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3.3 Material efficiency in companies of the manufacturing industry: classification of measures

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Abstract
Improving material efficiency in the manufacturing industry is a sustainability imperative for companies due to economic and environmental advantages such as the reduction of material costs and resource use. Innovative solutions in terms of material efficiency measures are diverse and widespread. As a systematic assessment of efficiency approaches and their effects are likely to support dissemination and deployment, this paper aims to develop an approach that helps to classify material efficiency measures. The classification approach presents different dimensions and properties of material efficiency measures based on a literature analysis regarding existing classification approaches as well as on work that has been conducted for the Eco-Innovation Observatory. The classification has been designed as basis for an empirical impact assessment of material efficiency measures based on a data sample that stems from the German Material Efficiency Agency.
Keywords:
Classification; Material Efficiency Measure; Sustainable Manufacturing

1 INTRODUCTION

Material engineering and processing companies are facing change. Growing constraints regarding material availability and increasing raw material prices are increasingly anticipated as entrepreneurial risks requiring preventive adaption strategies [1] [2]. At the same time, new business chances in terms of revenue growth, comparative cost advantages, an improved risk management and a better reputation appear to be tangible for those companies that manage those challenges pro-actively [3]. Pro-active businesses would not only be in the favourable position to realise these potentials, but also to “change the rules of the game” [4].

One opportunity for companies to meet the changing framework conditions is the implementation of measures that lead to an improved material efficiency and thus to a reduced use of material resources. Recently, data from case studies from the Germany Material Efficiency Agency (demea)—which offers support to consult small and medium sized enterprises regarding the implementation of material efficiency measures (MEMs)—were analysed by a number of studies and projects [5] [6] [7]. It was revealed that implementing simple and low-cost MEMs can lead to savings of around € 200,000 per company and year, corresponding to 2 % of the yearly company turnover and facing one-off investments of around € 130,000.

Nonetheless, the actual implementation in business leaves much to be desired—only one in seven of all companies and one in four innovating companies in the EU-27 are introducing those kinds of innovation that lead to a material use reduction [6]. Amongst others, the lack of entrepreneurial action can be traced back to barriers (e.g. uncertainties concerning the return on investment). In order to accelerate the application of MEMs, decision makers in business need to be better informed about MEMs, their costs and benefits. To this end, an improved understanding about the range of different MEMs would be useful.

The present paper addresses this subject. Based on the analysis of scientific articles, studies and other publications, it will present a possible classification approach of MEMs. The developed approach will be the future basis for an in-depth analysis of the demea case studies.

2 LITERATURE ANALYSIS

2.1 Definitions

The concept of efficiency compares the inputs of a system with the outputs of that system. Regarding material efficiency on a corporate level, the inputs of the system are physical resources that go into a production process with the output of produced goods (products and services), which have an economic value. The less material input is needed to generate the same amount of output (or the more output is generated with the same amount of input), the more efficient the system is. Correspondingly, a MEM would be an entrepreneurial action that has the aim to reduce the input of materials while the same economic output is generated with regard to the production of goods.

Material efficiency is closely related to the concept of resource efficiency, with the difference being that they have different system boundaries. The material efficiency concept focuses on one stage of a resource’s life-cycle, in contrast, the concept of resource efficiency is more broad as it regards the efficiency of a resource’s extraction, its use and resulting environmental impacts over all life-cycle stages [8]. This paper focuses on sustainable manufacturing und thus on the manufacturing phase, consequently, the efficiency term of this paper refers to the material efficiency concept.

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2.2 Method

A plethora of scientific knowledge regarding the subject of material efficiency has been generated over the past few years. In order to analyse the diffusion of the *classification of material efficiency measures in companies of the manufacturing industry* in the scientific discussion, a keyword search was conducted. As part of the search, the publication databases Web of Knowledge, Scirus, BASE, Google Scholar and ScienceDirect were scanned for publications that contain the following keywords and/or combinations of them (e.g. *material, efficiency, measure, categorisation*), as far as possible within the title and/or the full text:

- *material* OR *resource*,
- *efficiency* OR *productivity*,
- *measure* OR *strategy*,
- *classification* OR *categorisation*,
- *manufacturing*.

More than 20,000 documents (including redundant hits as well within as across databases) including the above mentioned keywords and/or combinations were found in the five databases. However, hits were screened only until a number of 150 entries per search query, so that around 4,000 documents were screened very roughly for a thematic relevance to the research question of this paper. As a result, around four dozen reviewed articles were considered to be the most promising and were used for a deeper analysis. Additionally, cross-references with further subjects such as (eco-)innovation, (cleaner) production, (sustainable) manufacturing etc. and links to further publications such as other journal articles, books and book chapters, conference contributions, project reports etc. were researched and included into the literature analysis as well.

3 CLASSIFICATION OF MATERIAL EFFICIENCY MEASURES

3.1 Terminology

The following approach including the ensuing terms will be used for the classification of MEMs: A MEM can be classified regarding different *dimensions*. Each dimension is described by a bundle of *properties*, of which only one property can be valid per dimension. It is possible to specify properties on further levels by introducing sub-properties. The collection of all valid properties across the different dimensions forms the *type* of the MEM. Distinguishing MEMs by their types, in terms of valid properties across the different dimensions, shall constitute this paper's approach of how to classify MEMs.

3.2 Classification approaches in the literature

In the course of the literature analysis, general insight regarding classification approaches of MEMs in scientific literature was gained.

Due to the fact that there are a lot of different terms when it comes to describing the material efficiency concept, the search for classification approaches of material efficiency measures was aggravated. In order to have a higher or better hit quota, additional expressions such as *resource efficiency,* etc. were included into the search. It is however evident that this choice was not able to cover the whole range of possible terms describing the same phenomenon (e.g. expressions such as *material* or *resource use* and *savings* or *benefits* would have been possible, too). There are also a number of synonyms for *measure* and *strategy* (e.g. *innovation*, *practice*, *action* or *opportunity*) and *classification* and *categorisation* (e.g. *typology*, *group*, *set* or *characteristic*).

A further factor making searches more challenging is the importance of the classification of MEMs for the respective publication. In most of the cases, the classification approach is more a methodological step on the way to analyse a specific research question than the essence of the scientific publication itself. As the classification happened more incidentally, the identification of classification approaches in the literature is possible in limited form only (e.g. as it is not necessarily listed in the publication title, however the titles were used for the rough screening regarding the thematic relevance of the publication).

Only a small number of the publications considered as promising developed a general approach of how to classify MEMs (e.g. in [5] [9] [10]). For the most part, the publications dealt with only one thematic area and therefore with only one classification dimension and its different properties (e.g. green technologies in [11] [12] [13]).

Furthermore, there are publications about MEMs that presented a bundle of common and concrete MEMs, however failed to introduce a general classification (e.g. in [14] [15] [16]).

3.3 Own classification approach

As a result of the literature analysis, the following thirteen dimensions and their properties to classify MEMs were identified. Some of the dimensions were further specified on a second- and third-tier level (see **Table 1**). The choice of dimensions and properties is not understood to be complete and exclusive—it is rather a first approach of how a MEM classification could look like.

General nature (dimension 1)

The general nature of a MEM gives an answer to the question of the pursued superior strategy: Is it a business model decision, a technical option, an organisational change or a personnel development measure? These four properties are the result of different approaches found in the literature. Other perspectives for the general nature of a MEM would have also been possible; for the most part they are, however, reflected in the following dimensions.

Due to the wide scope of the general nature dimension, the four properties are further specified on a second-tier level. Whereas the properties for the business model are based on a single and pertinent source [17], the technical material efficiency properties have been compiled on the basis of several approaches from diverse literature findings. Technical material efficiency changes can target a company's infrastructure, its product design, manufacturing method, production planning and production process, the sphere of manufacturing and it can be another technical strategy, too. This classification, however, is still too rough. Therefore a third-tier level has been introduced that specifies the technical material efficiency strategies:

- The infrastructure dimension distinguishes between changes regarding technology, machines, tools and the building including other equipment. The technology dimension again is manifold and could be further specified, such as into environmental, optical, automation, information and communication, production, energy, material and building technology and nano- and biotechnology [18]. Again, the environmental technologies could be further specified to e.g. cleansing, cleaner process and clean technologies, etc. [11].

- The product design determines the material use of a product during its life-cycle phases to an enormous extent—80 % of the economic cost and environmental and social impacts are fixed through the product design [19]. There are a lot of opportunities to determine the material use already in the design phase [20] [21] [22]: changes in the product function (e.g. combined functions), durability, size, construction, choice of materials (e.g. use of secondary raw materials) and auxiliary materials and considering resource efficiency aspects during the phases of manufacturing, packaging, use, reuse (or remanufacturing or recycling) and final waste treatment.
- The decision for a certain manufacturing method can be the subject of a MEM. Decisions regarding the following manufacturing method properties are possible: material flow structure (e.g. convergent material flows), cross linking of manufacturing steps (e.g. circular material flow), degree of repetition (e.g. serial production), physical arrangement of manufacturing steps (e.g. workshop production) and other technical determinants (e.g. changing from a chemical to a biological process).
- Whereas changes regarding infrastructure, product design, and manufacturing method are of a more long-term nature, modifications concerning the production planning are characterised by mid- and short-term actions. Setting the production program (e.g. volume of products to be produced in a certain period), materials management (e.g. determination of material requirement) and actual operation scheduling (e.g. capacity and sequence planning) is also part of technical material efficiency strategies.
- In connection with the production planning the actual physical production process offers further possibilities to influence material efficiency on a technical basis—in terms of production control (e.g. concrete job approval), machine setting (e.g. technical adjustments) and the operating of machines (e.g. optimised handling).
- The sphere of manufacturing also offers material efficiency opportunities in terms of actions regarding the workplace design [5], maintenance and cleaning, storage and cleaning and packaging.
- In addition to the named sub-properties of the technical material efficiency dimension, superior technical strategies that target quality management (e.g. implementation of a company wide monitoring, controlling and benchmarking system), use of information technology (e.g. new software) and a material flow management (e.g. in order to implement in-house and closed-loop material flows) have been introduced as final classification properties for technical MEMs.

Life-cycle stage (dimension 2)

The MEM can target different life-cycle stages: the phase of the resource extraction, manufacturing, transport, etc. The properties describing those phases have been taken from the supply chain operations reference model [23] and comprise the stages of plan, source, make, deliver and return.

The dimension of the planning level takes different time horizons into account. Planning decisions can be normative, strategic, tactical and operational [24] with decisions affecting the above listed technical material efficiency strategies (e.g. strategic decisions about product design, or tactical determination of the production program).

Corporate division (dimension 3)

The dimension of the corporate division comprises the properties management, corporate culture, human resources, research and development, product design, marketing, controlling, procurement, manufacturing, maintenance and cleaning, storage and logistics and packaging. These could be assigned to the life-cycle stages, too (e.g. research and development to planning or manufacturing to making)—it is, however, interesting to learn which corporate division is able to influence the material efficiency performance of the enterprise.

Mechanism (dimension 4)

The idea regarding a mechanism dimension has been taken from a methodology of how to describe sustainable manufacturing tactics [25]. It depicts how the material efficiency effect takes place. The concrete properties were chosen in analogy with the waste hierarchy defined by the European Union [26] that differentiates between prevention, reuse, recycling, recovery and disposal (as the latter one is not relevant in terms of material efficiency improvements, it is not included in the properties of this dimension).

Material (dimension 5)

A MEM reduces the use of materials. The material dimension gives an overview of the saved material type. On the first-tier level the dimension is simply characterised by input and by output material. In accordance with a guideline of how to calculate the material input per service unit [27], on a second-tier level, the input material is further specified by abiotic and biotic raw materials, energy sources and carriers, water, air, components, models, auxiliary and operating materials. Accordingly, the output material is further specified by main and by-products, waste, emissions, waste water and exhaust air.

Degree of change (dimension 6)

MEMs lead to a change in the respective company. To which degree that change takes place gives occasion to introduce a further classification dimension. Commonly, it is distinguished between small and high degree changes—in terms of e.g. incremental and radical innovations [28] [29] [30]. In this paper the focus lies more on business-related incremental than society-related radical changes, therefore an approach [31] is chosen that focuses more on incremental changes. Modification, redesign, alternatives, and (with respect to radical and system changes) creation are the properties of the degree of change dimension.

Degree of novelty (dimension 7)

Complementary to the degree of change, a differentiation regarding the degree of the MEM's novelty is possible. As the definition of novelty is not possible per se [32], a framework for comparison is necessary: Is the measure just new to the firm, but already implemented by other companies in the same market segment? Is it new to the market or new to the world? The answers to these questions are the properties chosen for the classification approach of this paper.

Directness of effect (dimension 8)

Whether the material reduction effect of a MEM occurs immediately after the implementation or is delayed by a certain amount of time or whether the effect occurs at the place where the measure has been implemented or further downstream is a further classification dimension. It is differentiated between direct and indirect effects [33] [34].

Measurability (dimension 9)

Related with the question regarding the directness of effect is the measurability of an effect. Effects can be measured on a quantitative (e.g. saved material amount through changed machine adjustments) or a qualitative basis (e.g. better housekeeping through awareness raising measures).

Risk structure (dimension 10)

The introduction of MEMs can pose a path dependence risk to the company in terms of the ecological, economic and technical reversibility [35]. These features could be taken as properties for the dimension of risk structure. However, a MEM could be all three—difficult to be reversed in ecological, economic and technical terms. Therefore, a differentiation between a low, middle and high risk, based on the different reversibility aspects are chosen as properties in order to describe the risk structure of a MEM.

Technical education (dimension 11)

The technical education that is needed in order to introduce and to implement the MEM is a further classification dimension of MEMs. The chosen properties for that dimension differentiate between maintenance personnel, engineering personnel and technology expert [9].

Implementation time (dimension 12)

The time that a measure needs to be implemented is a further dimension of MEM classification. The implementation time is short when it is below six months; it is medium when it takes between six months and one year. In case it takes longer than one year, the implementation time is long.

Measure duration (dimension 13)

The duration of the MEM constitutes another classification dimension. In case it has a five year life expectancy it is a short-term measure. With a lifetime between 5 and 20 years it is a medium-term and more than 20 years it is a long-term measure [9].

Table 1: Classification of material efficiency measures (first-, second- and third-tier level)

Dimensions		**Properties**				
1	**General nature**	business model	technical material efficiency	organisation	personnel development	
1.1	**Business model**	value proposition	target customer	distribution channel	relationship	value configuration
		core competency	partner network	cost structure	revenue model	
1.2	**Technical material efficiency**	infrastructure	product design	manufacturing method	production planning	production process
		sphere of manufacturing	other technical strategy			
1.2.1	**Infrastructure**	technology	machine	tool	building and equipment	
1.2.2	**Product design**	function	durability	size	construction	material choice
		auxiliary materials	manufacturing	package	use	reuse
		waste treatment				
1.2.3	**Manufacturing method**	material flow structure	cross linking of manufacturing steps	degree of repetition	physical arrangement of manufacturing steps	technical determinants
1.2.4	**Production planning**	production program	materials management	process organisation		
1.2.5	**Production process**	production control	machine setting	operating of machines		
1.2.6	**Manufacturing sphere**	workplace design	maintenance and cleaning	storage and logistics	packaging	
1.2.7	**Other technical strategy**	quality management	IT assistance	material flow management		
1.3	**Personnel development**	awareness raising and good housekeeping	position creation			

2	**Life-cycle stage**	plan	source	make	deliver	return
2.1	**Planning level**	normative	strategic	tactical	operational	
3	**Corporate division**	management	corporate culture	human resources	research and development	product design
		marketing	controlling	procurement	manufacturing	maintenance and cleaning
		storage and logistics	packaging			
4	**Mechanism**	prevention	reuse	recycling	recovery	
5	**Material**	input material	output material			
5.1	**Input material**	abiotic raw materials	biotic raw materials	energy sources / carriers	water	air
		components	modules	auxiliary materials	operating materials	
5.2	**Output material**	main products	by-products	waste	emissions	waste water
6	**Degree of change**	modification	redesign	alternatives	creation	
7	**Degree of novelty**	new to the firm	new to the market	new to the world		
8	**Directness of effect**	direct	indirect			
9	**Measurability**	quantitative	qualitative			
10	**Risk structure**	high risk	middle risk	low risk		
11	**Technical education**	maintenance personnel	engineering personnel	technology expert		
12	**Implementation time**	short (<6 months)	medium (6-12 months)	long (>1 year)		
13	**Measure duration**	short-term (<5 years)	medium-term (5-20 years)	long-term (>20 years)		

4 CONCLUDING REMARKS

Based on literature research, this paper has developed an approach of how to classify MEMs in companies of the manufacturing industry. The approach consists of thirteen dimensions that are specified by a number of properties (and where appropriate also on a second- and third-tier level), of which only one property per dimension is valid for a certain MEM. The collection of all valid properties regarding the thirteen dimensions forms the respective MEM type.

The approach does not claim to represent the entire reality, it is even highly likely that the dimensions and properties can be amended or refined. Changes in some other form could also be possible because defining distinct properties for dimensions that look from different perspectives on a similar issue cannot always happen without any overlap (e.g. packaging is a property of the dimensions product design, manufacturing sphere and corporate division).

Despite possible weaknesses, the developed classification approach could serve as the basis for a detailed analysis of case studies as conducted by the demea. MEM types shall be compared with each other in order to find patterns that allow deductions regarding MEM type-related material saving potentials (in physical and monetary terms), investment costs and payback times.

To give an example, measures in the demea cases comprise amongst others changes concerning the reduction of set-up times, changed temperature in the production process, use of filters, alternative coating method, re-use of dissolvent, improved definition of employee responsibilities, machinery cleaning, product size, use of IT in order to support production simulation and quality control of purchased commodities [36]. According to this paper's classification approach, they all target the technical material efficiency property within the general nature dimension. On a second- and third-tier level the MEMs are further specified by sub-properties such as process organisation (production planning), machine setting (production process), tool (infrastructure), technical determinants and material flow structure (manufacturing method), operating of machines (production process), maintenance and cleaning (manufacturing sphere), size (product design), IT assistance and quality management (other technical strategy). Identifying the properties of the remaining twelve dimensions and building the MEM types would be the next steps on the way to the classification of the given MEMs.

In order to accelerate the dissemination and deployment of MEMs in companies of the manufacturing industry, the classification of MEMs needs to take place on a larger scale combined with the deduction of MEM patterns and determination of the economic leverages and payback times.

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