staff and management, a local or regional network with other SMEs and supporting multipliers to enhance information sharing and awareness raising [18].

Beside the motivators named in the five categories above, 'visualization', 'comprehensibility', 'systematic', 'hands-on', and 'quick' were also identified as important driving features [39] improving ME in manufacturing SMEs.

3. Improving material efficiency in manufacturing SMEs

3.1. Basic requirements for an improvement approach

Any ME improvement approach for manufacturing SMEs must support decision making and feature low complexity.

Managers will ask for the necessary investments for improvements and the return on investment (ROI). Chances through ME will be compared with other business opportunities. Quick ROIs and a positive perception by management improve the chance that ME improvement measures will be implemented. The approach must deliver undoubted and convincing cash flow indication.

Secondly, a ME approach must be easy to understand and ready to implement. The acceptance will increase, if existing data from accountancy is suitable for such an approach and if further information can be acquired with little effort. Existing firms' manpower must be able to handle the approach with little extra effort and must be confident to use it with minimal training requirements. Clear step by step instructions with clear outcomes, the use of basic established tools like spreadsheets and unambiguous visualization of results and efficiency hotspots will significantly improve the chance of acceptance.

Third, testability is important in order to allow managers to concentrate in a first step only on hotspots (low hanging fruit) and to gain experience. Carefully selected trial projects can be used to motivate people, increase internal expertise and encourage the firm to launch subsequent projects. Testability can serve as a motivator for more activities.

3.2. Requirements for extension of the approach

Firstly, as mentioned in chapter 3.1, a ME approach should be tested in a selected part of the firm. After confidence has grown concerning its feasibility, efficiency and financial benefits, it should be spread out within the company and connected to established information technologies in manufacturing. The approach should serve as a basis for more complex environmental assessment instruments in order to verify environmental benefits.

The approach should also encourage manufacturing SMEs to launch ME improvement activities in the SC or support eco-design approaches, new service oriented business models and CE aspects like product service life extension, remanufacturing and recycling.

3.3. Concept for a suitable approach for manufacturing SMEs

In order to be attractive for manufacturing SME decision makers, a ME approach for such SMEs should include (1) a present and future cash flow indicator, (2) project management methods (3) a procedure description (4) and a minimized set of performance indicators.

As companies use different methods to determine the cash flow, the approach must be open for the integration of such different methods as net present value or earnings-expenses plans. Physical data are necessary to establish a sound basis for the cash flow analysis. Using Pareto analysis, only significant energy and material related resources should be identified [21]. Generally, those costs are retrievable from accounting with little effort.

Project management requires a person in charge who represents the "eco champion" (EC) and provides a clear management structure as stated in [30]. It is important to assign a manager with clear responsibility and accountability for the success of ME activities [40]. Project management requires the definition of targets, the compilation of work packages, milestones and regular reporting.

A description of a basic step by step procedure helps decision makers and the EC to appraise the extent of effort and required expert know how. Mutual understanding and motivation have to stand above technological topics. "Buy in" of all involved persons needs to be established first. The walk through the company and creation of simple process flow charts (bottom up approach) [21] are important prerequisites for understanding and communication. Collection of material, waste and energy flow data, their costs, compilation in spreadsheets and visualization of the findings for interpretation and decision making are further steps. The visualization of findings should enable the determination of improvement hot spots. Root cause analysis, opportunity identification [41], the creation of possible solutions and the investigation of implementation costs are further important steps.

In order to ensure in the long run minimization of overall resource demands and environmental burden the set of performance indicators should allow the differentiation between primary and secondary resources as well as non-renewable and renewable energy demand. This task is seen as critical for real material decoupling even though it increases the complexity for manufacturing SMEs. The proposed physical units used, should be energy and material weights both per time period, clearly indicating material and energy types. The amount of renewable energy can be derived in most cases from statistics for the local energy supply and by metering the company's own generation of renewable energy, if applicable. The amount of secondary material, e.g. recycled aluminum needs to be specified by the suppliers. Both parameters should be indicated as a percentage of total energy and material consumption.

3.4. Cash flow simulation

In order to show that firms will receive a reliable financial decision basis for ME improvement measures with a limited number of assessed data, simulations have been conducted based on a real case. The manufacturing SME was not willing to deliver some company core data, so unknown total consumptions, human resource, machine, equipment, building costs etc. have been estimated from publicly available national branch statistics. The material and energy cost made up 14 % of the annual turnover. The profit rate was estimated to be 3 %. In the simulation the growth factors of the stochastic variables are varied within ±20 % around a prescribed value. To determine the effect of parameter uncertainties, quantiles of the profit distribution are computed and displayed graphically. Two scenarios have been simulated: a low reduction alternative which requires a small investment, only modifying existing production equipment and a high investment scenario involving new technology implementation and offering significant material and energy savings. An annual price increase of 1.5 % for the above mentioned costs and turnover has been assumed for the cash flow analysis. Corporate tax considerations have been excluded as these vary considerably between countries. Figure 2 shows the 90 % and 50 % quantiles of the cash flow. Even under the described uncertain conditions, deciders receive a robust indication of the effects of the two investment alternatives.

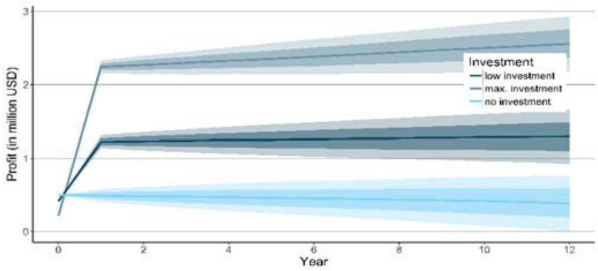

Fig. 2. Earning-expenses plan status quo versus low and high investment

The low investment alternative will decrease consumption costs on average by 21 % and increase profit from the second year on by 4 %. The technology change alternative will decrease consumption costs by 59% and increase profit on the long run by 11 %. The SME decided for the latter case.

3.5. Maturity level of the approach

The proposed approach is partly proven in practice. A decent level of maturity has been obtained concerning the effective collection and compilation of data on a static level in more than a dozen manufacturing SME projects from different industry branches in Germany. The creation of a simplified process flow chart, based on the initial company walks has proven to be an extremely important communication tool between all involved persons throughout the duration of the projects and served as a basis for simplified input-output-tables.

Collecting most material flow data and their unit prices has been a low effort challenge for the firms. Experience has been developed to handle and verify in an effective way missing data, while still ensuring a substantial analysis of optimization potentials.

Secondary material, renewable energy, SC and CE aspects have not been approached yet in practice. Monetary outcomes have been presented on a static annual past oriented basis. Suitable dynamic future oriented economic analyzing methods need to be evaluated and proven in practice.

The approach needs to be further developed concerning the adequate involvement and motivation of staff at the beginning of and during ME projects. In particular, change management aspects need to be considered in depth in order to establish the topic in the long run in manufacturing SMEs. A suitable solution, covering the needs of different manufacturing SME types has to be found and tested.

3.6. Extension possibilities and needs

The use of enterprise resource planning software is not the standard in SMEs [27]. Automated data collection reduces workload and increases transparency. For the data exchange in and the extension towards SCs and CE, which increases complexity, data collection needs to be supported by digitalization tools. Such tools must be tailored for manufacturing SMEs and simple to use.

3.7. Roadmap for improving material efficiency

In order to enable a ME-strategy for manufacturing SMEs, in SCs and considering CE aspects, it is necessary to follow an interdisciplinary approach including socio-economic aspects, digitalization technologies, business modelling knowledge and the use of simplified ME improvement procedures as indicated in Figure 3.

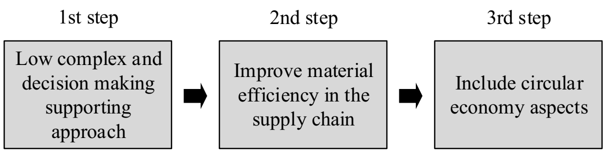

Fig. 3: Proposed material efficiency improvement procedure

The transformation towards more ME needs to achieve the following milestones of the roadmap:

- Attain and gain a critical amount of focal manufacturing SMEs to test and implement a simplified ME approach.
- Encourage such SMEs to work on their upstream and downstream SC concerning ME.
- Design of CE products and selection of according materials.
- Development of digital technologies empowering the information- and knowledge-exchange across the SC.
- Create business model innovations using new forms of cooperation in order to generate synergies, symbioses and increase the productivity of material along whole life cycles.
- Optimize the material flows in a continuous improvement process as a control loop and measure the performance.

4. Conclusion and outlook

In order to gain experience and provide confidence concerning the benefits of ME activities, manufacturing SMEs should start such activities on a low level of complexity in a part of the company. The investigations showed that even with limited data acquisition, a robust basis for financial decisions can be established. Based on this approach, such SMEs can subsequently extend and couple their ME activities to standardized environmental and cost assessment methods at a later stage. In order to achieve decoupling of resource consumption from economic growth, SC and CE aspects should be included.

A critical amount of manufacturing SMEs that play a central and multiplying role in different industry branches needs to be acquired for ME improvement goals. Implementation issues have to be observed from an interdisciplinary perspective considering also social science.

In addition, the governments have to create framework conditions that encourage manufacturing SMEs to initiate ME activities within their own borders and along the upstream and downstream SC. Supplementary research funding is needed to adapt existing tools, methods and business models towards a digitalized SC and CE. For example the development of a common methodological approach to enable manufacturing SMEs to assess, display and benchmark the ME of products, services and companies based on a comprehensive assessment of material impacts over the life cycle. Exchanging information on routes to ME between partners in SCs and across sectors, including manufacturing SMEs, can prevent waste, boost innovation and create new markets.

The focus in increasing the ME has to be on SMEs that take over a central role in the SC and have the strength to act as multipliers for ME initiatives. An important aspect in all efforts is that SMEs, which are already beginning to invest in ME, need to benefit from advances in knowledge and innovation.

This paper suggests that a wider range of enablers are required to enhance the attractiveness of ME-strategies for manufacturing SME business. Therefore, it is recommended that European and national policies intensify their focus on the environmental awareness of consumer preferences along the SC, the culture of enterprises and support the recognition of manufacturing SMEs innovative forms of business.

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