Energy Cost Accounting: Conventional and Flow-oriented Approaches

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Abstract

In more and more companies, energy efficiency and energy cost come to the fore. The scope ranges from energy consumption and energy delivery cost to energy losses and the infrastructure facilitating the use of energy. Their increasing importance asks for more transparency of the cost of energy consumption, losses, and conservation potentials. However, despite of the identified relevance, no mature concepts exist to record energy-related cost in a way that consumption and losses become transparent. Consequently, based on the characteristics of the production factor energy, the paper presents options for a sophisticated energy cost accumulation and assignment in conventional cost accounting and flow cost accounting methodology.

Key words: energy cost, energy cost accounting, flow cost accounting

1. INTRODUCTION

More and more, increasing energy prices, energy-related taxes, carbon levies on the input side and climate change and CO2 emission reduction on the output side attract notice to energy efficiency (useful measured as energy output to energy input) improvements and energy cost in industrial enterprises. But, energy cost and energy efficiency are often put on a level only with energy use and energy delivery cost. Energy losses and the energy-related infrastructure facilitating the use of energy (e. g., energy distribution networks, transformers, and heating systems) as well as the corresponding processes are mostly disregarded (Fünfgeld, 2006). But, neglecting energy losses and energy-related infrastructure and processes causes the risk that existing rationalization potentials remain idle (e. g., reducing compressed air consumption in manufacturing processes instead of reducing compressed air leakages). From this and the increasing importance of energy use and conservation it accrues the need for more transparency of energy consumption, losses and the resulting cost: The cost of energy use and loss should be systematically accumulated, assigned and analyzed in cost accounting. But energy consumption and losses and the cost they incur have been widely disregarded in economically as well as ecologically-oriented cost accounting concepts. In fact, over the last 50 years the subject "energy cost" has been taken up by researchers, but up to now no mature concepts exist to record the cost of energy use in a way that energy consumption as well as energy losses become transparent.

Against this background the paper's objective is twofold. First, the characteristics of energy and its cost accounting implications are presented as a prerequisite for an accumulation and assignment of the cost incurred by energy consumption and losses (section 2). Second, two accounting approaches are presented: (1) an energy cost accounting concept based on conventional German cost accounting (section 3), and (2) an energy-sensitive approach of flow cost accounting—a partial accounting system for the identification and analysis of energy

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inefficiencies and its interdependencies to conventional energy cost accounting (section 4). A summary and conclusions for further research are presented in the fifth section.

2. ENERGY AND COST ACCOUNTING

2.1 Major purposes of energy cost accounting

Cost accounting is a periodical report and a short-run internal profit and loss statement (Hummel & Männel, 1986). Commonly, it comprises the measurement, accumulation, assignment, and reporting of cost information resulting from the production and sales of goods and services. Cost accounting is a major means providing the management with short-run planning and control information. But, in "conventional" cost accounting, all the potential cost information needs cannot be considered simultaneously and at a high level. In particular, this applies to information and controlling needs of specific organizational units or the controlling of factors of success. In order to meet particular accounting purposes too, e. g., of energy and energy efficiency management, partial cost accounting concepts have been developed.

Energy cost accounting can be taken as such a partial cost accounting concept. Its objectives result from the management's need for information about and controlling of the company's energy consumption, losses, efficiency, and cost. To meet these needs it is necessary to identify and analyze the total energy-related consumption and losses of goods and services of the company's processes—in particular in manufacturing, logistics, energy supply and demand—in order to accumulate the costs related to the company's desired and undesired energy flows. This establishes the basis to provide information for energy-related planning, monitoring and controlling of production systems, process chains, internal logistic elements (e. g., forklifts and handling equipment), and the product portfolio (e. g., energy cost shares in the products' cost of production). Detailed information about energy consumption, losses and costs can be used to identify energy inefficiencies and saving potentials as well as to evaluate measures for improvements (e. g., measures to reduce process heat losses), to valuate internally generated energies (e. g., process heat, compressed air), energy and energy loss flows and to control the energy conserving behavior of the management and staff.

To provide the right energy related cost information in an appropriate granularity by energy cost accounting, the characteristics of industrial energy and energy consumption and their conceptual cost accounting implications have to be analyzed in advance.

2.2 Characteristics of the production and cost factor "energy"

In physics, energy is defined as the ability of physical systems to work on other physical systems and therefore produce dimensional changes, changes in positions and state changes in the systems (Moran & Shapiro, 2006). In business administration, energy (or energy sources) is a production factor whose generation, supply, waste disposal etc. cause costs. When considering physical and economic aspects of the production and cost factor energy, it shows miscellaneous characteristics that should be taken into account for the design of a partial cost accounting concept for energy cost accounting. These can be categorized as follows:

1. the diversity of energy sources and forms of energy
2. the actual energy demand as a demand for useful energy

3. fluctuations in energy supply and demand
4. implications from the laws of thermodynamics

Usually, companies simultaneously use several *energy sources* (e. g., coal, gas, electricity). The energy stored in these sources can be transformed into multiple forms of energy (e. g., electrical, thermal, chemical energy). Although, for most of the energy sources, it is possible to either purchase them or generate them in-house (e. g., electricity, heating steam), there are some energy sources that cannot be procured in the market. They have to be produced in-house (e. g., compressed air).

The necessity for in-house generation also applies to the *useful energy* that is the actual form of energy needed in production processes (e. g., mechanical energy, heat, light). Useful energy is not tradable. In fact, in every case some energy source has to be procured in the market and its energy has to be transformed into the needed useful energy by means of energy converters and other energy-related equipment (Lucas, 2010).

Beyond that, temporal, capacitive and quality *fluctuations* of the in-house energy supply and demand (e. g., times of day, frequently changing process conditions) contribute to a high diversity and complexity of the energy-related processes in a company.

Referring to the first law of *thermodynamics*, all energy consumed in a company can neither be created nor destroyed. It can only be transformed, i. e., changed from one form of energy into another (Moran & Shapiro, 2006). From an economic point of view this implies that energy is always both input (production factor) and output (product) of a process. Therefore, they are strictly speaking joint production processes that generate energy as main product or by-product (Riebel, 1955). Furthermore, as energy is input and output of every process and can only be transformed from one form into another, the input energy always consists of the share of energy that is transformed in useful energy (the amount of energy that is unavoidably needed to perform the intended process) and another share of energy (that may theoretically be avoided, but is also necessary to perform a real-life process and, thus, has to be classified as an energy loss; waste heat for the most part) (Moran & Shapiro, 2006; Lucas, 2010).

These characteristics cause various implications for energy cost accounting. They range from the energy cost definition over the accumulation and valuation of the energy consumption as well as the energy cost assignment, the determination of the cost of energy losses to the disclosure of energy costs in product costing.

2.3 Implications for energy cost accounting

If energy consumption is construed as a consumption of goods and services and costs as the monetary amount that is caused by the consumption of these goods and services (Götze, 2010; Horngren, Foster, Datar, 2000), then energy costs are the monetary amount that is caused by energy consumption. In most of the cases the consumption of goods and services can be appraised on the basis of factor prices (as the prices of production factors that can be procured in the market). However, as not all energy sources can be procured in the market and are tradable, respectively, not for all energy goods and services factor prices are available. As already described with the first two characteristics, the cost of nontradable and in-house produced energy has to be reverted to the factor prices of the final energy sources and energy converters used to produce these energies (Müller, 1964). Beyond that, also energy distribu-tion networks

(e. g., power cables, compressed air lines, heating and steam pipes), storages for energy sources (e. g., oil tank, water tank, coal storage tower), the disposal of energy-related wastes (e. g., ash, slag) as well as the corresponding management and administrative tasks cause a consumption of goods and services. Thus concluding, energy costs have to be defined as the total monetary amount that is caused by the consumption of goods and services for the internal energy supply (Schmidt, 1960; Kern, 1981; Fünfgeld, 1998).

Along with the first two characteristics, desired and undesired fluctuations in energy supply and demand pose a challenge for metering and accumulation of the energy consumption. On the one hand, given the diversity and complexity of a company's processes and with a view to the informative value of an energy cost accounting, a sophisticated and accurate metering and accumulation of the consumption (chronologically and with regard to contents) should be preferred. On the other hand, the more sophisticated the metering the higher the cost they incur. Therefore, the economic efficiency of energy cost accounting gives the limit for the granularity and accuracy of consumption measuring (Müller, 1964; Layer & Strebel, 1984).

The diversity of energy forms and the purposes of energy use will make the appraisement of the energy consumption difficult. To point that, the example of procuring and providing external energy (sources) like electricity or gas is used. Electricity and gas rates consist of different fix and variable price components (i. e., basic rate, kilowatt-hour rate, system usage fee, meter rent) whose amounts again vary dependent on the various drivers (e. g., quantity delivered, type of billing, duration of contract, load balancing) (Konstantin, 2009). So, already the determination of the delivery costs for such energy (sources) poses a further challenge. Moreover, the costs for internal transportation and supply to the points of use (e. g., for the energy distribution networks, energy converters) have to be included, too.

In terms of energy cost assignment, beside the already mentioned diversity and complexity of energy use also the characteristics derived from the laws of thermodynamics have to be considered – that energy input is transformed into useful energy and energy losses and that strictly speaking all processes are joint production processes. Firstly, the joint production process characteristic and the assignment of the cost of the process' main and by-products on the basis of the causer-pays principle or Riebel's identity principle are mutually exclusive. This is due to the fact that in joint production multiple products are created as part of one individual production process "for which there are no demonstrably clear-cut costs beyond those incurred for the main process" (Bragg, 2002, p. 348). Instead, the cost accountants have to make simplifying assumptions about the cost assignment. That means they have to use cost allocation rules that do not base on the causer-pays principle or the identity principle. Therefore, a determination of the costs of joint energy products (economical useful or not) on the basis of the causer-pays principle is only possible to a certain extent.

A second point refers to the purpose of energy cost accounting: If this is only to get to know the cost of the total energy-related consumption of goods and services, the differentiation between useful energy and energy losses does not play a role. But, if energy cost accounting should also provide information to identify energy saving potentials and/or to support ecological decisions like the selection of measures for emission reduction or for ecological reporting a disclosure of the costs of useful energy and energy losses seems to be reasonable.

After the characteristics of the production and cost factor energy and their implications for energy cost accounting have been presented, the current options of accumulating and assigning energy costs in a conventional, but energy-related cost accounting concept are discussed. Afterwards, the focus will be shifted to the appraisal of energy losses in a flow cost accounting approach.

3. CONVENTIONAL ENERGY COST ACCOUNTING

3.1 Overview

Initially to the third section, it has to be pointed out that the descriptions and discussions about energy cost and (energy) cost accounting solely refer to basics and principles of traditional German cost accounting methodology. Within this scope, independent of a particular cost accounting system (e. g., full or direct costing, current or standard costing) energy consumption and energy cost can generally be displayed following the characteristic stages cost-type accounting, cost center accounting, and product cost accounting (Fig. 1).

Using this basic structure three questions can be answered: (i) what energy costs are incurred by the consumption of goods and services for internal energy supply and demand (cost-type accounting)?; (ii) where (in what departments) the energy costs are incurred (cost center accounting)?; and (iii) for what products and services the costs are incurred and what operating result has been generated by the products (product cost accounting)?.

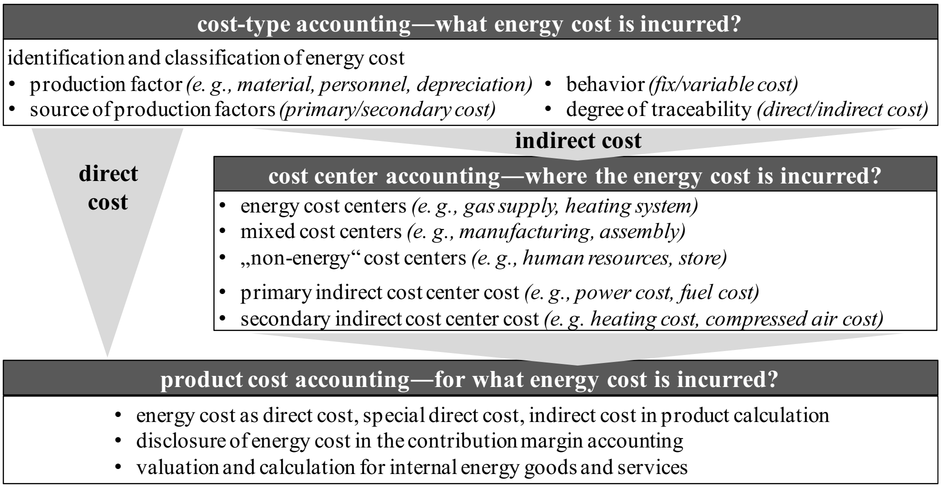

Fig. 1 – Basic structure of conventional German (energy) cost accounting. Source: compiled by the authors

3.2 Energy cost in cost-type accounting

The energy cost-type accounting concerns the costs incurred by the consumption of goods and services for internal energy supply and demand. In order to accumulate all energy cost within an accounting period in a sophisticated and accurate way and with respect to the different pursued accounting purposes they should be classified to several types of cost (Schweitzer &

Küpper, 2008). As the energy cost definition (see section 2.3) shows, energy cost is not only the monetary amount of energy sources that are acquired in the market, but also cost incurred by production factors consumed or used for internal energy supply like personnel, operating supply, energy systems (e. g., equipment and machines for the production and distribution of energy). This is also reflected by the literature, where energy costs are often categorized on the basis of *production factors* (e. g., *material cost:* delivery cost of energy sources; *personnel cost*: wages for employees in energy-related organizational units; *external services and labour:* third-party maintenance of energy equipment; *depreciation*: for energy equipment, etc.) (Fünfgeld, 2006; Wohinz & Moor, 1989) or cost centers (e. g., energy delivery cost, energy inventory and accumulation costs, costs of energy conversion and distribution, energy waste disposal, cost of energy management and administration) (Kern, 1981; Weizsäcker & Welsch, 1993). Energy costs can be enclosed in all "natural" (see classification by production factors) types of costs. To attain a high informative value of energy cost accounting, the energy cost contained in every type of cost should be disclosed separately.

In order to be able to realize a sophisticated and accurate accumulation, tracing and analyzing of energy costs in energy cost accounting, further categorizations are needed to be able to specify the real nature of the elements of energy costs. In terms of the *source of the production factors* primary and secondory costs can be distinguished. Primary costs are costs for production factors that can be procured in the market (i. a. energy sources like water, gas, oil). Secondary energy costs incur for energy (sources) that are manufactured in-house. While primary costs are determined and accumulated within the cost-type accounting, the secondary costs are calculated and assigned in the cost center accounting (Horn & Maier, 1992).

The *behavior of energy* cost relates to their sensitivity to changes in activities, production and/or sales volumes or the energy load resulting from a certain production level. In general, the output, sales, load ranges or a certain period of time etc. over which patterns of energy cost behavior remain unchanged is called relevant range. Only within this relevant range costs can be specified as variable or fixed costs. Variable energy costs (e. g., kilowatt-hour rate of electricity) are the sum of marginal energy costs over all units produced or kilowatt hours consumed. They change in dependence of the production, sales or load. In contrast, fixed energy costs (e. g., meter rent, basic rate of electricity) are not dependent on the level of production, sales or load (Weizsäcker & Welsch, 1993).

Furthermore, energy costs can be divided according to their *degree of traceability* to a certain cost object. In this context, cost objects can be intermediate products, final products, self-constructed assets, self-produced energy goods and services. Direct energy costs represent costs of energy-related resources that are related to a particular cost object and can be traced to it using the causer-pays principle or the identity principle. Indirect energy costs cannot be identified for single products. They are incurred for several cost objects (e. g., salary of a fire-man, depreciation for mean voltage transformers) and have to be allocated using appropriate allocation bases (e. g., number of staff, power input, square meters of floor space) (Lal & Sri-vastava, 2008). In fact, most energy costs are indirect costs. Strictly speaking, energy costs can only be classified as direct cost if an energy source is used as a raw material in manufac-turing processes like in iron smelting or if the energy consumption can be traced to a single final product, such as in production processes like aluminum electrolysis (Gaelweiler, 1981).

The measurement and determination of the consumption of energy related goods and services and their purchase prices are important prerequisites for the accumulation, assignment and analysis as well as the classification of energy costs in cost-type accounting. As measurement and determination of consumption and prices is also a wide and diverse field, it would go beyond the scope of the paper to deal with it in detail. Therefore, only two significant aspects are mentioned: (1) As already described for the energy prices and their drivers (section 2.3), the consumption measuring and valuation holds a lot of complexity and diversity; (2) The granularity of the measurements has to be fixed because it determines the degree of transparency of the energy consumption and losses of single consumers and the degree of responsibility for the energy use and loss that can be placed on the managers.

3.3 Energy cost in cost center accounting

Cost center accounting should provide a basis to assign the energy cost to the cost objects on the basis of the causer-pays principle and to plan and control the efficiency of the internal energy-related resources and activities. In cost center accounting the indirect energy costs are accumulated and allocated to the organizational units that incurred them. Therefore, the company is divided into separate cost centers. These are independent accounting units and responsibility areas that are headed by a cost center manager (Friedl, Hammer, Pedell & Küpper, 2009). Cost center accounting differentiates between

- indirect cost centers that provide common or specific goods and services for other indirect and the direct cost centers (e. g., maintenance department, heating system);
- direct cost centers where the products are manufactured (machining and assembly cost centers) and/or further product related activities are realized (material cost centers, selling and administration cost centers).

Additionally, concerning the disclosure of energy costs cost centers can be classified as

- energy cost centers that nearly solely fulfill the task of internal energy generation and supply for other cost centers (e. g., units responsible for heat or compressed air supply);
- mixed cost centers including energy consumers and producers, i. e., machines and equipment using energy inputs to manufacture the actual products as well as (re)usable energy outputs, i. a. the waste heat of a hardening shop that can be used for space heating;
- “non-energy” cost centers where energy is only an input and their consumers do not produce any economically usable energy output (e. g., selling and administration units).

Cost center accounting in general as for energy costs starts *with allocating the indirect costs* from the cost-type accounting to *the cost centers* (primary costs). Due to the fact that there are cost centers that provide (energy related) goods and services (service provider) for other centers (service receiver) the indirect energy costs of all delivered (energy related) goods and services have to be allocated now from the service providers to the receivers. The (energy) costs allocated to receiving cost centers are called secondary (energy) costs. For this *internal cost allocation* German cost accounting literature knows different procedures (see e. g., (Schweitzer & Küpper, 2008)). After the cost allocation is finished *allocation rates* for the indirect (energy) costs of the direct cost centers *can be calculated*. For that purpose the total indirect (energy) costs of a cost center are divided by the respective direct costs of the certain cost center (e. g. for the material cost center this is the direct material cost, for the machining and assembly cost centers this is the direct labor cost), the cost of goods manufactured or sold (for the selling and administration cost centers) or specific other activity units (as an alternative to allocate indirect cost especially in manufacturing cost centers). The allocation rates can be seen as an interface to the product calculation. There they can be applied in overhead calculation and product costing with activity units to calculate the overhead cost per cost object unit (Götze, 2010). Beyond that and under the assumption that reference values (standard cost) have been determined, the *profitability can be calculated* and controlled.

An energy-related cost center accounting provides information about the energy costs incurred in the various organizational units and therewith the respective possible cost savings. Thus, the mostly hidden pool of energy costs can be made more transparent and energy cost allocation rates for the product calculation can be computed.

3.4 Energy cost in product cost accounting

The stage of product cost accounting is twofold. While in product costing per unit the cost of the cost objects are calculated, in product costing per period the operating result is computed. In particular, when considering energy cost in detail, above all it has to be computed the percentage of the costs of goods manufactured that is made up of energy cost, the (negative) contribution of the energy cost to the operating result and the costs of energy goods and services produced in-house (Schweitzer & Küpper, 2008).

There is a great variety of different product costing methods whose practicability to calculate the product costs depends on the characteristics of the applying company or department (i. a. the manufactured volumes, product structures and variety, production processes and techniques) (Kilger, Pampel & Vikas, 2007). In companies with more than one product, individual or series production and multi-level manufacturing processes the overhead calculation is often used supplemented by the product costing with activity units.

The overhead percentage cost calculation can be realized as summary or differentiated calculation. In the more detailed differentiated overhead percentage cost calculation the overhead cost rates are separately computed for material, manufacturing, selling and administrative overhead costs using the cost allocation rates from the cost center accounting (section 3.3). As manufacturing costs are machine-dependent in many cases (i. a. because of a high degree of automation), they are often assigned to the products on the basis of a machine hour rate instead of a monetary allocation base (product costing with activity units or machine hours).

Overhead calculation can be applied to determine the cost of production of energy goods and services if they are the main output of energy production and supply processes (as for space heating, process heat, compressed air and so on), not only a by-product of the manufacturing processes (e. g., waste heat or waste gas) (for the problem of energy as a by-product see section 2.3). In its main aim, the overhead calculation computes the cost of production and the cost of sales of the main products of an (industrial) company. But with an energy-related specification, also the energy costs of the final products can be calculated.

For this purpose the literature discusses different basic ways to allocate energy costs to the products (Schmidt, 1960; Kilger et al., 2007, Hugel, 1965). First, energy costs can be traced to a particular cost object as direct costs, if externally procured or internally produced energy sources are raw material for the product, if the energy consumption can directly be traced to a single final product, and if the consumption measuring can be realized in an economically feasible way (section 3.2). Second, energy costs can be assigned to the products as special direct cost of manufacturing, if they cannot be traced to a single product unit (as cost object), but to particular batch, production order or product line. The declaration of energy costs as special direct cost is reasonable especially for energy-intensive production processes where the batches, orders or the products show significant differences in their energy usage (similar (Schmidt, 1960)). Third, the prevailing way of the disclosure of the energy costs in product calculation ist their allocation as energy overhead costs (see Fig. 2). On the one hand, the allocation can be realized on the basis of specific energy cost allocation rates, determined in the cost center accounting (section 3.3). On the other hand the allocation can be based on machine hour rates, particularly with regard to the fact that energy costs in manufacturing are often machine-dependent cost, that are measured per machine and machine hour and allocated to the products on the basis of the machine hours the single product needs to be manufactured.

direct material cost	material cost	cost of production	cost of sales
indirect material cost			
energy-related *(% of direct material cost)*			
remaining indirect material cost			
direct manufacturing cost (direct labor)	manufacturing cost		
machine-dependent indirect manufacturing cost			
energy-related *(energy cost per machine hour)*			
remainging machine dependent manuf. cost			
other indirect manufacturing cost			
energy-related *(% of other indirect manuf. cost)*			
remaining indirect manufacturing cost			
special direct manufacturing cost			
administrative overhead cost	selling and administrative cost		
selling overhead cost			
energy-related *(% of selling overhead cost)*			
remaining selling overhead cost			

Fig. 2 – Calculation sheet for energy-sensitive differentiating overhead calculation. Source: adopted from: Götze, 2010

After the cost of production and of sales are calculated and the sales revenues are known, the operating result can be computed in the stage of product costing per period. It can be realized as production-oriented total cost accounting or as marketing-oriented cost of sales accounting in simple or detailed forms. If energy costs have been disclosed in cost center accounting and product costing per unit, their contribution to the company's earnings can be highlighted here.

However, in an energy cost accounting based on a conventional cost accounting methods the cost of energy losses remain hidden in the cost of cost centers and products. A flow cost accounting approach seems more promising to shed light on this cost category and will, thus, be presented in the next section.

4. MATERIAL AND ENERGY FLOW COST ACCOUNTING

4.1 Objectives of an energy-sensitive flow cost accounting

Generally, flow cost accounting (FCA) aims at supporting material and energy flow-oriented analyzes and decision making to improve resource (material and energy) and cost efficiency. It integrates economic and ecological objectives in order to contribute to a reduced or more efficient material and energy use. Examples of the implementation of FCA in practice can be found in Germany and Japan (see, e. g., (Nakajima, 2006; Enzler, Strauß & van Riesen, 2003). Beyond that, the scope and basic procedures of FCA are described in the ISO 14051 (2011) (international standard) resp. DIN EN ISO 14051 (German standard) (see also Kokubu, Campos, Furukawa & Tachikawa, 2009).

It is important to note here that in most of the cases FCA is focused on material and sepa-rate analyzes of energy usage and loss are often neglected on the grounds that '[e]nergy flows can be thought of in the same way as material flows, especially since it is often in a material form (in the full sense of word, e. g., coal, oil, gas) that energy first enters a company' (Strobel & Redmann, 2002). However, because of the characteristics of the production and cost factor energy (see section 2.2) it can be concluded that energy, in particular electricity, heat and so on, cannot be seen as a material. So, the original material-driven FCA-approach should be enhanced to examine energy use and loss in more detail and constitute a material and energy flow cost accounting (MEFCA) (for first approaches to integrate energy flows see i. a. (Sygulla, Bierer & Götze, 2011; Götze, Schubert, Bierer, Goller & Sygulla, 2012). As the focus of our paper is on energy usage, loss and efficiency, the following explanations will emphasize the visualization and appraisal of energy and energy loss flows.

4.2 Procedure of Material and Energy Flow Cost Accounting

In particular, with MEFCA it is possible to visualize and quantify energy losses and shift them into the focus of managerial decision making. This is achieved by improving the overall transparency of the resource flows (material- and energy-related flows) in physical and monetary terms. The general procedure of MEFCA comprises three steps: (1) flow structure modeling, (2) physical quantification of flows (model of flown quantities), and (3) monetary quantification of flows (flow cost model).

(1) Flow structure modeling (flow structure model)

In a first step, the flow structure is modeled. It visualizes the material and energy flows and the corresponding loss flows of the system under consideration. After defining the system boundaries, quantity centers spatial or physical units transforming materials (handling, processing, storing, etc.) and energies (converting, transmitting) are identified. For every quantity center ingoing and outgoing flows can be identified and appraised in terms of physical (e. g., kg, MJ, MWh) and monetary units (e. g., Euro, Dollar). On the basis of the quantity center structure the frequent desired and undesired flows between the centers as well as input and output flows crossing the system boundaries are modeled (Fig. 3). The flows are classified as material or energy flows and corresponding loss flows.

Material flows are all movements of materials between various quantity centers that are directed to produce the intended products. Material losses comprise all scheduled (e. g., clippings and chips) and unscheduled (e. g., rejects and outdated or damaged products) losses of the quantity centers (Kokubu et al., 2009), even if they are part of internal recycling processes. *Energy flows* are all energy transmissions from and to energy-related quantity centers units providing energies for other quantity centers (e. g., energy conversion center in Fig. 3) and other quantity centers (e. g., manufacturing processes, waste disposal processes). Consequently, physical energy flows between energy-related and energy-intensive quantity centers exist. They are modeled like material flows. In contrast, in other quantity centers not producing any usable energy, but "only" semi- or fully-finished products the physical energy flows of these centers are only outgoing energy loss flows. Since only effective energy is used to 'produce' the product (and the material loss), there is no visible physical energy output flow (double colored arrows in Fig. 3). So the used effective energy can be seen as energy embodied into the product and the material losses.

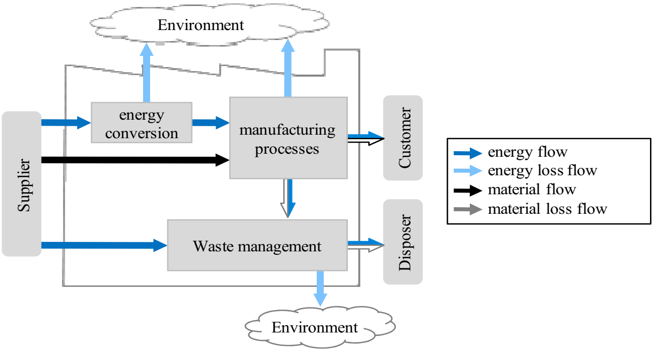

Fig. 3 – Material and energy flow model. Source: Sygulla et al., 2011

(2) Physical quantification of flows (model of flown quantities)

After developing the flow model, all flows are determined on a quantitative basis in terms of physical units. Every material and energy transformation within an individual quantity center and between different quantity centers is measured (or calculated) within a defined period. A balance of the in- and outgoing flows of every quantity center is drawn up to ensure that all transformations are registered. Since usual manufacturing processes are subject to the conservation of masses or energies, the use of a single mass or energy unit (e. g., kg, kJ) is generally advised for quantification (Kern, 1981; Fünfgeld, 1998).

(3) Monetary quantification of flows (flow cost model)

Indeed, based on the result of the second step, it is possible to identify and analyze energy-related (or in a more common sense resource-related) inefficiencies. However, since the cost effects of resource inefficiencies are highly relevant for economically intended decision making, the sole accounting based on physical quantities does not provide sufficient support. Thus, the model of flown quantities is supplemented by a flow cost model. Here, the flows are defined as *cost collectors* gathering the cost that can be assigned to them referring to the flown objects and their quantities (incurring the costs). ISO defines the major cost-types (ISO/DIS 14051, 2011) as follows:

- *Material costs* are determined by multiplying the physical amount of the particular materials by their specific input prices and summing up the results. The use of fixed input prices allows a consistent appraisal for all process steps.
- *Energy costs* are calculated similar to material costs. In contrast to the definition of energy cost as described in section 2 they cover only the delivery cost of purchased energies.
- *Waste management costs* occur in the context of handling material losses within a particular quantity center. They are only assigned to the material and energy losses.

Beyond these default cost-types, the explicit modeling of energy flows, energy loss flows and energy-related quantity centers should be consistent with a differentiated consideration of the corresponding cost. According to ISO, energy cost is the delivery cost of purchased energies. The system cost is differentiated (Götze et al., 2012) into

- *material-related system costs* as all expenses incurred by the in-house material flows except for material costs, energy and energy-related system costs, and waste management costs, e. g., labor, maintenance or transport costs; and
- *energy-related system cost*s as all expenses incurred by in-house generation, trans-formation, and transmission of energy, but do not comprise the delivery cost of purchased energies.

While, in the MEFCA, the material and energy costs are direct flow costs, the system cost and the waste management cost are indirect costs. They can in the best of the cases simply be traced to the quantity centers. Related to the flows they are indirect costs that have to be allocated to them using allocation rates (mostly, but not only on the basis of output mass ratios).

The cost assigned to the output flows consist of the cost of the corresponding input flows and the cost incurred in the respective quantity center. So, the input flows carry not only the material and energy cost of the underlying flown quantities of material and energy, but also parts of the indirect cost (system and waste management) of all quantity centers the material or energy has already passed (Fig. 4).

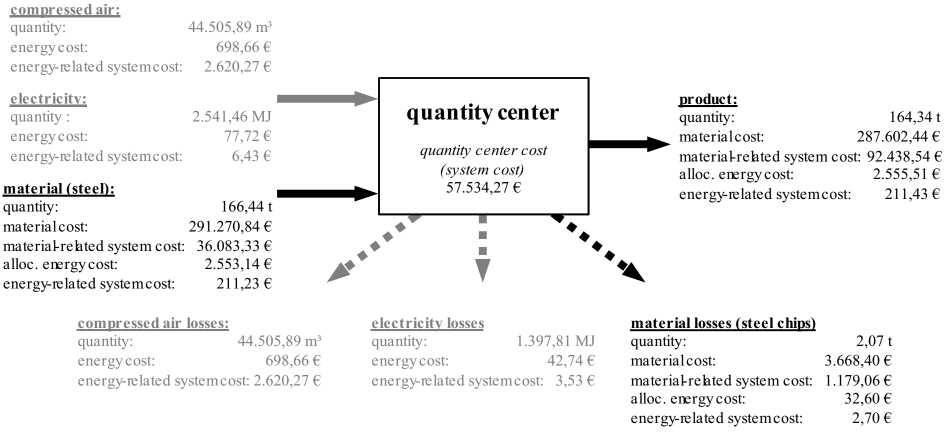

Fig. 4 – Example for a flow cost model of a quantity center. Source: Sygulla et al., 2012

The final result of the MEFCA procedure is a detailed flow model. On the one hand, it visualizes the material and energy flows and the loss flows. On the other hand, for all flows the flown quantities and the cost thereby incurred are determined including the cost of energy losses neglected by conventional cost accounting. This detailed information allows it to identify, in particular, economically reasonable energy efficiency improvement potentials.

4.3 Discussion MEFCA and conventional energy cost accounting

Generally, MEFCA can be taken as a comprehensive and closed instrument to identify and analyze energy inefficiencies. From this two questions arise: (1) Can MEFCA replace a conventional energy costing? (2) If not, can/should it be integrated with conventional energy costing to press home the advantages of both approaches?

First, like most of other environmental cost accounting approaches, MEFCA should be under-stood as a specific partial accounting method to improve economic and environmental deci-sion making with respect to material (and energy) usage. So, it does not (and cannot) replace the already existing body of conventional (energy) cost accounting methods and the cost knowledge generated by them. In particular, it does not provide useful support for decision-making on prices and product programs (types and quantities of products). Furthermore, building up a separate accounting cycle would cause redundant information generation cost.

Second, in fact, a conventional energy costing concept can provide a multitude of the information the MEFCA needs to appraise the cost of the flows. So, it is reasonable to identify and use the interdependencies between the two approaches (see Fig. 5).

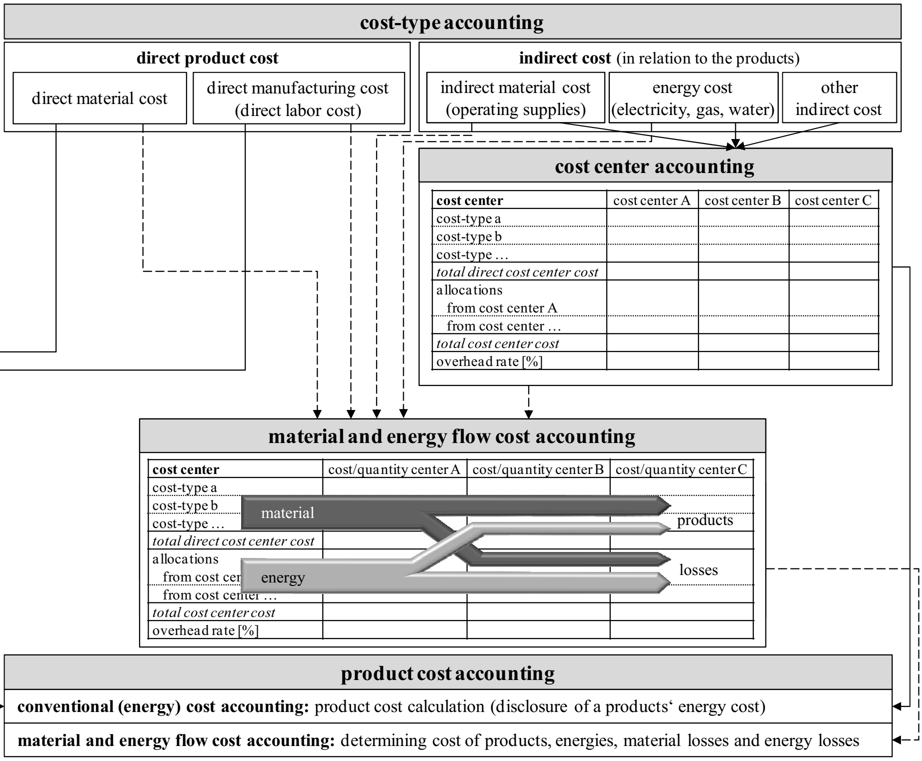

Fig. 5 – Interdependencies between energy costing and MEFCA. Source: compiled by the authors

Cost-type accounting provides a cost structure for energy cost accounting and MEFCA. Direct MEFCA costs are the direct and indirect material cost and the energy cost. The first category is represented by the cost-types of raw and auxiliary materials, operating supplies and purchase parts. The second category comprises the energy delivery cost differentiated by energy sources like electricity, natural gas, water etc. Indirect MEFCA costs are all other types of cost recorded in cost-type accounting, in particular depreciation, imputed interest, indirect salaries/wages, cost of external services and labor.

For German companies with their *cost center* structure a single cost center can be equal to a quantity center, comprise more than one quantity center and vice versa. In the first case, the cost center cost from conventional energy cost accounting can be taken as system and waste management cost in the corresponding quantity center cost. In the least case, reasonable allocation bases must be found to allocate the cost center cost to the various quantity centers.

The mapping of cost center cost to the quantity centers should be done before internal cost center allocations in energy cost center accounting. That's due to the fact that in every MEFCA quantity center the outputs are differentiated in desired (material, product, energy) and undesired (material and energy losses) goods and energies. Therefore, only the cost of desired materials/products or energies are input of the following quantity center. The costs of material and energy losses are input for waste management centers or are discharged. They are no longer part of the intended value chain. A mapping of cost center cost after internal allocations would distort the values contained in the intended products.

Because of the different purposes of energy costing and MEFCA, the cost assigned to the products respectively the products and losses in *product cost accounting* are not identical. Conventional product calculation traces direct material and manufacturing cost undifferentia-ted from cost-type accounting to product costing. The indirect costs are assigned to the products using overhead percentages, machine hours or process cost rates from cost center or process-based accounting. The calculation result is the cost of sales (including the cost of material and energy losses) as starting point or reference value for price and product program decisions.

In contrast, MEFCA does not include product costing in the common sense. On the one hand, taking the flows as cost collectors, the product flow (output flow) of the last production quan-tity center will carry the total cost of the product (product cost without material and energy losses). On the other hand, for every quantity center, the costs of energy and material losses are determined, and therewith, supply information for the identification of centers of ineffi-ciencies. Beyond that, the total amount of energy and material losses can be calculated with the MEFCA. This allows it to compare the total cost of losses with the total cost of the intended product.

5. CONCLUSION

In summary, the paper first discussed the characteristics of the production factor "energy" and, based on this, various implications for energy cost accounting. Second, it has been consi-dered whether and how energy cost can be integrated into the elements of conventional Ger-man cost accounting and what information can be generated with such an energy cost accounting concept. In summary, it can be stated that a differentiated accumulation and reporting of energy costs throughout the three cost accounting stages can already provide useful information about energy cost savings, the energy cost shares of the goods manufactured and so on. Third, an approach for the inclusion of energy cost in flow cost accounting was presented which seems to be useful to disclose the cost of energy losses and, thus, to identify energy (cost) saving potentials and to sensitize to the economic consequences of energy efficiency

It has to be pointed out that only the basics or main features of energy-related cost-type, cost center and product cost accounting as well as the MEFCA approach have been described. But, they are not sufficient for an implementation of solutions for all the mentioned characteristics of the production and cost factor energy. So, specifications for different forms and sources of energy are not integrated. Beyond that, plenty methodological problems arise concerning the measurement and planning of energy cost (in dependence of influencing factors), the allocation of cost to cost centers and quantity centers, and the determination of the amount of effective energy. Among others, the problems of different cost rates for different fluctuation intervals or process conditions and of joint production and its implications for product calculation have not considered. Thus, in order to increase the informative value of an energy cost accounting and with it the basis for decision making, further research is needed to refine the procedures of energy cost accounting with the aim of providing adequate solutions for the consideration of as much of the initially described characteristics as possible.

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