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TRACING MATERIAL FLOWS ON INDUSTRIAL SITES

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Abstract

There are several methods known in international practice and literature under the notion of Material Flow Analysis (MFA) which are appropriate to describe in physical terms the processes of industrial metabolism and natural resource use of different materials through micro- to the macro level. The purpose of this paper is to prove that material flow analysis is a useful and effectively applicable method also on the company level, with a logic analogous with that of macro-level MFA. That is company level MFA is a chain of logical components based on each other. Further results of the analysis are the exploration of relation between the aggregation level of data and the methods applied, and the analysis of how the micro- and macro level analysis are based on each other.

Keywords: Material Flow Accounting, company-wide accounts, input-output tables, company indicator-system, weighting methods.

1. The Theory of MFA in Short

Tracing material flow processes is an important environmental evaluation method of management processes (the principle of process orientation). Economy, economic organizations are built upon chains, 'sectors' of the biosphere, and with logic radically different from that of environmental processes. *Fig. 1* shows this scheme. If we could manage social material flows as it is done by nature, the conflict between nature and society could drastically be released. Thus, open material flow of the society should be closed. It is a basic aim to keep the material once uprooted from its original natural environment in social-economic material flow as long as possible.

The operation of this system, namely the industrial metabolism, can absolutely be described by physical laws, that is, the sum of material and energy inputs is equal to material and energy outputs plus the material and energy accumulated within the system. At the same time it is not enough – and impossible – to know the amount of input and output without knowing what kind of processes the material goes through that is, what its 'route' is within the given economic system. The task of MFA is to explore these 'routes' or material flows.

By translating this methodology to economy-wide level, the general scheme of Economy-Wide Material Flow Accounts could be obtained (see *Fig. 2*). This scheme explains how the material flows on economy-wide level can be described

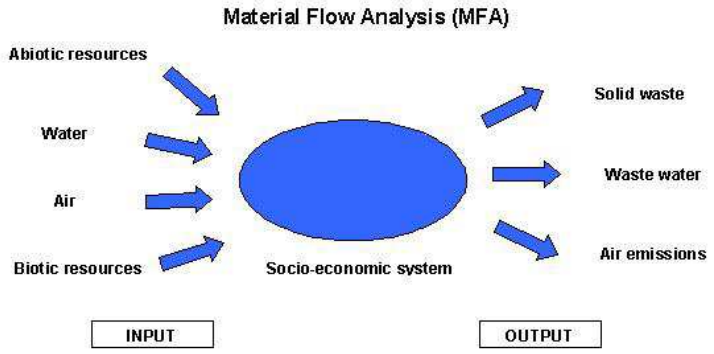

Fig. 1. The scheme of industrial metabolism (Source: HINTERBERGER et al. [1])

and grouped. Thus the task of material flow analysis is to trace the route of material from the point it gets into the system of industrial metabolism to the point it leaves the system. Meanwhile it has to be explored what percentage of the material is built into the product, what share gets into other systems and what percentage leaves – as a by-product or waste – the system. Naturally the borders of the system have to be defined, that is, from which point to which point we have to follow the material flow within the given economic system. It is important to highlight that we investigate a given economic system because materials leaving this system will not necessarily get into the environment, they may also enter another economic system. Accordingly we can distinguish two types of borders: borders between the technosphere and ecosphere and borders between two economic systems (HINTERBERGER, [1]). It is important to distinguish different flows, for instance direct and indirect, used or not used, household-related or other (Rest of the World = ROW) and we have to define the notion of physical assets in order to correctly model different material flows (EUROSTAT, [2]).

Material flow analysis is a methodologically highly effective and efficiently applicable tool that enables us to size up precisely the operation, characters and efficiency of processes of a given economy or economic actor. It gives us an information base which in the future may help us to underlie issues related to the environment-economy interface more adequately.

2. From Micro- to Macro Level?

Material flow analysis is classically prepared to countries, national economies (e.g. USA, Japan, Austria, Germany, the Netherlands (HINTERBERGER [1])). The purpose and most important result of these studies is to know the material flows, input and output values of the given country and thereby to evaluate the effectiveness and environmental pressures of the economy.

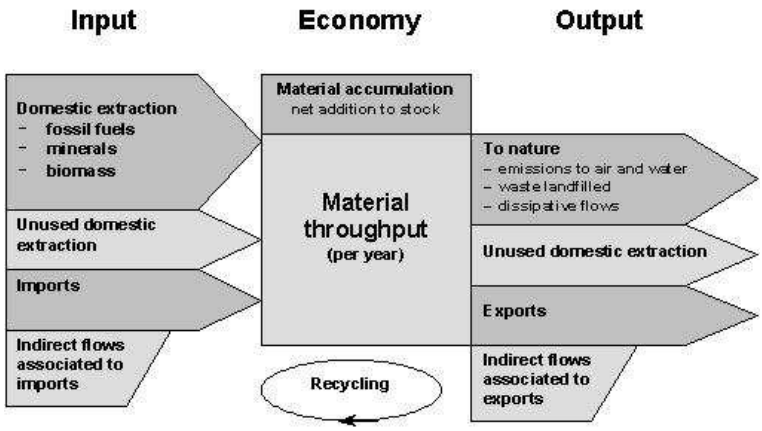

Fig. 2. General scheme of Economy-Wide Material Flow Accounts (Source: EUROSTAT [2])

At the same time MFA can be applied at several other levels of the economy [3]:

- Product and service level: this area is covered by life cycle analysis (LCA)
- Company level: Input-Output tables
- Economical sector level: 'bottom – up', or 'top – down' approaches
- Regional or national economy level: to underpin political decision-making.

Naturally different levels apply different approaches and methodologies, their basic logic is still the same: they try to measure material flows by measuring the quantities entering and leaving the system and staying within it. There are basically two possible ways to do this:

- LCA-based approach: can primarily be used to measure indirect flows
- Input-Output based approach: can be used to measure both direct and indirect material flows.

The listed fields of application are based on each other in a defined logical order, underpinning each others' operation. This order leads from micro to macro level, that is, by summing up the results of product and service level material flows we get the material flows of the company, by summing up company level material flows we get sector material flows etc. Naturally this process – contrary to the theoretical approach – in practice is not so *unambiguous*. For instance material flows of a product life cycle largely exceed the boundaries of the material flows of the producing company or the material flows of a company are not the sum of the material flows of all produced products, but they represent a wider range of material flows. Still, generally we can say that the logic outlined – at least in theory

– works. In this logical chain 'lower' levels serve as a source of information for 'higher' levels. Naturally information flow and 'interdependence' are also present within given levels.

If we investigate the logic of material flow analysis of different levels, we can also recognize the abovementioned system of relationship. Thus the inherent logic of the levels is built up analogously with the processes operating the whole MFA system.

The purpose of this study is to prove this for the company level. It will be proved that the steps of company level material flow analysis and its levels within the company are based on each other with a similar logic as the whole system. It will also be proved that the two lowest of the previously separated levels (see above), namely the product and company levels can be integrated with the integration of product level analysis into company level analysis. Further result of the study is the integration of the methodology of MFA with other company systems (management systems, accounting system, indicator system) and the qualitative analysis of integration possibilities of MFA into company decision making – and within this the companies' environmental and sustainability goals.

3. The Focus of the Analysis

The purpose of the analysis is to present the steps and levels of a company/site level material flow analysis. The investigated economic unit is the largest exporter of Hungary, AUDI HUNGARIA MOTOR Ltd., located in Győr. The system borders of the analysed system are at the borders of company operation and processes thus we analyse only processes and activities that belong to the actual range of activities of the company, and our scope of analyses does not cover the processes like raw material exploitation, auxiliary material production or material flows during product use.

In order to underpin the above conclusions, we have separated the steps of company/site level MFA into the following levels:

- Process level *(Level 1)*
- Technology level *(Level 2)*
- Product level *(Level 3)*
- Site level *(Level 4)*
- Other material flows *(Level 5)*

These levels, similarly to national economy level MFA are logically based on each other, serve as source of information or server of information for each other. The logical order of the levels – analogously with the country-wide or regional MFA – follows bottom-up logic, that is, the starting point or basis is the process level MFA followed by the others.

By summing up and synthetizing the results of levels we can get the material flows of the whole company/site. We will introduce concrete company solutions and methodologies when introducing the different levels.

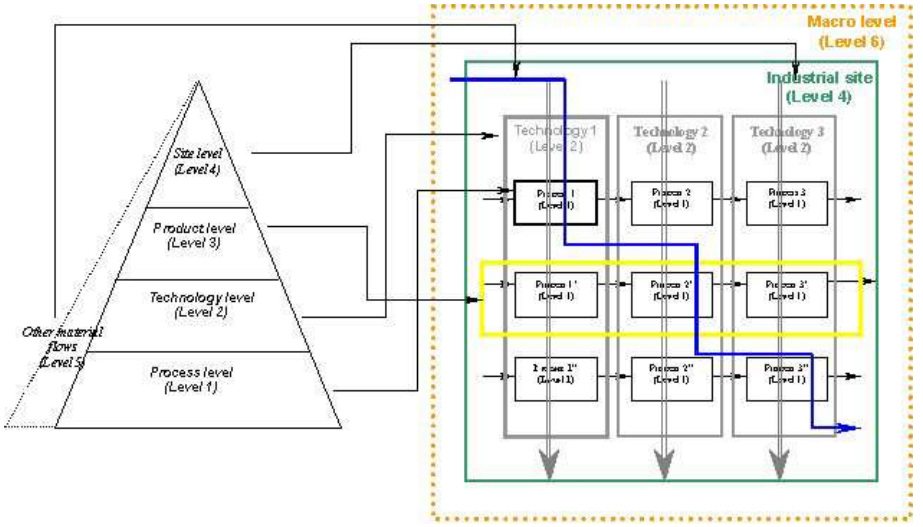

Fig. 3. Lamination of the different levels of MFA on industrial sites and its appearance in the company

4. Short Introduction of AUDI HUNGARIA MOTOR Ltd.

4.1. General Data

AUDI HUNGARIA MOTOR Ltd. (AHM) was established in 1993 as a 100% subsidiary of AUDI AG. The profile of the company is engine, engine component and automobile production. In 2004 it produced 1,480,630 engines and 23,580 automobiles. The number of employees is 5074 (2004), its annual turnover is 3924 million EUR (2004), out of that 251 million EUR was reinvested in 2004. The production depth of the company includes the whole production process from the working of incoming raw pieces, through the assembly of engines to the testing.

According to these data, the company is one of the largest companies in Hungary and is the largest exporter of the country.

4.2. Historical Overview

At the beginning of the 1990s AUDI AG decided to establish a new company site in order to expand engine production. After the long and substantial investigation – which included the investigation of 180 possible sites – in November of 1992 they chose Győr city in Hungary. The decision was supported by the location of the city, which facilitated the establishment of the logistic relationship with the mother

company located in Inglostadt, the highly qualified and cheap workforce available, the opportunity of maximal capital exploitation and the tax allowances provided by the country and the city.

As a result of all these advantages, in 1993 AUDI HUNGARIA MOTOR Ltd. was established with 2 million DM capital stock as a 100% property of AUDI AG. Production officially started in 1994, with the production of 4 cylinder 5-valve engines. Since than, the plant has developed exponentially, new and new engine types appeared in its supply, new and new factory buildings have been built. 1997 was a turning point of the company's life, after they decided to produce 6 and 8 cylinder engines in Győr. It was the time when they decided to start the production of the new, low-middleware category sports car of AUDI AG (Audi TT and TT Roadster) in Győr. After the extension of the profile, the production rose radically. Meanwhile it had become necessary to raise the capital stock to 100 million Euro. The company continuously expanded in the following years with the production of the modern Pumpe-Düse and diesel engines with common delivery-pipe and the generations of Fuel Stratified Injection (FSI) engines. As the end of Audi TT model cycle was approaching it was decided that the next type will also be produced in Győr. The profile was also expanded by settling a new technology, production of machine tools for automobile industry to AHM.

5. Possible Levels of Material Flow Analysis at AHM

5.1. Process-Level Material Flow Analysis (Level 1)

Processes give the basis of the operation of a system. Processes are the smallest sequences of operations which can be separated in their whole complexity and significantly differ from each other. For instance, it means that while – staying at the example of our concrete company – a certain step of mechanical workmanship of a component – e.g. the grinding - cannot be considered as a separable, independently observable element, according to this approach, the complete workmanship of a piece – e.g. the workmanship of the crankshaft – can be the subject of our analysis.

As the operation of the system can be traced back to these processes, the analysis of these elements is extremely important for the company level material flow analysis. As the technological characteristics of processes – e.g. the energy and raw material needs of work phases and on the output side the quantity of by-products and waste – are completely known, the input-output balance of the processes can be complied relatively precisely. It makes the analysis a bit complicated that processes are connected to each other, they may have common inputs or outputs and these inputs and outputs cannot always be divided among processes. In order to satisfy the data needs of the analysis we do not only need to know the technological characteristics of the process – that can also be defined as the conversion efficiency of the process (the units of product, waste and by-product produced from one unit of input material), we also need the input and output data of the system. On the input

side the invoicing and accounting system of different areas may be helpful, thanks to that all areas are treated as individual economic units (as a company in company) and precisely register the use of raw and auxiliary materials. These values can easily be distributed among processes, knowing the processes of the area. On the input side, the quantification of energy and other data important from the point of view of environmental protection (energy and heat usage etc.) can be considered as problematic, as there are no available data for the different areas. In this case professional estimate is the applicable method.

On the output side the amount of waste is known from the statements of the waste logistic system of the company. The quantity of other by-products such as spoilage, is also known as it is registered in the accounting system of the given area, because it is a cost factor.

To sum up: on the process level we can define the following sources of information: accounting system of the given area, general data of the whole company (energy, steam, gas etc.), distribution based on professional estimates, technological characteristics of technologies (e.g. conversion efficiency), data from the waste logistic system.

It is practical to represent the received data in an easily understandable way in order to facilitate decision-making about processes.

5.2. Technology Level Material Flow Analysis (Level 2)

By stepping one level up and summing processes we get to the level of technologies. Under technology we mean the processes, which are to a certain extent similar in one of their main characteristics (e.g. mechanical workmanship technology, maintenance technology etc.). In practice it means that processes to some extent different from each other work on different pieces but with the same technology. At AHM we can basically distinguish three main technologies, which are as follows: engine production, automobile assembling and maintenance technology. Engine production can be divided into two so-called sub-technologies: mechanical workmanship of engine components and engine assembly technology.

We can determine the material flows of technologies basically in two ways. The more complex way is to collect the material flows of all processes of the technology (bottom-up approach). It is a rather complicated method, because some quantities or flows – for example the ones that are on the border of two technologies (e.g. in case of a misoperation the absorbent used to clean the spoilage belongs to engine production or maintenance) – cannot be distributed between processes, thus in case of these processes it is hard or sometimes impossible to quantify information. The other opportunity is to start from technologies and not processes (top-down approach). In this case we assess the inputs and outputs of a given technology and try to quantify them from data available for the whole company.

This approach is much easier as most materials used by the company can be distributed among technologies with a great confidence. However, as it is mostly

based on professional estimates (e.g. what percentage of emulsion oil used will end up as emulsion as hazardous waste, what percentage gets into the emulsion grinder sludge, what percentage is stocked in the filter textile, what quantity will keep circling in the machines and what quantity will evaporate), this method is much less precise than the previous one which starts from process material balances. Relative precision and simplicity can be integrated by collecting data which are known on the process level, while in the case of the others we have to use the top-down approach.

However, on technology level it is very difficult to follow the whole material flows as the linkages of processes are very complex, the processes often run separately in time and place. Therefore it is not impossible to map wholly and precisely the material flows of a process, but it is often not possible with the resources available for the company. At this level therefore it is more common to use technology-related balances and accounts than to map and analyse individual material flows. These material balances reveal what kind of materials were used for a technology, what materials arose and what was the loss we can calculate with. These balances do not indicate internal phases, that is the processes, points and flows materials has been gone through after entering the system on the input side till the output material flows. The greatest advantage of this input-output analysis is that we can illustrate the material flows of a technology and the linkages among them in a simple and easily interpretable way. Thereby it is an easily perspicuous base for decision-making about the efficiency and environmental characteristics of the technology. Available information sources for this method are similar to information sources of process level MFA, with the extension that at this level it is much easier to handle data that are otherwise not recorded in a segmented way. *Table 1* illustrates the balance sheet of engine production at AHM.

5.3. Product-Level Material Flows (Level 3)

The exploration of product level material flows is an individual area of material flow analysis. Product-level MFA is special because it is complex. In order to precisely estimate and evaluate material flows of a product's life cycle, we have to extend the field of analysis and have to investigate the whole life cycle of the product (from cradle to grave). This naturally includes not only the actual production of the product, but also the processes before and after that. This methodology is the so-called life cycle assessment. This analysis is deeper, with broader borders of system than settled in this study. If we restrict the scope of life cycle analysis to the company's confines, we will observe only the part of the life cycle and material flows which are related to the operation of the company. The curiosity of this approach is that it is a mixture of the process and technology level approaches. More detailed description of the assessment of material flows of the whole life cycle can be read in current volume of Periodica Polytechnica, *Tracing Substances in the Technosphere and Products Herczeg M., Baranyi R.*

Table 1. Aggregated material balance sheet of engine production at AHM for 2003 (internal company material)

Engine production		2003	Washing lye	Emulsion	Refuse oil	Grid sludge with emulsion	Grid sludge with oil	Paper soiled with oil	Filter cloth	Polluted package	Glycol	Timber polluted with oil	Material left in engines	Oil transfer to techno-logy 2	Evapo-ration loss	Oil filter	Material left in machines	
2003		Ton	O_1	O_2	O_3	O_4	O_5	O_6	O_7	O_8	O_9	O_{10}	O_{11}	O_{12}	O_{13}	O_{14}	O_{15}	ton
	Summa	19 521.11	9 110.11	1 883.36	69.916	628.39	770.55	147.359	134.26	207.94	140.55	81.74	5 388.12	19.14	230.32	1.00	708.36	19 521.11
Emulsion oil	I_1	486.70	54.66	170.35		50.27			47.40	5.84					87.61		70.58	486.70
Emulsion additives	I_2	127.36	27.48	44.58		12.10				3.23					6.37		33.60	127.36
Lapping oil	I_3	56.60			28.30		11.32							2.83	14.15			56.60
Cooling- and lube-oil	I_4	284.71			27.97		26.97							0.28	1.72		227.76	284.71
Hydraulics- and lube-oil	I_5	301.40	27.33	30.20	3.09			58.94		6.24				6.03	18.87		150.70	301.40
Impregnating resin	I_6	7.74	6.19										0.77		0.77			7.74
Filter-ground	I_7	49.39					49.39											49.39
Filter cloth	I_8	80.15							80.15									80.15
Aluminium	I_9	297.60					297.60											297.60
Grey cast iron	I_{10}	958.01				566.02	385.28		6.71									958.01
Engine oil	I_{11}	5 277.90			10.56					5.28			5 225.12	10.00	26.85	0.10		5 277.90
Glycol	I_{12}	356.40									56.22		21.38		72.08		206.71	356.40
Oil filter	I_{13}	137.24											136.34			0.90		137.24
Adhesives	I_{14}	7.50								3.00			4.50					7.50
Flatted wood packaging	I_{15}	81.74										81.74						81.74
Packaging empty weight	I_{16}	176.75								176.75								176.75
Cleaners	I_{17}	95.00	66.50							7.60					1.90		19.00	95.00
Packaging paper	I_{18}	88.42						88.42										88.42
Water use	I_{19}	10 650.51	8 927.95	1 638.24							84.33				0.00			10 650.51
Total		19 521.11	9 110.11	1 883.36	66.92	628.39	770.55	147.36	134.26	207.94	140.55	81.74	5 388.12	19.14	230.32	1.00	708.36	19 521.11

5.4. Site/Company Level Material Flows (Level 4)

The highest level of company level material flow analysis is the assessment of the material flows of the whole company or site.

The operation of a company – as we mentioned earlier – is based on different processes and technologies made up of processes. Therefore if we would like to assess and quantify material flows on company level, there are basically two options we can choose from. If process level material flow analyses are available, we can create the company level MFA by integrating them. The other option is to integrate material flows on technology level and to get the company level MFA this way. The latter option is the simpler, however to some extent less precise method, considering our earlier conclusions. Naturally the higher, more complex level we analyse material flows on, the more aggregated and the more easily representable data we need. On the company level it means that instead of the earlier applied, detailed material flow maps and analysis on technology level, it is detailed material balances, the much simpler and more aggregated input-output invoices, which shows on the level of the whole company operation, what is the efficiency of material transformation, conversion into products on company level. The main characteristic of these material balances is simplicity and that they do not assess individual materials, but material groups, and link these aggregated data to material quantities within the products and emission on the output side.

In the background of this simplicity there is the approach, that economic units have to be handled as closed units, therefore the precise, detailed knowledge of processes and material flows within these units are irrelevant, because the input-output balance of the company reflects the relationship of the company and the environment. Naturally this is not so simple in practice, because in order to exactly know the operation of an economic unit, it is necessary to know the processes precisely, in detail within the unit.

Table 2 shows the input-output material balance sheet of AHM for year 2004 as an illustration.

5.5. Material Flows of Other Processes (Level 5)

The methods, levels introduced so far all analyse the material flows of a well delimitable functional unit with clearly definable system boundaries (process, technology, product, company). The other type of material flow analysis is not to assess the material flows of a module, but to trace the way of a material, component through the whole production, economic process. Tracing the way of a component, chemical within the economic system belongs to this group. This methodology has become known as Substance Flow Analysis. SFA is typically more difficult than MFA, as it is impossible to trace the whole route of a substance, as it can be built into several places, can leave the economic system anywhere. Assessing all these routes is beyond researchers. In spite of all this, several SFAs have been undertaken around the

Table 2. Aggregated input-output balance sheet of AHM for year 2004 Source: Audi [5]

Input	2004	Output	2004
Raw materials		Vehicle	23 580
Aluminium	37.5 t	Engine	1 480 630
Casting	12.3 t	Waste	33 432.5 t
Steal	3.9 t	Wastewater	226 801 m^3
Auxiliary materials			
Emulsion oil	219.1 t		
Hydraulics and lube-oil	508.3 t		
Engine oil	6 390.9 t		
Fuel	2 361.3 m^3		
Cleaner	113.8 t		
Adhesive	30 t		
Glycol	284.9 t		
Water			
Drinking water	413 834 m^3		
Energy			
Electricity	212 000 MWh		
Steam and hot water	80 070 MWh		

world and even in Europe. It is often irrelevant and unnecessary to trace the way of a substance within the company. In contrary it can be useful to follow the way of a concrete material as this can be useful to identify points of wasteful management or leakage. The creation of such a material level MFA might be very useful for decision makers and planners at the company, too.

Such analysis has been prepared for only one chemical, which is used in big quantities, namely emulsion oils. Emulsion is used for wet mechanical processing of work-pieces, to cool and grease tools and work-pieces. As the emulsion after leaving the production process has to be treated as hazardous waste and the disposal costs are high, it is reasonable to map its flow within the system in order to identify improvement, intervention points. The so-called Fluid Management Department was established to carry out this task. Its tasks are to trace the flow of emulsion

within the system, monitor emulsion state and to improve it with certain inhibitors if necessary and to explore optimization possibilities. After the department was established, as a result of its operation, the quantity of emulsion used and the closely related quantity of emulsion grinder sludge radically decreased in the following years. It is also very useful to know the exact flow of the chemical within the system and thereby it is easier to monitor the related processes.

5.6. Some More Levels Higher (Level 6)

As we mentioned in the introduction of our study, we can basically distinguish two levels of MFA, micro and macro levels. Naturally, we can divide these levels further. As we have seen, micro-level MFA can be prepared through levels, which are based on each other in a logical order. We may ask the question, whether this hierarchy can also be found on the macro level and where can micro-level analysis be found within this hierarchy. The answer is obviously yes, as the basis of macro level analysis is also a set of encompassable and from each other significantly different steps. These levels are – with some simplification - as follows:

- Sector level MFA
- Regional level MFA
- National level MFA

Naturally these levels have certain characters, data needs and analysis depth, what is not introduced within this study. It is much more important to answer the question, how company level MFA can be integrated into this system as an information basis. Since if we assess the material flows of companies within a sector – e.g. engine or automobile production – we can calculate the material flows of the whole sector by aggregating these data. If we do this within a region or country for all sectors, we will get the basic data of regional or even national level MFAs. Naturally, this is not so easy in practice, but we do not introduce it in detail now. To sum up, the most important result of a company level MFA is – besides that it provides information for decision-makers about the company's operation – that it serves as an information basis for sector level MFA and thereby indirectly for the national level MFA.

6. Data Need, Fields of Application

It is much easier to compile a micro-level MFA than a regional or national one. The reason is the availability of data. Nowadays as the market competition is and companies face a constant pressure to improve efficiency, it is an essential interest of companies to have a register system as extended as possible. This need was enhanced by the appearance of modern company management systems. To sum up, on company level almost all the necessary information is available, we only have

to find where. The following systems, data bases may be helpful to perform MFA, as we have already mentioned. The first and most important source of information is the accounting, invoicing system of the company. Information collected in this system almost covers the input-side materials of the company and several of the output side. It is advantageous if this accounting system is close to green accounting. (This tendency can be observed on national level, too, where national level MFA is related to the system of national accounts (SNA) and within this the system of national 'green accounts' (SEEA) (BARTELMUS, [4]).) Storage and stockpiling system data may also be useful for data collection. Modern computerized company management systems, like SAP integrate all these data sources. The advantages of these computer systems, data bases are inestimable, data are immediately available in the required form and depth even dynamically. The digital balance system, applied at AHM is a good example for this. This system communicates with the SAP and loads output data online, establishing immediate reference with the parallel (also digital base) waste recording system. Technical, technological descriptions of different technologies and the closely related continuous monitoring, occasional measurements can be useful to collect material flow data about the operation. On the output side company recording systems (e.g. product), environmental protection and other systems (waste recording system, emission cadastres, environmental measurements etc.) can be useful.

It can be asked, whether the results of an MFA can be used at the company and for what. The answer is yes. The results of MFA can be helpful to identify areas where the efficiency of the system is not sufficient and can be improved, and we can see the effects of the company's operation on the environment. The areas where the results of the analysis are most often used are: planning (strategic, tactical, operative), environmental protection, process design and control, invoicing, accounting etc.

7. Relation with Other Fields, Analysis

7.1. Company Balances

As it can be seen from the above, company level material flow analysis can mostly be imagined as a balance analysis. Consequently the closest relationship is with company balances, accounts. The purpose of company accounts is to record the operation of the company on the level of cash and material flows as precisely as possible. The already mentioned company management systems, invoicing, (green) accounting, logistic recording and other output side systems (see e.g. the waste logistic system) belong here. MFA can mostly contribute to these systems by a more precise mapping of data and material flows. We understand by this that while the system of company balances mostly deals with material flows, data on the company-environment (economic environment of the company) interface and only to less extent with material flows within the company, and the latter is the

main purpose of MFA. Thus MFA can contribute to make company balances more precise and to understand the meaning and impact of balance data better.

7.2. Environmental Management System

A properly operating environmental management system – similarly to other management systems – covers the whole operation of the company. Accordingly there can be defined a close connection between the system and company material flows. The basic aim of environmental management systems is to continuously improve environmental performance, what requires precise knowledge of processes and related material flows, as it is only possible to continuously improve physical environmental performance in this case. For this we naturally have to assess and measure precisely our processes and activities which may have an impact on the environment (identification of environmental impacts) and we have to follow up them continuously. The establishment and operation of a properly operating indicator system to observe indicators connected to the environmental factors of the company – with physical and management indicators – is a good measure to accomplish this aim. At AHM the identification of environmental factors is based on a so-called Leopold-matrix, weighted with an ABC analysis. The system of indicators belonging to the impacts identified this way, is developed by following the recommendations of ISO 14031 standard. The indicators recorded (namely 104 indicators) cover the whole company operation. As we could see above, environmental management systems deal with only the company-environment interface. Because MFA also serves to analyse the company-environment relationship and company environmental indicators cover the whole company sphere, indicators collected by the environmental management system can be the basis of a process-, product-, technology or company level MFA. Generally in order to assess material flows, we do not have to complete the environmental indicator system, only to harmonize them with other company indicators. We can simplify the system by weighting data (indicators) according to different environmental problems. The BUWAL 133 method, applied at AHM is a good example of this. This method is based on the notion of ecological scarcity. Environmental indicators collected are grouped into problem fields, and with the help of factors - partly natural scientific, partly based on the main goals of national environmental policy - identify four or five main problem-fields and calculate the so-called eco-pint values. With the help of this short-list of indicators it is much easier to develop company level material balances and to support decisions about environmental protection.

To sum up, a properly operating environmental management system and its basis, an indicator system, can be the starting point, basis of micro-level material MFAs.

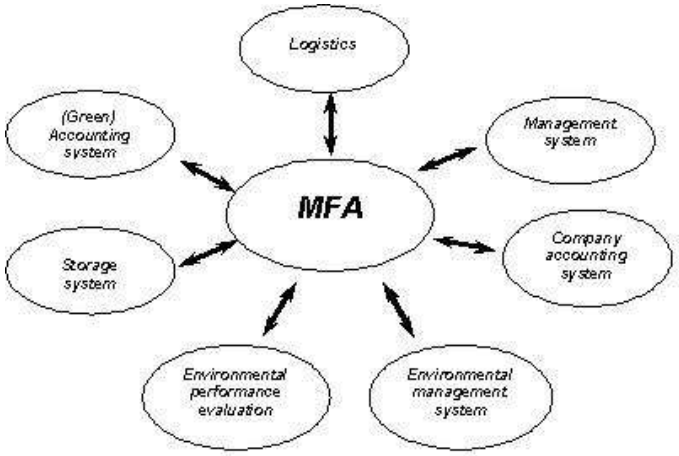

Fig. 4. Linkages between MFA and other company systems

8. Analysis or Accounting? Applied Models?

We can basically distinguish three main methods on both MFA and SFA levels, which are as follows:

- balance method
- static method
- dynamic approach

As the dynamic approach takes into consideration future changes, material flows, too, on the company level we can dispense with the application of this model.

Static and balance approaches are very different. As we could see above, the higher level we are on within the company frameworks, the less structured and detailed data we need (e.g. see process and company levels). That is, while on lower aggregation level (process, technology) we have to know every flow precisely, this is not an expectation on the level of input-output tables. Accordingly, applicable methodologies vary within the company framework, too. Process and technology level analysis can mostly be mapped by static methods. This methodology makes numerical and harmonized input and output data with the help of equations (a good example is the matrix approach of technology level material balances).

If we step higher in the logical chain, balance-like approach becomes dominant, that is we use input and output balances, data collection instead of precise mathematical calculations.

To sum up, within company frameworks as the aggregation level of data is growing, the applicable methods are getting more and more simple.

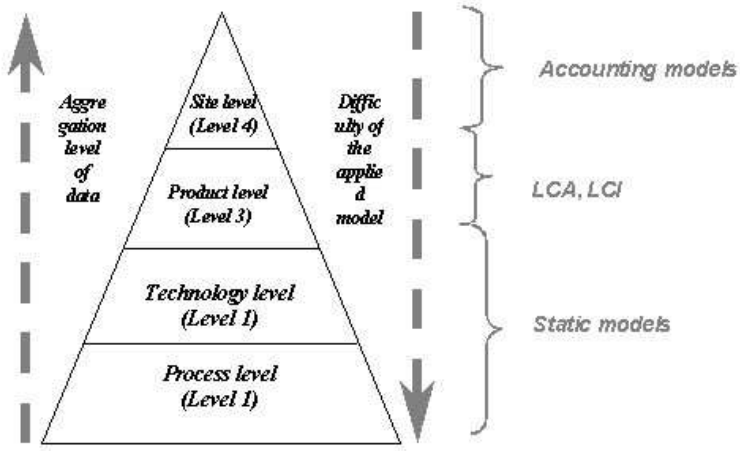

Fig. 5. Connection between data aggregation level and applied MFA methods

9. Summary

Material flow analysis – as a relatively new method – has been created to analyse and evaluate the relationships between economy and environment, the so-called industrial metabolism. Analysis can be conducted on both macro- and micro-level.

It is obvious that MFA also has to be considered as a process, and its steps develop the final result by being based on each other. The purpose of this study was to investigate application possibilities of company level MFA with the help of concrete examples, reveal its advantages, connection points to other systems, and to prove the assumption that micro level material flow analysis – similarly to macro-level MFA – is a chain of hierarchical steps.

We can conclude that – as material flows cover the whole operation of the company – by tracing material flows, analysing data and correcting the possible revealed inefficiencies MFA may enhance the environmental and economic performance of the company to a great extent.

It has also been proven that micro-level analysis can also be divided into logical elements which are based on each other, and serve as information base for each other.

As the aggregation level of data is growing step by step, the simpler and simpler methods are used for material flow analysis.

By integrating company level data we can step further in the logical chain to the macro level, when micro-level analysis can be the basis of sector-level analysis. Following this order, we can get to regional and company level MFA.

As we could see above, company level MFA is a good, adequate basis for company level decision making (strategic, tactical or operative level).

The most important advantage of company level material flow analysis is that it makes possible to integrate data and information of different systems of the

company (see paragraph 7) and thereby we can get a more precise and complex picture of the company's operation.

The closest relationship can be defined between MFA and the environmental performance evaluation system (which is the basis of the environmental management system). By extending environmental performance evaluation system in a way that would also consider the data needs of MFA, we could establish the basis of the methodology of an effectively working, constantly renewing company level material flow analysis.

To sum up, the micro-level – and within this company level – application of the methodology of material flow analysis is advantageous, moreover, desirable, because the results of the MFA enable us to get to know the relations and flows between the company and the environment precisely, making it possible for the economic unit to operate in a more sustainable way, considering the interest of the environment as much as possible.

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