3 Computer Aided Resource Efficiency Accounting

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3.1 Introduction

Resource Efficiency Accounting (REA) is a method developed by the Wuppertal Institute (Wuppertal, Germany) aiming at the lifecycle-wide ecological assessment of processes and products. The scope of the project CARE[1] (Computer Aided Resource Efficiency Accounting) was to develop an application method basing on the REA, which expands the existing economic controlling systems of enterprises by adding ecological information concerning environmental impacts. The innovative approach of the project is to supplement tools already deployed in the course of environmental and material flow accounting with ecological lifecycle data and ensure an efficient assessment process by the use of software and information technology. In the three-year-long project, the Wuppertal Institute, University of Stuttgart Institute for Human Factors and Techno-

[1] The project CARE is a joint research project funded by the Bundesministerium für Bildung und Forschung (BMBF, Federal Ministry of Education and Research, Fördernummer/ Reference No: 01 RU 0016/17).

logy Management (Stuttgart, Germany) and the Ingenieurbüro synergitec (engineering consultants) established the scientific basis. The central task was to demonstrate how flow cost based material and energy flow concepts can be expanded by a lifecycle perspective and how the associated data collection and generation process can be supported by the use of information technology (IT). At the same time the results were implemented and subjected to practical application tests on-site at the corporate partners: Nolte Möbel (furniture), Toshiba Europe (notebooks) and Muckenhaupt & Nusselt (special cables). The objective of these implementation projects was to integrate the economic-ecological assessment approach into already existing controlling systems at the participating companies. The integration should thus create a new basis for corporate decision-making aiming at the optimisation of material and energy flows as well as cost flows.

In the following sections, the motivation and conceptual design of the project will be presented; chapter 3.2 will then provide an in-depth description of the assessment methodology. Chapter 3.3 will finally describe the practical application oth the methodology.

3.1.1 Background

As a result of the opening of European internal markets, growing globalisation and the current economic development in Germany, enterprises are faced with increasingly intensified competitive pressure. As a response to these challenges, streamlining and rationalisation has prevailed in recent years, with workforce as the major cost factor frequently taking the spotlight. Other cost blocks are often disregarded, even if their share of the total costs is at least as high. Thus, considerable opportunities are overlooked that could financially relieve companies while modernising them at the same time. The question to be asked here is why efficiency aspects extending beyond the economies of scale and personnel costs play only a subordinate role in enterprises.

Experiences in recent years have clearly shown that a very high potential for reducing costs and improving the competitiveness of companies lies in increasing material efficiency. In a typical cost distribution of a manufacturing company, approx. 60 % of costs are attributed to materials, while e.g. only 25 % are ascribed to personnel.[2]

[2] See Bundesumweltministerium/ Umweltbundesamt (Federal Ministry for the Environment/ Federal Environmental Agency) (2001, p. 526)

Materials are thus the central factor for manufacturers and as such, have a direct effect on competitiveness. It can be stated that the associated saving potentials are not fully exploited in most enterprises. Accordingly, the costs of material and energy usage are frequently underestimated and cost-cutting is primarily equated with reductions in personnel costs while productivity is equated with work productivity.

Increasing material efficiency can lead to more added value, with a simultaneous reduction in the consumption of natural resources. According to the empirical findings of the management consulting company Arthur D. Little, increasing material efficiency can cut production costs by 20% in almost every case.[3]

3.1.2 Macroeconomic Objective Definition

The World Business Council for Sustainable Development has defined the objective for macroeconomic growth as the production of useable goods and services in conjunction with a continuously decreasing consumption of natural resources. To put it the other way around, creating as much prosperity as possible with a given amount of resources is one of the most important prerequisites for a sustainable economic system.[4] Such an integrated approach to resource consumption and costs can be described as "eco-efficiency"[5].

Material flows constitute an essential element for measuring eco-efficiency on the macro level. In this context, all material flows produced and initiated by a society are examined, from the exploitation of raw materials to the processing and use of products up to waste disposal. They form the physical basis of the economy and at the same time trigger a vast range of environmental changes. For measurability purposes, the Total Material Requirement (TMR) indicator is a suitable scale. It determines the total material consumption of an economy, including the "ecological rucksacks" associated with the respective material flows, that is to say all the total consumption and expenditures needed for the provision of materials.[6] For that reason not only the domestic material inputs are taken into account, but also material movements and consumption in foreign countries. Such movements and consumptions can derive from inputs required for producing the imported preliminary work, services and goods.

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[3] See Fischer et al. 2004, p. 247
[4] See articles in Weizsäcker et al. 2004
[5] See Schaltegger/ Sturm 1990
[6] See Bartelmus et al. 2001

The consideration of the total quantity of moved and consumed materials is also called a "lifecycle perspective".

The relationship between the economic performance (e.g. gross domestic product) and the TMR of an economy is described by means of the material productivity. In the macroeconomic dimension, an improvement in eco-efficiency means an increase in material productivity.

An absolute decoupling of the economic performance from the consumption of natural resources can be stated as a declared objective by every economy following a sustainability perspective. Sustainable development, in both the ecological and economic dimension, can only be achieved if economic growth does not lead to a real rise in the consumption of natural. Otherwise rebound effects would counteract any eco-efficiency progress. Since the beginning of the 1990s, environmental policy has been strongly promoting more and more preventive environmental protection measures – be it the United Nation's "Cleaner Production" programme (UNEP), the "Eco-efficiency Initiative" of the World Business Council for Sustainable Development (WBCSD) or the individual environmental protection plans instituted by various nations (e.g. Austrian Federal Government, 1996; BMU (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety), 1998). However, according to the third report of the European Environment Agency, this decoupling has not occurred to a sufficient extent yet.[7]

The microeconomic level plays a decisive role in the realisation of the macroeconomic objective: managers and CEO's have to recognise that the relevant "adjusting screws" lie in their own enterprises. Eco-efficiency can in this case be defined as a strategic guide rail for business decisions and planning. In the sense of a bottom-up-approach, this is an important prerequisite for eliminating the macro-societal rebound effects.

3.1.3 Eco-efficiency as a Strategic "Guide Rail" for Enterprises

The implementation of eco-efficiency options on the micro or company level assume that managers and stakeholders realise an inherent benefit in the implementation of the options, adopt this principle and implement it with concrete strategies and measures. An examination of company practice demonstrates that eco-efficiency is relevant for decision-making, if specific optimisation projects can show clear cost saving potentials. The most practical approach therefore lies in focusing on the internal material

[7] See European Environment Agency 2003

and energy flows. The efficient use of resources thus becomes a determining factor with respect to the competitiveness of the company.

For the application-oriented research, the question to be addressed is how this interrelationship can be represented in a feasible and operationally implementable manner on both an internal and cross-company level. This means that enterprises require methods and tools to facilitate them in determining the most efficient utilisation of resources and presenting the resulting benefits.

The following factors are crucial to the practicability and operationability of the methods and tools: (1) the processes for measuring, presenting and visualising resource efficiency have to ensure that the expenses and effort associated with the data collection and processing are kept as low as possible. This proves especially difficult if significant results are desired, i.e. the effectiveness of the indicators should be maintained. The needs of small and medium sized enterprises are frequently not met by complex assessment procedures, or the required personnel and financial means are not sufficiently available. As the first key requirement, methods and tools should therefore utilise existing data sources and data collection systems and be compatible with the company's existing systems and processes. (2) Furthermore, the mapping of the results is a crucial success factor. Extensive data and information concerning potential cost and success factors generally have to be taken into consideration when making decisions concerning rationalisation, streamlining and investments. But multidimensional results matrices on ecological consequences and detailed improvement options are less informative. Instead, ecological information on processes and products should be prepared and presented in a compact form that supplies easily understandable and significant supplementary information in addition to the already existing criteria. This allows the management of a company to use the information as an operational basis for decision making on process design. Such information can also support strategic business decisions, e.g. during the product planning process, and thus contribute to securing the medium- and long-term success of a company.

3.1.4 Data Diversity and Decision Support Systems

A multitude of data and information is needed for the economical and ecological assessment in enterprises. In manufacturing companies, sources for such data and information can be business information systems, such as Enterprise Resource Planning (ERP) systems or Plant Data Collection (PDC) systems. In such systems, information relevant to the company's cost and material flows are collected, processed and stored; this data can be used for assessing the resource efficiency of the enterprise.[8]

An important source for evaluating environmentally relevant factors and costs is the master data pertaining to, e.g., production planning and controlling (also see Section 3.2.5):

- The article master contains information on end products, assemblies and components, and may also include production and process materials.
- Bills of material depict the component composition of products.
- Activity charts describe production processes. An activity chart contains a description of the transformation of workpieces from the raw state into the manufactured state.
- The operating resources master data contains all the basic data about the individual operating resources and equipment. Operating resources and equipment comprise all the resources required for production, such as tools, machines and personnel. They are relevant insofar as that operating resources and equipment are substantial consumers in a production process.

The list shows that the use of company data plays an important role in assessing the resource efficiency of a company. If the available material flow and cost data are successfully utilised, the process of generating results within the scope of economical and ecological assessment can be much more efficiently designed. In contrast, business information systems do not include data for estimating the environmental impacts of companies' activities. For an effective assessment, ecological impact data needs to be linked with the information on material flows using existing indicators and impact assessment processes. To this end, the goal of the project CARE was to test, in practice, the suitability of the MIPS (Material Input per Service Unit, see Section 3.2.3) concept and the corresponding material intensity values for the purpose of assessing environmental impacts. In addition to the aforementioned business information systems, Environmental Management Information Systems (EMIS) represent a different, specific group of IT systems that can be used for assessing material flow related data under costs and environmental restraints. Hence, the project CARE examined the different options of using EMIS in combination with business information systems for the assessment of internal processes. A major outcome of this work is a Publicly Available

[8] Also see the results report from work package KP2.2 "ERP Systems and their Data Pool for Resource Efficiency Accounting" at http://www.oekoeffizienz.de/care/

Specification (PAS 1025)[9] for the exchange of environmentally relevant data between ERP systems and EMIS.

The PAS constitutes a standardisation in the form of a prenorm, which can be used at a later point in time e.g. for creating a DIN ISO standard. It was developed in co-operation with the Fraunhofer-Institut für Arbeitswirtschaft und Organisation IAO (Fraunhofer Institute for Industrial Engineering) and the companies: infor business solutions AG, TechniDataAG and ifu - Institut für Umweltinformatik Hamburg GmbH (Institute for Environmental Infomatics Hamburg GmbH).

The PAS describes an interface specification that enables the transfer of master data and any available movement data from ERP systems to an EMIS. Particularly for material flow management, such data is an important basis for conducting environmental impact assessments. The PAS 1025 thus represents an initial approach for the cross-system, standardised exchange of environmentally relevant data.

3.2 Methodological Approach

Based on the factors practicability and operation ability, a specific approach for implementing an IT-supported REA was developed in the project. This section describes the underlying approach of Resource Efficiency Accounting and presents the methodological approach for a practical enterprise-based application.

3.2.1 Definition and Limitations of Resource Efficiency Accounting

The efficient use of operating resources (in the sense of material and energy) pursues two fundamental objectives: on one hand, the internal activities related to the consumption of natural resources should be optimised, and on the other hand, associated costs should be reduced. The simultaneous consideration of these two objectives in conjunction with a continual improvement process is the task of Resource Efficiency Accounting. REA can therefore be seen as a decision supporting system for the enterprise. Data concerning internal material and energy flows and

[9] A PAS is a German prenorm, published by the German Institute for Standardization. The PAS 1025 can be obtained from the Beuth Verlag publishing house/ Deutschen Institut für Normung (DIN/ German Institute for Standardization)

costs involved therein is systematically collected, prepared and integrated into the existing internal decision-making process. Thus, the REA concept does not represent a new cost accounting system. The underlying cost concept comprises purchasing and procurement costs, production-related flow costs as well as the internal environmental costs.[10] The REA methodological approach aimes to expand environmental activity-based costing by adding material and energy flow information as well as ecologically relevant data from the pre-production chains. It therefore meets the criteria for an effective method tool, since lifecycle-wide data on ecological aspects are included via the mapping of pre-production chains. Accordingly, REA provides the starting point for expanding the cost accounting by adding the externalised environmental effects caused by enterprises.[11] However, this internationalisation takes place via the integration of ecological data and not through the extensive, costly and controversially discussed monetarisation of external effects.[12] Likewise, the lifecycle perspective is limited to ecological aspects. For the relatively complex procedure in the economic dimension refer to the approaches addressed by Fassbender-Wyands (2001) and Seuring (2001).

In mapping the objective function as a two-dimensional system with an integrated lifecycle perspective, REA differs significantly from existing environmental costs and process cost accounting methods.[13] First, it is based on material and energy flow optimisation concepts.[14] This applies to both the cost and material flow dimensions. In particular, the analysis of material and energy flows, i.e. knowledge of the temporal and locational distribution of deployed materials and energies in the course of the production, is an essential premise for being able to dynamically influence processes. To ensure further allocation of the material and energy data, all volumes/ quantities are recorded in weight units. In a second step, additional information on the lifecycle-wide ecological impacts is added.

Due to its orientation on internal material flows, REA can be practically and efficiently supported by business information systems as well as EMIS

[10] This definition of environmental costs is based on the systematic developed by Faßbender-Wynands 2001, p. 16. Due to the monetarisation issue, non-relevant microeconomic costs (costs of external effects) are not taken into consideration.

[11] See Schulz et al. 2000, p. 21

[12] See Busch/ Orbach 2003

[13] For a definition of environmental activity-based costing, see Letmathe/ Wagner 2002; for a comparison of the individual concepts, see Heupel/ Wendisch 2002, p. 3

[14] See Strobel/ Redmann 2002; Hockerts et al. 1999; Strobel/ Wagner 1997; Fischer/ Blasius 1995

(see Section 3.1.4). This can be realised on the basis of existing business information systems or in combination with EMIS. In particular, the environmental impact assessment step can be designed in an efficient manner by utilising the publicly available material intensity values for assessing the environmental impact.

3.2.2 Economic Dimension – Process Cost Accounting

The economic dimension of the REA takes data into consideration that is relevant for assessing the economic feasibility of decisions. This is primarily cost and activity accounting and the business accounting data. On principle, the economic dimension can be based on a company's existing cost accounting. However, the introduction of the REA presents itself an opportunity to conduct a critical analysis of the existing cost accounting allocation keys.

Mainly, material and energy consumption costs are often allocated to cost centres and cost units with low precision. This leads to distorting information on the actual cost distribution in a company.

The weak spots of traditional cost and activity accounting with respect to the provision of business information on eco-efficiency potentials are known and have been intensively discussed in the literature.[15] The causes for the limited expressiveness are considered to be lack of transparency in regards to (1) the company's process structures, (2) the company's cost structure, (3) the temporal structure of the cost incurrence and allocation as well as (4) the specific cost elements and structures.[16] To support decisions concerning this, conventional cost accounting systems were further developed and refined. In particular, process cost accounting is based on the concept that the activities of a company are categorised into processes and that operational procedures regarding material and energy flows, including their corresponding costs, are made transparent.[17] Process accounting is therefore especially well-suited as the basis of the economic approach of REA. Nevertheless, since there are expenses and efforts inherent in the process, it is only recommended for small enterprises to a limited extent.[18] Use of the REA is also possible within the scope of other

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[15] See e.g. Jasch 2001, p. 18; Remer 1997, p. 25 et seq.

[16] See Seuring 2001

[17] For a more detailed description of this, see Wagner/ Strobel 2003 as well as the Landesanstalt für Umweltschutz (State Institute for Environmental Protection) Baden-Württemberg 2000.

[18] See Loew 2001, p. 11

cost accounting systems, but crucial potentials can then easily be overlooked or are harder to identify.

3.2.3 Ecological Dimension – Material Intensity

In addition to economic information, REA provides company decision-makers with data concerning the ecological effects of their actions. The assessment data used in the REA is based on company internal material and energy flows. By means of a precise retracing of the internal material and energy flows, each process or product can be allocated to a specific, internal consumption. However, an assessment of the eco-effectiveness and eco-efficiency, two key factors in determining the "overall corporate sustainability"[19], based on this type of information is limited in scope. The outcome of internal flow analysis only enables a one-sided assessment of the ecological dimensions: If the outcome of a process optimisation or material substitution entails a reduced consumption of the respective material or energy, this is considered an ecological improvement. But beyond this, the method does not facilitate assessments and comparisons concerning various input factors (substances, materials and energy forms).

Moreover the issue of interdependencies and the complexity of ecological relationships also have to be taken into account: if material flow A is able to be reduced, how will material and energy flows B-Z react? Supposing other internal material flows are increased this way, how can it be assessed, in the course of an overall analysis, as to whether the ecological performance – allowing for all internal material and energy flows – improves or rather deteriorates? Furthermore, only examining internal effects, does not correspond to the concept of global sustainable development. Taken to the extreme, this would mean that a company outsources all procedures and processes not considered effective and efficient in terms of ecological aspects and subsequently presents itself as an ecologically successfully enterprise. For this reason, assessments and optimisations of ecological effectiveness and efficiency should always take into account the lifecycle-wide effects. I.e. the ecological effects of upstream and downstream processes have to be included in decisions. This affects the entire value-added chain as well as the using stage.

But how then can the aforementioned ecological interdependencies be recorded and mapped without counteracting or violating the factors and conditions previously described as essential to the practicability and operation ability of business tools? To this end, the data collected over the

[19] Dyllick/ Hockerts 2002

course of the material and energy flow analysis is linked with their respective material intensity value.[20] The inclusion of material intensities has three fundamental advantages: (1) Information on the ecological effectiveness can be derived from the results, since the material intensities describe the lifecycle-wide resource consumption of materials, energy and transports. (2) Complexity is significantly reduced, since results are represented as physical quantities. This enables a comparison of the different alternatives and substitutes, while also allowing a summation of different values of internal consumption forms. (3) Material intensity values do not have to be individually collected: they are provided for many substances and materials.[21]

For the purpose of determining the resource efficiency in the scope of internal assessment procedures, the material intensities are collected using the Total Material Requirement (TMR) defined on the macro level. The TMR value is based on the MIPS concept. MIPS stands for Material Input Per Service Unit.[22]

MIPS consists of two components, the Material Input (MI) and the Service unit (S). The material input comprises all materials primarily taken from or moved through nature, which are required on a system-wide basis, i.e. for production, demand and disposal processes. The determined material inputs are subdivided into five input categories; the unit of measurement is the mass in kg or t. The five input categories are: abiotic (non-renewable) raw materials, biotic (renewable) raw materials, soil/ground transport, water and air.

The TMR value sums up the first three categories, thus providing information about all material intakes, consumption and movements in the global environment. These inputs in the technosphere are called material inputs. The two categories water and air are not taken into account, since they usually do not contribute to new findings in terms of business optimisation decisions. In cases where this does not apply (e.g. when assessing the water conservation potentials in cleaning processes), these aspects can be separately taken into consideration.

The concept does not include output aspects; accordingly, resulting external effects and their damage potential are not mapped. This is certainly a weak spot if the claim of a comprehensive and all-embracing

[20] In this context, material intensity values are described as physical quantities (e.g. in kilograms or tons), see Ritthof et al. 2003, and not, as is the case e.g. with input-output analysis, in the form of monetary indicators; for more on the latter, see Wiehle et al. 2003, p. 49.

[21] See Wuppertal Institut 2003

[22] See Schmidt-Bleek 2004 and Schmidt-Bleek 1994

assessment is being pursued. However, to be noted here are three essential factors that nevertheless speak in favour of the approach of material intensities for ecological assessments: (1) scientifically, there is no definitive clarification regarding the way in which a comprehensive and all-embracing assessment can take place. This particularly applies to collection and evaluation approaches, e.g. in order to determine and compare different toxicity levels of substances or products. (2) A corresponding analysis and assessment is extremely time-consuming and costly, and would require a multidimensional results matrix. Consequently, this method is less suitable for application-oriented, practical processes. (3) To a certain extent, the output quantities not explicitly included are indirectly recorded via the input approach: all materials that are emitted or separated during the production process are first recorded and assessed as inputs.

3.2.4 Eco-efficiency: Objective Function

The objective of the REA is the simultaneous examination of economic and ecological aspects. As an objective function, REA hence defines both an economic and ecological dimension; both dimensions are mapped in a resource efficiency portfolio, thus permitting a differentiated analysis of processes and products. Therefore, one can differentiate between:

- an eco-efficient objective function,
- cost-efficient business strategies,
- resource-efficient business strategies, and
- ecologically-economically less relevant areas.

The REA can thus include individual operating processes as well as end products. In both cases, the objective of the portfolio is to provide Management with a decision-making basis for relative comparisons of two or more product or process alternatives. The individual axes of the portfolios are described by the material and energy flow based cost data (X-axis) and the material input oriented, ecological data (Y-axis). The respective values represent company-specific information, since they correspond to relative values of the overall company. The assessment is accordingly based on only two indicators that represent process costs as well as lifecycle-wide environmental impact data.

The goal of an ecological-economic optimisation of the product range and the internal processes is to include (in the scope of the eco-efficient objective function) as many as possible product variants and production processes of the company portfolio. Both, optimised products and processes, contribute to an increased resource productivity of the entire enterprise while simultaneously contributing to cost reductions.

3.2.5 REA and Data Collection Levels

The REA tool can be implemented or introduced in enterprises on a site, process and product level. The individual levels and the respective data collection steps are elaborated in the following sections.

The level of application depends on the company, internal and operational circumstances. The exploitation of the possible potentials depends on the expense and effort associated with them. Influencing factors include, for example, the absolute resource consumption, the ratio of material costs to the total company costs and the availability of the data.

REA on Company Level

The objective of the REA is to achieve transparency regarding internal material flows. When introducing Resource Efficiency Accounting, it is suitable to analyse the three levels: site, process and product. In a first step, the enterprise is viewed as a black box, and all incoming and outgoing material and energy flows of the company are registered. These material and energy flows are not assessed at this point, since this step is chiefly concerned with creating an initial overview of the corporate input and outputs.

For the most part, ecological input data is already available in companies (e.g. in Purchasing) or can be derived with little effort from existing information systems. Furthermore, there is a usually number of employees within a company that can provide information on material consumption. For example, the warehouse management department usually has data on consumption quantities and pertinent departments. Department heads and shift managers generally know which machines have downtimes and standstills and how much scrap is produced.

Data on the economic dimension is mostly already available in enterprises within the scope of other information systems[23] and can be taken from the cost and performance accounting or the business accounting (also see Section 3.1.4). For the cost accounting related analysis of a company's material flows, the accuracy with which the cost centre structure reflects the real material and energy flows of the company is a crucial factor. The following table shows where certain data can most frequently be found within an enterprise.

[23] See Hallay/ Pfriem 1992, p. 57

Table 3.1. Potential information sources and pertinent input-output balance data

Information Source	Available Data/ Information
Purchasing, Inbound Warehouse	• Goods received as indicated on delivery notes • Possible catch weight of materials • Type and amount of packaging materials used for incoming packaging
Interim Storage, Outbound Warehouse, Internal Logistics	• Consumption quantities of raw, production and process materials and pre-products for the individual departments, sites, machines, processes (via material requisition cards) • Annual inventory data • Quantities, volumes and weights of the manufactured intermediate and end products • Type and amount of packaging materials used for outbound packaging
Department Head, Shift Manager, Machine Operator	• Consumption quantities of raw, production and process materials and intermediate products • Energy/ water consumption data • Cost information • Type and quantity of waste/ scrap, volume of waste water
Environmental Protection Officer/ Management	• Consumption quantities of raw, production and process materials • Energy/ water consumption data • Figures related to type and quantities of waste water/ waste/ scrap • Emissions data
Waste/ Scrap/ Hazardous Goods Manager	• Specific waste/ scrap quantities and types • Allocation of waste/scrap quantities and types • Charge materials and quantity of hazardous goods/ substances • Storage/ location/ disposal of hazardous goods and substances • Recycling/ separation/ treatment • Data on emission volumes and types

Table 3.1 (Cont.)

Bookkeeping, Accounting	• Prices and quantities of pre-products, raw, production and process materials by means of registered incoming invoices • Costs and amounts of energy/ water consumption and waste water disposal as derived from the monthly/ annual financial statements of the supplier(s)/ waste disposal company • Data concerning waste/ scrap quantities, disposal routes and incurred costs from the invoices issued by the waste disposal companies • Costs incurred for handling emissions (e.g. filters)
Cost Accounting Controlling, Finance Department	• Primary (direct) costs of cost centres (e.g. for the material consumption/ requirement of individual processes/ machines) • Overhead (indirect) costs of cost centres (most often production and process costs, administration, lighting, etc.) • Analysis of the cost trends over time • Analysis of the cost trends according to cost categories

The input-output analysis has proven to be a practical method for collecting such data.[24] It is a collection and information tool, in which all relevant material and energy flows related to a reference period are structured and collected in accordance with a specified, comparable methodology.

In an input-output analysis, the way in which the data is collected should enable allocation of the corresponding rucksack factors in the form of material intensities, e.g. in kilograms or tons. Moreover, internal balances should be designed in a way that permits them to be continuously maintained and updated.

At the conclusion of the input-output analysis, material flow data is provided at the company level; the data can be used for formulating long-term company objectives and assigning precise indicators for evaluating these objectives in an understandable manner. Thus, for example, a reduction in the internal material flows by a certain factor can be controlled by means of an annual input-output balance. In addition, it is possible to reconcile such material flow data with economic indicators in

[24] See Hallay/ Pfriem 1992, p. 58

order to determine the resource productivity of the entire enterprise. Within the scope of internal and external communication, the results can be made available to stakeholders, such as employees or customers.

REA on Process Level

On the process level, the data collected in the input-output analysis is assigned, on a usage basis, to the individual production processes. This serves the purpose of identifying which company processes are responsible for what material and energy consumption. A process is to be understood as a sequence of functionally, spatially and temporally interconnected job steps, which aims at achieving a specific end result via the use of materials and energies.[25]

The black box view of the enterprise is resolved by representing the individual process in a process diagram. The process diagram can thus be oriented on available material flow plans or similar information and has flow diagram properties. The diagram shows the processes with their reciprocal interdependencies. The connecting links between the processes are the internal material and energy flows as well as the information flows. Separate input-output balances are prepared for the identified processes, thus ensuring that the share of each process in relation to the company's total material and energy flow is made transparent. The procedure for the corporate process analysis is described in the following.

The processes interact with the environment via material flows that enter or leave the company. The processes are only functionally linked in the process diagram, i.e. the flow factors are not quantified yet.

[25] See Hallay/ Pfriem 1992, p. 80

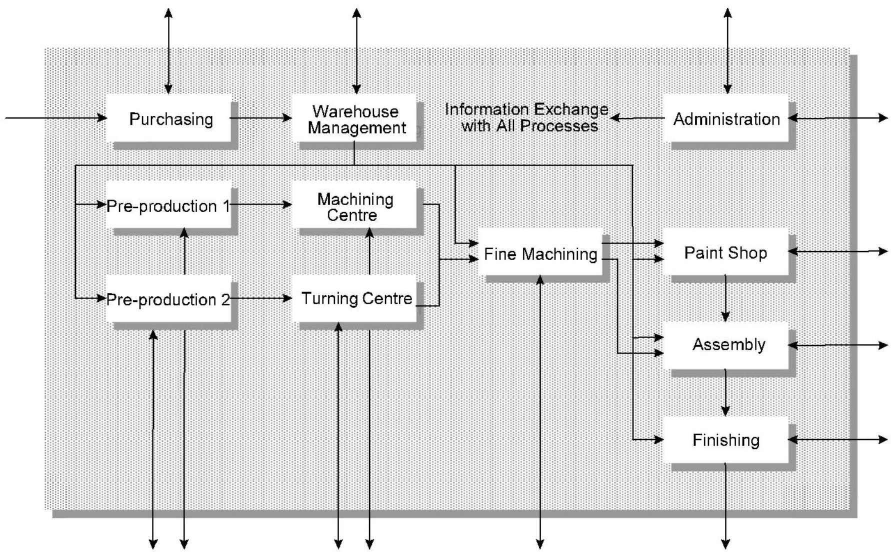

Fig. 3.1. Exemplary process diagram of a metal processing company

In a second step, the material flows are quantified within the scope of the process accounting. The process accounting aims at structuring and balancing the inputs and outputs of the individual processes to allow material intensities to be linked to the results in a further step. For the purpose of further structuring, it is suitable to subdivide the inputs into raw materials, process and production materials, energy and energy carriers. Wear and tear of operating resources is inherent in every production process, which is the reason why the operating resources have to be proportionally taken into account as material inputs when determining the total material consumption. In an initial approximation, it is possible to "quantitatively write off" the operating resources by means of linear depreciation over the period of their average useful life. Tool wear also falls into this category. Furthermore, other inputs also have to be included, such as material consumption arising from the services required for the process. A similar differentiation is carried out on the output side. The analysis of the output side is necessary for linking processes and procedures. Internal outputs are forwarded to downstream processes within the company. As a rule, the outputs comprise the main product of the process under consideration as well as internally processed by-products. External outputs consist of all the by-products (provided they are not internally processed), emissions, waste and residue materials, waste water, etc. of the process.

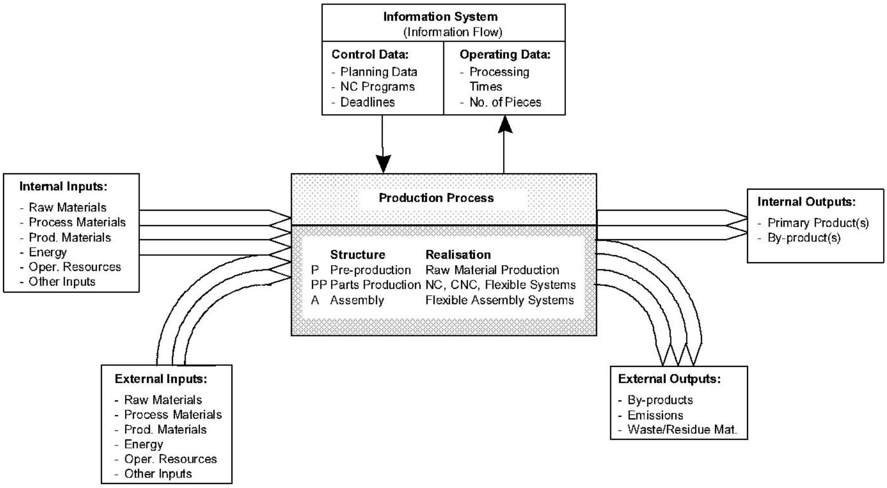

Fig. 3.2. Inputs and outputs of a production process

For each identified process, a separate input-output balance is created that includes all inputs and outputs in a structured form. The material flow factors are specified in standardised weight units such as kilograms (kg), in order to allocate to them, in the next step, the ecological rucksack in the form of material intensities.[26] To this end, an appropriate temporal or quantitative reference quantity is specified for assigning the material flow factors. This can be, e.g., a production shift or 1000 pieces of a defined intermediate product. The determination of the material intensity of a specific process is not based on the sum of all the inputs of a process: the (end) product to be manufactured is produced from raw and process materials on a step-by-step basis. Raw and process materials are counted at their point of entry into the production process. If they appear in further processing steps, they are not recorded again, otherwise the multiple counting would result in all of the company's inputs being cumulatively allocated to the last process (e.g. final inspection). It would then be impossible to perform a hot spot analysis on the process level focused on material or energy consumption. Consequently, *internal inputs* in the form of raw materials and process materials are not included in the equation on the process level. The basis for determining the material intensity of a process therefore results from the determined input quantities minus the internal raw and process materials. The determined materials and energy

[26] Two exceptions are electricity and water, which are specified in kWh and MJ, respectively.

consumptions are then correlated to the associated material intensities. The result of each of the individual inputs is described by means of the five MIPS categories, which are summed up in the next step for the purpose of determining the total material intensity of the process. The water and air categories are disregarded in the determination of the TMR value (see Section 3.2.3).

Since cost accounting does not usually allocate detailed individual costs for each input factor to individual processes, the costs of the processes are collected in a similar procedure.[27] This procedure is relatively simple, since the specific consumption quantities can be taken from the process-based input-output balances. The costs of the individual inputs for the entire company are available, but they only have to be allocated via consumption quantities and keys. Practical experience shows that the appropriate allocation and determination of process costs already results in a different picture of the company; often subprocesses which at times had been classified as rather irrelevant are now identified as significant cost drivers. The result of the process analysis is described by means of *a resource efficiency portfolio* on process level. It serves as basis of a "screening process" for identifying economic cost drivers and ecologically relevant areas within a company. The resource efficiency portfolio divides the processes with respect to the cost (EUR) and material/ energy consumption (based on material intensities) categories into four quadrants. The high and low rating is determined on a company-specific basis and is a relative index of all processes of a company.

[27] For more information refer to Schaltegger/ Müller 1998 or US Environmental Protection Agency 1998.

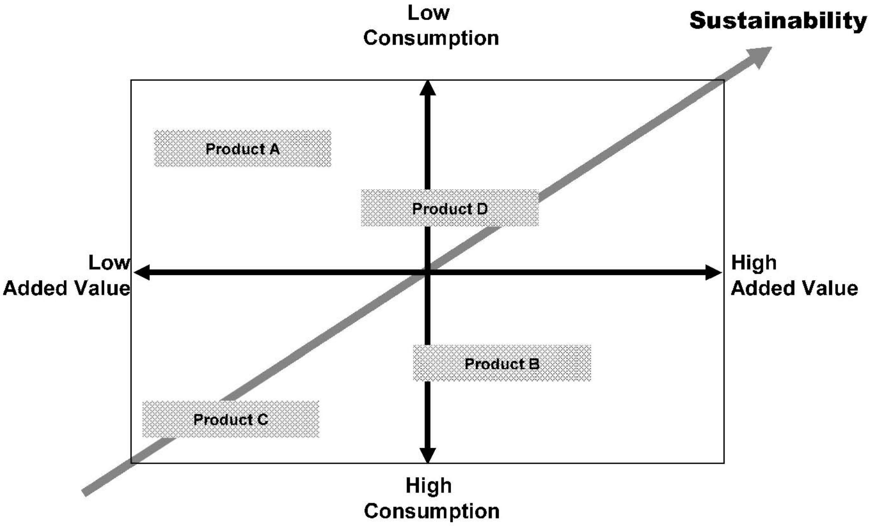

Fig 3.3. Example of a Resource Efficiency Portfolio on the process level

In the example (see Figure 3.3.), the paint shop would be the internal hot spot of the company. In regards to the goal of optimisation, processes should move into the premachining position of the chart. Various recommendations for action now arise as a result of allocating the individual processes to the respective quadrants (see Table 3.2).

Table 3.2. Action strategies for process optimisation derived from the resource efficiency portfolio on process level

	High Costs	Low Costs
Low Consumption	Selective approach, analysis and, if applicable, optimisation of individual cost factors	Good ecological performance and low economic relevance; thus no acute need for action
High Consumption	High ecological and economic relevance: top priority, hot spot on process level, systematic search for savings and substitution options	Selective approach, analysis and, if applicable, optimisation of individual input factors

The effective reduction of materials and energy is crucial to the economic-ecological success of the enterprise as a whole. The highest potentials result from the "high/ high" categories. They should be assigned top priority and could be the first processes to be subjected to an in-depth analysis, for example within the scope of an environmental protection program, since optimisation can result in the greatest savings effects here. Moreover, strategies for action can also be developed for the other quadrants; the respective processes then have to be handled in accordance with these strategies.

Depending on the objective of the internal process analysis, it can be of interest to disregard single factors when calculating the material intensity of a process. In some cases, for example materials that are used for a product (i.e. all raw materials) are determined by the design and should not be included in optimisation considerations within the course of a process analysis. In such cases, it can then be suitable to assess the process using only the material intensities of the deployed production materials and operating resources as well as the energy consumption.

REA on Product Level

Along with the process optimisations on product level, REA focuses on optimising the product range. To this end, REA strives to identify exemplary products in terms of eco-efficiency criteria. In this case optimisations potentials on the process level should have been realised. For a further optimisation on the product level, the company should have at least two different product ranges that provide a similar or identical customer benefit.

"Mass-based accounting" refers to a systematic classification and arrangement of the internal material and energy flows for each (end) product. The goal is to allocate the total consumption of the company to the manufactured products on a usage basis. Direct (individual) masses that are directly used for a product can be directly assigned to the product. Overhead (shared) masses cannot be directly allocated to a product, since they apply to several products at the same time (e.g. lighting or material inputs related to administration). In mass accounting, they have to be allocated to mass centres via an allocation key. In principle, mass centres comprise all of the operating equipment used for the production, distribution and sales of several products. Ideally, mass centres and cost centres are identical, thus facilitating the allocation process.

It becomes clear that in order to determine the internal material and energy flows of each (end) product, using a relatively detailed procedure, the consumption values of the individual processes can be summed up and allocated. The procedure is based on the results of the input-output analysis and the internal process analysis. The more detailed the preceding steps were carried out, the lower the effort required for the internal mass accounting. The material intensity values are included at the end of the calculation, when all inputs per product are summed up. The costs also form the basis for the assessment in the economic dimension. If a detailed cost accounting system exists, the values for calculatory individual unit costs can theoretically be adopted. Practical experience has demonstrated that a precise tracking and allocation of the costs determined on the basis of the material and energy flows can lead to a very different result.[28] Similar to the procedure for the ecological dimension, the individual cost factors of the processes have to be assigned to the products. As previously mentioned, an analysis of the existing keys for overhead costs (e.g. for energy consumption) is particularly important. It is precisely in that area where the largest number of deviations usually arises.

A one-sided cost accounting does not appear suitable here,[29] since in contrast to the process level, on which the manufacturing costs are especially relevant in regards to economic analysis,[30] relative factors in the form of added value have a larger economic significance at the product level. By means of profit per unit or contribution margins, the determined unit costs can therefore be used to generate information on the economic-efficiency of individual products.

Analogous to the analysis on the process level, the products are again arranged in a resource efficiency portfolio. In the following diagram (Figure 3.4.), the products are mapped according to their added value (EUR) and their material and energy consumption (based on material intensities). Again the border between high and low is determined on a company-specific basis. It is important to mention once again that this analysis deals with product alternatives. That means that product A can be substituted by product B, without significantly changing the benefit(s) for the customer/ consumer.

[28] For more information, please see e.g. Wagner/ Strobel 2003

[29] See Haake 1996, p. 21

[30] See Gotsche 1995, p. 10 et seq.

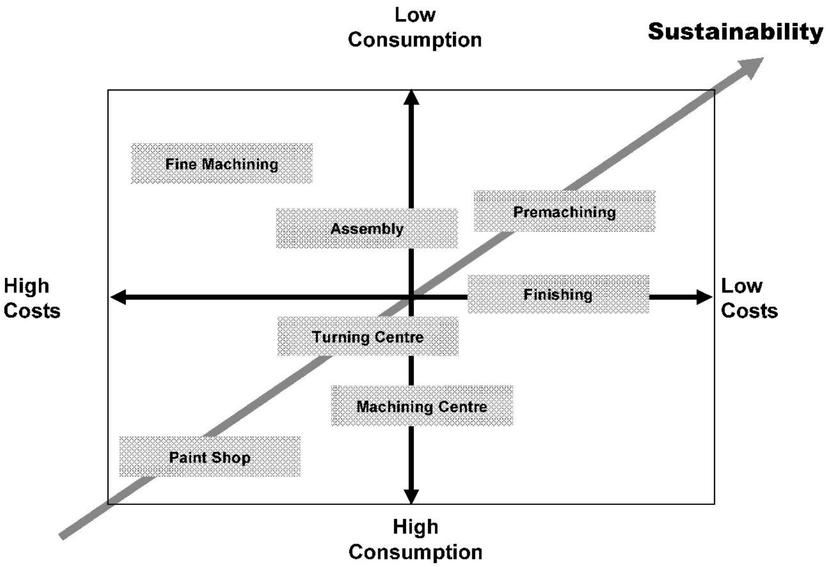

Fig. 3.4. The resource efficiency portfolio on the product level

Action strategies for product optimisation can be derived from the respective resource efficiency portfolios. The table 3.3 below provides an overview.

Table 3.3. Action strategies for product optimisation derived from the respective resource efficiency portfolio on product level

	Low Contribution Margin/ Profit per Unit	High Contribution Margin/ Profit per Unit
Low Consumption	Ecologically sound products; identifying potential(s) for increasing added value, e.g. using targeted marketing as low MI product	Economically and ecologically successful products; sales promotion through marketing as sustainable products
High Consumption	Less economically and ecologically advantageous products; aim should be substitution of products; if necessary tracing the causes on process level can be useful	Economically sound products; thus analysis of ecological weak spots via examination of substitution options for the used high-consumption or energy-intensive materials

For the discussion regarding the optimisation potentials, it was assumed that the products being analysed provide the same customer benefits and that process optimisation has already been implemented to the greatest possible extent. Therefore, the question to be addressed is: What suitable strategy should be defined if all optimisation potentials have been exhausted, but the economically successful products have a comparably high material and energy consumption? In this case, a more precise examination of the usage phase can be helpful. Potentials for reducing the consumption per defined service unit can especially be identified for use-intensive products. The difference between production and use intensive products is, that the production phase dominates the lifecycle-wide material consumption (e.g. furniture). With use intensive products the utilisation phase of the product is linked to the most dominant material consumption (e.g. washing machine). Thus, optimisation of the utilisation phase, e.g. by extending the product's service life, is in this case of central importance. In this regard, individual products are no longer assessed, but rather the services associated with the product. This approach attempts to emphasise a long-term service orientation and as a result, describe a two-fold effect: on one hand, the material intensity can be reduced, and on the other, additional benefits can be generated for the customer/ consumer.

Therefore a sustainable enterprise should aim at optimising the entire life cylce of a product. This plays a particularly important role in regards to product conception and design, since it is during these stages that the material consumption of the production, the utilisation phase and the recycling/ disposal phases are determined. A consideration of lifecycle aspects within the scope of the product design thus comprises optimisation of the material composition, reduction of the resource-consumption of the production and utilisation phases, a high repair and recycling capability of the end product as well as the disposal of residues and waste materials.[31] The economic dimension also calls for the early inclusion of these aspects during the production and product planning stages, since it is here that approx. 80% of the accrued costs are determined for the development, manufacturing and utilisation of products.[32]

REA Success Factors and Implementation Concept

As a central success factor for the implementation of the REA, the topic of resource efficiency should not be considered separately in management/ staff departments or specialised departments, but rather across all company

[31] See Schmidt-Bleek/ Tischner 1995, p. 21

[32] See Tischner 2001

departments and divisions. In the implementation projects, teams comprising five until eight people from various departments were formed within the companies. This approach was proved applicable, since the different experts could contribute their special know-how to the process. Furthermore, it created a basis for the company-wide acceptance of the REA.

The REA method presented here is based on detailed information about internal material and energy flows as well as the corresponding costs. Depending on the status of the cost accounting systems existing in the company, those costs sometimes have to be specially evaluated and allocated. As this process is a complex process, introduction of the REA on the basis of the described approach is dependent on the use of financial and personnel resources. However, this expense and effort is mainly required during the early stage of the project.

For the implementation a project team consisting of employees with key qualifications and competencies from all areas of the enterprise should be formed. To this end, the team should especially comprise employees who (1) possess experience and know-how regarding raw materials, consumption and purchasing quantities and who are in contact with suppliers and thus have an overview of the scope of delivery, delivery times, etc., (2) have a technical overview as well as longstanding employment with the company and therefore have precise knowledge on internal procedures, processes, operations, etc. and/ or (3) have IT experience or are in charge of operational/production control.

Based on the findings and experiences of the CARE project, a qualification concept was developed for conveying the contents, methodology and implementation of REA.[33] The concept consisted of four modular, interdependent qualification components to support employee training, the establishment of sufficient process transparency, the active inclusion and commitment on the part of the employees and the permanent embedding of the REA in the enterprise. Experience has proven that it is practical to design the introduction phase as a moderated process. The first step is therefore to designate someone in charge. This can be either a competent employee or an external moderator. His task is to plan and carry out the training measures and organise the activities. In principle, the REA is suitable for any company, regardless of size or sector. Nevertheless, company-specific differences exist, which can be either conducive or obstructive.[34] An in-depth implementation as described in the previous section may therefore be less feasible under real conditions. Material and

[33] See http://care-oekoeffizienz.de

[34] See Busch/ Beucker 2004, p. 142 et seq.

energy flow analysis can be associated with a high amount of expenses and effort. Especially for companies that are dealing with the topics of environmental costs and resource efficiency for the first time, it is often difficult to justify such expenses, since the cost-benefit ratio is hard to determine in advance. Furthermore, small and medium sized enterprises are frequently faced with an entirely different problem: they lack the necessary capacities required for an implementation process.

In this case they can conduct a more general initial analysis using a less complex model. The following section briefly outlines how a less complex "introductory" model – thus particularly appropriate for small and medium-sized enterprises – can be implemented on the process/company and product levels.

1. On process/ company level, the goal is to improve the eco-efficiency of the entire company by means of the targeted optimisation of a process. As a first step, the primary material and energy consumptions can be determined (as a guide number, 6-10 are sufficient). Usually, a complete input-output balance does not have to be prepared for this purpose. The relevant core factors are sufficient for a first analysis. The required annual consumption figures as well as the associated costs can e.g. be obtained from accounting. The corresponding total annual consumption figures are then linked with the respective material intensities[35], with the result being the lifecycle-wide impact of the most significant material and energy flows. This enables identification of the company's central consumption value(s). The next step is to identify the internal process that plays the main role in the consumption or processing and which, according to a subjective assessment, has or is presumed to have an optimisation potential. In general, these are processes, which also give rise to the greatest cost saving potentials. This process is thus also the internal hot spot; the eco-efficiency objective function strives to implement optimisation here, since this could lead to the most effective impact in terms of the entire company.
2. When focussing on product optimisation, the step of outlining and mapping the internal material and energy flows can be bypassed within the scope of an initial optimisation strategy. For the purposes of defining the eco-efficiency objective function, the main component(s) (guide number: 90% of the total weight) of products for which there are alternative production options should be identified first. The result should comprise specific weight information for each main component that is used for the end product. The respective product data can then be

[35] See http://www.mips-online.info

linked with the material intensities and subsequently summed up. The result describes the lifecycle-wide environmental impact of the various product alternatives. For the economic dimension, the relative profit share can be calculated. For this, the production costs of each product are taken from the cost and activity accounting. If there is insufficient information in regards to this, approximation values for the production costs can be determined using the accounting pertaining to the previously identified main component. The difference between the selling price and the production costs can then be formulated as the profit share of each product. The profit share in relation to the respective production costs can be designated as a relative profit share. In conjunction with the environmental impact, this value forms the basis for the eco-efficiency assessment of the product alternatives. The objective function can then either be a sales-increase of the product with the best economic-ecological performance or optimisation of the product with the worst result.

3.3 Case Study: Toshiba Europe

3.3.1 Initial Situation and Objective

Toshiba Europe GmbH - Regensburg Operations (TRO) is part of the globally operating Toshiba Group, which manufactures high-quality devices for the office, entertainment and medical electronics sectors. At the Regensburg/ Germany site, computer notebooks in a variety of models are produced and configured for the European market from assembly kits or from semi-finished products. Assembly and configuration processes take place in various production lines with varying levels of production depth ('Semi-Finished-Goods', 'Final Assembly and Test' and 'Frame'). Regensburg is a site with relatively low production depths. In principle, the consideration of lifecycle-wide environmental aspects is consequently of particular importance at the site, since this is the only way of providing effective decision-making support that maps the actual environmental impacts. Toshiba has undertaken to comply with internationally applicable environmental protection guidelines for the purpose of promoting environmental protection at all sites. A validated environmental management system in accordance with EMAS (EC eco-audit directive 1862/93) has already been in place at the Regensburg site since 1996. In line with the implementation of the environmental management system, the measurement and improvement of environmental performance are the key objectives of TRO's environmental management.

The aim of the CARE implementation project at TRO was to establish a systematic eco-controlling system at the Regensburg site. In this context, the existing environmental performance indicators (called "eco-efficients") should be more specifically assigned to specific causative agents. Furthermore, the environmental management system was to be expanded with a systematic and parallel consideration of the material flow related costs. In addition, the eco-controlling system should also be transferable to other Toshiba Group sites.

The Resource Efficiency Accounting method appeared suitable for generating pertinent indicators and integrating them into an ecological-economic decision-making system. The data collection and analysis steps could largely be supported by the already existing IT systems.

3.3.1 Procedure

With the aid of the EMIS Umberto®, an internal material flow analysis was performed in the course of the project. The results concluded that a large portion of the required materials and energy were already being efficiently used. Nevertheless the material flow analysis made evident that in addition to the product related primary mass flows, the mass flows attributed to the supplier packaging in the 'Final Assembly and Test' production line is conspicuously large. At the Regensburg site, supplier packaging particularly amasses due to the delivery of key components used for notebook production. The cost effects and environmental impact associated with the packaging were therefore subjected to a detailed analysis. As measurement indicators for analysing the resource efficiency of different transport packagings, the waste material costs and material intensity (MI) values of different packaging variants were recorded and compared. Figure 3.5 provides an example of the material flow analysis for individual relevant to packaging.

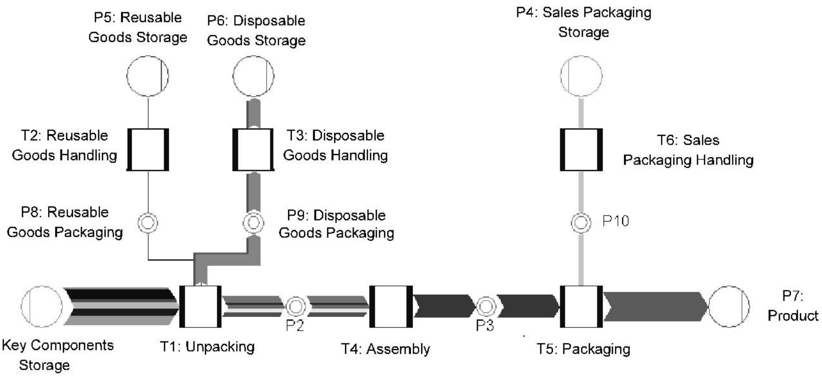

Fig. 3.5. Detailed analysis of packagings, utilising Umberto®

The detailed analysis found that transport packaging used by the various suppliers can greatly differ in terms of cost effects and environmental impacts at the site. The identified cost effects and environmental impacts of the packaging variants were compared with one another and contrasted as best case and worst case scenarios.

In detail, the waste material costs recorded for each packaging variant comprise the following:

- Unpacking costs: costs attributed to unpacking components at the site.
- Repacking costs: costs attributed to repacking components into boxes for supplying the production lines.
- Handling costs: costs attributed to transporting the packaging waste to the company's own disposal facility as well as to the sorting involved.
- Disposal costs: costs attributed to the waste being removed by various disposal companies.

In addition to the cost blocks described above, transport-specific costs for the different packaging variants were identified in relation to the country of origin, volume and weight.

The environmental impact of the packaging variants was determined in the form of streamlined LCAs[36] and with the inclusion of the corresponding MIT values as impact indicators for the respective lifecycle phases (production, utilisation and recycling/ disposal).

[36] For more on the Streamlined LCA approach, see Christiansen et al. 1997

3.3.3 Results of the Resource Efficiency Accounting at Toshiba

The most significant results of the analysis can be summarised as follows:

Costs: from among the cost blocks described above, the transport as well as the unpacking and repacking costs represent the largest cost effects of the supplier packaging. The potential savings justify the integration of the results into the existing procedures for evaluating suppliers. In comparison to the unpacking/ repacking costs, the handling and disposal costs reflect a relatively small share. They amount to less than 1% of the total sum of the waste material costs and transport costs. *Environmental Impacts:* the largest share of the environmental impacts attributed to supplier packaging arises from transporting the packaged products via air freight. In contrast, the environmental impact of the packaging itself amounts to only a small share (< 10%) of the environmental impacts caused by packaging.

In regards to the selection and optimisation of supplier packaging, the following statements can be derived from the aforementioned results:

- Reducing the quantity, mass and volume of packaging takes top priority from both a cost and environmental protection standpoint. Large mass and large volumes of packaging have a high correlation to high transport and personnel costs.
- The efficient utilisation, planning and arrangement of air transport represent a high priority from both a cost and environmental protection perspective. Since virtually all components are delivered via air freight, stopovers should be eliminated and the packaging volume should be as small and light-weight as possible.

The pivotal result of the Resource Efficiency Accounting at TRO thus underscored the fact that the various used materials do not represent the decisive factor for the optimisations, but rather how such materials are utilised and deployed. In this context, it was essential to not only precisely analyse the procedures and processes, but especially examine the lifecycle-wide environmental impacts through the use of an integrated method.

3.3.4 IT Based and Organisational Implementation of Resource Efficiency Accounting at Toshiba

In order to permanently embed Resource Efficiency Accounting as a tool for assessing supplier packaging at Toshiba, the results will most likely be integrated into the production database and incorporated into future business processes. In terms of IT support for analysing supplier packageing, excellent prerequisites exist at Toshiba, as component and product relevant data is already stored for quality assurance purposes. Since defined packaging variants can be assigned to specific components, expanding the master data structures in Toshiba's information system can enable allocation of environmental and cost-specific packaging indicators as well as an analysis of the actual arising costs and environmental impacts. The input and maintenance of the costs and environmental impacts in the form of MI values, as is required for such an analysis, is facilitated by a tool managed by the environmental management team at the Regensburg site. A prototype of the assessment tool was integrated into TRO's business information system during the course of the project.

The packaging-specific indicators can be evaluated using resource efficiency portfolios. The different departments at the Regensburg site are thus provided with specific evaluations for ecological-economic optimisations. The results of the analysis are mapped in the resource efficiency portfolio as economic values (euro per piece) and ecological values (material intensity per piece). This enables the direct comparison of materials, processes or products in regards to the ecological and economic characteristics. Two typical packaging alternatives of various suppliers are compared in figure 3.6, with the packaging from Supplier A being the more cost-effective and environmentally friendlier option.

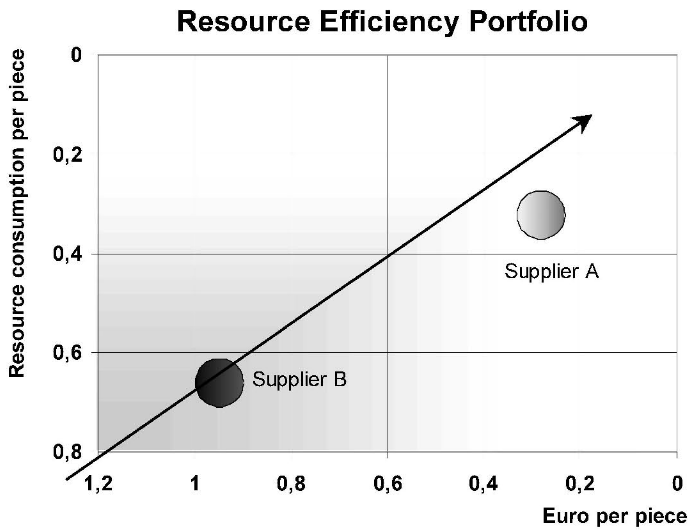

Fig. 3.6. Comparison of suppliers by means of supplier packaging in the resource efficiency portfolio

By defining specific controlling processes, the analysis can be integrated into existing TRO processes, for example supplier rating or quality management. Moreover, the results can be incorporated into existing assessment systems, e.g. management reviews. At present, the transferability of the method to further production lines is being tested.

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