

How to achieve energy and resource efficiency: Material and energy flow modeling and costing for a small and medium-sized company

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Abstract

The continuous increase of energy and resource efficiency requires a range of activities from measuring and metering data on energy and material usage to simulation and optimization of energy and material flows and their ecological and financial implications. This paper introduces a comprehensive modeling approach for the improvement of energy and resource efficiency, based on material and energy flows. The procedure, results and taken measures will be shown, using the example of a case study from textile industries.

Keywords:

energy and resource efficiency, flow modeling, economic and ecological evaluation, material flow cost accounting

1 Introduction

The efficient use of energy and resources is both, an imperative of corporate social responsibility and an opportunity for increased economic performance. Current studies reveal significant cost savings due to resource efficiency measures in small and medium-sized enterprises (in the following called SME) [1]. In addition, economists expect positive effects of resource efficiency measures on the job market [2]. Despite these evidences, resource efficiency is not yet part of the daily business in SME. This discrepancy is caused by a variety of reasons, including the perception of resource efficiency as a complex topic and the lack of suitable analytical instruments [3].

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Improved resource efficiency in enterprises and the resulting reduction of environmental impacts require the analysis of relations and interactions between technical, ecological and economical product and production decisions. One comprehensive approach for integrating these dimensions is the concept of corporate material flow modeling which is mainly based on the work of Möller [4] [5]. This article explains the concept in its scientific discourse and exemplifies its application with the help of a textile industry case study. The case study of SWU Spinnweberei Uhingen Textil GmbH (in the following called SWU) has been developed as part of a research project on energy and auxiliary optimized production [6]¹. SWU has been producing textile products for over 150 years and is counting about 100 employees at two sites in Baden-Wuerttemberg (the South-Western federal state of Germany) at present. In their plant at Waldkirch near Freiburg, SWU is spinning high-quality cotton-based yarns. At the Uhingen site close to Stuttgart these yarns are woven to industrial textiles mainly used for abrasive and printing blanket production. Both production sites use very large amounts of electric energy for the operation of machines, air-conditioning and cooling, and the generation of compressed air. SWU's mainly processed raw material is cotton. Although cotton is a renewable resource, its agricultural production is linked to considerably environmental impacts. Further important material inputs of the production systems are non-cotton based fibers, e.g. polyester.

The structure of this paper is based on the sequence of activities of the case study. At first, the modeling and accounting of material and energy flows of the two production sites is carried out (chapter 2.1). On this basis, products within the considered systems can be distinguished and assessed separately (chapter 2.2). Thereafter, material, energy and process costs are integrated (chapter 3.1) and further assessed by deploying material flow cost accounting, a concept developed to identify costs caused by inefficiency (chapter 3.2). An ecological assessment of the production systems and products is part of chapter 4. Chapter 5 presents case study results and concludes the paper.

2 Accounting for material and energy flows of production systems and products

Energy and resource efficiency measures concern both, the product as well as the production level. Most approaches to track and assess material and energy flows and their respective environmental effects refer to either products (e.g. product

¹ The project "Energie- und hilfsstoffoptimierte Produktion" (Energy- and auxiliary-optimized production) was coordinated by the Technical University Braunschweig and funded by the Federal German Ministry for Research and Education (BMBF). The project website is accessible on <http://www.effizienz-generator.de>.

carbon footprints or product related life cycle assessments²) or to production sites respectively (e.g. corporate carbon footprints or inventories in environmental management systems and sustainability reports³). The above mentioned material flow network approach by Möller integrates both, the view of the product and of the production system and serves as a basis for software solutions like Umberto⁴.

2.1 Material and energy flow modeling and accounting of production systems

Möller's material flow network approach is based on the Petri Net approach [7]. The material flow network approach consists of three functional components as depicted in Figure 1.

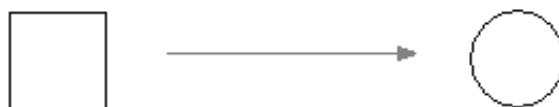


Figure 1: Functional components of material flow networks:
transition, arrow, place (from left to right)

Transitions (shown as square or rectangle) specify transformation processes of materials and energy. Places (shown as circle) serve as distribution and nodal points of material and energy flows. Connections (arrows) interlink transitions and places and contain material and energy flows.

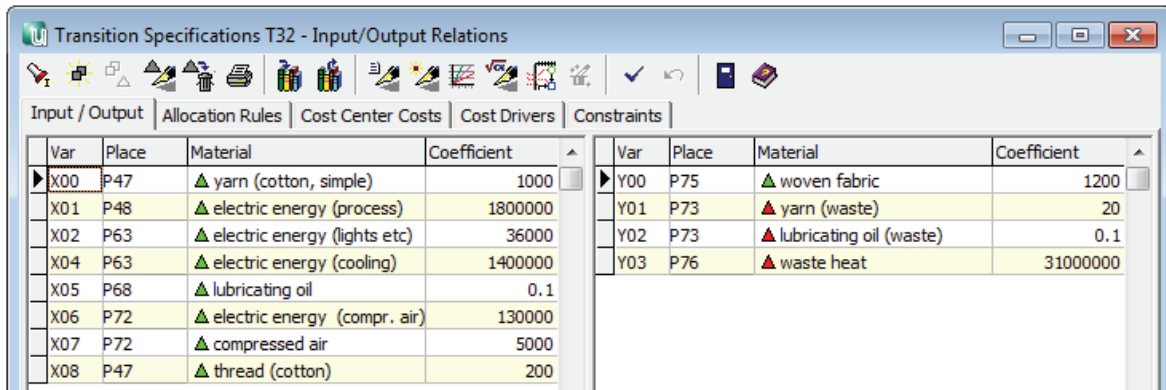
Transition specifications have the appearance of an input-output table. Figure 2 shows a linear specification using coefficients, i.e. inputs and outputs are directly proportional to each other. A doubling of the fabrics output will also lead to a doubling of all other entries like the energy demand, amount of waste etc. Such linear relations between the input and output are commonly used in environmental assessments like carbon footprints or life cycle assessments, but do not necessarily represent the real behavior of production systems. The energy consumption, for instance, might increase disproportionately to enhanced output quantity due to non throughput related portions of the energy demand (e.g. permanent energy demand

² See for instance international standards like ISO 14044 (2006): 'Environmental management - Life cycle assessment - Requirements and guidelines'; ISO 14040 (2009): 'Environmental management - Life cycle assessment - principles and framework'; ISO 14067 (draft version): 'Carbon footprint of products. Requirements and guidelines for quantification and communication'; PAS 2050 (2011): 'Specification for the assessment of the life cycle greenhouse gas emissions of goods and services'.

³ See for instance ISO 14064-1(2012): 'Greenhouse gases - part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removal'; ISO 14001 (2009): 'Environmental management systems - Requirements with guidance for use'; The Greenhouse Gas Protocol (2001): 'A Corporate Accounting and Reporting Standard'; Global Reporting Initiative (2002): 'Sustainability Reporting Guidelines'.

⁴ See <http://www.umberto.de/en>.

of monitoring equipment or lighting) or due to accelerating energy demand if processes are operated at full load.



Var	Place	Material	Coefficient
X00	P47	▲ yarn (cotton, simple)	1000
X01	P48	▲ electric energy (process)	1800000
X02	P63	▲ electric energy (lights etc)	36000
X04	P63	▲ electric energy (cooling)	1400000
X05	P68	▲ lubricating oil	0.1
X06	P72	▲ electric energy (compr. air)	130000
X07	P72	▲ compressed air	5000
X08	P47	▲ thread (cotton)	200

Var	Place	Material	Coefficient
Y00	P75	▲ woven fabric	1200
Y01	P73	▲ yarn (waste)	20
Y02	P73	▲ lubricating oil (waste)	0.1
Y03	P76	▲ waste heat	31000000

Figure 2: Linear transition specification of one of SWU's weaving machines

For this reason the material flow network approach enables transition specification via mathematical functions and non linear input/output relations as well as the definition of subnets (specification of transitions by modeling new material flow networks on a subordinated level).

Systems modeled in material flow networks are not limited to production systems, but might as well focus on a production line only or a whole region instead. System boundaries are settled by specific types of places (input or output places). In the case of SWU, input and output places were located at the production sites' boundaries. Figure 3 introduces the material flow network modeled at SWU.

The upper part represents the spinning plant in Waldkirch and resembles the actual production facility layout while the lower part represents the weaving plant in Uhingen. In this figure, icons are used to increase the recognizability of the modeled production and utility processes.

The computation of the modeled material flow network starts at any transition connected to a predetermined material or energy flow and makes use of the respective transition specification (e.g. the known or projected product output or raw material input). Once a transition is computed, resulting material and energy flows are written into the respective connections and trigger the computation of neighboring transitions via connection places. The computation is continued until no more uncalculated transitions are left and no more changes in places appear.

Input-output inventories for the production systems or parts of the systems can be derived once the computation has been accomplished. The inventories compile all material and energy flow inputs and outputs that enter or leave the system via system boundaries (see e.g. Figure 4).

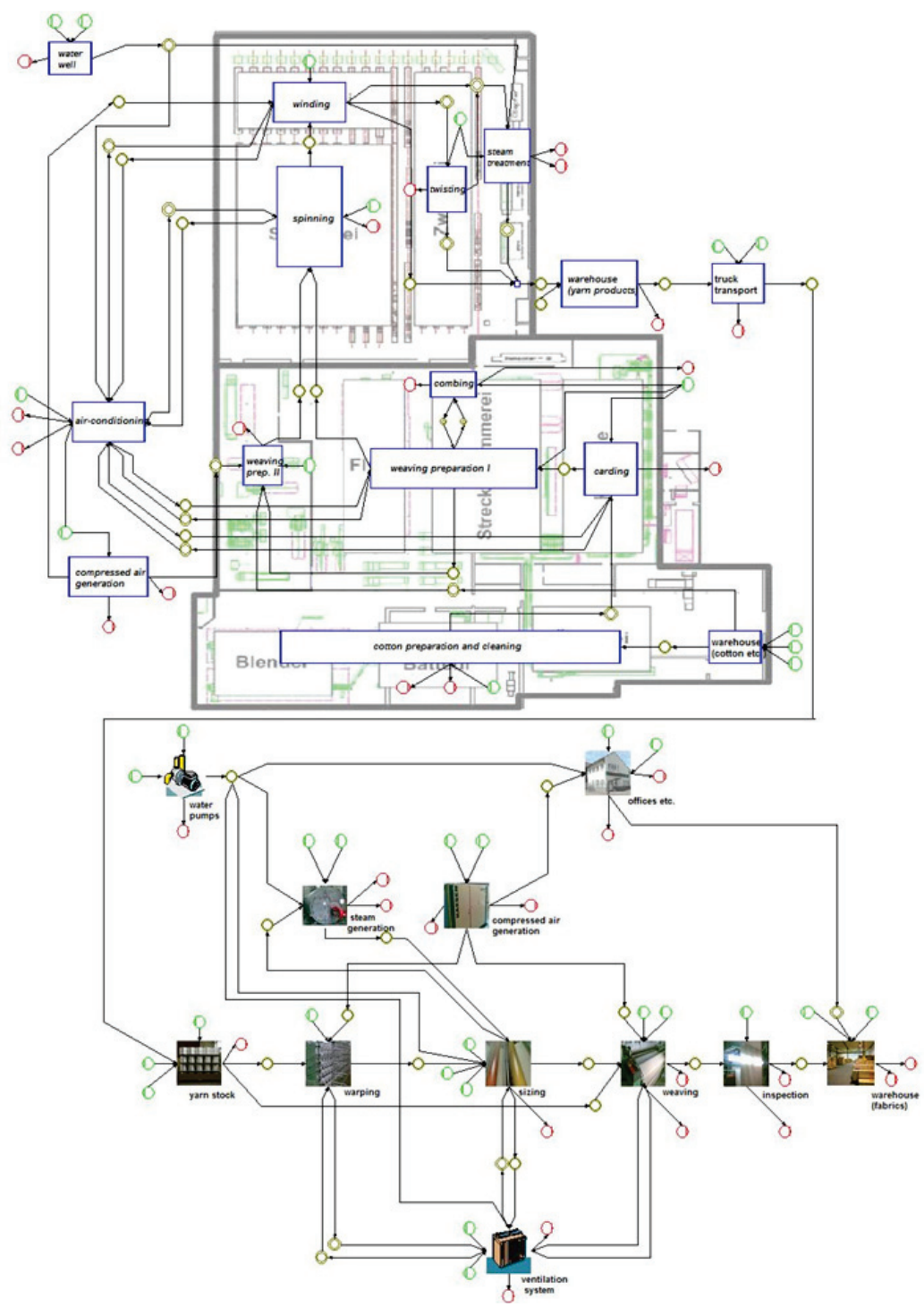


Figure 3: Material flow network of SWU's production sites

Input:			Output:		
Item	Quantity	Un	Item	Quantity	Un
01 primary and intermediate produc			01 primary and intermediate produc		
012 purchase			011 home production		
▲ special yarn purchase	16000 kg		▲ abrasive	260 t	
▲ yarn (simple, card.) purchase	13000 kg		▲ blanket	130 t	
▲ yarn (simple, combed) purchas	13000 kg		▲ other fabrics	64 t	
02 operating supplies			▲ thread (cotton)	25000 kg	
▲ fuel, mass	42000 kg		▲ thread (synt. + mix)	20000 kg	
▲ ambient air	730000 kg		▲ yarn (cotton, effect)	100000 kg	
▲ cardboard case	1800 kg		▲ yarn (cotton, simple)	31000 kg	
▲ diesel fuel	7200 kg		▲ yarn (synt. + mix., effect)	9500 kg	
▲ lubricating oil	340 kg		▲ yarn (synt. + mix., simple)	21000 kg	
▲ PE flat film	290 kg		06 waste		
▲ starch	17000 kg		061 fabrics waste		
03 energy			▲ fringe edge Big Bag	6900 kg	
031 electric energy			▲ fringe edge BW 100%	7500 kg	
▲ electric energy (compr. air)	750000 kW		▲ fringe edge mixture	3800 kg	
▲ electric energy (cooling)	68000 kW		▲ residue	28000 kg	
▲ electric energy (heating)	8200 kW		▲ sized thread	920 kg	
▲ electric energy (humidific.)	6.1 kW		▲ waste (carding)	41000 kg	
▲ electric energy (lights etc)	170000 kW		▲ waste (combing section)	43000 kg	
▲ electric energy (process)	2200000 kW		▲ waste (spinning)	4100 kg	
▲ electric energy (ventilator)	570000 kW		▲ woven fabric	5100 kg	
032 other energy			▲ yarn (waste)	3800 kg	
▲ freshwater energy	2100 kW		062 other wastes		
▲ fuel oil energy	470000 kW		▲ lubricating oil (waste)	340 kg	
04 raw materials			07 emissions		
Sum	Quantity	Un	Sum	Quantity	Un
kJ	1.5E10 kJ		kJ	1.5E10 kJ	
kg	4900000 kg		kg	4900000 kg	

Figure 4: Input-output inventory of SWU (modified entries due to confidentiality issues)

Another and more graphical way to visualize the computed material and energy flows are Sankey diagrams which adjust arrow widths according to the actual mass or energy content of a flow [8]. Hence Sankey diagrams show hot spots of material and energy flows and resource use respectively. They can be easily interpreted and help to communicate the modeling results within and outside an organization. Figure 5 shows a Sankey diagram for mass flows at the SWU site in Waldkirch. The main flow from cotton to yarn is as apparent as losses of material (e.g. about 78000 kg of material loss from carding) or the very high water demand for cooling water in the air conditioning process.

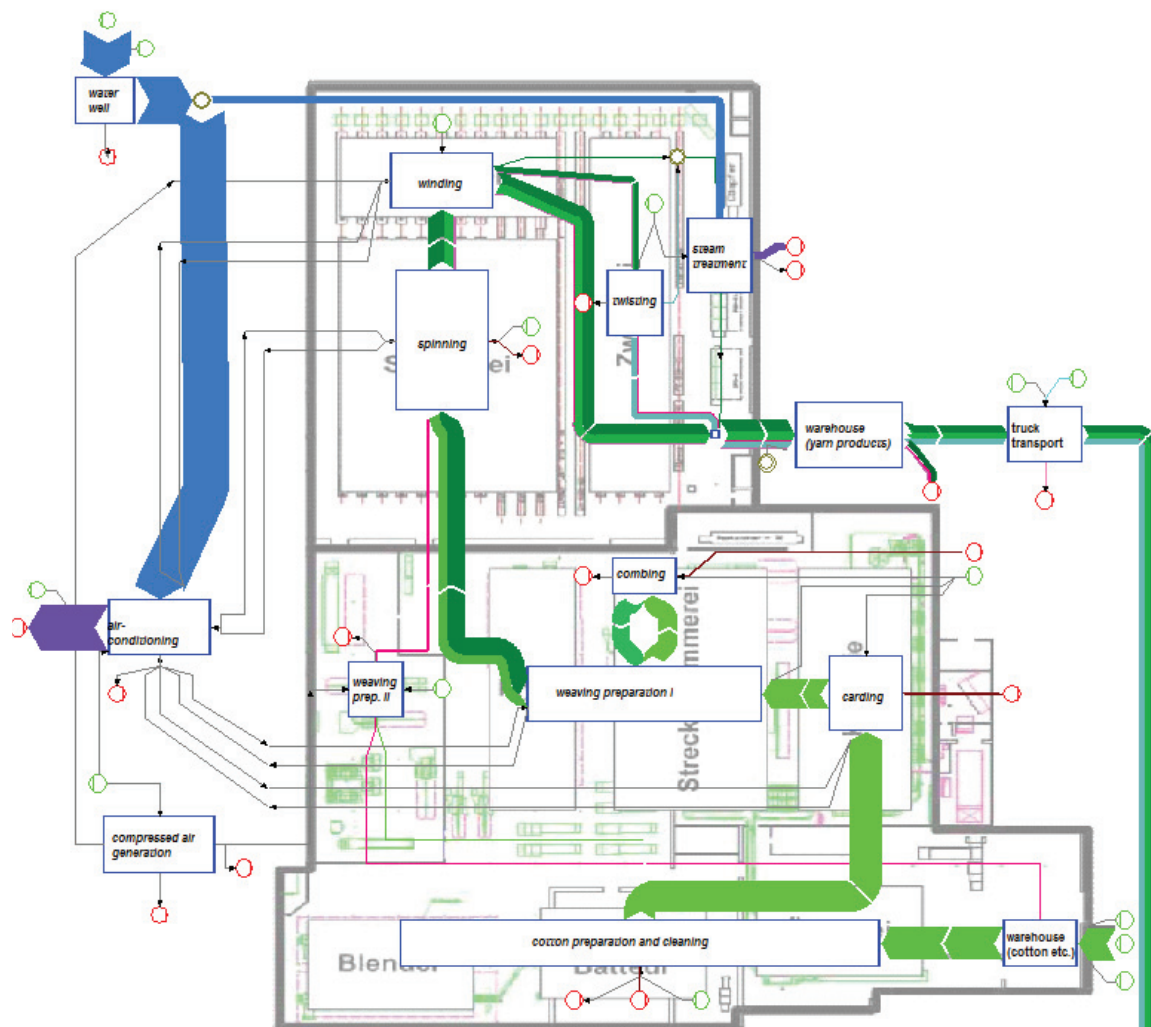


Figure 5: Mass-based Sankey diagram of SWU's production site in Waldkirch

The Sankey diagram in Figure 6 contains the energy flows of the Waldkirch site. It reveals that the air conditioning system requires large amounts of energy even in comparison to the major production step of spinning. This is due to the fact that high speed spinning only works at certain temperature and humidity levels.

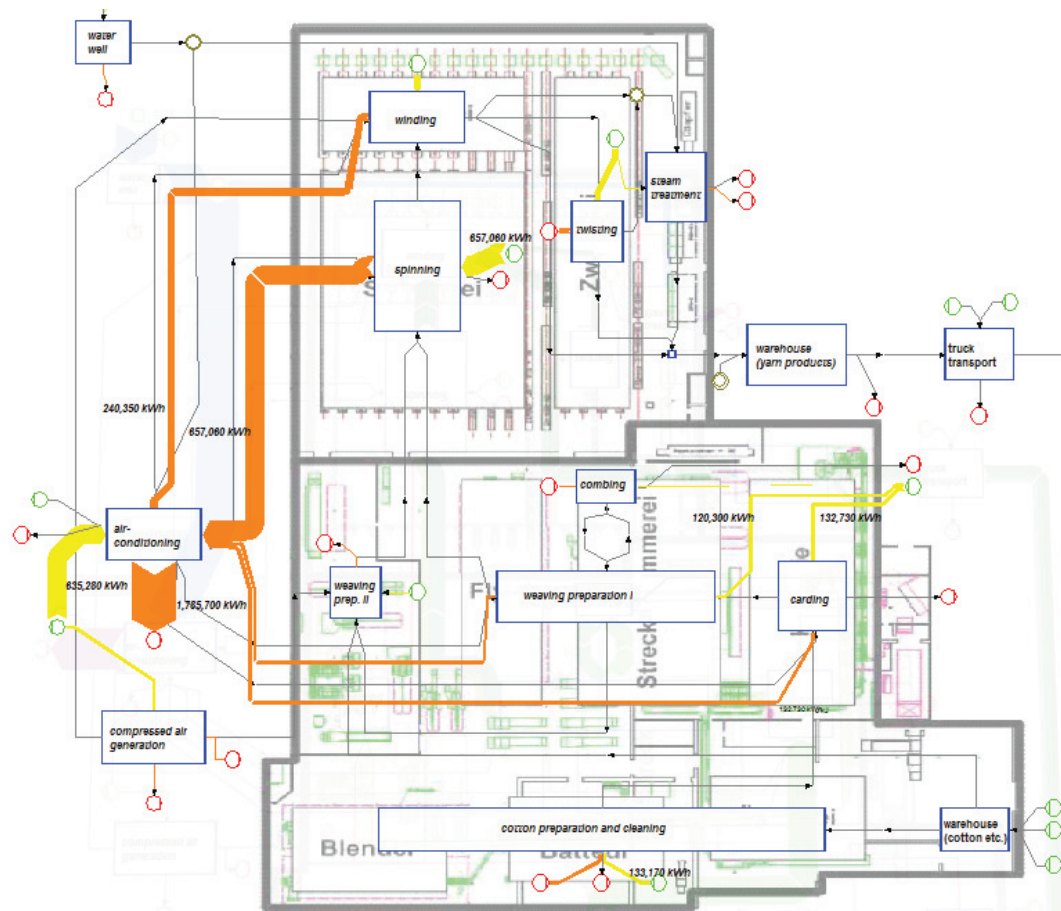


Figure 6: Energy-based Sankey diagram of SWU's production site in Waldkirch

2.2 Product specific accounting and assessment

In addition to the evaluation of the production systems, the analysis of products within the system is important to highlight product specific differences concerning energy and resource efficiency. For this purpose the material flow network approach makes use of Dyckhoff's production theory [9] to establish a so called "Leistungsverrechnung" i.e. the tracking and tracing of system expenditures (e.g. for material and energy inputs, wastes) to the system revenues (e.g. from final products) [4].

For this purpose, all material flows within the system need to be classified as *Goods*, *Bads* or *Neutrals*. Neutrals are neither considered as expenditure nor as revenue. An example is the takeout of oxygen from the ambient air for combustion purposes. Goods are valuable materials that are considered expenditure when used as input (e.g. purchase of raw materials) and revenue when leaving the system as output (e.g. sales of products). Bads are materials with a "negative" value, they cause expenditure when released as output (e.g. emissions or waste) and generate revenue when entering the system as input (e.g. a fee collected by a waste incin-

eration plant for treating the waste). Hence, the classification of Goods and Bads is important to distinguish between expenditures and revenues and to assign expenditures accordingly.

The specification of the weaving process in Figure 2 includes one revenue object only (the intermediate product woven fabric). All other inputs and outputs are necessary or accruing expenditures for producing the intermediate product. In this case the tracing of expenditures to revenues is straightforward. All expenditures are assigned to the revenue object. In many cases, processes (transitions) contain more than one revenue object and describe a co-production. In these cases allocation rules which describe how expenditures are assigned to the respective revenue objects need to be defined. Allocation rules might be based on mass, market price, volume, energy content, etc.⁵.

Figure 7 and Figure 8 show input-output inventories for two intermediate products of the spinning process, a “simple” yarn and a twisted and combed yarn (thread). The twisted and combed yarn has a significantly higher demand for cotton and energy and produces higher material losses. This can be explained by additional processes (the carded yarn is not processed through combing or twisting) and by the fact that the combing process needs to expel short fibers and hence causes material loss. An obvious approach to increase resource efficiency of SWU would be a production increase of carded yarn and a decrease of combed and twisted yarn. This is no alternative from a business and demand-driven perspective, though. It is rather necessary to increase the production system’s overall resource efficiency and to use the information for evaluating and communicating product specific differences in terms of production costs and environmental aspects.

Input:			Output:		
Item	Quantity	Unit	Item	Quantity	U...
03 energy			01 primary and intermediate product		
031 electric energy			yarn (cotton, simple)	1 t	
▲ electric energy (cooling)	108 kWh		06 waste		
▲ electric energy (heating)	13 kWh		061 fabrics waste		
▲ electric energy (lights etc)	149 kWh		▲ residue	47 kg	
▲ electric energy (process)	2,158 kWh		▲ waste (carding)	69 kg	
▲ electric energy (ventilator)	900 kWh		▲ waste (combing section)	62 kg	
04 raw materials			▲ waste (spinning)	7 kg	
▲ cotton	1,184 kg		07 emissions		
Sum	Quantity	Unit	Sum	Quantity	U...
kJ	11,979,261 kJ		kJ	11,979,398 kJ	
kg	3,523 kg		kg	3,523 kg	

Figure 7: Input-output inventory for 1 t of „simple“ yarn (slightly modified entries due to confidentiality issues)

⁵ Allocation is an important issue in cost accounting as well as in life cycle assessment. A comprehensive review of literature in this field is out of the scope of this paper.

Input:			Output:		
Item	Quantity	Unit	Item	Quantity	U...
03 energy			01 primary and intermediate product		
031 electric energy			thread (combed)	1 t	
electric energy (cooling)	113 kWh		06 waste		
electric energy (heating)	13 kWh		061 fabrics waste		
electric energy (lights etc)	221 kWh		residue	50 kg	
electric energy (process)	3,390 kWh		waste (carding)	73 kg	
electric energy (ventilator)	939 kWh		waste (combing section)	123 kg	
04 raw materials			waste (spinning)	7 kg	
cotton	1,253 kg		07 emissions		
Sum	Quantity	Unit	Sum	Quantity	U...
kJ	16,836,508 kJ		kJ	16,836,646 kJ	
kg	3,658 kg		kg	3,658 kg	

Figure 8: Input-output inventory for 1 t of combed and twisted yarn (slightly modified entries due to confidentiality issues)

3 Cost accounting evaluation of material and energy flows

Corporate decisions are usually taken on the basis of monetary calculations (cost savings, return on investment etc.). This is also true for resource efficiency measures. The assignment of physical expenditures and revenues can be used for costing purposes and for specific resource efficiency related approaches like material flow cost accounting.

3.1 Material flow network based cost accounting

Purchase prices for intermediates, raw material or energy can be easily combined with the production system and product specific physical input-output inventories described in the previous chapter⁶. Based on the material and energy flow related expenditures shown in Figure 7 and Figure 8, Figure 9 reveals the material and energy flow related costs for carded yarn and combed and twisted yarn. The physical differences result in a significant difference in production costs. The difference is even higher when depreciation of machinery only used for combed and twisted yarn is considered.

The material flow network based cost accounting approach provides a profound basis for subsequent decisions. SWU could for instance revise their product pricing and/or pay higher premiums for raw cotton that includes a lower portion of short fibers. In many SME and also in bigger companies, such detailed information is not

⁶ Additionally, further costs can be recorded and calculated (wages, depreciation, maintenance costs etc.) within transitions, for details cp. [4] and [10].

available from existing cost accounting systems. Instead of using actual resource consumption, energy and operating material consumption costs are e.g. allocated on basis of fix rates or production hours.,

	„simple“		combed+twisted	
03 energy				
031 electric energy				
▲ electric energy (cooling)	10.83 €		11.31 €	
▲ electric energy (heating)	1.29 €		1.34 €	
▲ electric energy (lights etc)	14.89 €		22.05 €	
▲ electric energy (process)	215.79 €		339.03 €	
▲ electric energy (ventilator)	89.95 €		93.95 €	
04 raw materials				
▲ cotton	1,401.85 €		1,482.87 €	
▲ municipal water	1.02 €		1.02 €	
06 waste				
061 fabrics waste				
▲ residue	-4.74 €		-5.01 €	
▲ waste (carding)	-6.88 €		-7.28 €	
▲ waste (combing section)	-49.39 €		-98.78 €	
▲ waste (spinning)	0.65 €		0.65 €	
07 emissions				
water				
▲ sewage	11.56 €		11.97 €	
Sum	Proportional Costs	U...	Proportional Costs	U..
Revenues	0.00 €		0.00 €	
Variable Costs	-1,686.83 €		-1,853.12 €	
Marginal Income	-1,686.83 €		-1,853.12 €	

Figure 9: Comparison of product-specific energy and material cost for 1 t of simple vs. 1 t of combed and twisted yarn (slightly modified entries due to confidentiality issues)

3.2 Material flow cost accounting according to ISO 14051

From the perspective of resource efficiency, any form of waste, undesired by-products, or even product outputs that need follow-up treatment or recycling, indicate inefficiency. A cost assessment of such inefficiencies is not trivial, though. While waste treatment and disposal costs are often known, these only account for the “tip of the iceberg”. Any form of material loss or inefficiency causes further and often much higher costs within the production system.

Material flow cost accounting (MFCA) is a costing approach that focuses on the proper assessment of such inefficiency or material loss related costs. MFCA has been developed in the 1990s and has recently been standardized as the international standard ISO 14051 [11] [12]. MFCA is treating wastes and remnants like

products or cost objects. Costs are not only assigned to products, but also to material losses, usually in proportion to their mass ratio⁷.

SWU's combing process in Waldkirch serves as an example, in the following. During combing, short cotton fibers are separated from the long ones, since certain product qualities can only be achieved with long fibered cotton. The combed out cotton fibers can still be sold as a by-product. The sales price normally is lower than the purchase price for cotton, though. With the assistance of a material flow cost calculation the material and energy flow based costs of the short fibers were calculated and confronted with the sales revenue of that remnant. Figure 10 and Figure 11 present the quantity based as well as the cost based evaluation. Along the way from the receiving warehouse to the combing the cotton is passed through several process steps. Each of these production steps consumes energy and auxiliaries and generates waste that causes disposal costs. Consequently, to "produce" one unit of remnant, the costs for cotton, energy and disposal rise. The proceeds of the remnants can just partly compensate the losses, so that a net loss of roughly 500 € per t of remnant occurs. This loss would be even higher if further cost groups such as depreciation cost or labor costs are considered⁸.

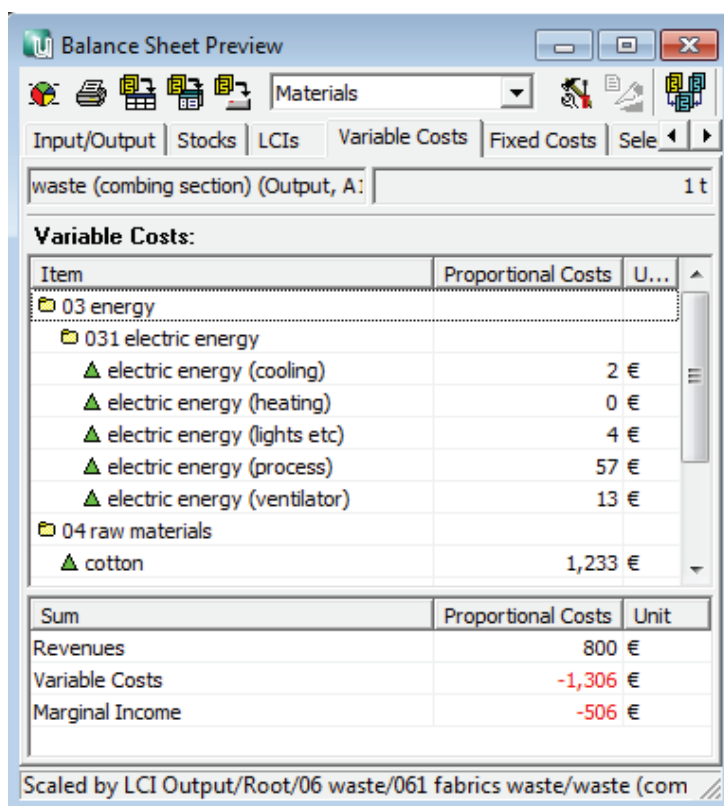
Input:			Output:		
Item	Quantity	Unit	Item	Quantity	Unit
03 energy			06 waste		
031 electric energy			061 fabrics waste		
▲ electric energy (cooling)	16	kWh	▲ residue	42	kg
▲ electric energy (heating)	1	kWh	▲ waste (combing section)	1	t
▲ electric energy (lights etc)	39	kWh	07 emissions		
▲ electric energy (process)	566	kWh	emissions (air) (a)		
▲ electric energy (ventilator)	133	kWh	▲ outgoing air (L)	18,590	m3
04 raw materials			energy		
▲ cotton	1,042	kg	▲ energy loss	754	kWh
▲ fresh air	18,590	m3	water		
▲ ground water	271	kg	▲ sewage	271	kg
Sum			Sum		
kJ	2,716,078	kJ	kJ	2,716,078	kJ
kg	1,313	kg	kg	1,313	kg

Scaled by LCI Output/Root/06 waste/061 fabrics waste/waste (combing sec 1 t = 1000 kg, scaling factor = 0.0201622144510468

Figure 10: Input-output inventory for 1 t of material loss from combing process (slightly modified entries due to confidentiality issues)

⁷ I.e. the ratio of physical product output to material loss defines the allocation rules for costs.

⁸ This is called system cost in MFCA.



Item	Proportional Costs	U...
03 energy		
031 electric energy		
electric energy (cooling)	2 €	
electric energy (heating)	0 €	
electric energy (lights etc)	4 €	
electric energy (process)	57 €	
electric energy (ventilator)	13 €	
04 raw materials		
cotton	1,233 €	
Sum		
Revenues	800 €	
Variable Costs	-1,306 €	
Marginal Income	-506 €	

Scaled by LCI Output/Root/06 waste/061 fabrics waste/waste (com)

Obviously, the loss calculated by MFCA cannot simply be avoided. Nevertheless, its consideration offers an opportunity to reconsider decisions in terms of resource efficiency. For instance, the purchase manager of SWU can precisely calculate what kind of mark-up will be appropriate if a decision between cotton with a large amount of short fibers and high quality cotton with a smaller amount of short fibers needs to be taken.

Figure 11: Material and energy flow cost of 1 t of material loss from combing process (slightly modified entries due to confidentiality issues)

4 Environmental assessment of material and energy flows

In the previous chapter it was shown how material and energy flows of a production system and the including products can be evaluated and visualized with the assistance of material flow based cost accounting. In a similar way it is possible to conduct an environmental assessment by combining material and energy flows with data on environmental impacts. For instance, an ecological backpack of 1.3 kg CO₂eq (carbon dioxide equivalents) could be assigned to each kg of cotton to determine its contribution to climate change⁹.

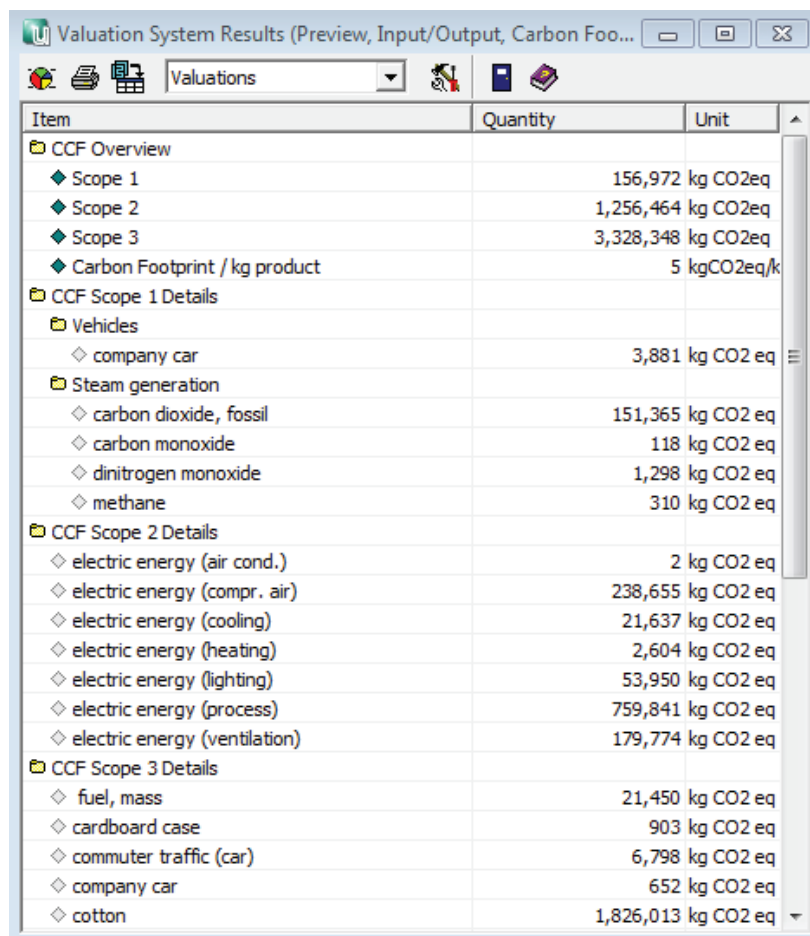
In general, material flow models provide a basis for complete calculation and evaluation of product life cycle assessments according to international standards¹⁰. In order to carry out a full life cycle assessment, the production system depicted in the

⁹ In the SWU case, such data was taken from the global life cycle inventory database ecoinvent, which is provided by the „Swiss Centre for Life Cycle Inventories“ (www.ecoinvent.org).

¹⁰ In particular ISO 14040 (Environmental Management – Life Cycle Assessment – Principles and Framework) and ISO 14044 (Environmental Management – Life Cycle Assessment – Requirements and Guidelines).

material flow network needs to be complemented by relevant upstream and downstream transitions (e.g., the cotton production in Africa, the energy generation at the supplier's site or product distribution activities).

In the case of SWU, life cycle assessment had been limited to a first rough analysis of the climate impact, considering both, the company and their products. Figure 12 shows some details concerning the company's corporate carbon footprint classified according to the scopes defined in the Greenhouse Gas Protocol [13]: direct emissions in scope 1, energy-related indirect emissions in scope 2 and all further indirect emissions in scope 3. While data quality and reliability for scope 1 and 2 was considered as very high, data quality for scope 3 had been a more delicate matter. Life cycle data for cotton, for instance, varies significantly depending on the source or database used. At the same time, the carbon footprint value for cotton affects the overall results substantially. To enhance this type of upstream life cycle data, further investigation and research would have been required which was out of scope of the case study.



Item	Quantity	Unit
CCF Overview		
◆ Scope 1	156,972	kg CO2eq
◆ Scope 2	1,256,464	kg CO2eq
◆ Scope 3	3,328,348	kg CO2eq
◆ Carbon Footprint / kg product	5	kgCO2eq/kg
CCF Scope 1 Details		
Vehicles		
◆ company car	3,881	kg CO2 eq
Steam generation		
◆ carbon dioxide, fossil	151,365	kg CO2 eq
◆ carbon monoxide	118	kg CO2 eq
◆ dinitrogen monoxide	1,298	kg CO2 eq
◆ methane	310	kg CO2 eq
CCF Scope 2 Details		
◆ electric energy (air cond.)	2	kg CO2 eq
◆ electric energy (compr. air)	238,655	kg CO2 eq
◆ electric energy (cooling)	21,637	kg CO2 eq
◆ electric energy (heating)	2,604	kg CO2 eq
◆ electric energy (lighting)	53,950	kg CO2 eq
◆ electric energy (process)	759,841	kg CO2 eq
◆ electric energy (ventilation)	179,774	kg CO2 eq
CCF Scope 3 Details		
◆ fuel, mass	21,450	kg CO2 eq
◆ cardboard case	903	kg CO2 eq
◆ commuter traffic (car)	6,798	kg CO2 eq
◆ company car	652	kg CO2 eq
◆ cotton	1,826,013	kg CO2 eq

Figure 12: Corporate Carbon Footprint overview and details (slightly modified entries due to confidentiality issues)

5 Results and conclusions

Accounting for material and energy flows and assessing related costs and environmental impacts requires the time and collaboration of several departments within a company, including top management, production planning and engineering, and accounting. The benefits of a systematic analysis of energy and resource efficiency issues are manifold, though. In the case of SWU the benefits included:

- Better understanding of cost drivers: Hot spots in terms of material and energy usage can be identified easily. Particular important energy users like the air compressors or the ventilation system have been improved continuously.
- Enhanced investment decisions: In the past, investment in more efficient spindles and motors in the spinning area had not been approved due to long amortization schemes. Considering the fact that more efficient devices produce less waste heat and hence reduce the demand for air ventilation and cooling, the amortization time came down to profitable levels.
- Additional information for costing decisions: Material and energy flow related cost accounting provides new and precise information on inefficiency related costs and product specific cost differences.¹¹
- Understanding of environmental relevance: Rough carbon footprint analysis improved the understanding of environmental consequences of products and production system and revealed major drivers of the company's environmental performance.
- External reputation and visibility: Figures and visualizations of energy and resource efficiency help to convince customers and business partners that SWU is managing the efficiency challenge well. Furthermore, the external certification of their environmental management system according to ISO 50001 was achieved smoothly due to the abundance of relevant information.
- Development of an energy and resource efficiency "culture": The improved understanding of the relevance of energy and resource efficiency improvements for the company's success has initialized a change of mindsets within the company. For instance, accountants show interest in leakage measurements for compressed air as they are aware of the cost saving potentials.
- Finally, the benefits can also be quantified: Up to know, SWU's energy and resource efficiency measures have led to annual cost savings well above 100,000 € which is by far more than the company expected in the beginning. These cost savings have a large share in the company's total profit.

¹¹ See chapter 3 for further details.

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