

CONTENT

| ABOUT THIS GUIDE | 4 |
|---|----------------|
| OVERVIEW OF METHODS AND TOOLS | 5 |
| WHY IS RESOURCE EFFICIENCY IMPORTANT FOR BUSINESSES? | 7 |
| WHAT DOES RESOURCE EFFICIENCY MEAN? | 8 |
| WHAT SHOULD BUSINESSES BEAR IN MIND WHEN IMPLEMENTING? | 9 |
| WHAT INFORMATION AND DATA IS REQUIRED? | 10 |
| PROCEDURES IN THE IMPLEMENTATION OF OPERATING RESOURCES EFFICIENCY MEASURES | 12 |
| 1 ANALYSIS 1.1 Analysis of production 1.2 Life cycle analysis | 13 13 25 |
| 2 SOLUTION DEVELOPMENT | 28 |
| 3 EVALUATION 3.1 Technical-economic 3.2 Evaluation of resource efficiency | 42 42 48 |
| 4 IMPLEMENTATION | 52 |
| 5 CONTROL | 55 |
| INTEGRATION INTO THE CONTINUOUS IMPROVEMENT PROCESS | 58 |
| BIBLIOGRAPHY | 59 |

ABOUT THIS GUIDE

Learn how you can take a step-by-step approach to implementing resource efficiency measures in your businesses. Find suitable methods and tools to support you in this.

There is a multitude of methods and tools that exist for different questions and problems and can be applied for the implementation of resource efficiency in the business.

The Resource Efficiency Guide helps you to tackle **resource efficiency measures** in your business **step by step** and helps you to find the right method or tool for each step.

Tools can be understood as matrix templates, tools available on websites or software solutions.

The methods listed in the guide are methodological recommendations. The selection of

individual methods should also be based on which methods are known to the business.

In order to select the appropriate method or tool, it is important to define the goal and the associated question in advance. The focus should not be on the method or the tool, but on the knowledge that can be drawn from it.

In addition to this brochure, the guide is also available as an interactive tool on the website www.ressource-deutschland.de/leitfaden-ressourceneffizienz (in German only). There you will find further descriptions of the respective instruments as well as links to further tools and methods.

OVERVIEW OF METHODS AND TOOLS

| Step | Method/Accessories | Page | |
|---|--|------|--|
| 1 Analysis I 1.1 Analysis of production | | | |
| Methods | Input-output analysis (rough analysis) | 14 | |
| | ABC analysis (rough analysis) | | |
| | Material flow analysis (detailed analysis) | 19 | |
| | Material flow cost calculation according to DIN EN ISO 14051 (detail analysis) | 21 | |
| Tools | Resource checks (rough analysis) | 17 | |
| | VDI ZRE Cost calculator: Material flow cost calculator (detailed analysis) | 23 | |
| 1 Analysis I 1.2 Life cycl | e analysis | | |
| Methods | MET-Matrix (rough analysis) | 26 | |
| 2 Solution development | 2 Solution development | | |
| Methods | Construction methodology | 30 | |
| | Integration in the Product requirements list | 33 | |
| | Resource-friendly design requiremements | 36 | |
| | Principles of Ecodesign | 36 | |
| | Brainstorming - creative search for solu- tions | 37 | |
| | Morphological box | 37 | |
| | TRIZ method for solving problems | 38 | |
| Tools | ECODESIGN Pilot | 39 | |
| | Strategies and measures | 39 | |
| | Process chains | 40 | |
| | Good practice examples and innovation radar | 41 | |
| | Films of the VDI ZRE | 41 | |

| Step | Method/Accessories | Page | |
|---------------------------------------|---|------|--|
| 3 Evaluation I 3.1 Technical-economic | | | |
| Methods | Technical-economic evaluation according to VDI 2225 Part 3 | | |
| | Consideration of life cycle costs | 46 | |
| Tools | VDI ZRE Cost calculator: Investment calculator | 47 | |
| 3 Evaluation I 3.2 Evalua | ition of resource efficiency | | |
| Methods | Cumulative energy demand according to VDI 4600 | 49 | |
| | Cumulative raw material demand according to VDI 4800 Part 2 | 50 | |
| Tools | VDI ZRE Cost calculator: CED, CRD, GHG calculator | | |
| 4 Implementation | | | |
| Methods | Workshops | 52 | |
| | Action plans | 54 | |
| 5 Control | | | |
| Methods | Key figures | 56 | |
| | Audit | 57 | |

Legend for the symbols in the guide:







Notes on required data

WHY IS RESOURCE EFFICIENCY IMPORTANT FOR BUSINESSES?

Resource efficiency pays off! Give your business a competitive advantage by implementing measures to increase resource efficiency.

In a survey commissioned by the VDI Centre for Resource Efficiency, more than 1,000 decision-makers from businesses in eight manufacturing sectors with 20 to 1,000 employees were asked about resource efficiency. Over 55 percent of respondents said they know business-

es in their industry that have achieved **competitive advantages through resource efficiency**.

They cited very different resource efficiency measures. Most frequently, they stated that they had optimised their manufacturing processes and reduced scrap and production losses by reworking.¹

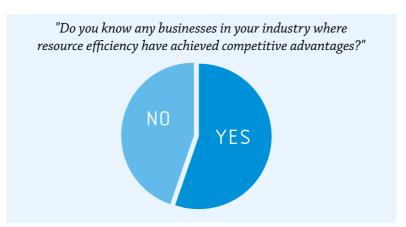


Fig. 1: Competitive advantages through resource efficiency¹

WHAT DOES RESOURCE EFFICIENCY MEAN?

Be aware of what is meant by natural resources and how the term resource efficiency is defined.

According to the directive VDI 4800 Part 1, resource efficiency is defined as the ratio of a benefit to its use of natural resources.²

The benefit can be a specific product or service or described by a function or functional unit. A functional unit serves as a reference value for describing a particular benefit in a solution-neutral way.

For example, the manufacture of 5,000 gears to transmit a torque of 200 Nm could serve as a reference value for the functional unit.

The focus is on the efficient and careful use of natural resources.

Natural resources include renewable and non-renewable primary raw materials, energy, air, water, surface area and soil, biodiversity and ecosystem services. Ecosystem services describe how soil, air and water act as sinks, i.e. absorb emissions and waste. Biodiversity (biological diversity) influences ecosystem services and contributes to maintaining their sink function.²

The natural resources of primary raw materials, energy, water and surface area are predominantly relevant for businesses. Due to its free availability as a raw material, air plays only a subordinate role.

WHAT SHOULD BUSINESSES BEAR IN MIND WHEN IMPLEMENTING?

The acceptance and success of measures to increase resource efficiency strongly depend on the extent to which employees are involved in the business.

Often the employees themselves can provide starting points or even precise ideas on how material and energy can be saved in the business.

In order to identify potential savings, it is also important to take a close look, exchange information with the employees responsible for the process and collect the right information and data.

Transparent communication is necessary in order to achieve the acceptance of all participants. It should not give the impression that individual employees are being checked and their work is being criticised.

Involving employees in the collection and processing of data also helps to create and strengthen their awareness of the efficient use of resources.

A resource efficiency project is best carried out with a small cross-departmental team. It is important that the project team is supported by the business management.

If it becomes clear that the management stands behind the resource efficiency project, it is easier for the project team to also experience acceptance and be encouraged by other employees.³



WHAT INFORMATION AND DATA IS REQUIRED?

Many data do not necessarily lead to great success. Think about what kind of data you need and how detailed you really need the data.

Since data collection or data entry can be very time-consuming and expensive, it makes sense to check whether the required data is already available in the business and, if so, who you can ask. Be aware that not all existing data in your business needs to be accurate. Check regularly whether the data is reliable and correct. The greater the need for information in an analysis, the greater the

effort involved in data collection. It is therefore advisable to estimate in advance the extent of the relevant data.

In order to make the effort plannable, it is particularly important for the manual collection of data to be limited in time. However, one should not be deterred by the effort of data collection. It makes more sense to start an improvement project with an initial estimation and handwritten than to fail due to data collection.

Information on consumption data can be obtained, for example, from invoices for raw materials and consumables purchases or from waste disposal. In order to obtain an unbiased picture of the actual state, however, all inputs and outputs of the relevant materials should be evaluated quantitatively. Since invoices often only contain total consumption, it can be useful to collect more accurate estimation data through discussions with employees or exact data through measurements. This option is particularly recommended in businesses that do not have differentiated production areas or broken down cost centers.

Progress will require staggered multiple data collection. It is therefore important to ensure, from the outset, that data sources are available and reproducible, at least in the medium term.

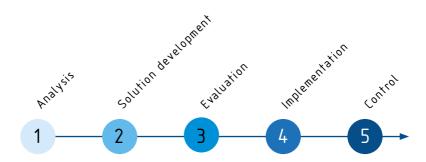
In order to make results comparable, it is important to create a uniform data basis.^{4, 5}

PROCEDURES IN THE IMPLEMENTATION OF OPERATIONAL RESOURCES FEFICIENCY MEASURES

The principle procedure in this guide is subdivided into five superordinate steps and is based on VDI directive 4801 "Resource Efficiency in Small and Medium-Sized Enterprises (SMEs)".

In this guide, the procedure for implementing resource efficiency measures is divided into the five superordinate steps of analysis, solution development, evaluation, implementation and control.³ In the individual implementation steps, a number of methods and tools are presented as examples.

Some of the steps are again subdivided into substeps. For example, in the important step of the analysis, a distinction is made between **rough and detailed analysis** and after analysis of the production and analysis of the life cycle. Steps 1 to 3 may have to be performed iteratively in order to select and subsequently implement a suitable solution.



1 ANALYSIS

The first step is the analysis of the actual situation. Only if you know where and how many resources are consumed in your business and how your products influence resource consumption can you take action for improvement.



Picture: © REDPIXEL/stock.adobe.com

In order to analyse the current situation in the business with regard to resource efficiency, two areas must be considered. On the one hand, what happens during production must be analysed (gate-to-gate), on the other hand, the entire life cycle of a product (cradle-to-grave) must be investigated. In both analyses, a distinction is made between a rough and a detailed analysis.

1.1 ANALYSIS OF PRODUCTION

In the first step of the **rough** analysis, the areas and processes to be considered in production are defined and their material flows examined. For the **detailed** analysis, suitable focal points to

work on are selected and a detailed examination of these areas is carried out. For this purpose, input and output flows are identified and quantified for the respective areas. The rough analysis of the production is usually carried out using the following steps:

- Determination of the areas and processes to be investigated
- 2. Preparation of material flow balances
- Evaluation and subsequent selection of areas on which to focus and work first



SUPPORTING METHODS (ROUGH ANALYSIS)

Input-output analysis

An input-output analysis helps to identify focal points for the implementation of resource efficiency measures. The data collected using this method can also be used for further quantitative analysis and evaluation.

The input-output analysis considers the internal quantity-based material consumption in the plant or in production.

The underlying question is: How efficiently are the purchased materials used in the business? The input-output analysis is based on the idea that the masses of materials and energy are retained during the production process. Raw materials, auxiliary and operating materials and energy become product, by-product, waste and waste heat.

By determining the input and output quantities and the corresponding costs, the value of the resources used can be directly compared with the resulting products and waste streams.

The data should be obtained from all relevant departments, possibly also through employee surveys. Input data can often be determined from accounting. Production statistics or invoices to customers can be used for the product-side output data. Waste data can be taken from the invoices of the disposal businesses or weighing slips. However, care should be taken to ensure that the quantities invoiced correspond

to the quantities accrued. Emission data shall be determined by exhaust gas or waste water analysis, while waste heat can be determined by measurements or efficiency calculations.⁵

It is advisable to present the data of the input-output analysis in tabular form. The comparison of input and output reveals resource efficiency and possible savings potentials of individual raw materials.

| Input | Quantity | Costs | Output | Quantity | Costs |
|-----------------------|----------|-------|--------------|----------|-------|
| Raw material 1 | kg | € | Product 1 | kg | € |
| Raw material 2 | kg | € | | | |
| Raw material 3 | kg | € | | | |
| Excipient 1 | kg | € | | kg | € |
| | kg | € | By-product 1 | | |
| | kg | € | | | |
| Operating material | kg | € | Waste | m3 | € |
| Water | m3 | € | Waste water | m3 | € |
| Energy | kW/h | € | Waste heat | kW/h | € |

Fig. 2: Structure of a table for input-output analysis (following⁵)

ABC analysis

ABC analysis is a **simple**, **qualitative method of analysis** used to differentiate between basic substances, processes, products or emissions and less important or insignificant subjects of investigation. For classification purposes, the issues to be examined are classified into the following three categories, which reflect the issue at hand:

A = very important

B = important

C = unimportant

Category A corresponds to an urgent need for action, while category B represents a medium-term need for action and category C represent that there is no need for action for the time being.

A so-called ABC/XYZ analysis is best presented in a 3x3 matrix.

The A-X field contains the objects with the highest need for action.

This method is often used for value frequency analysis. However, the logic can also be applied to the implementation of resource efficiency measures. The ABC or ABC/XYZ analysis can be per-

formed at the product, process or material level. To this end, the criteria relating to resource efficiency (e.g. material loss or scrap, energy input, recyclability) are defined and sorted into the appropriate categories. As an additional XYZ dimension, for example, the quantity-based consumption can be used.

Due to the rough categorisation and rather subjective evaluation, the results of the ABC analysis can only be compared to a limited extent. The weaknesses of the ABC analysis lie in the sometimes low objectivity of the evaluations. For example, the subjective information provided by this method may not allow for a full comparison of results, even if this tool is regularly used within a business. Nevertheless, the advantage of fast and easy application should not be underestimated. The ABC analysis is therefore well suited for a quick search for processes or organisational structures in need of improvement. The method can also be combined with other analysis methods (e.g. input-output analysis).

| | Х | Y | Z |
|---|----------------------------|---|---|
| A | Subject of investigation 1 | | |
| В | | | |
| С | | | |

Fig. 3: Worksheet for a 3x3 matrix³



SUPPORTING TOOLS (ROUGH ANALYSIS)

Resource checks of the Competence centre for Resource efficiency

The resource checks of the VDI Zentrum Ressourceneffizienz (VDI ZRE) will give you ideas on where there is potential in the business to operate more efficiently.

The resource checks consist of a catalogue of questions on the overriding topics of material efficiency, energy efficiency and employee involvement, which help you to gain an initial overview of potential savings in your business or building. A subsequent detailed evaluation provides measures, tools and methods for implementation. The VDI ZRE website offers several resource checks that are subdivided into various manufacturing processes - from injection moulding and painting to machining - to chemical processes or superordinate subject areas such as production infrastructure.

Especially for engineers or technicians in the field of mechanical engineering, the VDI ZRE offers access to the respective checks on the basis of the classification

of production processes according to the DIN 8580 standard according to casting, forming, cutting, joining and coating.

Many questions already refer to measures, methods or tools that can be used for further solution development or implementation. With the individual check configuration kit you can create a resource check tailored to the production processes. Depending on which manufacturing processes are used in the business, whether material efficiency, energy efficiency or both are to be considered, the check is compiled according to the requirements of the user.





What data is required?

Knowledge of internal processes is required. For special questions from the checklists, the appropriate responsible employees in the business may have to be consulted.



SUPPORTING METHODS (DETAILED ANALYSIS)

Material flow analysis

The material flow analysis is a continuation of the input-output analysis and focuses on the **localisation of the material and energy input** and the locations where **waste**, **waste heat** and **emissions** originate during operation. The path of materials and energy through every production step within the business is tracked.

Target definition and definition of the parameters to be considered

The chosen goal influences the scope of the analysis and the level of detail of the data collection. In order to get an overview, all material flows should first be recorded at the operating limit. The input-output analysis is a suitable method for a rough analysis. The individual positions can then be further prioritised using an ABC analysis.

2. Delimitation of the balance area

If you decide not to define the entire operation as a balance area, but to consider selected process flows, the balance area must be delimited according to the analysis.

3. Definition of the balance sheet period

A balance sheet year is often chosen for the period under consideration, as data from the business balance sheet can be used. The balance period can also be concretised further down to individual production months or product batches.

4. Recording and naming of production steps

The production process should be subdivided into all relevant production steps. Existing process descriptions, plant directories or cost center plans can be used as a basis. Each production step is then assigned to a display element on a task list.

5. Design of the flow diagram with qualitative material flows

The next step is to create a flow diagram. The input and output flows for the recorded production steps are recorded qualitatively in this system.

The flow chart should be created across departments so that a uniform overall view of the business is represented. This prevents individual departments from being viewed in isolation. In addition, a common understanding is created and problems can be named and localised more easily.

6. Quantitative recording of material flows

The input and output flows are quantified in units of mass for each production step of the flow chart shown. Care should be taken to ensure that mass maintenance is achieved, i.e. that mass inflow and outflow are the same for each step.

7. Interpretation and conclusions

When evaluating or interpreting the material flow analysis, particular attention should be paid to conspicuous waste and material losses. It is also advisable to determine the percentage of waste compared to the raw material used. In process steps with an unexpectedly high proportion, there may still be potential for savings.⁵

Material flow cost calculation according to DIN EN ISO 14051

In contrast to conventional cost accounting, material flow cost accounting (MFCA) can be used to determine where costs arise in the business due to material losses. Whereas in conventional cost accounting all costs are allocated to the product, the MFCA distinguishes between costs allocated to the product and those

arising from material losses. Thus the MFCA creates a completely different evaluation of process losses, in which all accumulated expenditures are assigned to the process. It can make a significant contribution to change towards production with the minimum possible loss of material.

Material flow cost calculation (MFCA) according to DIN EN ISO 14051 Material Quantity point Amount of material Cost of materials Energy costs Cost of materials System costs Energy costs Waste management costs System costs Material Final stock at material beginning of stock period Loss of material Cost of materials Energy costs System costs Waste management costs Conventional cost accounting Material Production Output process costs Amount of material Product Total product costs (ma-Cost of materials terial/process costs) Output Waste

Fig. 4: Material flow costing and conventional costing in comparison (following)⁸

Production systems are subdivided into so-called quantity points, which represent one or more parts of a process. Material input and output flows are allocated to the individual quantity points and evaluated in monetary terms.

Costs for energy, waste management and so-called system costs are allocated pro rata for the individual quantity points. Waste management costs are costs incurred for the handling and disposal of waste.

All other costs, such as personnel or room costs, are assigned to system costs.

If the material, energy, and system costs cannot be determined individually, a distribution key is used that is calculated on the basis of the material flows. The distribution key results from the quotient of all material quantities of a quantity point that flow into the product to the material input of a quantity point.⁸

Distribution key =

Material quantity of product

Material input of quantity point

The MFCA can be used to show the amount of material loss costs incurred in the individual production steps (quantity points). This makes it possible to identify areas with particularly conspicuous loss costs and possible starting points for conservation in operational processes.

In order to carry out this comprehensive analysis, information is required from various areas of the business, from the structure and organisation of material and energy flows, from technical process contexts, from quality control, from waste management and from accounting and cost accounting.



SUPPORTING TOOLS (DETAILED ANALYSIS)

Cost calculator of the Competence centre for Resource efficiency - Module: Material flow cost calculator

The cost calculator of the VDI ZRE is an online tool that can be used for quantitative analysis in businesses. The material flow cost calculator module is intended to support businesses in the systematic analysis and quantification of their material and energy costs.9

On the methodical basis of the material flow cost calculation according to DIN EN ISO 14051, occurring loss costs for individual process steps can be calculated and graphically displayed. The application of the tool also reveals the challenge of this detailed analysis, namely the acquisition of data. This usually requires the involvement of several departments. However, this can also be seen as an opportunity, as the various contact persons may provide further starting points for improvements.

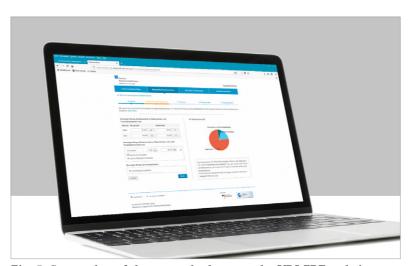


Fig. 5: Screenshot of the cost calculator on the VDI ZRE website



What data is required?

In order to use the tool and obtain a meaningful result, various data and information must be available:

- Composition of the product(s) to be considered according to material types and quantities: This data is frequently found in the parts lists, and the quantity data may have to be verified by measurements.
- Production quantity of the respective product: This is necessary if the analysis is carried out at annual or order level.
- Material and energy demand for the production of the respective product: In addition to materials that are product components, materials and quantities that are not product components (such as operating supplies) are also recorded. Material and energy requirements as well as the corresponding costs can be determined from purchasing or accounting.
- Technical process interrelationships and production
 processes of the production areas under consideration, material quantities used, material losses and rejects for the
 individual quantity points: The processed quantities, material
 loss quantities and scrap rates must either be requested from
 the respective process managers or measured or estimated.
- Process costs assigned to the individual quantity points in the
 cost types energy, waste management and system costs:
 As this cost allocation is not yet available as a rule, costs are to be
 allocated to the quantity units on the basis of rough measurements
 or percentage estimates. The cost items can be determined from
 the existing cost accounting or bookkeeping as far as they exist.

1.2 LIFE CYCLE ANALYSIS

By analysing the life cycle, not only the potential in one's own production can be taken into account, but also that for increasing resource efficiency over the entire life cycle.

The analysis of the products with regard to material composition, resource consumption in the life cycle phase as well as in recycling can represent starting points for the improvement of resource efficiency in the life cycle.

After a rough analysis and the selection of the priority products or life cycle phases, a detailed examination is carried out. This requires data on the various resource consumptions over the entire life cycle.

Detailed analyses are often very complex and time-consuming. A consideration of individual indicators such as the cumulative energy or raw material expenditure can be used for the evaluation Step 3 "Evaluation", p. 42].

The rough analysis of the life cycle is usually carried out on the basis of the following steps, which may be performed iteratively:

- Determination of the products/life cycle phases to be investigated and quantification of the benefits
- 2. Qualitative and quantitative rough analysis
- 3. Evaluation and subsequent selection of the life cycle phases to be optimised first



SUPPORTING METHODS

MET matrix

The MET-Matrix (Material, Energy and Toxic Emissions) is a matrix-based analysis tool and is suitable for the rough analysis of the life cycle phases of a product. In the matrix, material and energy demand as well as toxic emissions in the individual life cycle phases of a product are recorded and evaluated qualitatively and quantitatively.

In this way, high material and energy expenditures in the individual processes can be analysed over the entire life cycle and then possible approaches and measures for increasing resource efficiency in the product life cycle can be identified and prioritised.

In a simple table, the individual life cycle phases are entered in the first column. The other columns contain the associated processes, the materials or material expenditures used, and the energy demand. In a further column, toxic emissions that occur during the life cycle of the individual processes can be recorded.

| Phase of life | Process | Material | Energy | Toxic emission |
|---------------------|---------|----------|--------|----------------|
| Material production | | | | |
| Production | | | | |
| Utilisation | | | | |
| Recycling | | | | |
| Removal | | | | |

Fig. 6: Worksheet for the creation of a MET matrix (following)¹⁰



What data is required?

The MET-Matrix can be created in varying degrees of detail. It can be a simple qualitative evaluation, e.g. via a simple points score, or a more detailed evaluation by entering detailed information. The following data is required:

- Processes, materials and energy required in the production phase as well as toxic emissions can usually be easily determined for the manufacturing phase in the business.
- Data for the other life phases or materials and energy required in upstream processes may require considerable effort to be quantified. For a comparative quantification, indicators for the evaluation, such as cumulative energy demand (CED), can be used if necessary.



2 SOLUTION DEVELOPMENT

On the basis of the preceding analysis, the second step is to design suitable approaches to increasing resource efficiency.

The possible starting points for developing solutions can be divided into three categories: **product-related**, **process-related** and **product- and process-independent**.

Product-related measures

- · Material substitution
- · Lightweight construction
- Recyclability
- · Product Service Systems

Process-related measures

- · Process selection
- · Parameter optimisation
- Process development/ optimisation
- · Waste optimisation

Product/process independent starting points

- Disposition/warehousing
- (Packaging)
- · Transport
- · Cleaning/Cleaning agents
- · Compressed air

Product-related measures

often have the greatest impact on resource efficiency, as product development determines not only the most comprehensive share of costs, but also the majority of resource consumption over the entire life cycle. The increase in resource efficiency can take place in different stages of innovation. In addition to product improvement as the simplest stage, a distinction is made between redesign innovation, concept innovation and system innovation.

Although the effort increases with the respective stages, this can also lead to greater efficiency potential.

Not every business in the manufacturing sector that operates within value creation networks has an influence on product design. For these businesses, process-related solutions for increasing resource efficiency play an important role, especially since they can influence the manufacturing processes within their own plant boundaries themselves.

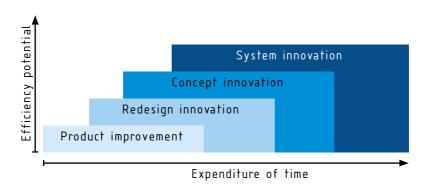


Fig. 7: Innovation stages to increase the resource efficiency of a product (following)¹

Product- and process-independent solution approaches include measures that affect the production infrastructure, such as technical building equipment, on the one hand, and work organizational measures, such as procurement or logistics, on the other.

In order to develop solutions as goal-oriented and imaginative as possible, it is advisable to proceed methodically. Various methodological approaches have been established, particularly for product development.



SUPPORTING METHODS

Construction methodology

Derived from a general process for solving problems, the directive series VDI 2221, VDI 2222 and VDI 2225 formulate the basics of methodical development and design of technical systems and products and present the step-by-step procedure in the development process.

The first step of a product development or product revision is the "clarification of the task".

The requirements for the product are defined. The following development steps - concept, design and elaboration phase - are oriented towards these requirements. The basic procedure described in the directive VDI 2221 - "Methodology for the development and design of technical systems and products" is supplemented by further directives.

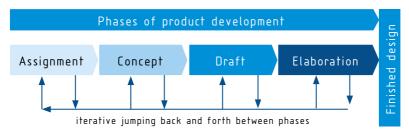


Fig. 9: Product development process according to VDI 2221

These deepen the approach in the individual phases of the product development process. The following VDI directives provide methodological support for the individual phases:

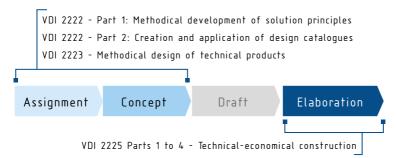


Fig. 8: Relevant VDI directives within the scope of product development

One design methodology based on this approach is **simultaneous engineering**, in which the listed tasks overlap or are performed in parallel. In addition to the possibility of reducing development times and thus costs, simultaneous

engineering promotes interdisciplinary teamwork. To allow resource efficiency aspects to flow into the development process, holistic product and process development must be implemented. The term "holistic" is used because in this model the use of resources over the entire life cycle is taken into account when developing solutions. The development process requires iterative jumping back and forth between phases in order to

control and adjust partial results. In order to assess the economic and ecological impacts of the partial results, an evaluation of the life cycle must be considered at an early stage in the development process.¹¹

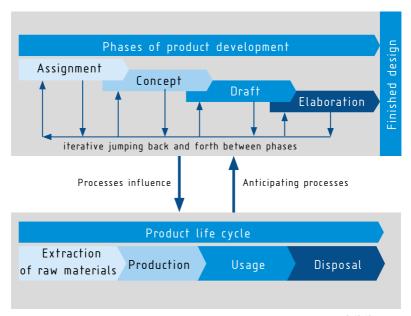


Fig. 10: Simultaneous engineering with holistic evaluation^{2, 12, 13}

Integrate resource efficiency aspects into the product requirements list

The requirements of such a list (or a specification) can in principle be subdivided into requirements and wishes. The development or the product must meet certain requirements.

A distinction can be made between fixed requirements (e.g. exact dimension specifications), minimum, maximum or interval requirements (e.g. adjustment options in certain areas). Requirements can also be expressed (explicit) or unspoken (implicit). Implicit requirements can be those that are self-evident and are therefore not formulated.¹⁴

The requirements can be further differentiated into technical-economic and organisational requirements.

In addition to technical requirements and costs, technical and economic requirements also include legal framework conditions, standards and industrial property rights as well as interfaces.

Interfaces can include the technical environment as well as man, society and the environment.¹⁴

The product developer can orientate himself on directives for creating technical requirements. This can be done, for example, according to the following example.

| Main characteristic | Examples |
|------------------------|---|
| Geometry | Dimensioning, expansion options |
| Kinematics | Movement type, and direction, maximum speed |
| Strengths | Size and direction of occurring forces, weight, stiffness |
| Energy | Efficiency, power consumption, energy losses |
| Material | Properties of input and output materials, excipient, material properties |
| Signal | Signal inputs and outputs, display types, monitoring function |
| Safety and security | Safety technology, regulations |
| Ergonomics | Ergonomic design, operability |
| Manufacturing | Manufacturing processes used, quality requirements (toler-ances), restrictions in manufacturing |
| Assembly | Regulations for assembly and installation, construction site assembly |
| Transport | Transport routes due to dimensioning, hoist restrictions, shipping requirements |
| Usage | Noise emissions, special requirements of the place of use, occurring wear |
| Maintenance | Maintenance and repair requirements, necessary mainte- nance measures |

Fig. 11: Directive for main features of a requirements list^{13, 14}

After the collection and structuring of design requirements, the documentation should be formal. In the requirements list, the individual requirements should be noted with designation, specifications and characteristic as well as assignment of responsibilities and date. Since the requirements list is passed on in the work steps of the development process,

it is used for the documentation of requirement changes, additions and adjustments.¹² If a product development focuses on resource efficiency aspects, these have to be taken into account when creating the list.

The following requirements are examples of how resource efficiency can be taken into account in product development:¹¹

Examples of possible requirements that include resource efficiency aspects:

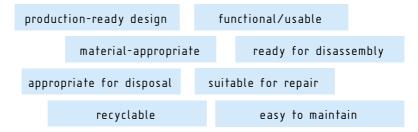
- The planned loss in production should be less than 10% of the material input.
- The product is modular in its essential components.
 Individual modules are interchangeable.
- 30% of the materials used are secondary raw materials.
- Motors with energy efficiency level IE3 or IE4 are used for the electric motors of the main drives.
- The product meets an award criteria (e.g. in Germany "Blauer Engel").
- Condition monitoring is integrated in order to implement predictive maintenance.

Resource-friendly design requirements

Product developments can address different design requirements. These are summarised under the term "Design for X". Some focus on resource efficiency in product design.

The individual design requirements can be addressed by different product-related strategies and measures.

The following resource efficiency aspects can be demanded of the product to be developed: 11

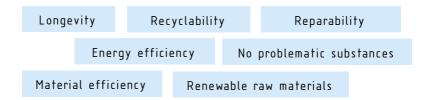


Principles of Ecodesign

The resource efficiency of a product can also be achieved through eco-design approaches. Ecodesign is a systematic approach to the design of envi-

ronmentally friendly products.

The goal is to reduce the environmental impact of the product over its entire life cycle. ¹⁶ The principles of eco-design include: ¹⁷



Brainstorming - creative search for solutions

Brainstorming in a small group of five to eight people is a wellknown and common method for finding creative ideas. This method aims to generate a **multitude of ideas** in a short period of time.

An essential aspect of this is that **no criticism or direct evaluation of** the proposals is expressed. The evaluation and exclusion of ideas will take place in a separate session. A moderator presents the problem and visualises the ideas that have emerged. The goal is to combine ideas and think ahead through the different associations of the participants.

In order to receive as wide a range of proposals as possible, participants should come from different business sectors and have different expertise.¹⁴

Morphological box - systematic search for solutions

The Morphological box is a method for systematic solution finding. The approach of this method is to structure subfunctions or partial problems and partial solutions (PS) and to obtain different total solution approaches by **combining different partial solutions**.

A Morphological box can be applied at different levels of concretisation.

Physical effects, concrete solution drafts or concrete components can be used as partial solutions and combined with each other.

In addition, Morphological boxes can also be nested, i.e. the partial solution of one Morphological box can be derived from another.¹⁴

| Partial solution | PS1 | PS2 | | PS3 |
|------------------|-----------------------|--------------|---|------------------|
| Absorb dirt | Suction | Brush | | Electrostatics |
| Provide energy | Rechargeable S | Air pressure | | Flywheel |
| Transfer energy | Fan wheel | Brush | | Cohesion |
| Provide space | Case | Bag | | Vacuum cartridge |
| | | | 7 | |

Fig. 12: A Morphological box using the example of the development of a table vacuum cleaner¹⁵

TRIZ method for solving problems

The term TRIZ goes back to the acronym of the Russian term for "theory of inventive problem solving" and was developed by engineer and scientist Genrich Saulowitch Altschuller.

On the basis of systematic patent analyses, he found principles for the development of innovations and derived from them a methodology that "provides developers with a concentrate of experience and knowledge with user directives for systematic innovation^{*18}. Different methods and tools support the developer in the problem solving process.

Directive VDI 4521 Part 1 defines the principles and terms of the TRIZ method. The directive VDI 4521 Part 2 describes corresponding tools and methods.



ECODESIGN Pilot

The online tool ECODESIGN
Pilot of the Institute of Design
Sciences of the Vienna University
of Technology supports product developers and designers
in integrating environmentally
oriented product improvements
into the development process.
Depending on the phase of life
with the greatest environmental
impact, the tool recommends

appropriate ecodesign measures. The tool offers access to appropriate measures depending on whether a product is raw material-, manufacturing-, transport-, use- or disposal-intensive or has an assistant who recommends measures depending on the product composition and the required resources in the life cycle phases.¹⁹

Strategies and measures of the Competence centre for Resource efficiency



Picture: © Gecko Studio/stock.adobe.com

The online tool of the VDI ZRE provides systematic access to the solution development of resource efficiency strategies and measures. Based on the directive VDI 4800 Part 1, various strategies are presented that contribute to

increasing resource efficiency.²⁰ In addition to explanations of strategies and measures themselves, corresponding examples are presented in which the implementation of the measures in practice is shown.

Process-related strategies and measures focus on increasing resource efficiency in the actual manufacturing process itself. For example, resource savings can be achieved through the selection of manufacturing processes or the efficient dimensioning of production resources.

In contrast to process- and product-related measures, process- and product-independent measures affect the production infrastructure or organisational measures.

Process Chains of the Competence centre for Resource efficiency



Picture: © Milkos/panthermedia.net

The process chains of the VDI ZRE compile compactly relevant information for resource efficiency in specific production processes of forming,

cutting, joining and coating.
In addition, various process-oriented process chains in chemical process engineering and higher-level process chains such as production infrastructure or selected industries are dealt with.

In this tool, efficient techniques, examples of good practice and research projects are prepared for individual process steps in the respective areas.

Good Practice Examples and Innovation Radar of the Competence centre for Resource efficiency



Picture: © Vladru/panthermedia.net

The examples of good practice²¹ and the innovation radar²² on the

VDI ZRE website offer a comprehensive collection of proven technologies as well as the latest developments for improving resource efficiency and serve as inspiration for the development of solutions in one's own business. Both tools offer filter options for different technology areas (e.g. plastics, metal or surface technology) and life cycle phases.

Films of the Competence centre for Resource efficiency



Picture: @ AndreyPopov/panthermedia.net

On the YouTube channel of the VDI ZRE you will find examples of good practice from businesses that have already implemented technologies and measures. They give ideas and impulses on how you can increase resource efficiency in your business.²³



Picture: © Coloures-Pic/stock.adobe.com

3 EVALUATION

In order to implement a suitable measure, different solution approaches must be evaluated according to their technical feasibility, economic efficiency and influence on resource efficiency.

When selecting optimisation measures, the evaluation of the technical and economic feasibility on the one hand and the increase in resource efficiency to be achieved on the other contribute to the decision-making process. Depending on the measure, a comprehensive evaluation can become very complex, so that simplified evaluation methods can also be applied.

3.1 TECHNICAL-ECONOMIC

The basic prerequisite for a measure to be implemented is **technical feasibility**. However, how the technical implementation takes place in detail can vary greatly.

For the technical evaluation of a solution, it is advisable to define wishes and technical properties in addition to fixed requirements and minimum requirements. By a point evaluation different solution variants can be evaluated. An ideal solution can serve as a reference.

In addition to the technical evaluation, the **economic evaluation** is decisive for the selection of variants. For products, the cost of goods manufactured can be used as a basic criterion.

When making investment decisions for process improvements, the implementation costs are to be considered accordingly. However, not only the pure

acquisition costs should be taken into account, but also the total life cycle costs, i.e. the costs incurred during both the use and recycling phases of the investments.



SUPPORTING METHODS

Technical-economic evaluation according to VDI 2225 Part 3

The method of technical-economic evaluation serves to support complex development processes. It is assumed that there are several solutions for each problem, but that these can be implemented differently due to different requirements.

The technical-economic evaluation takes place only after the elaboration of possible solutions and can compare these both technically and economically with each other.

The development requirements are initially divided into three categories: Fixed requirements, minimum requirements and wishes. All requirements and wishes should be formulated in a target-oriented way, such as low

noise instead of high noise level. Fixed claims are subsequently removed from the evaluation, since they must be fulfilled in any case, i.e. they are not negotiable.

The next step is to apply a point score to the different feasible options in order to make different requirements comparable. It is recommended to use a scale from 0 to 5 points: 0 points for unsatisfactory and 5 points for very good and ideal characteristic fulfillments. The reference value for the ratings should be an ideal solution, i.e. a product that fully meets all the evaluation criteria. The points system expresses how close the respective solution approach is to the ideal.

In order to be able to compare the developed solutions with the ideal solution, a size X can be introduced. This size is also called technical value. It shall be calculated as follows:

$$x = \frac{p_1 + p_2 + p_3 + \dots p_X}{n * p_{max}} = \frac{p_{am}}{p_{max}}$$

n is the number of evaluated solutions, \mathbf{p}_{max} the technical value of the ideal solution, i.e. normally 5 or the maximum value of the evaluation scale. \mathbf{p}_1 , \mathbf{p}_2 ... \mathbf{p}_x are to be replaced by the respective evaluations of the solutions. They result in \mathbf{p}_{am} , which outputs the arithmetic mean of the evaluated solutions. The technical value of the ideal solution is $\mathbf{X} = \mathbf{X}\mathbf{i} = \mathbf{1}$.

The aim is to achieve the highest possible technical value. In practice, a value of 0.8 already proves to be extremely high, while values below 0.6 are considered unsatisfactory.

In addition to the technical features, there may be other overriding objectives, such as minimum weight or special ergonomics. These goals should be shown separately in the evaluation list or included in the evaluation on a particularly weighted basis.

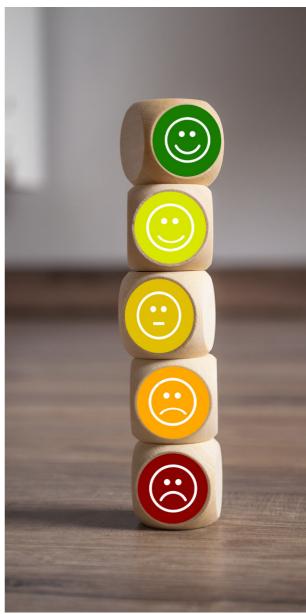
Since in businesses the technical aspect goes hand in hand with the economic efficiency, there is an analogous evaluation scheme for this as for the technical value. Almost exclusively production costs are taken into account. Conservation resulting from increased productivity should

be included in the technical evaluation as far as possible. For the economic evaluation, the costs are chosen as the sole yardstick.

For orientation, a size Y can be assumed, which represents the ratio of the respective manufacturing costs of the variants to the ideal manufacturing costs.

$$y = \frac{H_i}{H} = \frac{0.7 \, H_{per}}{H}$$

The ideal production costs can be estimated at 70 percent of the permissible manufacturing costs, which can be derived from market studies. In order to assess the technical and economic value in summary, these can be presented in a so-called s-diagram.²⁴



Picture: © floor-fotodesign/panthermedia.net

Consideration of life cycle costs

In the case of new investments, only the acquisition costs are often taken into account in operational practice. However, for investments in resource-efficient plants and processes, the **costs** over the entire life cycle are decisive for an economic evaluation.

Although the purchase costs of efficient plants can be higher, these additional costs pay off through the reduced use of materials and energy during the useful life. Life cycle costs (LCC) include all costs incurred by a system during its entire service life.

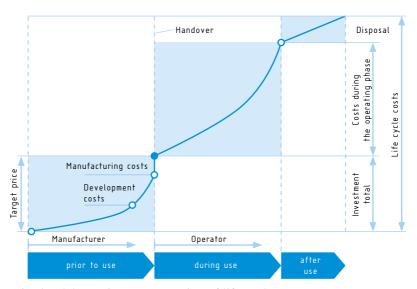


Fig. 13: Schematic representation of life cycle costs (own representation) 25



Cost calculator of the Competence center for Resource efficiency - Module: Investment calculator

The cost calculator of VDI Zentrum Ressourceneffizienz (VDI ZRE) contains an investment calculator for the economic evaluation. This enables businesses to compare different investment alternatives and to calculate payback periods and the net present value of the investments.

Often only the acquisition costs are taken into account in investment decisions. Especially in the case of plants that are in operation for several years or even continuously, it is advisable under certain circumstances to make a higher initial investment and still save costs over the duration of use, since a lower material or energy input is necessary for operation. Lower maintenance costs may also be incurred.

With the investment calculator not only the investment costs, but also the life cycle costs can be taken into account, i.e. costs incurred during use and for the utilisation phase of the investments. These cost items are based on the VDMA 34160 specification.



What data is required?

In order to evaluate from when the acquisition of a new, resource-efficient asset will be profitable, the cost items of the existing asset must be determined on the one hand, and estimates must be made of the cost items of the investment alternatives on the other. In order to determine these, suppliers can be requested or cost estimates can be made.

3.2 EVALUATION OF RESOURCE FEFICIENCY

A comprehensive evaluation of resource efficiency can be very complex and often requires information on resource consumption over the entire life cycle. The directive VDI 4800 Part 1 provides the methodical framework for the evaluation of resource efficiency and defines the methodical bases and accounting principles.

However, a complete life cycle analysis is not always mandatory for every measure. Sometimes an improvement in one life phase can mean a deterioration in another life phase or the reduction of one resource can result in an increased need for another resource. In order to avoid selective improvements at the expense of the overall optimum, the rele-

vant processes and influencing factors must be investigated.²
Various indicators can be used to evaluate resource efficiency, such as cumulative energy demand (CED), cumulative raw material demand (CRD) or greenhouse gas emissions (GHG).

The methods Cumulative energy demand according to VDI 4600 and Cumulative raw material demand according to VDI 4800 Part 2 can already be used in step 1 for the detailed analysis of the life cycle [Step 1 "Analysis", p. 25]. The greenhouse gas emissions can be determined according to the method of life cycle evaluation according to the standards DIN EN ISO 14040 and 14044.



Cumulative energy demand according to VDI 4600

Cumulative energy demand (CED) is a method or indicator that can be used to evaluate the resource efficiency of products or services, taking into account the life cycle. It is calculated from the sum of all primary energy expenditures over the life cycle phases of a product or service: production, use and disposal.

The CED is composed of the cumulative energy demand and the cumulative non-energy demand (material use). It can also be grouped under cumulative non-renewable and regenerative demand. The non-renewable demand can be divided into a fossil and a nuclear share. The indicator is mostly used for comparative evaluation

based on a functional unit.

The functional unit serves as a comparison unit that makes it possible to quantify the benefit in a solution-neutral way.

For example, the transport of a predefined number of people over a certain distance can be used as a functional unit for comparing transport alternatives.

The result is the energy demand in joules or a common energetic order of magnitude (e.g. megajoules).²⁶

The CED is methodically described in the directive VDI 4600. In the directive VDI 4600 Part 1, examples are compiled which provide the user with assistance in determining the effort.²⁷

Cumulative raw material demand according to VDI 4800 Part 2

A further indicator for evaluation of the resource efficiency is the **cumulative raw material demand (CRD)**. It is calculated from the sum of all raw materials with the exception of water and air, which enter a system, e.g. a product.

The CRD comprises all raw materials and energy raw materials required during the life cycle phases of production, use and disposal. The indicator is expressed in units of weight, e.g. tonnes with reference to a functional unit.

For example, raw materials can be grouped into biotic, metallic and energetic raw materials as well as construction and industrial minerals.

In addition to the raw material input, the criticality of the raw material plays a decisive role in the evaluation. Criticality can be divided into supply risk and vulnerability of businesses to supply bottlenecks. According to the directive VDI 4800 Part 2, a total of 16 criteria are defined, which are assigned to the following three categories.

| | CATEGORY 1 | CATEGORY 2 | CATEGORY 3 |
|----------|--|--|---|
| | Static range | Country concentration of reserves | Business concentration of global production |
| | Coupled production | Country concentration of production | Global demand impulse |
| Criteria | Recycling | Geopolitical risks of world production | Substitutability |
| | Logistical | Regulatory situation | Raw material price |
| | restrictions | of world production | fluctuations |
| | Restrictions due to natural phenomena | / | / |

Fig. 14: Categories and associated supply risk criteria²⁸

The vulnerability of businesses depends on the degree to which they are affected and on the strategic and operational adaptability of the businesses. The degree of concern depends on influencing factors such as the required quantity of a raw material or the purchase value of the respective raw material in the total raw material purchase value. Factors of influence for strategic adjustment possibilities are e.g. substitution possibilities or the existence of a procurement strategy in case of a bottleneck. Influencing factors for operational adjustment options include your own negotiating skills with suppliers or sufficient stocks of the raw material concerned.²⁸ More information on raw materials can be researched at Deutsche Rohstoffagentur DERA der Bundesanstalt für Geowissenschaften und Rohstoffe BGR (German Raw Materials Agency of the Federal Institute for Geosciences and Natural Resources).²⁹



SUPPORTING TOOLS

Cost calculator of the Competence centre for Resource Efficiency - Module: CED, CRD, GHG calculator

In the module CED-, CRD-, GHG-calculator of the VDI ZRE cost calculator businesses get an easy access to this complex method of resource efficiency evaluation. In order to assess one's own production or own products, calculations can be carried out on cumulative energy demand (CED), cumulative raw material demand (CRD) or greenhouse gas emissions (GHG), depending on the quantities of materials and energy used.



What data is required?

The required material types are entered into the computer, differentiated according to components and non components of the product, as well as the quantity-based consumption. Environmental profiles (CED, CRD and Global Warming Potential (GWP)) are already available for some materials and energy sources. These come from the free database "process-oriented basic data for environmental management instruments (ProBas)". Further values for environmental profiles can be added manually.



Picture: © Chalabala/panthermedia.net

4 IMPLEMENTATION

For the implementation of measures, responsibilities must be defined and all affected employees must be involved.

When implementing resource efficiency measures, it is advisable to form a project team with appropriate expertise and clearly communicated responsibilities. In order to implement measures efficiently, not only the goals but also the background of the measures should be clarified. It is also extremely important to actively involve all affected employees.



> SUPPORTING METHODS

Workshops

Workshops serve to deal intensively with a topic in smaller groups. Moderation plays a decisive role in a successful workshop.

The moderator's tasks include the introduction to the topic, the design and control of the course of the conversation and the discussion, the visualisation and the subsequent documentation of the results. In the best case, he or she will be involved in the organisational preparation so that the goal of the workshop can be defined together and a contact person is available for any ambiguities regarding content.³¹

The goal of a workshop can be to involve employees and to promote experiential work and learning, such as was implemented in the funded project "Production-related sustainability competence (ProNaK)".

Participants of the workshops from different disciplines and employment groups should be motivated to develop a reference to the topic of sustainability and resource efficiency and to initiate and implement improvements on the basis of their own experience.

Ideally, three workshops, including intermediate practical phases, are held in which initial ideas can already be implemented. In addition, a workshop will be held with managers to prepare them to support employees in their training and to embed the measures in the existing structures of the business.³²

Quality circles derived from quality management are another example of a workshop format and can also contribute to the implementation of resource efficiency measures.⁶

Action plans

Action plans help to track and document improvement measures and their implementation status.

In order to achieve strategic and operational goals, it is often necessary to formulate individual measures and tackle them consistently. It is crucial not only to establish a timeframe and financial framework for implementation, but also to determine those responsible for implementation who regularly monitor and monitor

the status of implementation. Action plans can be adapted as a form to the requirements of the respective business. The following figure shows an example of an action plan template for the implementation of a measure.³³

It is recommended to use follow-up lists to visualize the implementation status in the affected areas on site in order to communicate to the employees the processing status of individual measures.

| Strategic goal: | Reduction of material use in production by 10% |
|--------------------------------|--|
| Operational goal: | Optimisation of metalworking processes |
| Key figure/ characteristic: | Material input (metals) per produced component |

| | Individual actions | | |
|---------------------|-----------------------|----|--|
| | 1. Waste optimisation | 2 | |
| Resource | Steel | | |
| Savings (material) | kg | kg | |
| Savings (costs) | € | € | |
| Investment cost | € | € | |
| Time frame | | | |
| Responsible person | | | |
| State of fulfilment | | | |

Fig. 15: Template for an action plan (following)³⁴

5 CONTROL

If improvement measures are established in the business, their success should be regularly monitored and controlled



Picture: © AndriyPopov/panthermedia.net

In order to be able to measure and monitor the increase in resource efficiency on a sustainable basis and to continuously improve it, it is advisable to monitor it on the basis of key figures. A regular evaluation of the key figures promotes the regular adjustment and improvement of the operational resource efficiency. This can be done by carrying out internal audits.

A survey of businesses in the manufacturing industry commissioned by VDI ZRE has shown that although businesses record resource-related key figures, for the most part only total consumption. Only rarely are individual production areas continuously monitored and controlled.

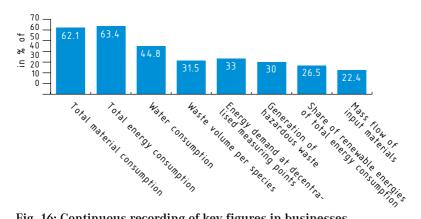


Fig. 16: Continuous recording of key figures in businesses with 50-249 employees (following) 35



> SUPPORTING METHODS

Key figures

So-called **Key Performance Indicators (KPIs)** are used in business administration to evaluate the success, performance or capacity utilisation of a business, individual organisational units or machinery.³⁶

Key figures serve to track implementation and make success visible. Therefore they should be as simple and comprehensible as possible.

In order to ensure the long-term success of resource efficiency measures, resource consumption should be continuously monitored, for example on the basis of resource-related key figures.

Key figures for resource efficiency can be mapped at different levels. For example, location, production, process or plant-related key figures can be formed. In addition, resource efficiency indicators can also be defined

for products.³ As a rule, the key figures take material, energy and water consumption as well as waste generation into account, calculated on the basis of a reference value. The figure on the right shows examples of some resource-related key figures.

The visualisation of key figures is an essential success factor, as it supports the attention and identification of the employees with the key figures. The key figures should be made visible on site and the employees should be aware of the effect of their actions on the key figure.

The visualisation of key figures alone can have a positive effect on employee behavior and thus on resource consumption. The effect is all the greater if the employees not only evaluate the key figures, but also collect and manage them themselves.

| | Example | Unit |
|--------------------|---|--------------------------------|
| Location-based | Annual demand for sheet steel | t/year |
| Production-related | Paint consumption per painted surface area | kg/m2 |
| Process-related | Waste steel sheet in the stamping pro- cess per produced component | kg/component |
| Plant related | Energy demand (standby) Punching line per time unit | kWh/shift (8 hours each) |
| Product-related | Fuel consumption per line | l/100 km |

Fig. 17: Examples of Resource-Related Key Figures

Audit

An audit serves as a control instrument that carries out a target/actual comparison using checklists. A distinction is made between internal and external audits.

During external audits, independent external consultants check whether legal regulations or standard requirements, e.g. for the certification of management systems, are complied with. Internal audits are usually carried out by internal business personnel who are not, however, active in the area to be audited.⁶

Standardised audits exist for certified quality, environmental and sustainability management as well as energy management. The DIN EN ISO 19011 standard contains a directive for auditing management systems. DIN EN 16247 defines the requirements and framework conditions for an energy audit.

INTEGRATION INTO THE CONTIN-UOUS IMPROVEMENT PROCESS

The increase in resource efficiency can also be integrated into existing management systems and can thus become part of the continuous improvement process.

The increase in resource efficiency should not only be seen as a temporary project, but also as part of a continuous improvement process. In particular, if management systems such as

shop floor management, quality, environmental or energy management are already implemented in the business, improvement measures can be integrated to increase resource efficiency.



Picture: © ponsulak/panthermedia.net

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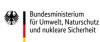
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