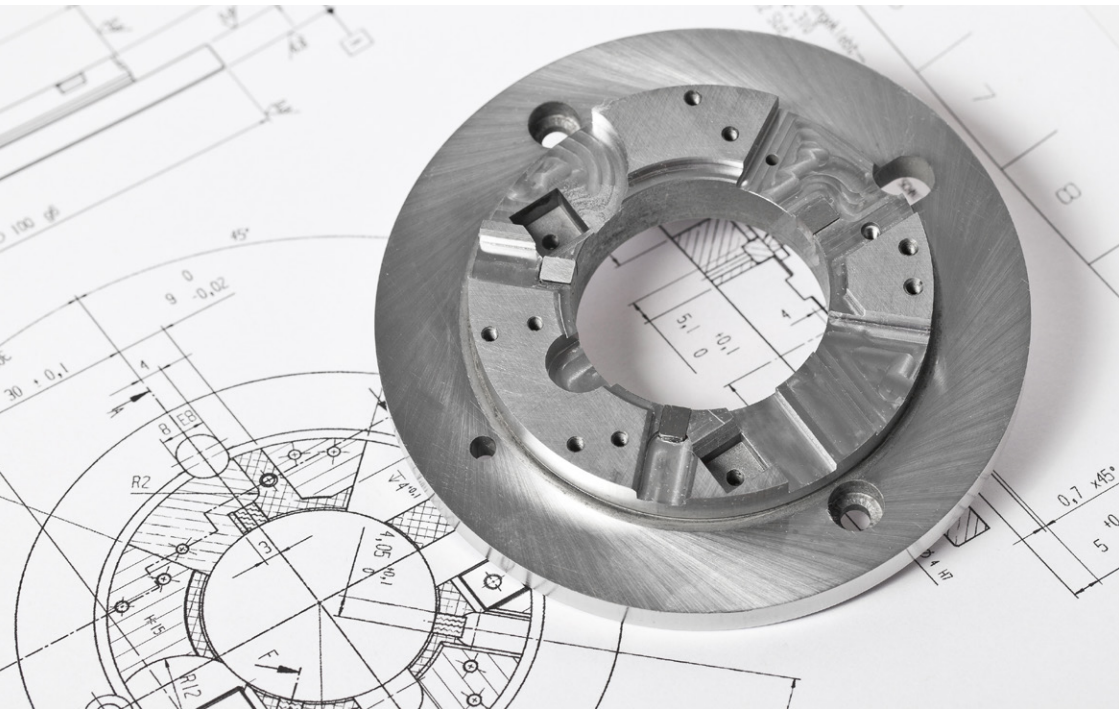


VDI ZRE Publications: Brief analysis No. 20

## Resource efficiency through product development measures



## VDI ZRE Brief analysis No. 20: Resource efficiency through product development measures

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The brief analyses of VDI ZRE provide an overview of current developments related to resource efficiency in research and industrial practice. They each contain a compilation of relevant research results, new technologies and processes as well as examples of good practice. The brief analyses thus provide a broad audience from business, research and administration with an introduction to selected areas of resource efficiency.

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product development measures

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## LIST OF ABBREVIATIONS

|                          |  |
|--------------------------|--|
| <b>ABS</b>               | Acrylonitrile-butadiene-styrene copolymer (thermoplastic terpolymers)                      |
| <b>AGG</b>               | Output variable (in Figure 21)   |
| <b>Al</b>                | Aluminium  |
| <b>BASF</b>              | Baden aniline & soda factory   |
| <b>BMUB</b>              | Federal Ministry for the Environment, Nature Conservation, Construction and Nuclear Safety |
| <b>BMWi</b>              | Federal Ministry of Economics and Energy   |
| <b>CAD</b>               | Computer-Aided Design (German: computer-aided design)                                      |
| <b>CED</b>               | Cumulative energy demand   |
| <b>CO<sub>2</sub></b>    | Carbon dioxide   |
| <b>CO<sub>2-eq</sub></b> | Carbon dioxide equivalent  |
| <b>CRD</b>               | Cumulative raw material demand   |
| <b>DDSA</b>              | Design Decision Support Assistant (method selection tool)                                  |
| <b>DIN</b>               | German Institute for Standardization e.V.  |
| <b>E</b>                 | Disposal   |
| <b>EcoM2</b>             | Ecodesign Maturity Model   |
| <b>EC</b>                | European Community   |
| <b>EGG</b>               | Input variable (in Figure 21)  |
| <b>EN</b>                | European standardization   |
| <b>FMEA</b>              | Failure Mode and Effect Analysis   |
| <b>GaBi</b>              | Holistic accounting (software program)   |

|                   |   |
|-------------------|---|
| <b>GWP</b>        | Global warming potential (greenhouse gas potential)   |
| <b>ISO</b>        | International Organization for Standardization  |
| <b>n. a.</b>      | not specified   |
| <b>SMEs</b>       | Small and medium-sized businesses   |
| <b>LCA</b>        | Life Cycle Evaluation (LCA)   |
| <b>LCC</b>        | Life Cycle Costing  |
| <b>LED</b>        | Light-emitting diode  |
| <b>MET</b>        | Material flow, energy consumption, toxic emissions  |
| <b>MJ-eq</b>      | Megajoule equivalent  |
| <b>N</b>          | Utilisation   |
| <b>n</b>          | Undefined number  |
| <b>P</b>          | Production  |
| <b>PDM</b>        | Product data management (systems)   |
| <b>PLA</b>        | Product line analysis   |
| <b>ProBas</b>     | Process-oriented basic data for environmental management instruments                            |
| <b>ProgRes II</b> | German Resource Efficiency Programme II   |
| <b>PSS</b>        | Product Service System  |
| <b>R</b>          | Raw material extraction   |
| <b>RAL</b>        | Reichs Committee for Delivery Conditions (German Institute for Quality Assurance and Labelling) |
| <b>TRIZ</b>       | Theory of inventive problem solving   |
| <b>UBA</b>        | Federal Environment Agency  |
| <b>IP</b>         | Eco-labels  |

|             |                                       |
|-------------|---------------------------------------|
| <b>VDI</b>  | Association of German Engineers e. V. |
| <b>VDMA</b> | German Engineering Federation e. V.   |

## 1 INTRODUCTION

Product development has a fundamental influence on the resource efficiency of a product. Resource-conscious and forward-looking product development can significantly influence the use of materials and consequently the cost expenditure along the entire product life cycle. With regard to finite resources, it should be a pillar of the strategic orientation of the business.

Product development has to meet a multitude of requirements. This includes<sup>1</sup>

- the use of innovative technologies and materials,
- the consideration of changing and fast-moving markets as well as
- reducing product development time and costs while increasing complexity, quality and functionality.

These requirements are accompanied, for example, by an increased share of electronics and software, a dissipative distribution of materials in the product, increased cost pressure and lower profit margins. This is precisely why it is important to include resource efficiency aspects into the product development process - this conserves resources, reduces costs and at the same time generates competitive advantages.

A resource-oriented objective in product development already determines to what extent a product will be suitable for production, dismantling, repair and maintenance, material or recycling. Resource efficiency measures taken into account in product development, such as adequate joining processes, recyclability or lightweight construction, promote resource-efficient handling of raw materials and influence the costs incurred. The majority of manufacturing costs - sources report up to 85 %<sup>2</sup> - are already defined in product devel-

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<sup>1</sup> Cf. Reinhäckel and Schilling (2007).

<sup>2</sup> Cf. Ehrlenspiel (2007) in VDI 4800 Sheet 1 (2016), p. 34.

opment. The integration of resource efficiency measures can therefore reduce manufacturing costs and, in the case of product take-back by the business at the end of the utilisation phase, disposal costs.

Nevertheless, businesses are often not very sensitized to the need to design their products in a resource-compatible way. A lack of practical experience often results in challenges in the introduction and management of product-related resource efficiency strategies.<sup>3</sup> In most cases, environmental and sustainability aspects are only integrated into the product design via legal requirements, e.g. the Ecodesign Directive 2009/125/EC. The German government's Resource Efficiency Programme II requires that "minimum and information requirements for producers regarding material efficiency, service life and recyclability of products"<sup>4</sup> be incorporated into legislation once the suitability has been established.

This brief analysis is therefore mainly aimed at actors in product development in small and medium-sized businesses (SMEs). It should serve as an aid to action and a source of ideas for incorporating resource efficiency aspects into new product and adaptation developments beyond the legal framework.

For this purpose, the phases of product development are systematized in the brief analysis, a holistic view of the product development process is explained and different innovation levels for improving the resource efficiency of a product are presented. The analysis provides an overview of resource efficiency strategies and concrete measures as well as their integration possibilities into the product development process. Furthermore, life-cycle and process-related methods for evaluating and integrating resource efficiency strategies as well as standards and directives to support the product development process are presented.

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<sup>3</sup> Cf. Pigosso et al. (2013), p. 160.

<sup>4</sup> BMUB (2016), p. 53.

## 2 INTEGRATION OF RESOURCE EFFICIENCY INTO PRODUCT DEVELOPMENT

### 2.1 The classic and the integrated process of product development

Product development is the process from the product idea to the finished product design. The result of the product development process, i.e. the product design, represents an essential factor of the entrepreneurial success and can already determine a large part of the total product costs and qualitative characteristics.<sup>5, 6</sup>

The product development process varies from business to business, with fundamental decisions tending to remain the same.<sup>7</sup> The procedure can also be generalized in its flow. Following the decision to implement a product idea, VDI Directive 2221 divides the further product development process into four phases:

- (1) clarifying and specifying the task,
- (2) the concept phase,
- (3) the design phase and
- (4) the elaboration phase.

These four phases form the framework of this brief analysis. They are further subdivided into seven work steps which, depending on the progress of the process, are run through completely, partially or several times iteratively and lead to a respective work step result.<sup>8</sup> Only a **new design** passes through all product development phases. The concept already exists in the **adaptation design** phase, while changed product requirements are taken into account and implemented in the design phase (Figure 1).<sup>9</sup>

---

<sup>5</sup> Cf. Owner et al. (2014), p. 5.

<sup>6</sup> Cf. Cock and merchant (2002), p. 751.

<sup>7</sup> Cf. Krishnan and Ulrich (2001) in Manner (2007), p. 28.

<sup>8</sup> Cf. VDI 2221 (1993), p. 9.

<sup>9</sup> Cf. Ehrlenspiel and Meerkamm (2013), pp. 748, 744 and 751.

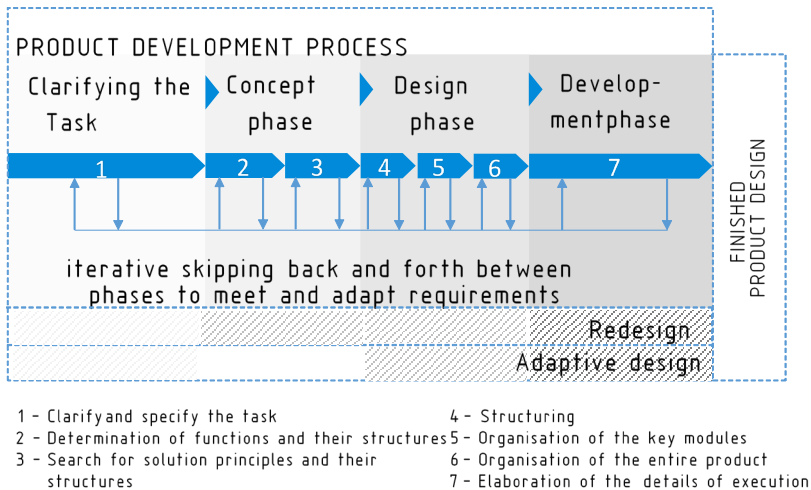


Figure 1: Procedure of the classic product development process<sup>10</sup>

Due to rapid product change, shorter innovation cycles, more complex products and global supply and demand structures, the purely classical approach to product development is no longer sufficient. Rather, a goal-oriented combination of organisational, methodological and technical measures must contribute to ensuring that today's requirements on product innovations are met. This is done through so-called **integrated product development**.

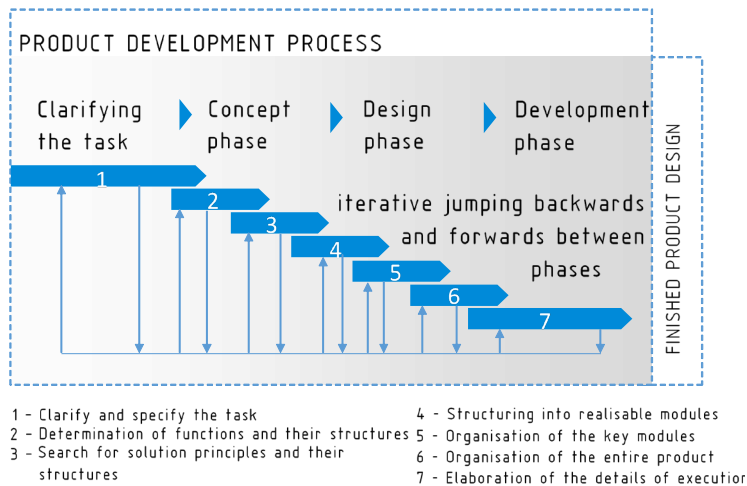
Many products now consist of mechanical, electrical, electronic, hydraulic and/or pneumatic components and offer additional immaterial services such as predictive maintenance. As an intelligent system, this already detects a malfunction in a machine before it occurs.

Such complex product systems require an integrated approach during the development phase in order to successfully meet the challenges of "time, costs and quality" under increasing economic and innovation pressure. If an integrated product development is successfully implemented, e.g. through

<sup>10</sup> According to VDI 2221 (1993), p. 9 and Pahl et al. (2013), p. 17.



simultaneous engineering<sup>11</sup>, a business can benefit from shorter development times at lower costs and improved quality at the same time (Figure 2).<sup>12</sup>



**Figure 2: Approach of the integrated product development process<sup>13</sup>**

There are a variety of approaches and methods that help to promote an integrated process during the product development process. Four essential factors determine the overall success of an integrated product development: People, methodology, organisation and technology.<sup>14</sup> The supporting elements per factor are summarised in Figure 3.

<sup>11</sup> Simultaneous engineering shortens the product development time by processing the individual phases of the product development process (phases 1 - 7 in Figures 2 and 3) in parallel or overlapping time, improving coordination between the project teams of the individual stages and thus optimizing correction loops.

<sup>12</sup> Cf. Ehrlenspiel and Meerkamm (2013), p. 195.

<sup>13</sup> According to VDI 2221 (1993), p. 9 and Ehrlenspiel and Meerkamm (2013), p. 331.

<sup>14</sup> Cf. Ehrlenspiel and Meerkamm (2013), p. 195.

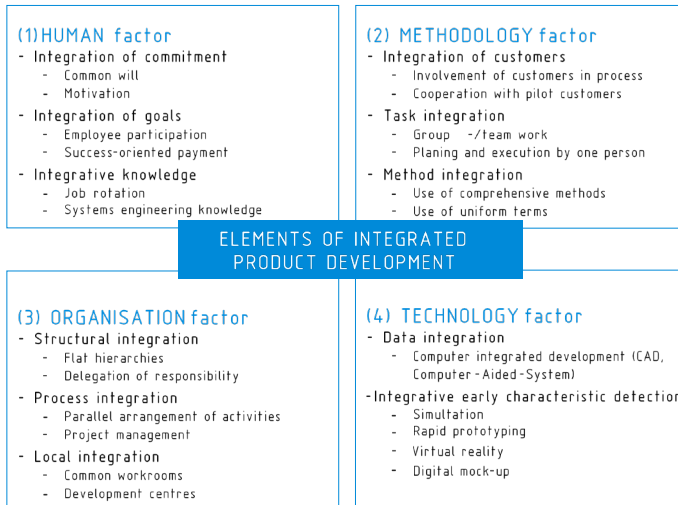


Figure 3 : Elements of integrated product development<sup>15</sup>

In addition to the elements listed in Figure 3, interdisciplinary teams are a key success factor in integrated product development. Team members from different disciplines and process stages provide a comprehensive view of the development of a product. Thus, for example, the perspective of production preparation, disposal, design, sales, materials management or even the supplier can be included.

This cooperation of product, production and sales defining areas along the phases of the product development process (clarification of the task, concept, design and elaboration phase) forms the basis for an integrated product development.<sup>16</sup> Under the assumption that resource efficiency is a business strategy, integrated product development also promotes the cross-cutting consideration of resource efficiency aspects, which are defined differently in the individual teams depending on the specific objective (Chapter 3.2).

<sup>15</sup> Based on Erlenspiel and Meerkamm (2013), p. 209.

<sup>16</sup> Cf. Erlenspiel and Meerkamm (2013), p. 229.

### 2.1.1 Resource Efficiency Aspects in Clarifying the Task

The first step of the product development process, the **clarification of the task**, serves the aggregation of necessary information and results in a requirements list for the product (1)<sup>17</sup>. This list of requirements is passed on along the subsequent work steps and used as documentation of changes, additions and adjustments to requirements.<sup>18</sup>

Depending on the customer's wishes or the product idea, the list of requirements should already include resource efficiency requirements to be considered in the product development process. Thus it can be determined how, for example, a product is to be designed for recycling or assembly or, more specifically, whether, for example, it is to be subject to certification by the "Blue Angel".

Examples of **requirements for** a product in relation to the Resource efficiency:

- The product shall be designed in such a way that the planned loss in production is less than 10 % of the material input.
- The product has a modular structure. The modules are interchangeable.
- 30 % of the materials used are secondary raw materials.
- At least electric motors of energy efficiency level III are used for main drives.
- A service is sold via the product (Product Service System).
- The product meets the requirements of the "Blue Angel".
- The status is monitored (predictive maintenance<sup>19</sup>).
- The condition of e.g. pH value, solution, cooling lubricant is monitored.

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<sup>17</sup> The numbers in brackets correspond to the steps in Figures 1 and 2.

<sup>18</sup> Cf. VDI 2221 (1993), p. 9.

<sup>19</sup> Predictive Maintenance enables a machine to detect an error before it occurs.

### 2.1.2 Resource efficiency aspects in the concept phase

In the **concept phase**, functions are determined according to the list of requirements and solution principles are sought.<sup>20</sup> In a first step, the overall function and subsequent sub-functions of the product to be developed are determined, structured and combined (2). The resulting functional descriptions are, for example, "convey liquid", "distribute air", "supply water" or "offer protection". The functions reveal logical and physical dependencies and form the basis for finding basic solutions to implement these functional structures (3). Chemical, physical and other effects are selected to perform the determined functions. Physical effects include force, pressure, momentum, speed, electric current or magnetic flux.

Depending on the function, the material types to be used are roughly determined (e.g. plastic, metal, wood) and the active surfaces on which the implementation of the selected physical effects is forced are designed.<sup>21</sup> The result is at least one solution in principle which defines the effective structure of the product to be developed as, among others. Schematic sketch, circuit or description.<sup>22</sup> In order to take resource efficiency into account, it is possible, for example, to select mechanisms of action that are already less subject to wear and tear.

At the level of the principle solutions, no fundamental examples with a positive contribution to resource efficiency can be cited without reference to the concrete application case.

### 2.1.3 Resource efficiency aspects in the design phase

In the **design phase**, the basic solution is divided into modules which make the realizable subsystems or system elements visible in the form of arrangement sketches, graphs, logic plans or flowcharts (4). The key modules are then roughly designed to identify and implement optimization options (5). Resource-efficient design is achieved, for example, by reducing component

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<sup>20</sup> Cf. Pahl et al. (2013), p. 341.

<sup>21</sup> Cf. Pahl et al. (2013), p. 341.

<sup>22</sup> Cf. VDI 2221 (1993), p. 10.

sizes or using an integrated construction method. The result is preliminary drafts of the relevant modules. These are finally determined by additional detailed information and the linking of all subsystems, resulting in the overall draft (6).<sup>23</sup>

Examples of the **design phase** of a resource efficiency product:

- Minimize component sizes (miniaturisation)
- insert remanufactured components (remanufacturing<sup>24</sup>)
- Standardising and modularising components and component groups
- Address expandability and upgradeability of the product in design
- Designing connection techniques that are easy to dismantle
- Use secondary raw materials (e.g. recycled plastic granulate)
- choose bio-based materials and alternative materials (e.g. high-strength steels)

#### 2.1.4 Resource efficiency aspects in the elaboration

The **elaboration phase** or the process of designing finally documents the first three process phases in the form of individual, group and overall drawings (7).<sup>25</sup> The product can be manufactured with the prepared design documentation. Numerical methods such as the finite element method (FEM) and suitable simulation software (e.g. Ansys, Matlab Simulink) can be used to check and optimize the actual functionality of both product-specific and manufacturing process parameters.

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<sup>23</sup> Cf. VDI 2221 (1993), p. 11.

<sup>24</sup> Using remanufacturing, old parts are processed by standardized industrial processes in such a way that they correspond in quality to at least one equivalent new part.

<sup>25</sup> Cf. VDI 2221 (1993), p. 11.

Examples of the **development phase** of a product to promote resource efficiency:

- Optimum dimensioning of joints (e.g. exploiting the actual tensile strength of bolts)
- Optimal dimensioning of wall thicknesses (e.g. of plastic parts)
- Simulating the flow behaviour of liquid plastic in the injection mould
- Optimal positioning of the mould sprue for injection moulded parts
- simulate dynamic behaviour of complex systems

## 2.2 Efficient use of resources through a comprehensive consideration of the product life cycle

The development of a product requires continuous control and adaptation of the partial results of the product development process (steps 1 to 7 in Figure 1 and Figure 2). In order to be able to assess the economic and ecological effects and consequences of complex product development processes in their course, an evaluation of the effects over the entire life cycle of the product is elementary.

The evaluation of product development processes requires a holistic approach. Holistic in this context means that the effects and consequences of the product to be developed are to be estimated over the entire life cycle of the product (Figure 4). This enables a business, for example, to record unnecessary environmental pollution, avoidable waste and, in particular, excessive resource consumption already in the product development phase and to prevent them (e.g. via the cumulative raw material demand, CRD). The cumulative energy demand (CED) calculated can also be used to illustrate any overcompensation effects: The energy required to produce a resource-efficient product can be more than compensated for by the energy-efficient use of the product during its utilisation phase.

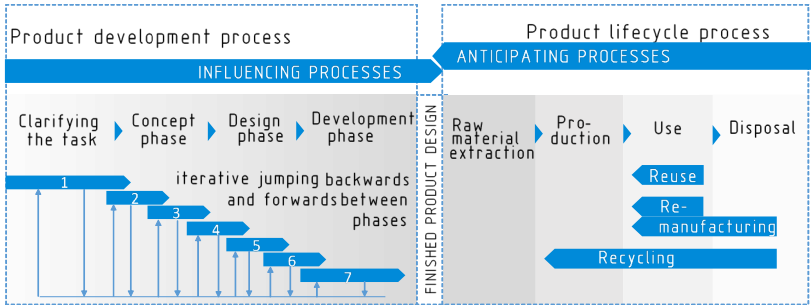


Figure 4: Integrated product development with holistic evaluation<sup>26</sup>

The evaluation over the entire life cycle of the product to be developed not only provides information about the expected environmental impacts and resource consumption, but also about the costs (Life Cycle Costing<sup>27</sup>, LCC). In the manufacturing industry, the material costs for the production of products account for the largest cost block in the business at approx. 43 %.<sup>28</sup> In the product development phase, a major influence on material costs can already be exerted if resource efficiency strategies are observed and a life-cycle evaluation is applied to estimate the ecological and economic consequences of the product to be developed.

However, the scope of influence over product development is limited.

Table 1 shows the characteristics of the life cycle phases that can or cannot be directly influenced by product development.

<sup>26</sup> Following VDI 2221 (1993), p. 9, VDI 4800 sheet 1 (2016), p. 33 and Pahl et al. (2013), p. 17.

<sup>27</sup> Life Cycle Costing is a systematic analysis of the cash flows of a product system along its entire life cycle.

<sup>28</sup> Cf. VDI Center Resource Efficiency GmbH (2017e), p. 12.

Table 1: Scope of influence over product development<sup>29</sup>

| Direct influence of product development through definition:  | No direct influence from product development:   |
|--|---|
| Raw material extraction/production   |   |
| <ul style="list-style-type: none"><li>• The type of materials used (e.g. metals or plastics) and the concrete composition (e.g. alloy and composites)</li><li>• Quantity of material types used (How much material per product use?)</li></ul>                         | <ul style="list-style-type: none"><li>• Raw material, energy and emission efficiency of mining, conversion and further processing of raw materials and primary materials</li><li>• Resource efficiency of transport processes</li></ul>   |
| Utilisation phase  |   |
| <ul style="list-style-type: none"><li>• Type of energy used (e.g. electrical or chemical)</li><li>• specific energy consumption per unit of use</li><li>• Type of emissions produced (e.g. pollutants, dust and noise)</li><li>• absolute energy consumption</li></ul> | <ul style="list-style-type: none"><li>• concrete type and intensity of use (characteristics of user behaviour)</li><li>• Terms and conditions of use (e.g. room temperature, indoor/outdoor temperatures)</li></ul>   |
| Disposal phase   |   |
| <ul style="list-style-type: none"><li>• specific pollutant and impurity contents</li><li>• Degree of separation of the various materials contained and impurities</li><li>• Circulation effort for the different materials</li></ul>                                   | <ul style="list-style-type: none"><li>• Degree of collection and supply to the disposal processes (collection efficiency)</li><li>• Combination and operation of the disposal processes</li><li>• Pollutants/interference substances for the specific type/mode of operation of the disposal processes</li><li>• Raw material, energy and emission efficiency of the recycling processes themselves</li></ul> |

However, a lifecycle-related evaluation can be used to include processes such as raw material extraction, which results from the selected material type, in the evaluation process via assumptions and specifications. It also shows to what extent a selected type of material has an impact on the environment and whether adequate material substitutes, such as more efficient raw material extraction, can even reduce the environmental impact while maintaining the same product quality and costs.

<sup>29</sup> Cf. Jepsen et al. (2014), pp. 10 – 12.



## 2.3 Innovation stages to increase the resource efficiency of a product

The increase in resource efficiency depends on the respective system level. The more comprehensive the system level, the greater the resource efficiency potential. Four different system levels or innovation levels can be distinguished (Figure 5)<sup>30</sup>.

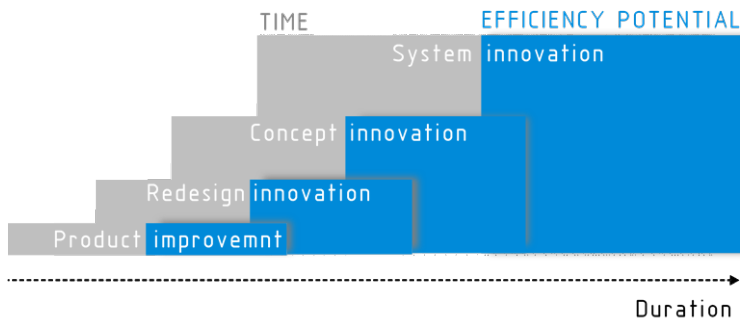


Figure 5: Innovation stages/system levels<sup>31</sup>

The **product improvement** makes modifications to the existing product, such as geometry changes or material substitutions. In this way, small resource efficiency potentials can be tapped in a small time window. Product changes can also result from changes in the manufacturing process, e.g. due to the process changeover to near-net-shape forming.<sup>32</sup> If the product example "automobile" is considered, the substitution of steels by aluminium allows a weight reduction and thus a fuel saving.<sup>33</sup> The work of the VDI ZRE provides, among other things, examples of product improvement. These are

- the use of lightweight construction materials (e.g. high-strength steels, brief analysis "Resource efficiency in lightweight construction"<sup>34</sup>),

<sup>30</sup> Cf. Oberender (2006), p. 19.

<sup>31</sup> According to VDI 4800 sheet 1 (2016), p. 35.

<sup>32</sup> The practical examples for the individual innovation stages also relate to the improvement of the production process, whereby in this case the production equipment represents the product.

<sup>33</sup> Cf. VDI 4800 Sheet 1 (2016), p. 35.

<sup>34</sup> Cf. Kaiser et. al. (2016).

- the surface coating using the lotus effect for better cleaning and care of products (brief analysis "Resource efficiency through bionics"<sup>35</sup>),
- bio-based base oils for use with lubricants (brief analysis "Resource efficiency of bio-based materials in the manufacturing industry"<sup>36</sup>).

In **redesign innovation**, improvement already includes central subsystems of a product. Thus, at least the design of the product is redesigned, adapted, expanded or optimized. Existing production processes must or can be completely replaced by alternative manufacturing processes. The "automobile" example shows that the integration of a hybrid engine instead of a classic combustion engine represents a redesign innovation.<sup>37,38</sup> Other examples related to manufacturing systems are

- the demand-oriented generation of compressed air through the use of electronic ballasts (study "Resource efficiency through industry 4.0"<sup>39</sup>),
- the adaptation of the pressure of an injection moulding machine to the viscosity of the molten plastic granulate for filling into the intended mould (film "Plastics: Less material, more quality"<sup>40</sup>),
- the use of pore burners in furnaces instead of the solution annealing process in furnaces (Film "Stainless steel casting without fire"<sup>41</sup>).

In **concept innovation**, the entire product concept is reworked, renewed and revised, resulting in completely new product structures, subsystems and sub-assemblies. In the case study of the "automobile", the replacement of a

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<sup>35</sup> Cf. Niebaum et al. (2017).

<sup>36</sup> Cf. Saulich (2016).

<sup>37</sup> Cf. VDI 4800 Sheet 1 (2016), p. 35.

<sup>38</sup> The practical examples for the individual innovation stages also relate to the improvement of the production process, whereby in this case the production equipment represents the product.

<sup>39</sup> Cf. Schebek et al. (2017).

<sup>40</sup> Cf. VDI Zentrum Ressourceneffizienz GmbH (2017b).

<sup>41</sup> Cf. VDI Zentrum Ressourceneffizienz GmbH (2017c).

conventional small car with an electric city car describes a concept innovation.<sup>42, 43</sup> Other examples are

- the use of a ceramic matrix to preheat ladles for melting metal instead of preheating them over an open fire (film "Stainless steel casting without fire"<sup>44</sup>) and
- the use of casting processes instead of milling processes in production (film "Fine casting instead of a coarse plane"<sup>45</sup>).

**System innovation** involves a major change in product concepts and their infrastructures. In the case of the "automobile", the creation of a combined, smart transport system in which the individual components (cars, traffic lights, bicycles, etc.) communicate with each other would be an example of system innovation.<sup>46</sup> Other examples are:

- the use of digital systems in the value chain by industry 4.0. Process optimisation right up to the supplier can be achieved, for example, by means of material flow visualisation through real-time data acquisition, in order to reveal further resource efficiency potentials across value-added stages (study "Resource efficiency through industry 4.0"<sup>47</sup>),
- the development of industrial symbioses (economic integration of neighbouring businesses with the goal of cascading the use of residual materials and energy and sharing infrastructure, services and social facilities<sup>48</sup>).

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<sup>42</sup> Cf. VDI 4800 Sheet 1 (2016), p. 35.

<sup>43</sup> The practical examples for the individual innovation stages also relate to the improvement of the production process, whereby in this case the production equipment represents the product.

<sup>44</sup> Cf. VDI Zentrum Ressourceneffizienz GmbH (2017c).

<sup>45</sup> Cf. VDI Zentrum Ressourceneffizienz GmbH (2017d).

<sup>46</sup> Cf. VDI 4800 Sheet 1 (2016), p. 35 f.

<sup>47</sup> Cf. Schebek et al. (2017).

<sup>48</sup> Cf. The Waste and Resources Action Programme (2017).

### 3 RESOURCE EFFICIENCY MEASURES IN THE PRODUCT DEVELOPMENT PROCESS

In product development, it is decided how a product is designed to be maintenance-friendly, recyclable, easy to assemble or repair. Adequate materials are selected, component shapes or modular elements are designed and the use of technology is determined. Resource efficiency is playing an increasingly important role in competitiveness and thus entrepreneurial success.

The selection and definition of product characteristics, especially in the task clarification, concept and design phases, should ideally take resource efficiency aspects into account. For this purpose, actors in product development have various resource efficiency strategies and concrete measures at their disposal (Figure 6, Chapter 3.1 and Chapter 3.2).

Nevertheless, the implementation of such resource efficiency aspects in the product development process has so far lagged behind the possibilities. The reasons for this are<sup>49</sup>

- the lack of systematisation, directives and knowledge sharing of practical experience to introduce resource efficiency aspects,
- the lack of experience in implementing successful pilot projects in established business processes,
- the lack of integration of resource efficiency aspects into business management or strategic business alignment,
- Difficulties in selecting and prioritising resource efficiency measures.

In order to facilitate the integration of resource efficiency aspects for businesses, various applications in the product development process were created to provide assistance.

The Ecodesign Maturity Model (EcoM2), for example, aims to assess the status quo of resource efficiency measures applied in a business. The model can then be used to gradually integrate untapped resource efficiency potentials

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<sup>49</sup> Cf. Pigosso et al. (2013), p. 161.

into product life cycle management and related processes as well as strategic business goals and drivers.<sup>50</sup>

Resource efficiency potentials can be evaluated and tapped using various methods. The product developer has a variety of methods at his disposal for a life cycle evaluation and for a product development-related evaluation (Figure 6, Chapter 3.3). The "Design Decision Support Assistant" (DDSA) tool can support the product developer in selecting the appropriate evaluation method. This comprises 29 methods from which appropriate evaluation methods are selected according to the product developer's defined criteria.<sup>51</sup>

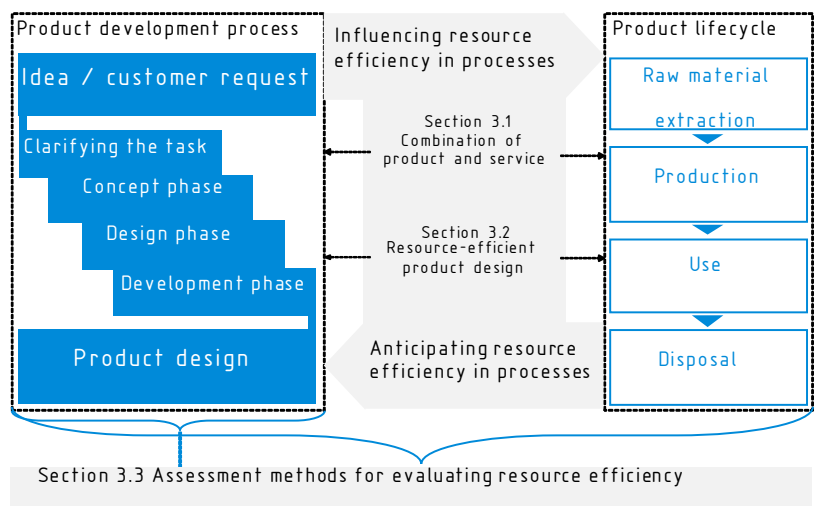


Figure 6: Resource efficiency strategies and evaluation methods<sup>52</sup>

<sup>50</sup> Cf. Pigosso et al. (2017).

<sup>51</sup> Cf. Buchert et al. (2017), p. 403.

<sup>52</sup> Following VDI 2221 (1993), p. 9, VDI 4800 sheet 1 (2016), p. 33 and Pahl et al. (2013), p. 17.

### 3.1 Resource efficiency through the combination of product and service

The Product Service System is a marketable combination of products and services that together are able to meet a user's need.<sup>53</sup>

Three types of Product Service Systems (PSS) can be distinguished depending on the distribution of service and product shares (Figure 7).<sup>54</sup>

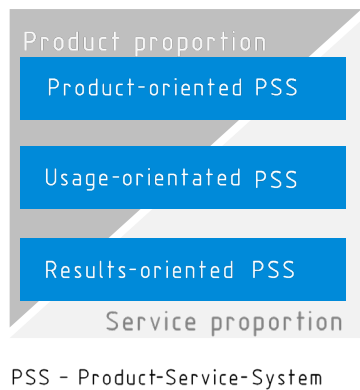


Figure 7: Three categories of product service systems<sup>55</sup>

The **product-oriented product service system** focuses on the product. The manufacturer can offer an additional service to the product, e.g. a consulting service. If, for example, the manufacturer offers product take-back after the end of the utilisation phase, attention should be paid in this case, but also in general, during the product development process to the design of the product in such a way that it is suitable for dismantling, repair or maintenance, recycling and disposal (Chapter 3.2.2, Chapter 3.2.5).<sup>56</sup>

<sup>53</sup> Cf. Goedkoop (1999), p. 18.

<sup>54</sup> Cf. Tukker (2004), p. 248.

<sup>55</sup> According to Tukker (2004), p. 248.

<sup>56</sup> Cf. Gräbke et al.(2010), p. 2036.

With **use-oriented product service systems**, the customer is provided with the use of a product. The manufacturer assumes the warranty for the function, e.g. through maintenance and repair work. Product ownership remains with the manufacturer during the entire utilisation phase, to whom the product is returned at the end of the usage phase. Typical examples of use-oriented product service systems are construction and production machine leasing or rental.<sup>57</sup>

The **result-oriented product service systems** include the category with the highest service share. Contracts with the customer are concluded for a service to be rendered, which includes, for example, the cleaning of a defined surface area. Invoicing is therefore made for each service unit rendered, e.g. in euros per square metre of cleaned surface area. A typical example of this is chemical leasing (blue box). Other examples are the billing per hour flown for engines<sup>58</sup> or a fixed price per cubic meter of compressed air used<sup>59</sup>. In all examples either the chemical, the engine or the compressed air machine is monitored, maintained and taken back by the manufacturer.

#### Example chemical leasing<sup>60</sup>

Chemicals that are not reactive but recoverable can be traded between businesses using the innovative business model of chemical leasing. Instead of the classic quantity-related payment (e.g. €/t), a result-oriented payment is made (e.g. €/m<sup>2</sup> cleaned surface area).

The change in remuneration creates an economic interest for the chemical manufacturer to reduce the consumption of chemical products by the user through process optimisation instead of increasing the quantity-based sale of chemicals (Figure 8).

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<sup>57</sup> Cf. Gräble et al. (2010), p. 2036.

<sup>58</sup> Cf. Rolls-Royce (2012).

<sup>59</sup> Cf. Kaeser Compressors Se (2017).

<sup>60</sup> Cf. Leismann et al. (2012), p. 37 et seqq.

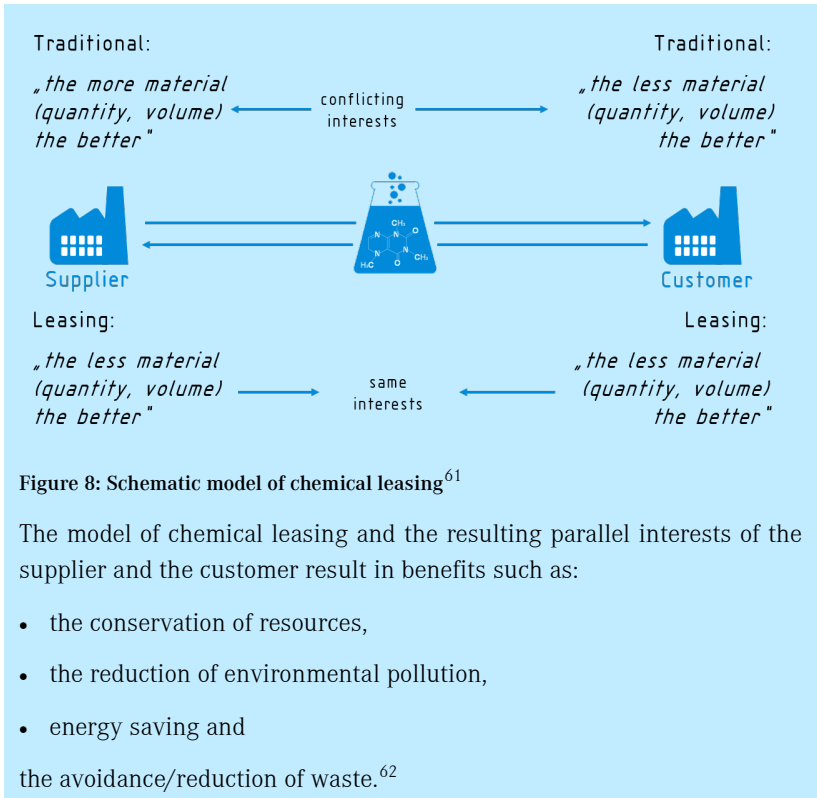


Figure 8: Schematic model of chemical leasing<sup>61</sup>

The model of chemical leasing and the resulting parallel interests of the supplier and the customer result in benefits such as:

- the conservation of resources,
  - the reduction of environmental pollution,
  - energy saving and
- the avoidance/reduction of waste.<sup>62</sup>

Particularly in the case of products which are intended to be used or result-oriented product service systems, care must be taken to ensure that the product design during the product development phase is suitable for dismantling, repair or maintenance and that it is optimised for use, recycling and disposal (Chapter 3.2). In this way, the provider of product service systems improves its economic and ecological balance. Further advantages and disadvantages resulting from product service systems are summarized in Table .

<sup>61</sup> According to Leismann et al. (2012), p. 38.

<sup>62</sup> Cf. Leismann et al. (2012), p. 37 et seqq.



Table 2: Environmental impacts of product service systems<sup>63</sup>

| Positive environmental impacts  | Negative environmental impacts   |
|---|--|
| <ul style="list-style-type: none"><li>• Use of durable products and low-consumption and/or high-performance equipment</li><li>• Consideration of technical-ecological progress</li><li>• Promotion of recycling- and disposal-friendly construction</li></ul> | <ul style="list-style-type: none"><li>• greater consumption-related wear/overuse</li><li>• (too) long use of inefficient equipment</li></ul> |

3.2 Resource-oriented product development and concrete resource efficiency measures

In product development, the design requirements for the product to be developed are defined and implemented. That includes:

- a product design suitable for production,
- a product design suitable for dismantling,
- product design suitable for repair and maintenance,
- a material appropriate product design,
- functional/usable product design or
- a product design that is suitable for recycling and disposal.

These requirements are summarized under the term "Design for X", whereby many requirements also serve the principles of eco-design<sup>64</sup>. The principles of eco-design include:<sup>65</sup>

- the longevity of the product,

<sup>63</sup> Cf. Leismann et al. (2012), p. 20.

<sup>64</sup> Ecodesign is a systematic approach to product design in order to reduce the environmental impact of a product over its entire life cycle by means of an adapted product design (Cf. Federal Environment Agency (2017)).

<sup>65</sup> Cf. ecopoly (2012).

- the reparability of the product,
- the material efficiency of the product,
- the energy efficiency of the product,
- the low level of problematic substances in the product,
- the use of renewable raw materials in the product and
- the recyclability of the product.

The "Design for X" strategies and the principles of eco-design are compared in Figure 9. This shows which strategies and ecodesign principles can be linked.

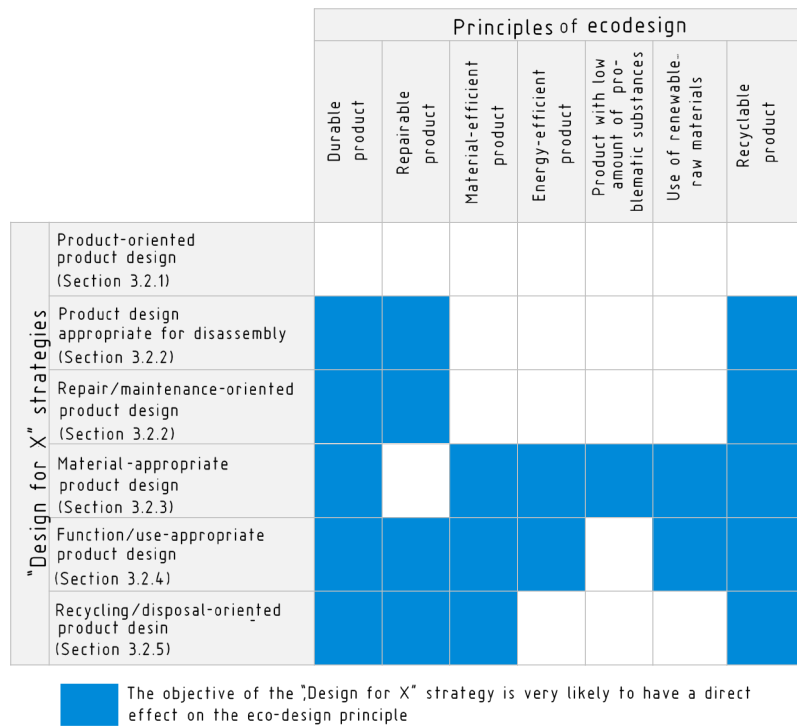


Figure 9: Linking design for X strategies and ecodesign principles (derivation in appendix)

For example, a product design that is suitable for dismantling is highly likely to facilitate the circulation of the product, as it can be more easily broken down into its components, e.g. for further component reuse or recycling.

The design for X strategy listed in Figure 9 can be extended or further detailed and are therefore not to be understood as conclusive. Some strategies may exclude others or create a conflict of objectives. A product design suitable for production does not necessarily have to correspond to a product design suitable for use or recycling. In the opposite case, however, synergies also arise. A product design suitable for dismantling is often accompanied by a product design suitable for repair or maintenance.

### 3.2.1 Production-oriented product design

Production-oriented product design is aimed at reducing the amount of work involved in the production process. Components and component groups to be assembled can, for example, be reduced using an integrated construction method (combining several components in one).<sup>66</sup> This results in reduced waste generation (rejects) and material and energy savings in the process. However,<sup>67</sup> it is also possible, for example, to divide complex components into component parts that are easy to produce, while taking into account a possible increase in assembly effort.

Further resource efficiency strategies for the implementation of a **production-oriented product design** are<sup>68, 69</sup>

- the optimization or reduction of the number of surfaces and the surface area size of the product,
- the reduction of manufacturing steps and in-house production, for example through a considered purchase of components, such as remanufactured components,

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<sup>66</sup> Cf. Kalweit et al. (2012), p. 600 et seqq.

<sup>67</sup> Cf. VDI 4800 Sheet 1 (2016), p. 42.

<sup>68</sup> Cf. Kalweit et al. (2012), p. 600 et seqq.

<sup>69</sup> Cf. VDI 4800 Sheet 1 (2016), p. 42.

- the reduction of the machining volume and the reduction of tool wear and the occupancy times of operating resources through intelligent designs or constructions of the product, for example near-net-shape prototyping or forming,
- the optimisation of production by standardising the manufacturing process: standardised series, use of uniform tools and increase in batch sizes (multiple use, use of series or kits).

### 3.2.2 Dismantling and repair-oriented product design

The product design for dismantling is designed to simplify the dismantling process as much as possible. At the same time, this benefits the repair, maintenance and service friendliness of a product as well as its recyclability and thus its service life and recyclability. In practice, for example, an integrated design, i.e. the reduction of the number of components, as well as adapted joining processes (including Click mechanisms instead of adhesive joints, additive manufacturing) lead to easier dismantling. Particularly for products manufactured as so-called product service systems (Chapter 3.1), optimised servicing, maintenance and reparability must be ensured.

Resource efficiency strategies for the implementation of a **product design suitable for dismantling** are among others:<sup>70</sup>

- the tracking of a simply structured building structure with the same dismantling and joining directions,
- the arrangement of fasteners or disassembly connections so that they are easy to find and accessible,
- the choice of connection elements or dismantling connections in an easily detachable design,
- the reduction of fine motor work during removal or positioning, the design of user-friendly gripping and moving spaces,

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<sup>70</sup> Cf. ECODESIGN Pilot (2017a).

- ensuring the functionality of the connecting elements or disassembly connections along the entire life cycle, e.g. by means of protective devices,
- the guarantee of reversible assembly processes and
- the reduction of the dismantling time and the dismantling ways by e.g. established, simple and/or standardised assembly techniques.

Resource efficiency strategies for the implementation of **repair-oriented product design** include:<sup>71, 72</sup>

- following a simple building structure for easy cleaning and the use of dirt-repellent surfaces,
- steering the inevitable wear on components that are easily replaceable or repairable,
- the choice of a simple wear detection to avoid loss of reserves in case of too early maintenance and consequential damage in case of too late maintenance,
- making the product user aware of upcoming service units of the product by means of information such as signal lamps and
- the design of fasteners and sub-assemblies for standardized tools to avoid the use of special tools for maintenance/repair.

### 3.2.3 Material-specific product design

An important lever for the implementation of material efficiency in production, use and disposal is the material-compatible product design. In product development, it can be specified that the amount of material to be used must be kept to a minimum, that the weight of the product must be reduced and/or the environmental impact caused by the materials used must be minimised (for example, certification with the "Blue Angel" as a product requirement). For this purpose, the number of components can be reduced or an adequate

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<sup>71</sup> Cf. Kalweit et al. (2012), p. 600.

<sup>72</sup> Cf. ECODESIGN Pilot (2017b).

selection of materials (e.g. Secondary raw materials, bio-based raw materials, lightweight construction).

Other resource efficiency strategies that promote **material appropriate product design** are:<sup>73, 74</sup>

- the optimization of component size, number and design (e.g. wall thickness and component design),
- the processing of materials with a good environmental or life cycle evaluation (application of indicators such as cumulative raw material demand (CRD) or cumulative energy demand (CED), Chapter 3.3),
- the avoidance and reduction of problematic, hazardous and toxic materials and components,
- the use of materials made from renewable raw materials (provided that no more raw material is needed than can grow again in the same period, that cultivation is environmentally compatible and that there is no competition for land use with food production<sup>75</sup>),
- the use of secondary raw materials and recyclable raw materials to promote recycling,
- the application of wear protection, corrosion protection and hard material coatings,
- the avoidance of inseparable material composites or of components and sub-assemblies made of one material each (single-material parts),
- the avoidance of raw materials and components that require environmentally hazardous and/or socially problematic raw material extraction.

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<sup>73</sup> Cf. Kalweit et al. (2012), p. 600.

<sup>74</sup> Cf. ECODESIGN Pilot (2017c).

<sup>75</sup> Cf. VDI 4800 Sheet 1, p. 22.

### 3.2.4 Function- and use-oriented product design

The most resource-intensive phase of life is the utilisation phase, especially for energy-consuming products. The behaviour of the user can be positively controlled by constructive measures or an incorrect use can be avoided by indicative measures.<sup>76</sup>

Resource efficiency strategies that support **functional product design** include:<sup>77</sup>

- ensuring high product reliability, e.g. through design measures such as protective systems to protect against overloads,
- ensuring high product quality by, among other things, reducing disturbance variables,
- the calculation or facilitation of further technological developments through the upgradability of the product,
- allow the product to be readjusted or adjusted to compensate for wear in the product,
- the striving for a product design that is as robust as possible with a simple functional structure at the same time.

Resource efficiency strategies that support **product design that is appropriate for use**:<sup>78</sup>

- the prevention of product misuse that has a detrimental effect on the environment,
- the display of the current energy or resource consumption of the product during use,
- the reduction of energy requirement during use by improving efficiency,

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<sup>76</sup> Cf. VDI 4800 Sheet 1 (2016), p. 23.

<sup>77</sup> Cf. ECODESIGN Pilot (2017d).

<sup>78</sup> Cf. ECODESIGN Pilot (2017e).

- the avoidance of waste during use, also through the use of recyclable auxiliary and operating materials,
- the coordination of the service lives of the components used and the use of a timeless design and
- the design of usable surfaces.

### 3.2.5 Product design for recycling and disposal

The adaptation of the product design to potential recycling processes supports the recyclability of materials and protects primary raw materials through the use of secondary raw materials. In particular, the easy separability of the processed materials and the absence of material composites promote recyclability.<sup>79</sup>

In addition to resource efficiency strategies, resource efficiency strategies to promote **product design that is suitable for recycling and disposal** also include product design that is suitable for dismantling, repair and materials:<sup>80</sup>

- ensuring that recyclable materials are easy to remove and separate,
- ensuring that materials used are eligible for recycling,
- the use of recyclable surface coatings,
- ensuring that fuels and pollutants are easy to remove,
- the calculation of the type of collection and the point of generation of the waste,
- information about the type of disposal of the product on the product itself,
- compliance with the marking of all materials used in accordance with standards (if standards and directives are available) and

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<sup>79</sup> Cf. Kalweit et al. (2012), p. 607.

<sup>80</sup> Cf. ECODESIGN Pilot (2017f).



- the calculation of possibilities for the reuse of entire sub-assemblies (re-manufacturing).

### 3.2.6 Practical examples

#### (1) Resource-efficient design of LED lamps

Seidel GmbH has developed LED lamps that consist of only seven components and can be assembled using plug connectors. The use of glue and tin for soldered joints was saved. Instead of cast aluminium bodies, an aluminium sheet was used for cooling the LEDs, which reduced the amount of material used by half.

Through further resource efficiency measures, it was possible to reduce the total cost of raw materials by 90 % and energy demand by 50 % compared with conventional LEDs. As a result, the LED lamps were able to meet the strict criteria of the "Blue Angel" (RAL-UZ 151) and are certified with its seal.

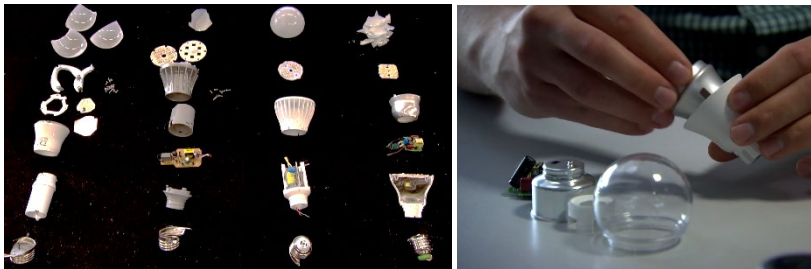


Figure 10: Comparison of LED lamp design (left: four conventional LED lamps; right: Seidel GmbH LED lamp)<sup>81</sup>

#### (2) Resource-efficient textiles

The textiles of Climatex AG meet the ecodesign criteria of longevity, recyclability and the use of renewable raw materials. They regulate temperature and

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<sup>81</sup> Cf. VDI Zentrum Ressourceneffizienz GmbH (2017).

humidity, i.e. they can insulate both cold and heat. Other properties include flame retardancy and tear resistance.<sup>82</sup>

A joining technology that interlocks natural fibres and synthetic fibres enables the materials to be separated according to type after the utilisation phase, so that the textiles are completely recyclable. By fulfilling the ecodesign criteria, the business's textile products are certified with the Cradle to<sup>83</sup>Cradle mark.

### (3) Resource-efficient automotive lacquer

The technical properties of BASF's automotive paint enable it to reflect the infrared radiation of sunlight. The temperature of the body can be reduced by 20°C and that of the interior by 4°C. This optimization reduces the air conditioning of vehicles, reduces the fuel consumption of conventional cars and extends the range of electric cars by reducing energy consumption.<sup>84</sup>

### (4) Resource-efficient partition wall

Airbus has developed partition walls for aircraft that are 45 % lighter than comparable products. By additive production of the partition wall and the development of a lightweight alloy material, weight, fuel and consequently CO<sub>2</sub>-Emissions per aircraft can be reduced by ten tons per year. The partition walls are of modular design and can also be installed in existing aircraft. In addition, the material used is completely recyclable.<sup>85</sup>

### (5) Resource-efficient demolition hammer

The demolition hammer developed by Hilti AG is characterised by its repair-friendly design. Wear parts can thus also be changed by the operator. After

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<sup>82</sup> Cf. Federal Prize Codesign (2016), p. 14.

<sup>83</sup> Products that receive the Cradle to Cradle certificate use environmentally safe, healthy and recyclable materials, solar energy or other forms of regenerative energy and a responsible use of water (Cf. Type of brown (2017)).

<sup>84</sup> Cf. Federal Prize Codesign (2016), p. 22.

<sup>85</sup> Cf. Federal Prize Code Design (2016), p. 30.

the utilisation phase, the user can return the device to Hilti AG, where the tool is sent for adequate recycling.<sup>86</sup>

3.3 Methods and tools for the evaluation of resource efficiency

Product development has a decisive influence on the life cycle of a product. The resulting consequences can and should be assessed through a holistic evaluation. A large number of complex and less complex methods and tools exist for this purpose (Figure 11, Chapter 3.3.1).

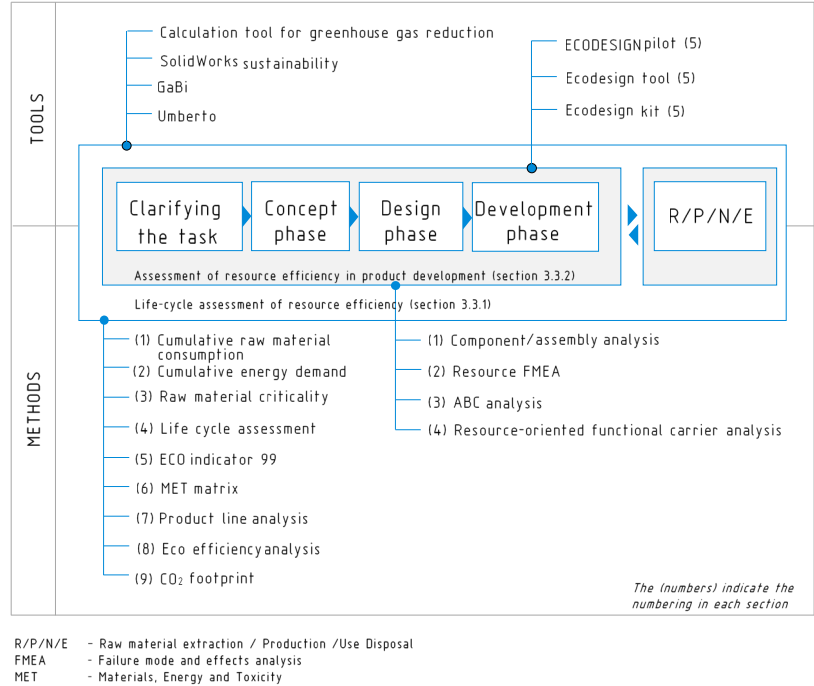


Figure 11: Methods and tools for evaluation of the resource efficiency<sup>87</sup>

<sup>86</sup> Cf. Federal Prize Code Design (2016), p. 53.

<sup>87</sup> Following VDI 2221, p. 9, VDI 4800 sheet 1 (2016), p. 33 and Pahl et al. (2013), p. 17.

During the product development process, further methods enable the evaluation of the status quo of resource efficiency. These methods focus on improving technical properties that lead to a resource-efficient product (Chapter 3.3.2). These tools include software and other tools that implement the methods.

### 3.3.1 Life cycle evaluation of resource efficiency

#### (1) Cumulative raw material demand (CRD)

Cumulative raw material demand (CRD) refers to the "sum of all raw materials entering a system - except water and air - expressed in units of weight"<sup>88</sup>, e.g. tonnes of raw materials consumed per tonne of product. The cumulative raw material demand therefore includes all raw materials and energy raw materials required to produce, use and dispose of a product. These can be grouped into biotic, metallic and energetic raw materials as well as construction and industrial minerals. The aggregated data basis required for the evaluation refers to a functional unit<sup>89</sup> (e.g. 2,000 working hours per year). This ensures comparability and defines the benefits of the system.

Figure 12 shows an example of balanced cumulative raw material demands for two different energy storage technologies within a uniformly defined framework.<sup>90</sup>

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<sup>88</sup> Giegerich et al. (2012), p. 22.

<sup>89</sup> The functional unit is the quantified benefit of a product system for use as a unit of comparison.

<sup>90</sup> Cf. VDI Zentrum Ressourceneffizienz GmbH, draft (2017).

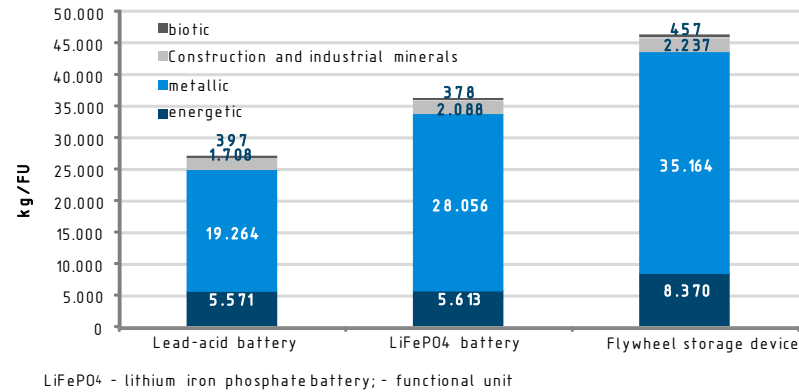


Figure 12: Example: Cumulative raw material consumption of energy storage technologies<sup>91</sup>

The application of the method is complex and requires a well-founded database, which is made available in databases such as the freely accessible ProBas database of the Federal Environment Agency<sup>92</sup> or the ecoinvent database subject to licensing (Table 3).

Table 3: Goal, complexity and application tools of the cumulative raw material demand

| Trait                         | Expression   |
|-------------------------------|--|
| Goal of the method            | Determination of raw material demand over the entire life cycle of a product or service  |
| Complexity of the method      | High   |
| Tools for applying the method | among other things Umberto NXT®, GaBi®, SolidWorks ® Sustainability Databases: ProBas (www.probas.umweltbundesamt.de), ecoinvent |

(2) Cumulative energy demand (CED)

Cumulative energy demand (CED) is defined as "the total primary energy expenditure associated with the production, use and disposal of a product or service"<sup>93</sup>. The cumulative energy demand is therefore the sum of the energy

<sup>91</sup> Cf. VDI Zentrum Ressourceneffizienz GmbH, draft (2017).

<sup>92</sup> Link to the ProBas database [www.probas.umweltbundesamt.de](http://www.probas.umweltbundesamt.de)

<sup>93</sup> VDI 4600 (2012), CF. 6.

required to production, use and disposal of a product or service. In addition, it can be grouped into primary energy sources.

- CED, exhaustible: CED-fossil, CED-nuclear
- CED, regenerative: CED-biomass, CED-wind, CED-sun, CED-hydropower

The balancing of the cumulative energy demand also requires a well-founded data basis, which must be related to a functional unit, i.e. the comparison unit. The result is energy demand that is spent, for example, in megajoules per functional unit.

Figure 13 shows an example of the cumulative energy demand for the comparison of three energy storage technologies for a defined scope of investigation.<sup>94</sup>

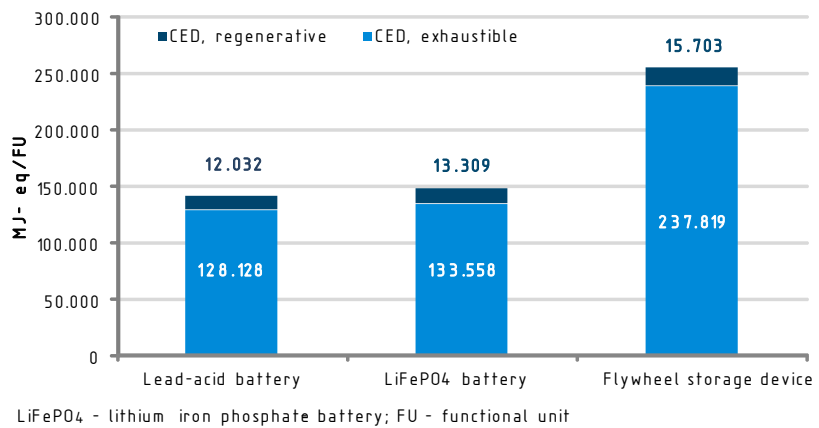


Figure 13: Example: Cumulative energy demand of energy storage technologies<sup>95</sup>

Also the calculation of the CED is characterized by a high complexity. Possible software-based application tools are listed in Table 4.

<sup>94</sup> Cf. VDI Zentrum Ressourceneffizienz GmbH, draft (2017).

<sup>95</sup> Cf. VDI Zentrum Ressourceneffizienz GmbH, draft (2017).

Table 4: Goal, complexity and application tools of the cumulative energy demand

| Trait                         | Expression  |
|-------------------------------|---|
| Goal of the method            | Determination of energy demand over the entire life cycle of a product or service   |
| Complexity of the method      | High  |
| Tools for applying the method | among others: Umberto NXT®, GaBi®, SolidWorks®, Sustainability Databases: ProBas (www.probas.umweltbundesamt.de), ecoinvent |

(3) Evaluation of raw material criticality

Critical raw materials are raw materials on which the economy is heavily dependent and which are subject to geological, structural and geopolitical supply risks.<sup>96</sup>

The evaluation of raw material criticality enables the evaluation of the so-called vulnerability of a reference system (e.g. a business) to supply bottlenecks of certain raw materials.<sup>97</sup>

According to VDI 4800, Sheet 2, the determination of raw material criticality is tied to a total of 16 criteria which are assigned to three categories (Figure 14).

<sup>96</sup> Cf. Federal Environment Agency (2015), p. 8.

<sup>97</sup> Cf. VDI 4800, sheet 2, draft (2016), p. 8.

| Criteria | Category 1<br>Geological, technical and structural criteria | Category 2<br>Geopolitical and regulatory criteria | Categories 3<br>Economic criteria            |
|----------|---|--|--|
|          | Static range  | Country concentration of reserves                  | Corporate concentration of global production |
|          | Combines production/secondary production                    | Country concentration of production                | Global demand impulse                        |
|          | Recycling   | Geopolitical risks of world production             | Substitutability                             |
|          | Logistical restrictions                                     | Regulatory situation of world production           | Raw material price fluctuations              |
|          | Restrictions due to natural events                          |  |  |

Figure 14: Three categories and 13 criteria of raw material criticality assessment<sup>98</sup>

The criteria are evaluated for static range using indicators such as the ratio of reserves to global annual production. The value range of the indicators is divided into four classes (Figure 15).<sup>99</sup>

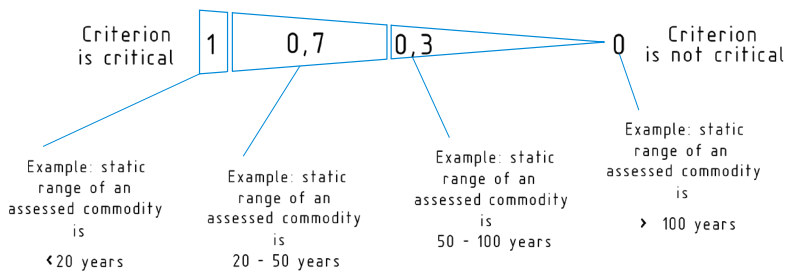


Figure 15: Value range for evaluating raw material criticality<sup>100</sup>

The directive VDI 4800 sheet 2 already offers raw material data sheets that evaluate the criticality of the supply risk of selected raw materials. If such information is not available, each criterion must be assessed individually (Table 5).

<sup>98</sup> Cf. VDI 4800, sheet 2, draft (2016), p. 9.

<sup>99</sup> Cf. VDI 4800, sheet 2, draft (2016), p. 9.

<sup>100</sup> According to VDI 4800, sheet 2, draft, (2016), p. 9.



Table 5: Goal, complexity and application tools of raw material criticality

| Trait                         | Expression   |
|-------------------------------|--|
| Goal of the method            | Determination of the supply risk and vulnerability of a raw material |
| Complexity of the method      | medium to high   |
| Tools for applying the method | no application tools available                                       |

(4) Life cycle evaluation

The international standards DIN EN ISO 14040 and DIN EN ISO 14044 describe the principles and requirements of the life cycle evaluation. It is defined as "the compilation and evaluation of the input and output flows and potential environmental impacts of a product system throughout its life cycle"<sup>101</sup>. Input flows such as energy, raw materials and supplies as well as output flows such as waste and emissions are balanced over the product life cycle. The data are used to calculate various impact categories, such as abiotic resource consumption, acidification potential, eutrophication potential or greenhouse gas potential, which make a statement about the holistic environmental impact along the life cycle. Figure 16 shows an example of the greenhouse gas potential, i.e. the amount of carbon dioxide emissions from various energy storage technologies that were balanced within a defined framework.<sup>102</sup>

<sup>101</sup> DIN EN ISO 14040 (2009), p. 7.

<sup>102</sup> Cf. VDI Zentrum Ressourceneffizienz GmbH, draft (2017).

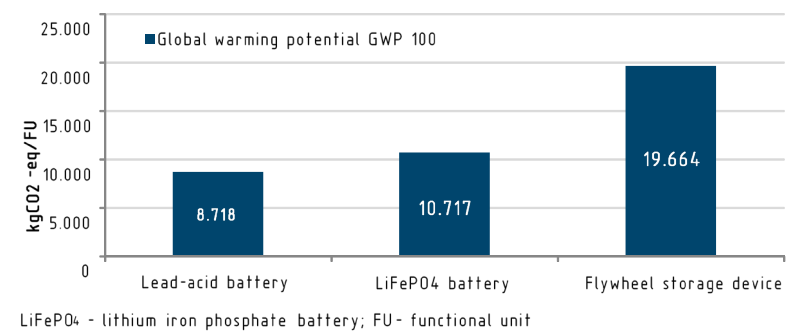


Figure 16: Example: Greenhouse gas potential of energy storage technologies<sup>103</sup>

The comparability must be guaranteed, like with the CED and CRD, over a functional unit, thus a comparison unit. The database for the complex calculations can also be databases such as ecoinvent or ProBas (Figure 16).

Table 6: Goal, complexity and application tools of the life cycle evaluation

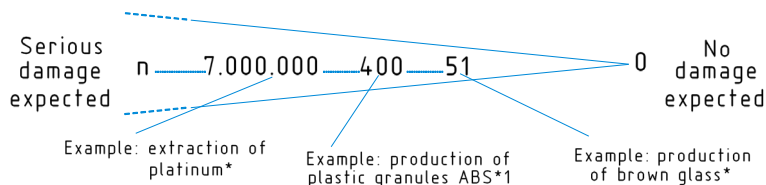
| Trait                         | Expression  |
|-------------------------------|---|
| Goal of the method            | Determination of the environmental impact over the entire life cycle of a product system, such as carbon dioxide emissions (global warming potential) |
| Complexity of the method      | High  |
| Tools for applying the method | among others Umberto NXT®, GaBi®, SolidWorks®, Sustainability Databases: ProBas (www.probas.umweltbundesamt.de), ecoinvent                            |

(5) ECO Indicator 99

The Eco-Indicator 99 is a method for estimating the damage-oriented effect of environmental influences caused by a product or product system along its entire life cycle. The evaluation is carried out in three loss categories. The damage caused by the product or product system to the categories of human health, ecosystem quality and resource stock is therefore quantified.

<sup>103</sup> Based on VDI Zentrum Ressourceneffizienz GmbH, draft (2017).

The complex methodology calculates a key figure. The higher it is, the higher the damage in the three damage categories caused by the product (Figure 17).<sup>104</sup>



\* Values date from the year 2000

1 acrylonitrile- butadiene - styrene copolymer (thermoplastic terpolymers)

Figure 17: Key figures as a result of the Eco-Indicator99<sup>105</sup>

This key figure is based on three steps:

- (1) A database of the relevant emissions, resources used and land uses must be researched,
- (2) a calculation of the damage caused by these material and energy flows must be carried out; and
- (3) a weighting of the three damage categories results in the key figure of the Eco-Indicator99.

The calculations, in particular of the second step, can be carried out using common software solutions (Table 7).

<sup>104</sup> Cf. Ministry of Housing, Spatial Planning and the Environment (2000), p. 7.

<sup>105</sup> Based on Ministry of Housing, Spatial Planning and the Environment (2000), p. 38 et seqq.

Table 7: Goal, complexity and application tools of the Eco-Indicator99

| Trait                         | Expression   |
|-------------------------------|--|
| Goal of the method            | Determination of a key figure for the amount of damage caused by the product   |
| Complexity of the method      | medium to high   |
| Tools for applying the method | among others Umberto NXT®, GaBi®, SolidWorks®, Sustainability Databases: ProBas (www.probas.umweltbundesamt.de), ecoinvent |

(4) MET matrix

The MET matrix (M: material flow, E: energy consumption, T: toxic emissions) is a qualitative method for determining resource consumption during the product life cycle. This method can be used, for example, during the idea collection phase or the concept phase.<sup>106</sup> Table 8 illustrates the structure of a MET matrix.

<sup>106</sup> Cf. VDI 4801, draft (2016), p. 26.

Table 8: MET Matrix<sup>107</sup>

|                               | Process | Material flow<br>(input/output)                                       | Energy consump-<br>tion<br>(input/output)  | Toxic emissions<br>(output)  |
|-------------------------------|---------|---|--|--|
| Raw<br>material<br>extraction | 1       | Identification of the raw materials of the product or product system. | Energy required for the extraction, processing and transport of raw materials, among other things. | Identification of potentially hazardous raw materials and waste generated during raw material extraction.                |
|                               | 2       |   |  |  |
|                               | ...     |   |  |  |
| Product<br>manufactur-<br>ing | 1       | Identification of the materials required for production.              | Evaluation of the energy consumption necessary for production.                                     | Identification and quantification of emissions resulting from production; identification of packaging waste.             |
|                               | 2       |   |  |  |
|                               | ...     |   |  |  |
| Utilisation                   | 1       | Identification of materials required for use.                         | Evaluation of the energy required in the utilisation phase.  | Identification and quantification of waste resulting from the utilisation phase.   |
|                               | 2       |   |  |  |
|                               | ...     |   |  |  |
| Recycling/<br>Disposal        | 1       | Identification of materials required for disposal.                    | Evaluation of the energy required for the disposal/recycling of the product.                       | Identification and quantification of waste generated during recovery/disposal (including recycled or re-used materials). |
|                               | 2       |   |  |  |
|                               | ...     |   |  |  |

The procedure is relatively simple, while the overview provided by the MET matrix allows quick conclusions to be drawn about the impact of the product or product system on the categories of material flow, energy consumption and toxic emissions (Table 9).

Table 9: Goal, complexity and application tools of the MET Matrix

| Trait                         | Expression   |
|-------------------------------|--|
| Goal of the method            | Qualitative and quantitative evaluation of the environmental impact of a product or product system |
| Complexity of the method      | Low  |
| Tools for applying the method | no tools necessary   |

(5) Product Line Analysis (PLA)

<sup>107</sup> In the style of eco3e (2017) and VDI 4801, draft (2016), p. 26.

Product line analysis is another method of evaluating the environmental impact of a product. In addition, this method also considers the economic and social impacts. For this purpose, a product line matrix is created analogous to the MET method, the criteria of which are defined in advance (Table 8). The selection of research criteria is based on three areas: nature, society and the economy Table 10).

Table 10: Research criteria from the fields of nature, society and economy<sup>108</sup>

| Research criteria   |  |  |
|---|--|--|
| Ecological criteria   | Economic criteria  | Social criteria  |
| <ul style="list-style-type: none"><li>• Energy demand</li><li>• Raw material consumption</li><li>• Air pollution</li><li>• Groundwater, surface water and marine pollution</li><li>• Pollutant entry into the soil</li><li>• Decimation and eradication of plants and animals</li><li>• Influence on biotopes and eco-systems</li><li>• Climate change, threat to the ozone layer, acid rain</li><li>• Radioactivity and radiation exposure</li><li>• ...</li></ul> | <ul style="list-style-type: none"><li>• Price</li><li>• Measurable quality</li><li>• Subjective quality</li><li>• Advertising/Marketing</li><li>• Market power</li><li>• Individual costs</li><li>• External costs (follow-up costs)</li><li>• Economic dependence</li><li>• Distribution effect</li><li>• ...</li></ul> | <ul style="list-style-type: none"><li>• Quality of work</li><li>• Job satisfaction</li><li>• Accidents at work</li><li>• Pollutant load on the Workplace</li><li>• Health compatibility of the product</li><li>• General social values, such as operational reliability, security of supply, self-determination</li><li>• Legally sanctioned values such as equal opportunities or freedom from forced labour</li><li>• ....</li></ul> |

For the product line analysis there is no exactly defined procedure. For each selected criterion, adequate information must be researched for each life cycle phase, which must be documented in a comprehensible and transparent manner. The further qualitative evaluation is then dependent on the user.<sup>109</sup>

<sup>108</sup> Austrian (n.a.), p. 10 et seqq.

<sup>109</sup> Cf. Austrian (n. a.), p. 10.

Table 11: Goal, complexity and application tools of product line analysis

| Trait                         | Expression   |
|-------------------------------|--|
| Goal of the method            | Qualitative and quantitative evaluation of the environmental impact of a product or product system |
| Complexity of the method      | medium   |
| Tools for applying the method | no tools necessary   |

(6) Eco-Efficiency Analysis

The eco-efficiency analysis shows the relationship between the economic value added and the ecological damage caused by a product or process. Various key figures can be used for the eco-efficiency analysis. For the ecological dimension, for example, this can lead to CO<sub>2</sub>-Emissions or cumulative raw material demand (CRD), for the economic dimension e.g. the return on investment or the contribution margin (Figure 18).<sup>110</sup>

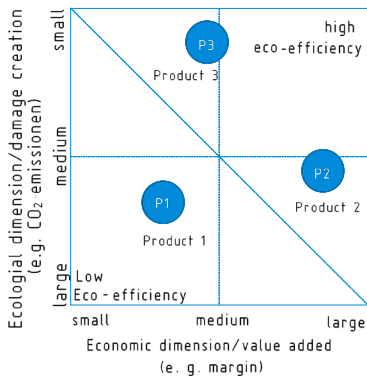


Figure 18: Exemplary presentation of the results of the eco-efficiency analysis

The eco-efficiency analysis supports investment decisions, optimises products with regard to ecological aspects or shows a possible strategic orientation of the product portfolio towards sustainable products (Table 12).<sup>111</sup>

<sup>110</sup> Cf. Schaltegger et al. (2007), p. 109.

<sup>111</sup> Cf. Schaltegger et al. (2007), p. 109.

Table 12: Goal, complexity and application tools for eco-efficiency analysis

| Trait                         | Expression  |
|-------------------------------|---|
| Goal of the method            | Support in investment decisions, evaluation of the ecological performance of a product                |
| Complexity of the method      | High  |
| Tools for applying the method | For the ecological dimension Umberto NXT®, GaBi® and SolidWorks®, Sustainability etc. can be helpful. |

(7) CO<sub>2</sub>-Footprint or CO<sub>2</sub>-Balance

The CO<sub>2</sub>-Balance calculates the total life cycle carbon dioxide emissions caused by a product or product system. Either only carbon dioxide emissions can be considered or other emissions converted into CO<sub>2</sub> equivalents can be included.

The CO<sub>2</sub> balance can be drawn up for different investigation limits, such as per person, per business, per city, per country or per activity. Some freely accessible application tools are available for this purpose (Table 13).

Table 13: Goal, complexity and application tools of CO<sub>2</sub> balancing

| Trait                         | Expression  |
|-------------------------------|---|
| Goal of the method            | Determination of the total CO <sub>2</sub> emissions of a product or product system   |
| Complexity of the method      | medium  |
| Tools for applying the method | <ul style="list-style-type: none"><li>• Calculation tool greenhouse gas reduction of the Energy Agency NRW (Link: <a href="http://www.energieagentur.nrw/klimaschutz/co2/berechnungstool_treibhausgas-minderung">www.energieagentur.nrw/klimaschutz/co2/berechnungstool_treibhausgas-minderung</a>)</li><li>• among others also Umberto NXT®, GaBi®, SolidWorks®, Sustainability or databases ProBas or ecoinvent</li></ul> |

3.3.2 Evaluation of resource efficiency within the limits of the product development process

Improving the resource efficiency of a product or product system already requires the consideration and application of strategies in the product development phase (Chapter 3.2). In the following, various methods are presented



which support the exploitation of resource efficiency potentials in the product development phase. Further methods that address resource efficiency in the product development phase can be found, for example, in the resource savings book of the German Engineering Federation (VDMA)<sup>112</sup>.

(1) Component/sub-assemblies influence analysis

The component/sub-assemblies influence analysis is a procedure for identifying constructive material efficiency potentials. It is determined for which components/sub-assemblies there is high potential for reducing constructive or production-related material waste. These can then be subject to a further optimization loop.

Simple forms and evaluation scales can be used for this purpose. A 0-1-3-9 rating scale provides an opportunity to determine the level of influence of a sub-assembly on resource requirements (Table 14).<sup>113</sup>

Table 14: Example of a Sub-assembly Influence Analysis Matrix<sup>114</sup>

| Process   | Resource   | Sub-assemblies |                 |                  |
|-----------|------------|----------------|-----------------|------------------|
|           |            | Sub-assembly I | Sub-assembly II | Sub-assembly III |
| Process a | Resource 1 | 0              | 1               | 3                |
|           | Resource 2 | 3              | 9               | 1                |
| Process b | ...        | 1              | 1               | 9                |
|           | ...        | 0              | 1               | 9                |
| Total     |            | 4              | 12              | 22               |

0 = no influence on resource expenditure  
1 = low influence on resource expenditure

3 = medium influence on resource expenditure  
9 = high influence on resource expenditure

The sum or total value provides information about the sub-assembly with the highest potential influence on resource expenditure and shows for which sub-assemblies resource efficiency measures (Table 15, Chapter 3.2) are promising. In the case of the example in Table 14, Sub-assembly III should be examined more closely with regard to resource efficiency measures.

<sup>112</sup> Cf. VDMA (2016).  
<sup>113</sup> Cf. VDMA (2016), p. 71.  
<sup>114</sup> According to VDMA (2016), p. 72.

Table 15: Goal, complexity and application tools of sub-assemblies influence analysis

| Trait                         | Expression   |
|-------------------------------|--|
| Goal of the method            | Identification of sub-assemblies/components with the highest resource efficiency potential and revision of these in the design and elaboration phase |
| Complexity of the method      | medium   |
| Tools for applying the method | <ul style="list-style-type: none"><li>• Forms,</li><li>• Data processing programs such as Excel</li></ul>  |

(2) Resource Failure Mode and Effect Analysis  
(Resource FMEA)

*The Failure Mode and Effect Analysis (FMEA)* aims to identify defects at an early stage of product and process development. This means that cost-intensive error elimination during the production process or product use can be prevented as early as the development phase.<sup>115</sup>

The Resource **Failure Mode and Effect Analysis (Resource FMEA)** is a further development of the classic FMEA. Instead of possible errors, bottlenecks in the upstream value chain are identified for the business. The purpose of the resource FMEA is to define measures to mitigate the supply risk of considered resources.<sup>116</sup>

According to the VDMA's resource savings book, a resource FMEA is carried out in seven sub-steps: preparation, bottleneck analysis, risk evaluation, definition of measures, evaluation and decision, re-evaluation after implementation of measures and follow-up (Figure 19).

<sup>115</sup> Cf. Theden and Colsman (2013), p. 78 – 89.

<sup>116</sup> Cf. VDMA (2016), p. 93.

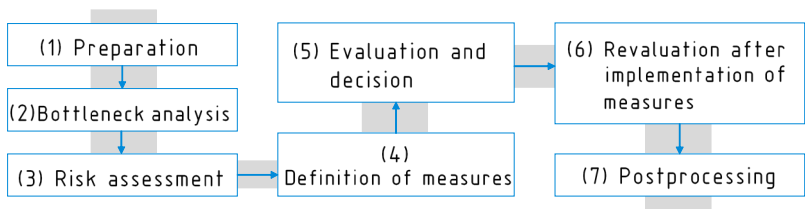


Figure 19: Process flow of a resource FMEA<sup>117</sup>

Especially in the preparatory phase, potentially critical raw materials are pre-selected (1). For example, the method of determining raw material criticality can be helpful here (Chapter 3.3.1, (3)). The bottleneck analysis lists and evaluates all possible bottlenecks for the selected raw materials (2). Bottlenecks are, for example, limited availability or barriers to trade. The potential bottlenecks are then assessed according to their risk, i.e. their probability of occurrence (3). Based on this, measures are derived for the resources with the highest bottleneck risk, which are assessed with regard to their applicability (weighing the benefits against the costs) and selected in the event of a positive evaluation (4.5). After implementation, a further evaluation of the situation is carried out and, if necessary, the implementation of measures is adjusted. The follow-up provides for documentation of the complex process of the resource FMEA in order to reduce the high costs for similar or subsequent projects (6, 7, Table 16).<sup>118</sup>

Table 16: Goal, complexity and application tools of the resource FMEA

| Trait                         | Expression  |
|-------------------------------|---|
| Goal of the method            | Identification of resource bottlenecks in the upstream value chain and derivation of measures to reduce the supply risk |
| Complexity of the method      | High  |
| Tools for applying the method | <ul style="list-style-type: none"><li>• Forms</li><li>• Data processing programs such as Excel</li></ul>                |

<sup>117</sup> Cf. VDMA (2016), p. 93.

<sup>118</sup> Cf. VDMA (2016), p. 94 et seqq.

(3) ABC analysis

The ABC analysis is a simple tool to define essential and non-essential substances or resources within a consideration system. The classification or prioritisation with the letters A, B and C is carried out with reference to a question or a criterion derived from it, e.g. the quantity of resources to be used in the product, the costs of the resources or the supply risk of the resources. Class A has the highest priority and class C the lowest (Table 17).

- A = very important/very problematic → Urgent need for optimisation
- B = important/problematic → Optimisation requirements advisable
- C = unimportant/unproblematic → no/low need for optimisation.<sup>119</sup>

As a result, an ABC analysis can compare the planned materials with the derived criteria and sometimes draw conclusions with regard to a new choice of, for example, bio-based materials.

Table 17: Example of an ABC analysis<sup>120</sup>

| Resource       | Evaluation criterion          |                                |                    |
|----------------|-------------------------------|--------------------------------|--------------------|
|                | Required quantity per product | Raw material costs per product | Supply criticality |
| Raw material 1 | C                             | A                              | A                  |
| Raw material 2 | A                             | B                              | B                  |
| Raw material 3 | A                             | C                              | B                  |

The results of the ABC analysis must be related to the respective situation and weighed up. A further, more detailed analysis can answer open questions in the next step (Table 18).

<sup>119</sup> Cf. Schaltegger et al. (2007), p. 51.

<sup>120</sup> According to Schaltegger et al. (2007), p. 51.

Table 18: Goal, complexity and application tools of ABC analysis

| Trait                         | Expression   |
|-------------------------------|--|
| Goal of the method            | Identification of major influencing factors (e.g. quantity of raw materials) on resource consumption     |
| Complexity of the method      | Low  |
| Tools for applying the method | <ul style="list-style-type: none"><li>• Forms</li><li>• Data processing programs such as Excel</li></ul> |

(4) Resource-oriented functional carrier analysis

The function carrier analysis analyses components and sub-assemblies of a product and evaluates their function with regard to their importance or necessity. Potentials for the reduction of used or planned resources can be identified and unnecessary components or inefficient use of resources can be counteracted. The sequence of a function carrier analysis takes place in six steps (Figure 20).<sup>121</sup>

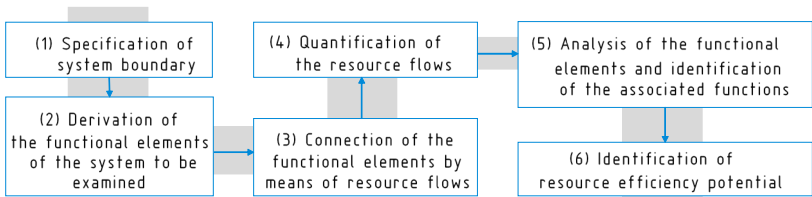


Figure 20: Procedure of a resource-oriented function carrier analysis<sup>122</sup>

The frame of consideration is defined by the definition of the system boundary (1), which can refer to an entire product or only to product components. These are subdivided into their function carriers or into their sub-assemblies/components (2), then the input and output resource flows (e.g. substances, energy or signals) are determined and interconnected (3). The resource flows to be optimised, such as waste heat or waste, are then derived from this. The resource flows are then quantified (4) and the functional relationships between input and output resource flows of the functionaries are illuminated ((5), Figure 21).<sup>123</sup>

<sup>121</sup> Cf. VDMA (2016), p. 110.

<sup>122</sup> According to VDMA (2016), p. 109.

<sup>123</sup> Cf. VDMA (2016), pp. 110 - 114.

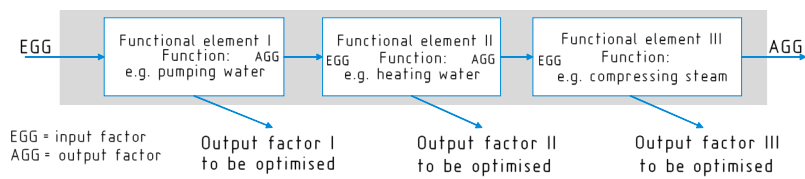


Figure 21: Schematic representation of a function carrier analysis<sup>124</sup>

Further possible resource efficiency potentials can thus be derived from the quantified resource flows and the functional interrelationships or statements can be made about unnecessary function carriers or function carriers with more efficient functions ((6), Table 19).

Table 19: Goal, complexity and application tools of the functional analysis

| Trait                         | Expression   |
|-------------------------------|--|
| Goal of the method            | Reduction of the resources used by identifying unnecessary components                                |
| Complexity of the method      | medium   |
| Tools for applying the method | <ul style="list-style-type: none"><li>Forms</li><li>Data processing programs such as Excel</li></ul> |

(5) Product design tools

In addition to strategies for evaluating and analysing resource efficiency in product development, there are other tools that can be used during the development phase.

These include the **ECODESIGN pilot** of the Institute of Engineering Design of the Vienna University of Technology. It is a software-supported, free tool designed to support product developers and designers in integrating environmentally friendly and resource-efficient strategies into the product development process.<sup>125</sup>

- Internet address: [www.ecodesign.at](http://www.ecodesign.at)

Another internet-based tool is the **Ecodesign-Kit** of the Federal Ministry for the Environment, Nature Conservation, Construction and Nuclear Safety and

<sup>124</sup>According to VDMA (2016), p. 116.

<sup>125</sup> Cf. Ecodesign Pilot (2017g).

the Federal Environment Agency. It is understood as a toolbox consisting of 36 topic papers that offer basic principles, methods and practical examples in a focused form on all aspects of resource-efficient and environmentally friendly product development.<sup>126</sup>

- Internet address: [www.ecodesignkit.de](http://www.ecodesignkit.de)

The **ECO DESIGN TOOL** represents a qualitative decision support in the product design process. Ecologically relevant aspects such as useful life, service life or separability are assigned to the subject areas of use, material and realisation. The displayed aspects can be linked with each other via a map system and thus enable a multi-dimensional view.<sup>127</sup>

- Internet address: [www.ecodesigntool.com](http://www.ecodesigntool.com)

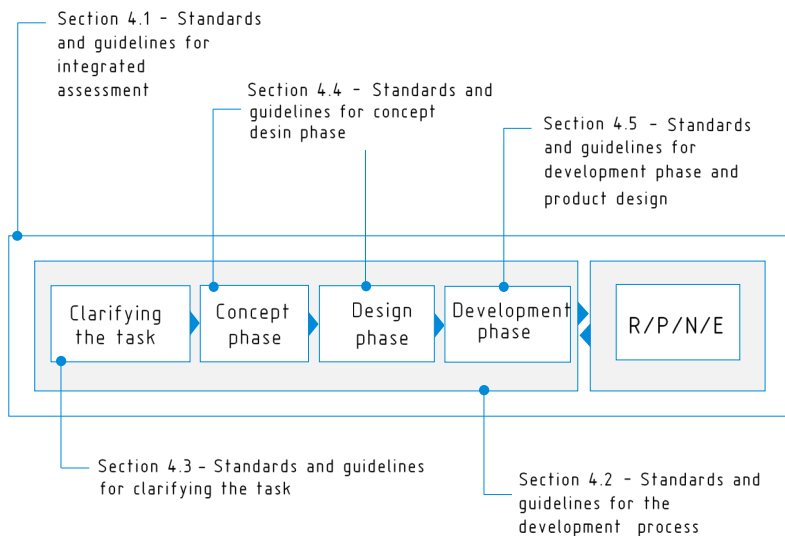
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<sup>126</sup> Cf. Ecodesign Kit (2017).

<sup>127</sup> Cf. Ecodesign Tool (2017).

## 4 STANDARDS AND DIRECTIVES FOR SUPPORTING THE PRODUCT DEVELOPMENT

Standards and directives can support the product development process. They can be used for the individual phases, from the clarification of the task to the elaboration phase, for the entire product development process and also for the holistic evaluation. Chapter 4.1 addresses resource efficiency as part of the holistic evaluation. The remaining chapters 4.2 to 4.5 contain directives without reference to resource efficiency, but are listed for the sake of completeness and to round off the topic (Figure 22).



R/P/N/E - Raw material extraction/Produktion/Use/Disposal

Figure 22: Chapter overview of standards and directives<sup>128</sup>

<sup>128</sup> Following VDI 2221 (1993), p. 9, VDI 4800 sheet 1 (2016), p. 33 and Pahl et al. (2013), p. 17.



4.1 Standards and directives for holistic evaluation

Table 20 lists standards and directives that describe the requirements and principles of methods for holistic evaluation, such as the cumulative raw material or energy demand.

Table 20: Standards and directives for life-cycle evaluation

| Document number  | Standards and directives for life-cycle evaluation: Title and content   |
|------------------|---|
| VDI 4800 Sheet 1 | <b>Resource Efficiency - Methodological Foundations, Principles and Strategies</b><br>The VDI directive contains the basic principles and principles of life-cycle evaluation and strategies that support resource-efficient action.  |
| VDI 4800 Sheet 2 | <b>Resource efficiency, evaluation of raw material demand</b><br>The VDI Directive covers the methodology for determining the cumulative raw material demand (CRD), the water and land input and the evaluation of raw material criticality, including vulnerability and supply risk (Chapter 3.3.1 (1)).   |
| VDI 4600         | <b>Cumulative energy demand (CED) - Terms, calculation methods</b><br>The VDI Directive describes the methodology for balancing the cumulative energy demand, i.e. the energy consumption required for a product or product system along its entire life cycle (Chapter 3.3.1 (2)).   |
| VDI 4600 Sheet 1 | <b>Cumulative energy demand - examples</b><br>The VDI directive shows examples of how to determine the cumulative energy demand using, for example, photovoltaic modules or an offshore wind farm.  |
| DIN EN ISO 14040 | <b>Environmental management - Life cycle evaluation - Principles and framework conditions</b><br>The standard conveys principles and framework conditions that are linked to the methodological concept of the life cycle evaluation. The concept of the life cycle evaluation includes the recording and evaluation of the environmental impacts of products, processes and services over their entire life cycle (Chapter 3.3.1 (4)). |
| DIN EN ISO 14044 | <b>Environmental management - Life cycle evaluation - Requirements and instructions</b><br>The standard specifies the requirements and procedures required for the implementation of a life cycle evaluation (Chapter 3.3.1 (4)).   |
| DIN EN ISO 14045 | <b>Environmental management - Eco-efficiency evaluation of product systems - Principles, requirements and directives</b><br>The standard describes the principles, requirements and directives of the eco-efficiency analysis (Chapter 3.3.1 (8)). Eco-efficiency determines the relationship between the economic value added and the ecological damage caused by a product or process.  |

## 4.2 Standards and directives for the product development process

Table 21 shows directives and standards that address information, methods and, for example, inventive problem solving within the limits of the product development process. The list of VDI directives and standards can be extended and should therefore not be regarded as exhaustive.

**Table 21: Standards and directives for the product development process**

| Document number                             | Standards and directives for the product development process: Title and content  |
|---|--|
| VDI 2243                                    | <b>Recycling-oriented product development</b><br>The VDI Directive provides information, guidance and decision-making aids for product development to improve the recyclability of the product.  |
| VDI 4521<br>Sheet 1 to 2                    | <b>Inventive problem solving with TRIZ</b><br><b>Sheet 1 - Basics and terms</b><br>The VDI Directive Sheet 1 provides descriptions of the contents, i.e. Basics and terms of the TRIZ method (method of inventive problem solving).<br><b>Sheet 2 - Goal description, problem definition and solution prioritization</b><br>The VDI Directive Sheet 2 describes tools and methods of the TRIZ procedure. |
| DIN EN 62430; VDE 0042-2:2010-02            | <b>Environmentally conscious design of electrical and electronic products</b><br>The standard describes a generally applicable procedure for integrating environmental aspects into the design and development processes of electrical and electronic products and systems.  |
| DIN EN ISO 14006                            | <b>Environmental management systems - Directives for the consideration of environmentally compatible product design</b><br>The standard addresses product-related environmental aspects that can be monitored or influenced by an organization.  |
| DIN CEN/TS 16524;<br>DIN SPEC 33925:2013-12 | <b>Mechanical products - Methodology to reduce environmental impacts in product design and development</b><br>The Technical Specification describes an ecodesign methodology that businesses can use to apply ecodesign criteria to minimise the environmental impact of the product to be developed.  |
| VDI 2221                                    | <b>Methodology for the development and design of technical systems and products</b><br>The VDI directive conveys, among other things, the work steps, work results and generally applicable and cross-sector fundamentals of the methodical development and design of technical systems and products.  |
| VDI 2206                                    | <b>Development methodology for mechatronic systems</b><br>The VDI directive supports the methodical, cross-domain development of mechatronic systems. The directive focuses on the procedures, methods and tools for the earlier phases of development, in particular the design phase.  |

| Document number | Standards and directives for the product development process: Title and content  |
|-----------------|--|
| VDI 2218        | <b>Information Processing in Product Development - Feature-Technology</b><br>The VDI directive provides an overview of feature technology. This includes among other things definitions and examples for the implementation of feature technologies in practice. |
| VDI 2219        | <b>Information Processing in Product Development - Introduction and Operation of PDM Systems</b><br>The VDI directive describes the structured procedure for the initial introduction or change of product data management systems (PDM systems).                |

4.3 Standards and directives for clarifying the task

Table 22 contains, among other things, the VDI Directive 4070 on sustainable management, especially in small and medium-sized businesses. Sustainability goals can already be firmly anchored in the development of management processes, which in turn should be reflected in the product requirements (Chapter 2.1.1).

Table 22: Standards and directives for clarifying the task

| Document number     | Standards and directives to clarify the task: Title and content  |
|---------------------|--|
| VDI 4070<br>Sheet 1 | <b>Sustainable business practices in small and medium-sized businesses - Guidance for sustainable business practices</b><br>The VDI directive formulates directives for the implementation of sustainability-oriented management processes, especially in small and medium-sized businesses (SMEs). The principles include the following <ul style="list-style-type: none"><li>• Recognition of social responsibility,</li><li>• Taking into account and balancing the interests of stakeholders,</li><li>• Transparency,</li><li>• holistic approach and</li><li>• use of instruments of sustainability management.</li></ul> |
| VDI 2222<br>Sheet 1 | <b>Construction methodology</b><br><b>Sheet 1 - Methodical development of solution principles</b><br>The VDI directive is a detailing and extension of the directive VDI 2221 (Table 21) and deals with work steps 1 to 3, whereby work step 1 comprises the clarification and specification of the task.<br><br>Further details are given in Table 23 on the following page   |

### 4.4 Standards and directives for the conceptual and design phase

Table 23 lists directives related to the concept and design phase. These include VDI 2222 Part 1 and VDI 2223, both of which belong to the roof directive VDI 2221 (Table 21).

Table 23: Standards and directives for the concept and design phase

| Document number     | Standards and directives for the concept and design phase: Title and content   |
|---------------------|--|
| VDI 2222<br>Sheet 1 | <b>Construction methodology</b><br><b>Sheet 1 - Methodical development of solution principles</b><br>The VDI directive is a detailing and extension of the directive VDI 2221 (Table 21) and deals with the work steps 1 to 3, including Figure 1 (1 - clarifying the task, 2 - determining functions and their structures, 3 - finding principle solutions). Among other things, the methodology and the type of documentation used to derive the "principal solution" are described. |
| VDI 2223            | <b>Methodical design of technical products</b><br>The VDI directive is a detailing and extension of the directive VDI 2221 (Table 21) and deals with the work steps 4 to 6, including Figure 1 (4 - Structuring into feasible modules, 5 - Design of the decisive modules, 6 - Design of the entire product). The directive explains in particular the design in precision engineering and mechanical engineering.   |

### 4.5 Standards and directives for the development phase

Table 24 shows directives and standards dealing with the elaboration phase. These include the methodology of construction - in general and in various industries - as well as business-oriented fundamentals.

Table 24: Standards and directives for the elaboration phase

| Document number | Standards and directives for the development phase: Title and content  |
|-----------------|--|
| VDI 2209        | <b>3-D product modelling - Technical and organisational requirements - Procedures, tools and applications - Economic use in practice</b><br>The VDI Directive describes the use of 3D product models, as these have the following advantages over 2D systems: <ul style="list-style-type: none"><li>• more complete product models,</li><li>• fewer documents to be created and managed individually, as many documents are (partially) automatically derived from the 3D product models,</li><li>• early recognition and avoidance of problems and consequently fewer optimization cycles in the product development process.</li></ul> |

| Document number          | Standards and directives for the development phase: Title and content  |
|--------------------------|--|
| VDI 2211<br>Sheet 2      | <b>Information processing in product development - Calculations in construction</b><br>The VDI directive illuminates the calculation tasks before and parallel to the design process of a mechanical engineering designer.   |
| VDI 2225<br>Sheet 1 to 4 | <b>Design methodology - technical-economical design</b><br><br><b>Sheet 1 Simplified cost calculation</b><br>This VDI directive describes a simple calculation procedure for material and manufacturing cost estimation.<br><br><b>Sheet 2 Tables</b><br>This VDI directive provides numerical values for relative material cost shares and material costs.<br><br><b>Sheet 3 Technical-economic evaluation</b><br>This VDI directive provides a detailed description of two methods of cost and profitability accounting for practical application in design.<br><br><b>Page 4 Design gauge</b><br>This VDI directive shows how technical and economic requirements are to be taken into account or calculated in the design. |
| VDI 2234                 | <b>Economic basics for the designer</b><br>The VDI directive conveys the basics of cost and economic efficiency accounting for design (including short calculations, estimation procedures).   |
| VDI 2235                 | <b>Economic decisions in design - methods and aids</b><br>The VDI directive provides methods and tools for economic decisions during design.   |
| VDI 2244                 | <b>Designing safety-oriented products</b><br>The VDI directive describes safety-relevant influences as well as their constructive consideration for all technical products which pose a danger to humans and the environment.  |
| VDI 2249                 | <b>Information processing in product development – CAD Usage Function</b><br>The VDI directive presents CAD systems using various applications in mechanical engineering, plant construction and electrical engineering.   |

## 5 PRODUCT DECLARATION AND PROCUREMENT

The product declaration is an essential factor in drawing attention to the environmental friendliness or resource efficiency of a product - in particular for the procurement of a business. It can also help in the product development process to make environmentally friendly or resource-efficient requirements on the product to be developed.

Three different types of environmental labels and declarations are distinguished according to DIN standards: type I, type II and type III. The individual types are explained in key points in Table 25.

Table 25: Types of environmental labels according to DIN standards<sup>129</sup>

| Environmental labelling  | Eco-labelling and environmental declaration   | Declaration   |
|--|---|---|
| According to DIN EN ISO 14024 TYPE I   | According to DIN EN ISO 14021 TYPE II   | According to DIN EN ISO 14025 TYPE III  |
| <ul style="list-style-type: none"><li>• are aimed at private and commercial consumers</li><li>• have a special environmental quality</li><li>• are relevant for public procurement</li><li>• have a high credibility and are mostly very well known</li><li>• require third-party certification</li><li>• involve interested parties</li></ul> | <ul style="list-style-type: none"><li>• are mostly aimed at consumers</li><li>• often focus on a single environmental aspect</li><li>• apply in principle also to complex information</li><li>• are the sole responsibility of the manufacturer as a voluntary self-declaration</li></ul> | <ul style="list-style-type: none"><li>• are aimed at manufacturers in the supply chain, trade and commerce, and less at consumers</li><li>• are based on a life cycle evaluation</li><li>• provide comprehensive quantitative and verified information</li><li>• represent environmental impacts without evaluating them</li><li>• are suitable for all products and services</li><li>• enable data aggregation along a value chain</li><li>• require independent verification by third parties</li></ul> |

A famous example of Type I environmental labelling is the "Blue Angel". DIN 14021 defines a total of 17 selected terms for Type II which can be applied to a product. These include the terms compostable or recyclable. The Type III declarations, which are listed in DIN 14025, are far more complex.

<sup>129</sup> According to BMUB (2014), p. 15.

The ISO 14020 series of standards provides a basis for product-related environmental information at the international level. The standard describes the "how" of the implementation of environmental labels (Table 25) and defines nine principles as clear directives (Figure 23).



Figure 23: Nine principles of product-related environmental labelling<sup>130</sup>

<sup>130</sup> Based on BMUB (2014), p. 18 et seqq.

Product-related environmental information plays a particularly important role in procurement, both public and internal. They should be transparent and easy to understand.

The Federal Environment Agency can tell you which other requirements and information must be observed when procuring environmentally friendly products. Training materials should further anchor environmentally friendly procurement in public institutions (Table 26).

Table 26: Training material for environmentally friendly procurement<sup>131</sup>

| Training script number | Title  |
|------------------------|--|
| 1                      | Fundamentals of environmentally friendly procurement   |
| 2                      | Legal foundations of environmentally friendly public procurement                             |
| 3                      | Introduction to the use of eco-label product criteria  |
| 4                      | Strategic market observation and market analysis   |
| 5                      | Introduction to the calculation of life cycle costs and their use in the procurement process |
| 6                      | Obstacle analysis for environmentally friendly procurement using a self-evaluation tool      |

These documents also show product developers from businesses what requirements are placed on environmentally friendly products by public institutions.

<sup>131</sup> Cf. Federal Environment Agency (2017).



## 6 CONCLUSION

The brief analysis shows that product development has a very large influence on the resource efficiency of a product. Not only the consumption of raw materials and the environmental impact are reduced, but also costs can be significantly saved. The majority of the resulting manufacturing and material costs are determined during product development. Resource efficiency measures consequently open up a high economic potential and create competitive advantages.

In current practice, however, resource efficiency strategies and measures are often insufficiently integrated into the product development process. Reasons for this include a lack of practical experience in implementation or difficulties in selecting and prioritising resource efficiency strategies and measures<sup>132</sup>. From a systematic point of view, however, the extent to which a product will be suitable for manufacture, dismantling, repair, material, function or recycling should already be determined during product development. For example, a business was able to reduce its raw material costs by 90 % and its energy demand by 50 % compared with conventional competing products by designing products that were suitable for repair, dismantling and production and by complying with the requirements of the "Blue Angel".<sup>133</sup>

The result or environmentally sound product design should therefore be subject to life-cycle analysis and evaluation. The use and disposal phases are also included in the rough consumption calculations here. This ensures that the resource efficiency measures actually result in lower material and energy demand along the entire life cycle and that unnecessary environmental pollution, waste and increased resource consumption are avoided.

In addition to life cycle-related analysis and evaluation, product developers have other methods at their disposal to determine resource efficiency potentials within the limits of the product development process. This includes, for example, the resource FMEA (Failure Mode and Effect Analysis)<sup>134</sup>. This

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<sup>132</sup> Cf. Pigosso et al. (2013), p. 161.

<sup>133</sup> Cf. VDI Zentrum Ressourceneffizienz GmbH (2017a).

<sup>134</sup> Cf. VDMA (2016), p. 93.

method can be used to identify resource shortages in the upstream stages of the value chain and to derive measures to reduce the supply risk. A further example is the sub-assembly influence analysis, which identifies the components with the highest resource efficiency potential in order to revise them in the design and development phase.

If requirements from environmental labels are observed and complied with in product development, declarations on the product can generate further competitive advantages. Well-known environmental labels are, for example, the "Blue Angel" or "Seal clarity". Public institutions in particular, but also other stakeholders, are called upon to procure in an environmentally sound manner and to orient themselves towards environmental labels and declarations.

The brief analysis shows that the integration of higher-level resource efficiency strategies and concrete measures in the product development process opens up efficiency potentials that generate cost savings in production and competitive advantages in the market for businesses.

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## BIBLIOGRAPHY

**BMUB (2016):** Deutsches Ressourceneffizienzprogramm II – Programm zur nachhaltigen Nutzung und zum Schutz der natürlichen Ressourcen. Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB), Berlin, November 2016.

**BMUB (2014):** Umweltinformationen für Produkte und Dienstleistungen – Anforderungen – Instrumente – Beispiele [online]. Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB), [retrieved on 17. July 2017], available at: [http://www.bmub.bund.de/fileadmin/Daten\\_BMU/Pool/Broschueren/umweltinfos\\_produkte\\_dilei\\_broschue\\_bf.pdf](http://www.bmub.bund.de/fileadmin/Daten_BMU/Pool/Broschueren/umweltinfos_produkte_dilei_broschue_bf.pdf)

**Braungart, M. (2017):** Die Cradle to Cradle®-Zertifizierung [online]. Büro Braungart [retrieved on: 7. July 2017], available at: <http://www.braungart.com/de/content/kontaktimpresum>

**Buchert, T., Halstenberg, F., Bonvoisin, J., Lindow, K. und Stark, R. (2017):** Target-driven selection and scheduling of methods for sustainable product development. *Journal of Cleaner Production*, Vol. 161 (2017), Elsevier, pp. 403–421.

**Bundespreis-Ecodesign (2016):** Mehr als schön – Die Preisträger und Nominierten des Bundespreises Ecodesign 2016 [online]. Internationales Design Zentrum Berlin, [retrieved on 14. July 2017] available at: <https://www.bundespreis-ecodesign.de/downloads/3309/BroschreWanderausstellungBundespreisEcodesign2016.pdf>

**DIN EN ISO 14040:2009-11:** Deutsches Institut für Normung e. V., Umweltmanagement - Ökobilanz - Grundsätze und Rahmenbedingungen, Beuth Verlag GmbH, Berlin.

**eco3e (2017):** Indicators [online]. Institute ENSAM of Chambéry, [retrieved on 14. July 2017], available at: <http://eco3e.eu/en/base/indicators/>

**ECODESIGN KIT (2017):** Ecodesign Kit [online]. Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB) & Umweltbundesamt, [retrieved on 17. July 2017], available at: <https://www.ecodesign-kit.de/home-willkommen/>

**ECODESIGN Pilot (2017a):** Erhöhung der Demontagefreundlichkeit [online]. TU Wien, [retrieved on 14. July 2017], available at: <http://pilot.ecodesign.at/pilot/ONLINE/DEUTSCH/PDS/DETAILS/717.HTM>

**ECODESIGN Pilot (2017b):** Verbesserung der Wartbarkeit [online]. TU Wien, [retrieved on 17. July 2017], available at: <http://pilot.ecodesign.at/pilot/ONLINE/DEUTSCH/PDS/DETAILS/715.HTM>

**ECODESIGN Pilot (2017c):** Zielgerichtete Materialwahl [online]. TU Wien, [retrieved on 14. July 2017], available at: <http://pilot.ecodesign.at/pilot/ONLINE/DEUTSCH/PDS/DETAILS/701.HTM>

**ECODESIGN Pilot (2017d):** Optimierung der Funktionsweise des Produkts [online]. TU Wien, [retrieved on 14. July 2017], available at: <http://pilot.ecodesign.at/pilot/ONLINE/DEUTSCH/PDS/DETAILS/710.HTM>

**ECODESIGN Pilot (2017e):** Verbrauchsreduktion in der Nutzung [online]. TU Wien, [retrieved on 14. July 2017], available at: <http://pilot.ecodesign.at/pilot/ONLINE/DEUTSCH/PDS/DETAILS/713.HTM>

**ECODESIGN Pilot (2017f):** Wiederverwendung von Produktteilen [online]. TU Wien, [retrieved on 14. July 2017], available at: <http://pilot.ecodesign.at/pilot/ONLINE/DEUTSCH/PDS/DETAILS/718.HTM>

**ECODESIGN Pilot (2017g):** ECODESIGN Pilot [online]. TU Wien [retrieved on 17. July 2017], available at: [http://www.ecodesign.at/forschungsprojekte/ecodesign\\_pilot/DE/](http://www.ecodesign.at/forschungsprojekte/ecodesign_pilot/DE/)

**ECODESIGN Tool (2017):** Ecodesign Tool [online]. Koslowski & Dwalischwili GbR, [retrieved on 17. July 2017], available at: <https://www.ecodesigntool.com/>

**Ehrlenspiel, K. (2007):** Integrierte Produktentwicklung: Denkabläufe, Methodeneinsatz, Zusammenarbeit. 3. Auflage, Carl Hanser Verlag, München, ISBN 978-3-446-40733-6.

**Ehrlenspiel, K. und Meerkamm, H. (2013):** Integrierte Produktentwicklung: Denkabläufe, Methodeneinsatz, Zusammenarbeit. 5. Auflage, Carl Hanser Verlag, München, ISBN 978-3-446-43548-3.

**Eigner, M.; Roubanov, D. und Zafirov, R. (2014):** Modellbasierte virtuelle Produktentwicklung. Springer-Verlag, Berlin Heidelberg, ISBN 978-3-662-43815-2.

**Giegrich, J.; Liebich, A.; Lauwigi, C. und Reinhardt, J. (2012):** Indikatoren / Kennzahlen für den Rohstoffverbrauch im Rahmen der Nachhaltigkeitsdiskussion [online]. Umweltforschungsplan des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit, im Auftrag des Umweltbundesamtes, UBA-Texte 01/2012, [retrieved on 14. July 2017], available at: <http://www.uba.de/uba-info-medien/4237.html>, also available as PDF at: <https://www.umweltbundesamt.de/sites/default/files/medien/461/publikationen/4237.pdf>.

**Goedkoop, M. J.; van Halen, C. J. G.; te Riele, H. R. M. und Rommens, P. J. M. (1999):** Product Service systems, Ecological and Economic Basics. The Netherlands Ministry of Spatial Planning, Housing and the Environment, Den Hag, also als PDF available at: <http://teclim.ufba.br/jsf/indicadores/holan%20Product%20Service%20Systems%20main%20report.pdf>

**Gräble, M.; Thomas, O.; Fellmann, M. und Krumeich, J. (2010):** Vorgehensmodelle des Product-Service Systems Engineering. Überblick, Klassifikation und Vergleich. In: Böhmman, T. und Leimeister, J. M.: Proceedings der Teilkonferenz Integration von Produkt & Dienstleistung – Hybride Wertschöpfung, im Rahmen der Multikonferenz Wirtschaftsinformatik, 23. – 25.02.2010, Göttingen, Books on Demand, Norderstedt, pp. 31–42.

**Hahn, D. und Kaufmann, L. (2002):** Handbuch Industrielles Beschaffungsmanagement: Internationale Konzepte – Innovative Instrumente – Aktuelle Praxisbeispiele. 2. Auflage, Springer-Verlag, Berlin Heidelberg.

**Jepsen, D.; Volz, S.; Reihlen, A.; Wirth, O.; Vollmer, A. und Spengler, L. (2014):** Themenbereich B. Grundlagen und Prinzipien des Ökodesign. Themenblock 2: Umweltbezogenes Prozesswissen. Produkt- oder Prozesseigenschaft [online]. Ökopol Institut für Ökologie und Politik, Hamburg, [retrieved on: 14. July 2017], available at: [http://ipp-netzwerk.hamburg.de/netzwerk/upload/public/media/1424815766\\_B2\\_1\\_Produkt\\_Prozesseigenschaft.pdf](http://ipp-netzwerk.hamburg.de/netzwerk/upload/public/media/1424815766_B2_1_Produkt_Prozesseigenschaft.pdf)

**Kaeser Kompressoren Se (2017):** Betreibermodelle [online]. Kaeser Kompressoren Se, [retrieved on 7. July 2017], available at: <http://www.kaeser.de/loesungen/betreibermodelle/>

**Kaiser, O., Krauss, O., Seitz, H. und Kirmes, S. (2016):** Ressourceneffizienz im Leichtbau [online]. VDI Zentrum Ressourceneffizienz GmbH, [retrieved on 17. July 2017], available at: [http://www.ressource-deutschland.de/fileadmin/user\\_upload/downloads/kurzanalysen/Kurzanalyse\\_17\\_Ressourceneffizienz\\_im\\_Leichtbau.pdf](http://www.ressource-deutschland.de/fileadmin/user_upload/downloads/kurzanalysen/Kurzanalyse_17_Ressourceneffizienz_im_Leichtbau.pdf)

**Kalweit, A.; Paul, C.; Peters, S.; Wallbaum, R. (2012):** Handbuch für Technisches Produktdesign – Material und Fertigung – Entscheidungsgrundlagen für Designer und Ingenieure. 2. Auflage, Springer Verlag, Berlin Heidelberg, ISBN 978-3-642-02641-6.

**Krishnan, V. und Ulrich, K. T. (2001):** Product Development Decisions: A Review of the Literature. Management Science, Jan. 2001, 47 (1), pp. 1 – 21.

**Leismann, K.; Schmitt, M.; Rohn, H. und Baedeker, C. (2012):** Nutzen statt Besitzen. Auf dem Weg zu einer ressourcenschonenden Konsumkultur. Heinrich-Böll-Stiftung, Berlin, Schriften zur Ökologie, Band 27, also available as PDF at: [https://www.boell.de/sites/default/files/Endf\\_NutzenStattBesitzen\\_web.pdf](https://www.boell.de/sites/default/files/Endf_NutzenStattBesitzen_web.pdf)

**Ministry of Housing, Spatial Planning and the Environment (2000):** Eco-indicator 99 – Manual for Designers – A damage oriented method for Life Cycle Impact Assessment [online]. Ministry of Housing, Spatial Planning and the Environment, [retrieved on 14. July 2017], available at: [https://www.pre-sustainability.com/download/EI99\\_Manual.pdf](https://www.pre-sustainability.com/download/EI99_Manual.pdf)

**Niebaum, A., Seitz, H. und Kaiser, O. (2017):** Ressourceneffizienz durch Bionik [online]. VDI Zentrum Ressourceneffizienz GmbH, [retrieved on 17. Okt. 2017], available at: [https://www.ressource-deutschland.de/fileadmin/user\\_upload/downloads/kurzanalysen/VDI\\_ZRE\\_Kurzanalyse\\_Nr.\\_19\\_Ressourceneffizienz\\_durch\\_Bionik\\_bf.pdf](https://www.ressource-deutschland.de/fileadmin/user_upload/downloads/kurzanalysen/VDI_ZRE_Kurzanalyse_Nr._19_Ressourceneffizienz_durch_Bionik_bf.pdf)

**Oberender, C. (2006):** Die Nutzungsphase und ihre Bedeutung für die Entwicklung umweltgerechter Produkte. Fortschritt-Berichte VDI, Reihe 1 Konstruktionstechnik/Maschinenelemente, Nr. 385, VDI Verlag 2006, Berlin.

**Ökopol (2012):** B1 Ökodesign-Prinzipien [online]. Behörde für Stadtentwicklung und Umwelt Hamburg, [retrieved on: 7. July 2017], available at: <http://ipp-netzwerk.hamburg.de/netzwerk/index.php?topic=86>

**Österreicher, C. (k. A.):** Fallbeispiel: „Die Produktlinienanalyse am Beispielprodukt ‚Handy‘“ [online]. beratung.supervision & coaching, [retrieved on 17. July 2017], available at: [http://www.umweltbildung.at/cms/praxisdb/dateien/403\\_pdf.pdf](http://www.umweltbildung.at/cms/praxisdb/dateien/403_pdf.pdf)

**Pahl, G.; Beitz, W., Grote, K.-H. und Feldhusen, J. (2013):** Konstruktionslehre – Methoden und Anwendung erfolgreicher Produktentwicklung. 8. Auflage, Springer Verlag, Berlin Heidelberg, ISBN 978-3-642-29568-3.

**Pigosso, D., Rozenfeld, H. und McAloone, T. (2013):** Ecodesign maturity model: a management framework to support eco design implementation into manufacturing companies. *Journal of Cleaner Production*, Vol. 59, Elsevier, pp. 160 – 173.

**Pigosso, D. und McAloone, T. (2017):** Ecodesign Maturity Model (EcoM2) [online]. Technical University of Denmark, [retrieved on 4. August 2017], available at: <http://www.ecodesign.dtu.dk/EcoM2>

**Reinhäckel und Schilling (2007):** Virtuelle Prototypen – Möglichkeiten und Grenzen [online]. *RTejournal – Forum für Rapid Technologie*, Vol. 4(2007), [retrieved on: 14. July 2017], available at: <https://www.rtejournal.de/ausgabe4/1160>

**Rolls-Royce (2012):** Rolls-Royce celebrates 50th anniversary of Power-by-the-Hour [online]. Rolls-Royce, 30. Okt. 2012, [retrieved on 7. July 2017], available at: <http://www.rolls-royce.com/media/press-releases/yr-2012/121030-the-hour.aspx>

**Saulich, K. (2016):** Ressourceneffizienz biobasierter Materialien im verarbeitenden Gewerbe [online]. VDI Zentrum Ressourceneffizienz GmbH, [retrieved on 17. July 2017], available at: [http://www.ressource-deutschland.de/fileadmin/user\\_upload/downloads/kurzanalysen/2016-Kurzanalyse-VDI-ZRE-15\\_Biobasierte-Rohstoffe\\_Webversion\\_mit\\_Links\\_01.pdf](http://www.ressource-deutschland.de/fileadmin/user_upload/downloads/kurzanalysen/2016-Kurzanalyse-VDI-ZRE-15_Biobasierte-Rohstoffe_Webversion_mit_Links_01.pdf)

**Schaltegger, S.; Herzig, C.; Klieber, O.; Klinke, T. und Müller J. (2007):** Nachhaltigkeitsmanagement in Unternehmen [online], Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Econsense – Forum Nachhaltige Entwicklung der Deutschen Wirtschaft e.V., Centre für Sustainability Management, [retrieved on 17. July 2017], available at: [http://econsense.de/sites/all/files/nachhaltigkeitsmanagement\\_unternehmen.pdf](http://econsense.de/sites/all/files/nachhaltigkeitsmanagement_unternehmen.pdf)

**Schebek, L. et al. (2017):** Ressourceneffizienz durch Industrie 4.0 – Potenziale für KMU des verarbeitenden Gewerbes [online]. VDI Zentrum Ressourceneffizienz GmbH, [retrieved on 17. July 2017], available at: [http://www.ressource-deutschland.de/fileadmin/Redaktion/Bilder/Newsroom/Studie\\_Ressourceneffizienz\\_durch\\_Industrie\\_4.0.pdf](http://www.ressource-deutschland.de/fileadmin/Redaktion/Bilder/Newsroom/Studie_Ressourceneffizienz_durch_Industrie_4.0.pdf)

**The Waste and Resources Action Programme (2017):** What is industrial symbiosis? [online]. The Waste and Resources Action Programme, [retrieved on 7. July 2017], available at: <http://www.wrap.org.uk/content/what-industrial-symbiosis>

**Theden P. und Colsmann, H. (2013):** Fehlermöglichkeits- und -einflussanalyse (FMEA) nach QS-9000 [online]. QZ-online.de – Portal für Qualitätsmanagement, [retrieved on: 17. July 2017], available at: <https://www.qz-online.de/qualitaets-management/qm-basics/methoden/fmea/artikel/fehlermoeglichkeits-und-einflussanalyse-fmea-nach-qs-9000-270675.html>

**Tukker, A. (2004):** Eight types of Product-Service System: Eight ways to sustainability? Experiences from SusProNet. Business Strategy and the Environment, 13 (4), pp. 246 – 260.

**Umweltbundesamt (2015):** Elemente einer erfolgreichen Ressourcenschonungspolitik – Position Oktober 2015 [online]. Umweltbundesamt Dessau-Roßlau, [retrieved on 14. July 2017], available at: [https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/uba-positionspapier\\_elemente\\_einer\\_erfolgreichen\\_ressourcenschonungspolitik\\_2015\\_web\\_0.pdf](https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/uba-positionspapier_elemente_einer_erfolgreichen_ressourcenschonungspolitik_2015_web_0.pdf)

**Umweltbundesamt (2017):** Umweltfreundliche Beschaffung: Schulungsskript 1 – Grundlagen der umweltfreundlichen Beschaffung [online]. Umweltbundesamt, [retrieved on 17. July 2017], available at: <https://www.umweltbundesamt.de/publikationen/umweltfreundliche-beschaffung-schulungsskript-1>

**VDI 2206:2004-06:** Entwicklungsmethodik für mechatronische Systeme. Verein Deutscher Ingenieure e.V., Beuth Verlag GmbH, Berlin.

**VDI 2221:1993-05:** Methodik zum Entwickeln und Konstruieren technischer Systeme und Produkte. Verein Deutscher Ingenieure e.V., Beuth Verlag GmbH, Berlin.

**VDI 4600:2012-01:** Kumulierter Energieaufwand (CED) - Begriffe, Berechnungsmethoden. Verein Deutscher Ingenieure e.V., Beuth Verlag GmbH, Berlin.

**VDI 4800 Blatt 1:2016-02:** Ressourceneffizienz - Methodische Grundlagen, Prinzipien und Strategien. Verein Deutscher Ingenieure e.V., Beuth Verlag GmbH, Berlin.

**VDI 4800 Blatt 2:2016-03 (Entwurf):** Ressourceneffizienz – Bewertung des Rohstoffaufwands. Verein Deutscher Ingenieure e.V., Beuth Verlag GmbH, Berlin.



**VDI 4801:2016-02 (Entwurf):** Ressourceneffizienz in kleinen und mittleren Unternehmen (KMU) - Strategien und Vorgehensweisen zum effizienten Einsatz natürlicher Ressourcen. Verein Deutscher Ingenieure e.V., Beuth Verlag, Berlin.

**VDI Zentrum Ressourceneffizienz GmbH (2017a):** Materialeffiziente Produktion von LED-Lampen [online]. VDI Zentrum Ressourceneffizienz GmbH, [retrieved on 7. July 2017], available at: <http://www.ressource-deutschland.tv/themen/allgemeines/materialeffiziente-produktion-von-led-lampen/>

**VDI Zentrum Ressourceneffizienz GmbH (2017b):** Kunststoff: Weniger Material, mehr Qualität [online]. VDI ZRE GmbH, [retrieved on 17. July 2017], available at: <http://www.ressource-deutschland.tv/themen/kunststoffverarbeitung/kunststoff-weniger-material-mehr-qualitaet/>

**VDI Zentrum Ressourceneffizienz GmbH (2017c):** Edeldstahlguss ganz ohne Feuer [online]. VDI ZRE GmbH, [retrieved on 17. July 2017], available at: <http://www.ressource-deutschland.tv/themen/metallverarbeitung/edelstahlguss-ganz-ohne-feuer/>

**VDI Zentrum Ressourceneffizienz GmbH (2017d):** Feines Gießen statt grober Hobel [online]. VDI ZRE GmbH, [retrieved on 17. July 2017], available at: <http://www.ressource-deutschland.tv/themen/metallverarbeitung/feines-giessen-statt-grober-hobel/>

**VDI Zentrum Ressourceneffizienz GmbH (2017e):** Wettbewerbsvorteil Ressourceneffizienz. Definitionen, Grundlagen, Fakten und Beispiele. VDI Zentrum Ressourceneffizienz GmbH, Berlin, also als PDF available at: [http://www.ressource-deutschland.de/fileadmin/user\\_upload/bilder/publikationen/VDIZRE\\_faktencheck\\_2016\\_web.pdf](http://www.ressource-deutschland.de/fileadmin/user_upload/bilder/publikationen/VDIZRE_faktencheck_2016_web.pdf)

**VDI Zentrum Ressourceneffizienz GmbH, Entwurf (2017):** Bewertung des Ressourcenaufwands – Energiespeichertechnologien. available at: <http://www.ressource-deutschland.de/publikationen/studien/>

**VDMA (2016):** Ressourcen-Sparbuch: In drei Schritten zu effizienteren Maschinen und Anlagen. VDMA Verlag, Frankfurt am Main.

**Weise, J. (2007):** Planung und Steuerung von Innovationsprojekten. Dissertation. Technische Universität Berlin, Deutscher Universitäts-Verlag, Berlin.

APPENDIX

Table 27: Objectives of design for X strategies that are highly likely to directly determine an ecodesign principle

| Design for X Strategies and Resource Efficiency Measures   | Longevity | Reparability | Material efficiency | Energy efficiency | Problem substance prevention | Use of renewable raw materials | Recyclability |
|--|-----------|--------------|---------------------|-------------------|------------------------------|--------------------------------|---------------|
| Production-oriented product design <sup>135</sup>  |           |              |                     |                   |                              |                                |               |
| Integrated construction  | -         | -            | -                   | -                 | -                            | -                              | -             |
| Reduction of the machining volume, e.g. forming close to the final dimensions  | -         | -            | -                   | -                 | -                            | -                              | -             |
| Reduction of production steps  | -         | -            | -                   | -                 | -                            | -                              | -             |
| Intelligent purchase of components   | -         | -            | -                   | -                 | -                            | -                              | -             |
| Standardisation of the manufacturing process through standardised series, use of uniform tools and increase in batch sizes | -         | -            | -                   | -                 | -                            | -                              | -             |
| Product design suitable for dismantling <sup>136</sup>   |           |              |                     |                   |                              |                                |               |
| Ensure accessibility to fasteners and attach the disassembly fasteners so that they are easy to locate                     | X         | X            | -                   | -                 | -                            | -                              | X             |
| Ensure reversibility of assembly operations  | X         | X            | -                   | -                 | -                            | -                              | X             |
| Goal for a building structure suitable for dismantling with uniform dismantling and joining directions                     | X         | X            | -                   | -                 | -                            | -                              | X             |
| Use easily detachable connections  | X         | X            | -                   | -                 | -                            | -                              | X             |
| Ensure the operability of the detachable connections over their entire service life  | X         | X            | -                   | -                 | -                            | -                              | X             |

<sup>135</sup> Cf. Kalweit et al. (2012), p. 600 f.

<sup>136</sup> Cf. ECODESIGN Pilot (2017b).

| Design for X Strategies and Resource Efficiency Measures  | Longevity | Reparability | Material efficiency | Energy efficiency | Problem substance novelty | Use of renewable raw materials | Recyclability |
|---|-----------|--------------|---------------------|-------------------|---------------------------|--------------------------------|---------------|
| Repair-oriented product design <sup>137, 138</sup>  |           |              |                     |                   |                           |                                |               |
| Reduce fine motor work, make gripping and moving areas user-friendly and use established or standardised assembly techniques                | X         | X            | -                   | -                 | -                         | -                              | X             |
| Allow for easy cleaning and observe slightly angled construction  | X         | X            | -                   | -                 | -                         | -                              | X             |
| Steer unavoidable wear to replaceable components  | X         | X            | -                   | -                 | -                         | -                              | X             |
| Use of simple wear detection  | X         | X            | -                   | -                 | -                         | -                              | X             |
| Show required service intervals of the product  | X         | X            | -                   | -                 | -                         | -                              | X             |
| Avoidance of required special tools   | X         | X            | -                   | -                 | -                         | -                              | X             |
| Material/material-specific product design <sup>139, 140</sup>   |           |              |                     |                   |                           |                                |               |
| Optimisation of component size and design   | -         | -            | X                   | -                 | -                         | -                              | -             |
| Use of materials with a good environmental balance sheet  | X         | -            | X                   | X                 | X                         | X                              | X             |
| Avoid toxic materials/ constituents   | -         | -            | -                   | -                 | X                         | -                              | X             |
| Use of materials from renewable raw materials   | -         | -            | -                   | -                 | -                         | X                              | -             |
| Application of wear protection, corrosion protection and hard material coatings   | X         | -            | -                   | -                 | -                         | -                              | -             |
| Avoidance of the use of inseparable material composites, use of components/sub-assemblies each made of one material (single-material parts) | -         | -            | -                   | -                 | -                         | -                              | X             |
| Avoid raw materials and components with known problematic origin  | -         | -            | X                   | -                 | -                         | -                              | -             |

<sup>137</sup> Cf. Kalweit et al. (2012), p. 600.

<sup>138</sup> Cf. ECODESIGN Pilot (2017a).

<sup>139</sup> Cf. Kalweit et al. (2012), p. 600.

<sup>140</sup> Cf. ECODESIGN Pilot (2017c).

| Design for X Strategies and Resource Efficiency Measures  | Longevity | Reparability | Material efficiency | Energy efficiency | Problem substance reparability | Use of renewable raw materials | Recyclability |
|---|-----------|--------------|---------------------|-------------------|--------------------------------|--------------------------------|---------------|
| Design for X Strategies and Resource Efficiency Measures  | Longevity | Reparability | Material efficiency | Energy efficiency | Problem substance reparability | Use of renewable raw materials | Recyclability |
| Functional product design <sup>141</sup>  |           |              |                     |                   |                                |                                |               |
| Ensure high product reliability   | X         | -            | -                   | -                 | -                              | -                              | -             |
| Ensure high functional quality and reduce the influence of malfunctions   | X         | -            | -                   | -                 | -                              | -                              | -             |
| Provide for upgradeability of the product, enable technological leaps forward   | X         | -            | -                   | -                 | -                              | -                              | -             |
| Provide product for multifunctional use as different functions  | -         | -            | X                   | -                 | -                              | -                              | -             |
| Provide adjustability and adjustability to compensate for wear and tear   | X         | -            | -                   | -                 | -                              | -                              | -             |
| Implement simple functional principle or simple building structure  | X         | X            | -                   | -                 | -                              | -                              | X             |
| Goal for robust design  | X         | -            | -                   | -                 | -                              | -                              | -             |
| Usage-oriented product design <sup>142</sup>  |           |              |                     |                   |                                |                                |               |
| Avoid environmentally harmful misuse as far as possible   | -         | -            | -                   | X                 | -                              | -                              | -             |
| Display current consumption of the product in the utilisation phase   | -         | -            | -                   | X                 | -                              | -                              | -             |
| Improve energy demand in the utilisation phase by increasing efficiency and choosing a more suitable functional principle | -         | -            | -                   | X                 | -                              | -                              | -             |
| Enabling the use of renewable energy sources in the utilisation phase   | -         | -            | -                   | X                 | -                              | X                              | -             |
| Enable the lowest possible consumption or use of environmentally friendly or renewable raw materials for product use      | -         | -            | X                   | -                 | -                              | X                              | -             |

| Design for X Strategies and Resource Efficiency Measures                              | Longevity | Reparability | Material efficiency | Energy efficiency | Problem substance novelty | Use of renewable raw materials | Recyclability |
|---|-----------|--------------|---------------------|-------------------|---------------------------|--------------------------------|---------------|
| Avoid waste from the utilisation phase or make it recyclable                          | -         | -            | -                   | -                 | -                         | -                              | X             |
| Coordinate the service life of the individual components and choose a timeless design | X         | -            | -                   | -                 | -                         | -                              | -             |
| Make surfaces usable  | -         | -            | X                   | -                 | -                         | -                              | -             |

<sup>141</sup> ECODESIGN Pilot (2017d).

<sup>142</sup> ECODESIGN Pilot (2017e).

| Design for X Strategies and Resource Efficiency Measures  | Longevity | Reparability | Material efficiency | Energy efficiency | Problem substance longevity | Use of renewable raw materials | Recyclability |
|---|-----------|--------------|---------------------|-------------------|-----------------------------|--------------------------------|---------------|
| Recycling and recycling-friendly product design <sup>143</sup>                                  |           |              |                     |                   |                             |                                |               |
| Simplified removal of pollutants enables  | -         | -            | -                   | -                 | -                           | -                              | X             |
| Enable material separation for recycling purposes   | -         | -            | X                   | -                 | -                           | -                              | X             |
| Enable easy disassembly   | X         | X            | -                   | -                 | -                           | -                              | X             |
| Ensure compatibility of materials for recycling   | -         | -            | X                   | -                 | -                           | -                              | X             |
| Select surface coating with base material that is compatible with recycling                     | -         | -            | X                   | -                 | -                           | -                              | X             |
| Allow removal of operating materials and unavoidable problem materials                          | -         | -            | X                   | -                 | -                           | -                              | X             |
| Consider disposal options at the end user and indicate instructions for disposal on the product | -         | -            | -                   | -                 | -                           | -                              | X             |
| Identify all materials in accordance with standards   | -         | -            | -                   | -                 | -                           | -                              | X             |
| Check the reuse of entire sub-assemblies if possible (remanufacturing)                          | -         | -            | X                   | -                 | -                           | -                              | X             |

<sup>143</sup> Cf. ECODESIGN Pilot (2017f).

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