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# MATURITY MODEL FOR EVALUATION OF RESOURCE EFFICIENCY IN MANUFACTURING SMEs

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***Abstract:*** *Increasing global competition constraints have changed the corporate landscape in the last few years. The aim of producing goods with fewer resources not only leads to ecological advantages but also leads to economic advantages. To face this trend, a lot of companies in the manufacturing industry are anxious to increase performance and to use resources efficiently. The objective of this paper is to provide a model and a software tool which enable self-assessment of manufacturing SMEs (small and medium-sized enterprises) regarding resource efficiency with relatively low effort. The development of the maturity model is made based on the EFQM (European Foundation for Quality Management) Model as an established basis model and approved development framework. Besides the construction of the model architecture, also the criteria which represent resource efficiency are defined. At the end of the paper, the tool's usability and practicability are validated by implementing it in a manufacturing SME.*

***Key words:*** *maturity model, resource efficiency, process improvement, manufacturing, small and medium-sized enterprises.*

## 1. INTRODUCTION

Increasing competitive constraints have changed the corporate landscape in the past years [1]. Producing goods with fewer resources [2] promises a significant competitive advantage, not only ecological. Furthermore, global trends as increasing resource scarcity and increasing prices as well as climate protection have become more important [3]. To face these trends, producing enterprises strive to maximize their internal performance and their efficiency of resources. According to a study conducted by the Fraunhofer IAO in 2010, most of the companies asked profit from cost reductions and increasing competitive advantages, due to increasing of resource efficiency [2]. The monetary saving potential of the resource material alone is estimated to 220,000 € per year and enterprise [4].

Watts S. Humphrey described the assessment as an important topic to evaluate the own position: "If you don't know where you are, a map won't help" [5]. Therefore, the implementation of sustainable measures to improve resource efficiency needs a reflection of the degree of resource efficiency first. Maturity models enable the evaluation of processes and corporate divisions. In addition to that, maturity models offer a roadmap to integrate improvements, which can be used by companies. This methodology promotes to act targeted and offers the possibility to reflect the implemented measures.

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## 2. STATE OF THE SCIENTIFIC KNOWLEDGE AND NEED FOR ACTION

In this chapter, the framework of the paper is described and the relevant terms are defined. Furthermore, the need for action is delineated.

### 2.1 Production and SMEs

A lot of definitions for the term production are available in literature. Corsten subdivided the definition into the following three groups [7]:

- production as a factor combination process;
- production as a phase of the business procedures;
- production as a value-creating process.

Steven described the production as a factor combination process. He defined the production as a process whereby operational factors respectively inputs are combined with procedures which result in products respectively outputs. [8]. Figure 1 illustrates a production system, based on [7, 8].

Furthermore, the manufacturing industry is assigned to the secondary industrial sector, according to the three-sector theory of Fisher, Clark and Fourastie [8].

In general, optimizing productions means facing the conflict of the targets: quality, costs and time. Optimizing goal entails a negative impact to the other goals [8].

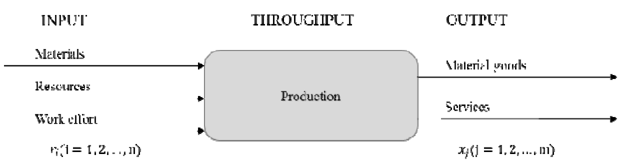


**Fig. 1.** Production system based on [7, 8].

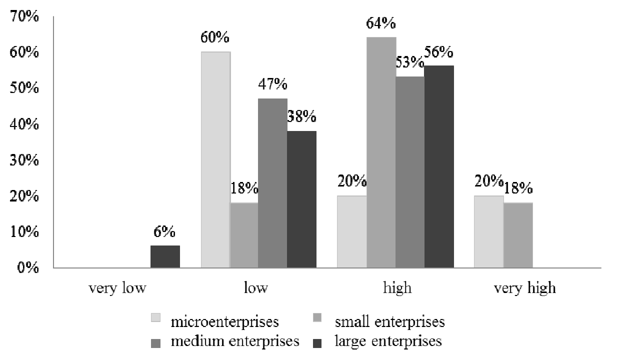


**Fig. 2.** Resource efficiency in enterprises according to [2].

As SMEs (small and medium-sized enterprises) are the targeted audience of the maturity model, SMEs are defined in this paragraph. According to the advice 2002/362/EG of the EU commission, SMEs have less than 250 employees and either not more than an annual sales of 50 million € or an annual balance sheet total of not more than 43 million € [9]. In terms of resource efficiency, SMEs do not have the same knowledge as bigger enterprises [2]. This issue is illustrated in Fig. 2.

### 2.2 Efficiency and resources within productions

According to Steven, the efficiency criteria can be deduced from the economical principle [8] also known as the rational principle of the economic acting. It has two characteristics which are the maximum principle and the minimum principle. In both cases, it is fundamental to avoid waste [7]. In industry, the two terms effectivity and efficiency are often mixed up. Effectivity means to do the right things whilst efficiency means to do the things right [8]. According to different theme complexes, the definition of resources is quite different. Often they are defined as natural resources as soil, biological diversity, biotic natural resource, water and air [10]. In production, resources are defined as energy and material [2]. Westkämper defined resources as capital, humans, material, energy, tools, machines, information and knowledge [11]. The definition for this paper is based on the work of the Fraunhofer Project Group done in 2012. Resources are subdivided into the following five categories [12]:

1. energy;
2. material;
3. human;
4. machine;
5. management.

### 2.3 Maturity Models

Maturity models conduce to analyze and to assess enterprises respectively their products, processes or their organization, and furthermore to evaluate their degree respectively level of maturity concerning certain criteria. The basis is a stage model which characterizes levels of abilities by sequential maturity levels. By fulfilling of defined criteria, the achievement of a higher level of ability, and thus a higher level of maturity, is attested [13]. A higher maturity level guarantees defined, structured and standardized processes [14]. Thereby, besides the evaluation of the enterprise, maturity models also show a catalog of measures to achieve the next maturity level [13]. Thus, not only the temporary state but also the progress is made measureable. Therefore, maturity models are a perfect methodology to assess or benchmark processes or strategic positions [13, 15].

In this paragraph, some of the most common maturity models are described:

- Capability Maturity Model;
- Capability Maturity Model Integration;
- European Foundation for Quality Management Excellence Model;
- Software Process Improvement and Capability Determination Model.

Besides the development of the models, also their structure, there assessment systematic and their application area(s) are described.

**Capability Maturity Model.** The Capability Maturity Model (CMM) was developed by the Software Engineering Institute (SEI) between 1986 and 1991, commissioned by the US Ministry of Defense, in order to optimize software processes [14, 16]. The maturity levels are divided into the five steps: Initial, Repeatable, Defined, Managed and Optimized [14]. The model was advanced to the following models, among others: Capability Maturity Model for Software (SW-CMM), Systems Engineering Capability Model (SECM) and the Integrated Product Development Capability Maturity Model (IPD-CMM). The application of the CMM challenged organizations, because it was necessary to use more than one maturity model to assess different departments. The potential of improvement was limited, due to the divergent architecture and approaches of the specific maturity models [17].

**Capability Maturity Model Integration.** The Capability Maturity Model Integration (CMMI) is also an advancement of the CMM. The aim of the model is to optimize whole business processes. The business processes are described through four process categories. Twenty-two process areas are assigned to these categories. Each process area can consist of several processes [17]. The assessment is based on a default roadmap [14].

**European Foundation for Quality Management.** As a reaction of high performance requirements in terms of quality, the European Foundation for Quality Management (EFQM) was established in 1988 by 14 European organizations. In 1993 the EFQM Excellence Model was published. The model offers a holistic approach for self-assessment, benchmarking, and external assessment [18]. The framework consists of nine criteria. These criteria are subdivided into five enabler criteria and four results criteria. Enabler criteria encompass process, structure and importance of an organization. The results criteria conform the performance and outputs. The criteria are subdivided into 32 sub criteria to which reference points are attached [18, 19].

**Software Process Improvement and Capability Determination.** The British initiative to develop a process assessment model results into the SPICE model (Software Process Improvement and Capability Determination), documented in the international standard ISO/IEC 15504 [20]. The model has two dimensions.

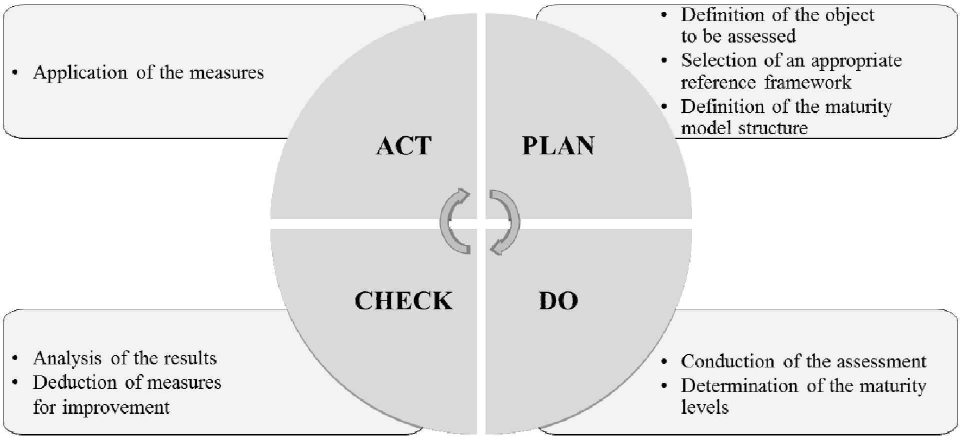


**Fig. 3.** Maturity model assessment based on the PDCA principle.

A process dimension, which is divided into five process categories, and a capability dimension [20]. Within the process dimension, the processes are described according to their purpose and results, and are thus measureable. The assessment is done by means of six capability levels and nine process attributes [20]. To reach a higher level of maturity it is necessary to fulfill the requirements respectively process attributes of the level below entirely and the process attributes of the level directly below largely.

**Principle of Maturity Models.** After detailing the most common maturity models, the principle of maturity level assessments is described. The determination of a maturity level is done within assessments, most often by using questionnaires or check lists, through assessing defined criteria. Result of such an assessment is the actual maturity level of the assessed organization [21]. The process of the maturity level assessment is done according to the PDCA principle (plan do check act). The PDCA principle is based on a circuit which enables continuous improvement [22]. Figure 3 illustrates the maturity level assessment and improvement based on the PDCA principle.

The selection of the suitable assessment model depends on the complexity of the model, the size of the enterprise and the knowhow of the employees. Depending of the financial and personal abilities three options for assessments are available [14]:

- self-assessment;
- self-assessment with support by external assessors;
- assessment through external assessors.

### 2.4 Need for action

Maturity models to assess organizations are well known in science as well as in industry. Unfortunately, there is a lack of knowledge when it comes to the investigation of the degree respectively level of resource efficiency. Moreover, according to Erhardt and Pastewski, a huge amount of SMEs have no or only a little expertise in terms of resource efficiency [2]. It is necessary for SMEs to have a concrete guidance which enable them to investigate their degree of resource efficiency with minor effort.

Therefore, scientists from the Chair for Manufacturing and Remanufacturing Technology at the University of Bayreuth and the Fraunhofer Project Group for Process Innovation developed a maturity model and a software tool to assess the resource efficiency, especially for manufacturing SMEs. The development and the results of the work are described in this paper.


**Fig. 4.** Framework of de Bruin et al. [6].

## 3. SCIENTIFIC APPROACH

The focus of this paper is the assessment of resource efficiency. The assessment is based on a maturity model instead of key figures to be able to develop a holistic and systemic management structure.

The main focus is the development of a maturity model for resource efficiency especially for manufacturing SMEs. The development of the maturity model is based on the framework of de Bruin et al. [6] which is a structured and scientifically proved procedure. Figure 4 illustrates the six step framework of de Bruin et al.

In a first step, the SME-specific needs for a maturity model were identified. In the next step a literature study was done to identify a framework which could be used as a basis for the development of the maturity model. In the third step the framework for the maturity model was developed, followed by the conduction of the core criteria to describe resource efficiency. The realization of the theoretical maturity model was done by using Microsoft Excel. The Excel tool consist of three parts respectively sheets, which are: a sheet for the date collection, a sheet for the calculation of the degree of resource efficiency and a sheet for the presentation of the assessment results. In the last step, the software tool was validated by using it for the assessment of the resource efficiency in a manufacturing SME.

## 4. DEVELOPMENT OF THE MATURITY MODEL

In this chapter, the development of the maturity model to evaluate resource efficiency is described. The development was done based on the approach of De Bruin et al. [6]. The approach is structured in a six phase framework. In a first step, the application and the specific requirements have to be defined. In the second step, the design phase, the architecture of the model has to be developed. The results are the requirements of the model. The step populate comprises the description of the criteria and sub criteria. Furthermore, it includes a method to measure the variables. Within the step test, the model needs to be evaluated regarding the requirements defined before. The realization and continues advancement of the model and concept have to be done in the phase deploy respectively maintain [6]. Within this paper, the steps one to four are shown.

### 4.1 Requirements on a maturity model to assess the resource efficiency of manufacturing SMEs

Before developing a maturity model it is crucial to define the requirements of the intended application area. The development of maturity models is incorporated with clash of interests and conflicting goals [13].

A maturity model which fits to the needs of manufacturing SMEs has to combine some core criteria. On the one hand it has to be simple and manageable time wise [23]. On the other hand, due to missing financial resources, it should be feasible without external support [23]. Furthermore the complexity of the structure should be limited to a minimum [13, 23]. The purpose of the model should be a continuous process of improvement instead of a fundamental restructuring [13]. Furthermore, the result should be a plain and defined guidance. Moreover, the possibility of benchmarking should be given [13].

### 4.2 Selection of a reference framework

In the first step of the development, the definition of the scope of application was done. Therefore, a reference framework which fits to the needs of resource efficiency and manufacturing SMEs had to be chosen. According to Becker at al., the development of a maturity model based on a reference framework is a common approach. The methods can be enhanced and be combined to a new set [21]. Following, the maturity models described before are compared against each other. The CMM was not considered, due to the fact that it is not up to date anymore and that the CMMI is the advancement of it [21].

The advantage of the CMMI is the combination of an incremental and a continuous variant. The continuous variant allows an independent consideration of different departments of organizations whereas the incremental variant allows a thoroughly comparability and gives clear guidelines [14]. The two types of application complement each other and allow flexibility in the presentation of results. In industry, the CMMI is one of the most used models [24]. Also the EFQM is generally valid and prevalent [13]. An easy to use and clear structured self-assessment which gives a first impression of the stage of development [25] is an advantage for the application at SMEs. The advantage of the SPICE model is the possibility to analyze organizations on the process level [20]. Nevertheless, besides the automotive sector, there are hardly any branch specific models [20]. Furthermore, a comparison across industry sectors is hardly possible due to the missing process reference model and the missing process assessment model [20]. Considering the requirements for manufacturing SMEs, defined in the previous chapter, the three reference models (CMMI, EFQM, SPICE) were assessed due to the following criteria:

*Table 1*

**Assessment of reference frameworks**

| | CMMI | EFQM | SPICE |
|---|---|---|---|
| **Documentation** | Yes (very detailed) | Yes | Yes (in ISO/IEC 15504) |
| **Reliability** | Yes (proved) | Yes (proved) | Yes (proved) |
| **Self-assessment** | Possible, not designed for that application primarily | Possible (basics available) | Possible |
| **Continuous improvement** | Yes | Yes | Yes |
| **Derivation of methods for improvements** | Partly, with sub practices | Yes, with the RADAR-Logic | Yes, with a reference model |

- documentation;
- reliability;
- possibility for self-assessments;
- continuous improvement;
- derivation of methods for improvement.

Table 1 shows the results of the assessment of the framework models regarding the requirements of manufacturing SMEs.

On a first view it seems to be that all of the three framework models are suitable for the usage in manufacturing SMEs. However, there are fundamental differences between the models if considering the complexity of the models.

In general, the three models can be used for self-assessments, but that does not mean that the model structure and the documentation facilitate that option. The structure of the SPICE model was developed especially for measuring software quality. Furthermore, the usage of the SPICE model is not suitable, due to the weak prognostic validity [26]. The CMMI has two disadvantages, the possibility of misinterpretations and the effort needed to use the model. That brings us to the conclusion that it is only suitable to use the model as a team of experts [14]. According to the EFQM webpage, the EFQM model allows generic assessments of "sustainable excellence" [25]. Indeed, it is necessary to have detailed descriptions of the internal processes and structure [26], nevertheless, it is possible to use the model in three steps of complexity. At the end of the day, the first step is on a cause-effect-diagram.

To ensure transparency, a detailed description of all enablers and results criteria is provided [25]. Compared to the SPICE model, the EFQM model has a more mature and established application model.

Based on the arguments above, the EFQM Excellence Model was used and adapted for this paper.

*Table 2*

**Framework of the model**

| | |
|---|---|
| **Purpose** | Support for the measurement and the assessment of resource efficiency within organizations |
| **Target group** | Managers within manufacturing SMEs |
| **Novelty value** | Usage and recombination of structures of established maturity models |
| **Application area** | Assessment and improvement of own enterprise |
| **Maturity concept** | Cross-sectoral; suitable to identify weaknesses |
| **Assessment** | Inquiry method: self-assessment;<br>Inquiry technic: questionnaires;<br>Responsibility: management |

### 4.3 Definition of the Framework and the Maturity Levels

In this section of the paper, the framework of the maturity model as well as the maturity levels were defined and described.

According to De Bruin et al., the first step when designing a maturity model, is the definition of the application as well as the specific requirements.

The designated core topic of this maturity model is resource efficiency within productions. The target group are manufacturing SMEs, which would like to use the maturity model for self-assessments. Therefore, the focus of the maturity model is the self-assessment of resource efficiency within manufacturing SMEs.

The objectives for the model are, on the one hand, the identification of weaknesses, and on the other hand, the reveal of recommendations in order to increase the resource efficiency within the production. A summary of the defined framework is illustrated in Table 2.

The framework was used as basis for the following developments.

Subsequent to the definition and description of the framework, the maturity levels for the maturity model were defined.

In general two approaches are available to describe maturity levels. The top-down-approach starts with the definition of the maturity levels, followed by the description of the necessary measures. Whereas, at the bottom-up-approach, the requirements are defined first, followed by the maturity levels. According to De Bruin et al., it is advisable to use the top-down-approach with limited experience in designing of maturity models [6].

The modelling of the maturity levels was done based on the EFQM models, whereas, the distinction of the maturity levels was done according to the EFQM and the CMMI model.

Thus, five maturity levels (ML) were defined, which are the basis for the maturity model, and therefore, enable the description respectively classification of manufacturing SMEs in terms of resource efficiency. The evaluation intervals (Ev. Interval) facilitate the illustration of the maturity levels regarding resource efficiency.

*Table 3*

**Description of the maturity levels**

| ML | Ev. Interval | Definition | Description |
|---|---|---|---|
| 5 | 100% | Continuous improvement | Generic comprehension of resource efficiency<br>Continuous and sustainable process of improvement |
| 4 | 75% | Managed | Achievement of measureable success<br>Targeted application of methods of improve resource efficiency |
| 3 | 50% | Defined | Implementation of methods<br>Introduction successful<br>Standardization recognizable |
| 2 | 25% | Introduced | Knowledge regarding improvement of resource efficiency<br>Introduced, party implemented |
| 1 | 0% | Incomplete | No evidence of resource efficiency<br>Missing awareness regarding resource efficiency |

The five defined maturity levels for the maturity model to assess resource efficiency in manufacturing SMEs are illustrated in Table 3.

### 4.4 Definition of Criteria to Assess Resource Efficiency

In this section, the before described and defined framework of the model had to be filled. Therefore, the definition of the criteria to assess resource efficiency were defined and described.

Based on the EFQM framework model, the criteria were subdivided into five enabler and four results criteria. These nine criteria typify respectively represent the key topic resource efficiency. The five enable criteria were defined as: energy, material, human, machine and management. Each criterion was specified through sub criteria. It was crucial to use generalized criteria which are appropriate for the application in certain industry sectors.

The definitions are based on the dissertation of Slawik [23] and under consideration of [2, 12]. Influencing factors were the common approaches to assess and optimize resource efficiency, the seven wastages and the potentials of industrial resource efficiency according to [23].

The five enabler criteria, including their sub criteria, as well as the key figures to measure the resource efficiency, are shown in Table 4.

In contrast to the enabler criteria, the results criteria were not specified regarding resource efficiency but represent general corporate objectives. This is done because resource efficiency aims, like other measure, to maximize generic corporate objectives such as the monetary value of the company. The criteria and also the evaluation were taken from the framework model EFQM. The results criteria, including their sub criteria and criteria to measure the corporate objectives, according to the EFQM [25] are shown in Table 5.

*Table 4*

**Description of the enabler criteria**

| Enabler criteria | Sub criteria | Key figures to measure the resource efficiency |
|---|---|---|
| Management | Quality | Deviation of the planned production schedule<br>Clarity of the planning |
| | Qualification | Targeted advanced education |
| | Inventory planning | Measures to reduce stock |
| Machine | Plant productivity | Amount of unplanned operating condition<br>Amount of unnecessary operating condition |
| | Level of the equipment | Observance of standards |
| | Production faults | Effort for quality assurance<br>Waste |
| Human | Employee productivity | Idle time |
| | Employee protection | Ergonomics at the work places<br>Performance reduction due to external circumstances |
| | Motivation | Sick absence rate |
| | Qualification | Gap between advanced education<br>Educational level |
| Energy | Consumption | Overall Equipment Efficiency (OEE)<br>Loss of energy |
| | Source of energy | Rate / supplier change |
| Material | Amount of raw materials and supply | Ratio input / output<br>Reject rate |
| | Quality of raw materials and supply | Rework<br>Supplier performance |

*Table 5*

**Description of the results criteria**

| Results criteria | Sub criteria | Criteria to measure the corporate objectives |
|---|---|---|
| Customer-oriented | Customer satisfaction | Customer survey |
| | Customer requirement | Suggestion scheme |
| Employee-oriented | Engagement | Company suggestion system<br>Bonus payment |
| | Employee loyalty | Employee turnover |
| Society-oriented | Public image | Publicity<br>Advertising efforts |
| Key results | Financial indicators | Financial solidity<br>Productivity<br>Operating results |
| | Success factors | Market position |

### 4.5 Evaluation of the Criteria

In the last step of the development of the maturity model, the before defined criteria had to be evaluated. The evaluation was performed divergent to the framework model EFQM. The enable criteria are essential for the maturity model for resource efficiency whereas the results criteria represent the corporate objectives. Therefore, the weighting factor of the enabler criteria, in relation to the results criteria, is defined as 3:1. Consequently, the enabler criteria have an influence of 75% to the overall maturity level. According to the EFQM model, the single criteria were also evaluated. The evaluation of the enable criteria was done considering the evaluation of monetary potential of resources by Slawik [23]. The evaluation of the results criteria was done according to the EFQM framework model. Fig. 5 shows the results of the evaluation of the criteria.

## 4. DEVELOPMENT OF A SOFTWARE TOOL TO DETERMINE THE MATURITY LEVELS

Based on the before developed maturity model, a software tool, which allows SMEs to profit from the research done, was developed. The tool was developed in Microsoft Excel due to the wide dissemination level of the software. The tool is divided into three segments respectively sheets. The first sheet can be used to enter the user data, the second sheet is used for the calculation of the maturity level and the third sheet is used to show the results of the assessment. The first segment was designed as a questionnaire. The user is asked questions regarding the criteria and sub criteria defined before. Due to the fact, that the data availability in manufacturing SMEs is not the best, the questions asked were kept simple. Furthermore, according to the maturity levels defined, five potential answers were described for each question. The users have to decide, which answer fits best to their situation.

After entering the data, the evaluation results are displayed directly. In addition to the overall maturity level of resource efficiency, also the results of the criteria and sub criteria are displayed. Besides the presentation of the numbers, the results are furthermore displayed as spider diagrams, as shown in Fig. 6.

This type of presentation enables the user to compare two evaluations of the own company and thus to review the improvement measures implemented.

## 5. VALIDATION

After the development of the tool, it was validated in a manufacturing SME. The SME chosen for the validation is a tradition-rich family owned manufacturer of precision components for the automotive industry.

In the first step, the data were gathered by using the Microsoft Excel based software tool. The input of the data was performed without any problems.

The result of the evaluation was an overall maturity level of three, which describes the resource efficiency of the SME as *Defined*. The five enabler criteria were performed between level two and level four, each. As positive result, the sub criterion motivation of employees (within the criteria human) and the supply of energy (within the criteria energy) have to be mentioned. The only criterion which was in the critical range (level 1) was the level of equipment. The reason for that was the assessment of the equipment strictly regarding resource efficiency. Also modern machines are not on a high level automatically.

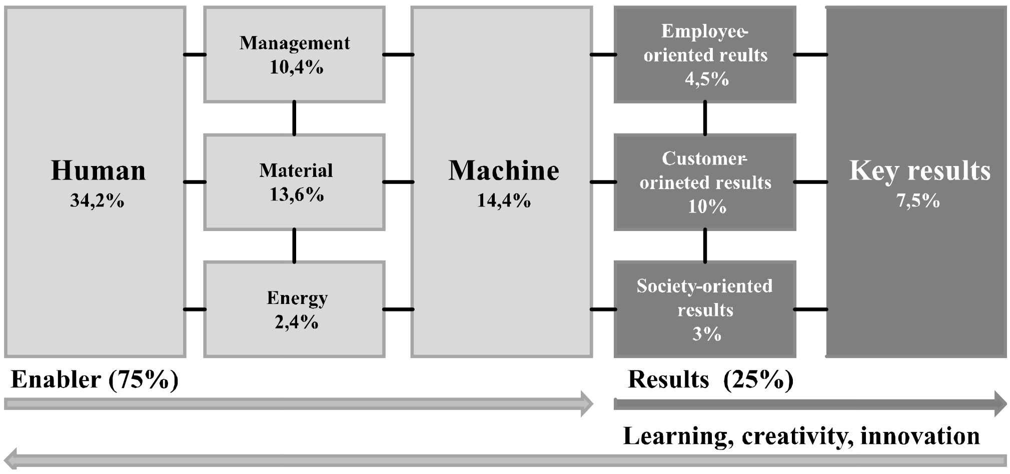


**Fig. 5.** Evaluation of the criteria.

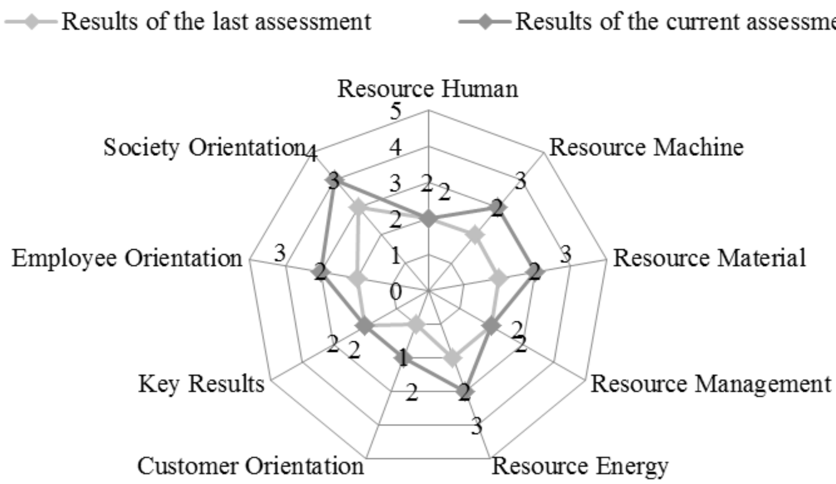


**Fig. 6.** Example of the assessment results.

Overall, the usability of the tool was ranked high. The questionnaire was easy to use and the presentation of results was understandable. As a disadvantage it was mentioned, that the qualitative interpretation of the answers provided, contains the risk of misinterpretation. Furthermore, the results of the evaluation where valued as realistic by the representative of the SME.

## 6. CONCLUSION AND OUTLOOK

One of the biggest challenges, which manufacturing SMEs face nowadays, is the increasing competitive pressure. The increase of resource efficiency is an effective approach to improve the competitiveness of manufacturing companies. Furthermore, maturity models are an effective method to assess processes.

Within this paper, a maturity model to assess the resource efficiency in manufacturing SMEs was developed. Furthermore, the model was transformed into a software tool, which was validated within a manufacturing SME.

The model and the tool developed, enable manufacturing SMEs to assess the resource efficiency of their processes, to identify potentials of improvement and to review the implementation of optimization measures, based on self-assessments.

In further research, the maturity model will be verified in expert workshops. Furthermore, the software tool will be improved and updated to minimize the possibility of misinterpretation of qualitative interpretations within the questionnaire.

At the end of the day, the paper supports manufacturing SMEs to become more resource efficient and thus to increase their competitiveness.

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