"MFA AND LCA AS TOOLS IN WASTE MANAGEMENT"

H. Stevanović-Čarapina [a]

[a] Faculty for Environmental Governance and Corporate Responsibility ,
University Educons, Sremska Kamenica

Abstract

The growing concern for environmental problems in the current economy has spurred the study of the way materials and substances flow through the economy, resulting in many different types of analysis. A diverse set of tools has been developed in Industrial Ecology to tackle the problems caused by human economic activity. These instruments include Life Cycle Assessment (LCA) and Material Flow Analysis (MFA).

The choice of appropriate surveying and treatment methods of waste is currently one of the main tasks in waste management. Due to increasing circuitry and anthropogenic accumulations into the environment material aspects are reasonable more important than ever. The material flow analyzing became one of the most reliable methods in quantitative detection and is applied as a basic utility in rating waste management systems.

The aim of this paper is to make a first step in bridging the gap between the various types of analysis of material flows in the economy, by discussing the main differences and similarities of 2 employed model types: Materila (substance) flow analysis and Life cycle assessment.

Key words: *LFA; MFA, waste management* ,

I. Introduction

Climate change and other environmental threats have come more into focus during the last years. In order to meet these challenges, environmental considerations have to be integrated into a number of different types of decisions made both by business, individuals, and public administrations and policymakers. Information on environmental aspects of different systems is thus needed, and many tools and indicators for assessing and benchmarking environmental impacts of different systems have been developed [1].

Decision-making with environmental consequences can be important at different levels: from operational to strategic, from consumer products to general facilities. Types of decision situations, may be as follows: strategic planning and capital investments (green building, waste management); eco-design, product development; operational management (green procurement); communication and marketing (eco-labeling, product information). Data can come from different spatial requirements: local (site specific), regional (site dependent),global (generic); from different temporal requirements: steady state / comparative static, dynamic ..[2,3].

1.1. Industrial ecology

Many environmental problems can be directly related to flows of substances, materials and products through the economy. Several methods for describing physical flows have been developed to study such flows, but these include no description of economic mechanisms (allocation, optimization, substitution) or costs and benefits. Economic models, on the other hand, have mainly focused on abstract externalities and do not explicitly describe the flows and transformation of materials. It appears that an integration of these two classes of models is desirable [4].

Industrial Ecology is a relatively new, interdisciplinary field of research, analyzing the interaction between industrial activity and nature. So far, there is no standard definition of Industrial Ecology, but whatever the definitions may be, all authors more or less agree on at least three key elements of the industrial ecology / metabolism perspective [2,5-7].:

a) it is a systemic, comprehensive, integrated view of all the components of the industrial economy and their relations with the Biosphere.
b) it emphasizes the biophysical substratum of human activities, i. e. the complex patterns of material flows within and outside the industrial system, in contrast with current approaches which mostly consider the economy in terms of abstract monetary units, or alternatively on energy flows.
c) it considers technological dynamics, i. e. the long term evolution (technological trajectories) of clusters of key technologies as a crucial (but not exclusive) element for the transition from the actual unsustainable industrial system to a viable industrial ecosystem.

The first step for putting Industrial Ecology into practice is to study the Industrial Metabolism, that is, to carry out studies of material and energy flows. This analytical approach can show how, effectively material and energy resources are utilized through all sectors of socio-economic activity. This helps to understand the issues and identify priority areas for action. Therefore, Industrial Metabolism studies should be one of the critical elements in the planning process of a developing country. [8].

Although being a young field, Industrial Ecology has developed a diverse set of tools. This paper focuses on two of the most important instruments, Life Cycle Assessment (LCA) and Material Flow Analysis (MFA). LCA essentially identifies the environmental effects caused by a product over its whole life cycle. It is an instrument at micro level, analysing the basic cause of environmental impacts, the product. MFA on the other hand is a macro level tool that quantifies physical inputs and outputs of an economy at a highly aggregated level [6]. The general idea of MFA and other related instruments is to measure the size of the industrial metabolism [6].

2. Methodology

2.1. Material Flow Analysis

Material flow analysis (MFA) (also referred to as substance flow analysis; SFA) is an analytical method of quantifying flows and stocks of materials or substances in a well-defined system. MFA is an important tool to assess the physical consequences of human activities and needs in the field of Industrial Ecology, where it is used on different spatial and temporal scales.

The Organisation for Economic Co-operation and Development (OECD) defines MFA as: *„Material Flow Analysis (MFA) is the study of physical flows of materials into, through and out of a given system (usually the economy). It is generally based on methodically organised accounts in physical units. It uses the principle of mass balancing to analyse the relationships between material flows (including energy), human activities (including economic and trade developments) and environmental changes*.“ [9].

The methodology is described in detail in [10]. It accounts for the inputs and the outputs of the economy, as well for the stock of materials. The stock includes building, infrastructure, machinery and durable consumer goods. The flows include materials that are processed into products and the corresponding emissions as well as material that accrues in fabrication but is not used as an input to the economy.

MFA is a systematic assessment of flows and stocks of materials within a system defined in space and time. In other words, it is a method to determine, describe and analyze the metabolism of e.g. industries, regions or materials. The idea is to connect the sources, the pathways and the intermediate and final sinks of a material. MFA uses a specific terminology, which may vary from an author to another. The terminology used here is the one presented in Practical Handbook of Material Flow Analysis [9].

Because of the law of conservation of matter, the results of an MFA can be controlled by a simple material balance comparing all inputs, stocks, and outputs of a process..
The application of the method consists of the following steps:
- System analysis, consisting of the definition of a system border, processes and goods
- Determination of mass flows
- Calculation and balancing of goods
- Schematic presentation and interpretation of results

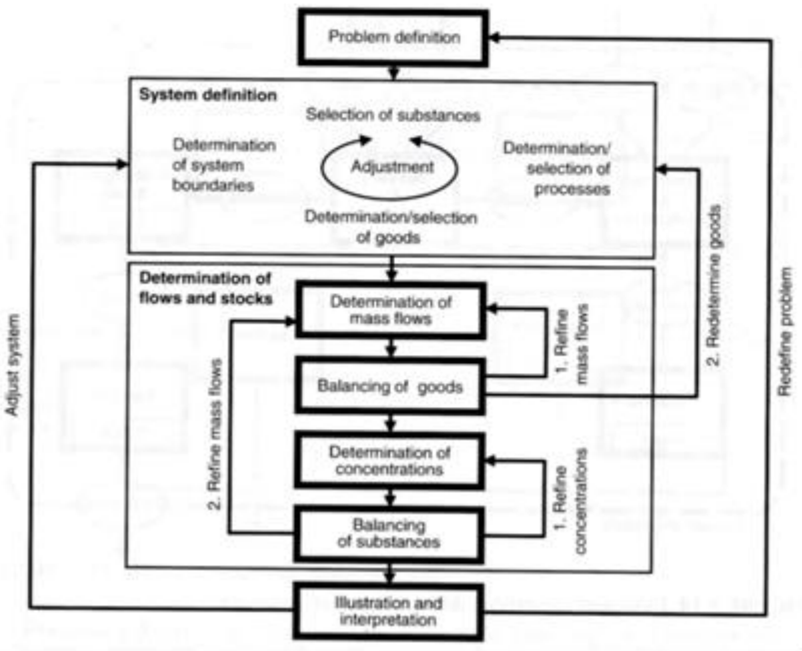

Figure 1: Procedures for MFA. [8].

Main objectives of MFA study are :
- Delineate system of material flows and stocks
- Reduce system complexity while maintaining basis for decision-making
- Assess relevant flows and stocks quantitatively, checking mass balance, sensitivities, and uncertainties
- Present system results in reproducible, understandable, transparent fashion
- Use results as a basis for managing resources, the environment, and wastes
- Monitor accumulation or depletion of stocks, future environmental loadings
- Design of environmentally-beneficial goods, processes, and systems

With respect to the analysis of efficient and environmentally friendly resource use MFA has been applied in Europe in the following way:

- Time series of imports, exports, and domestic extraction of different substances, materials and goods show how the resource basis of a country develops over the years.
- Time series of domestic material consumption per capita show how the material needs of the domestic production and private consumers change over time.
- Time series of GDP over direct material input show how the resource productivity of an economy develops National MFA based on sectorial disaggregation shows the material flows between the different sectors, the build-up or depletion of anthropogenic stocks, the recycling or final storage of materials, domestic extraction imports and exports as well as emissions into the environmental media. This shows how the system works and allows identifying hot spots as focal points for further action.

Note:
MFA provides environmental pressure indictors but does not address environmental impacts

Numerous application of MFA can bi as follows:

1. *Industrial Ecology*
- Controlling pathways for materials use and industrial processes
- Creating loop-closing industrial practices
- Dematerializing industrial output
- Systematizing patterns of energy use
- Balancing industrial input and output to natural ecosystem capacity

2. *Environmental Management and Engineering*
- Environmental impact statements
- Remediation of hazardous waste sites
- Design of air pollution control strategies
- Nutrient management in watersheds
- Planning of soil-monitoring systems
- Sewage sludge management

3. *Resource and Waste Management*
- Resource Management: Analysis, planning and allocation, exploitation, and upgrading of resources
- MFA uses in waste management
  - Modeling elemental compositions of wastes
  - Evaluating material management performance in recycling/treatment facilities
  - Examples: – Regional material balances – Single material system analysis

Material Flow Analysis (MFA) is a family of different methods . A common feature is the focus on material flows, especially on the input side. Different MFA methods have different objects in focus. Here are three types briefly mentioned:

1. Total Material Requirement (TMR),
2. Material Intensity Per Unit Service (MIPS) and
3. Substance Flow Analysis (SFA).

4. Life Cycle Assessment

Life Cycle Assessment records the environmental consequences caused by a product throughout its whole life cycle, “from cradle to grave”. The life cycle of the product comprises in general such diverse aspects as resource extraction, manufacturing of materials and energy, manufacturing of the product, use, maintenance, and waste treatment. [11].

Especially LCA has recently been gaining importance in European environmental policy. It is intended to support decisions with respect to purchase, improvement, design, and so on. LCAs can produce results at the level of the interventions (emissions, extraction of natural resources), at the level of impact categories (global warming, toxicity), at the level of damage to endpoints (human health, material welfare), or at the level of one single indicator..

Life Cycle Assessment (LCA) evaluates the environmental impact of a product, of a process or of a system in relation with a precise function. It's mainly a comparative tool used to evaluate the environmental pressure of products or systems, with the objective to highlight the production steps which can be optimized. Recent developments by the SETAC (Society for Environmental Toxicology and Chemistry) and the elaboration of ISO norms define the four steps of a LCA. methodology according ISO 14040 consists of four phases (Figure 2):

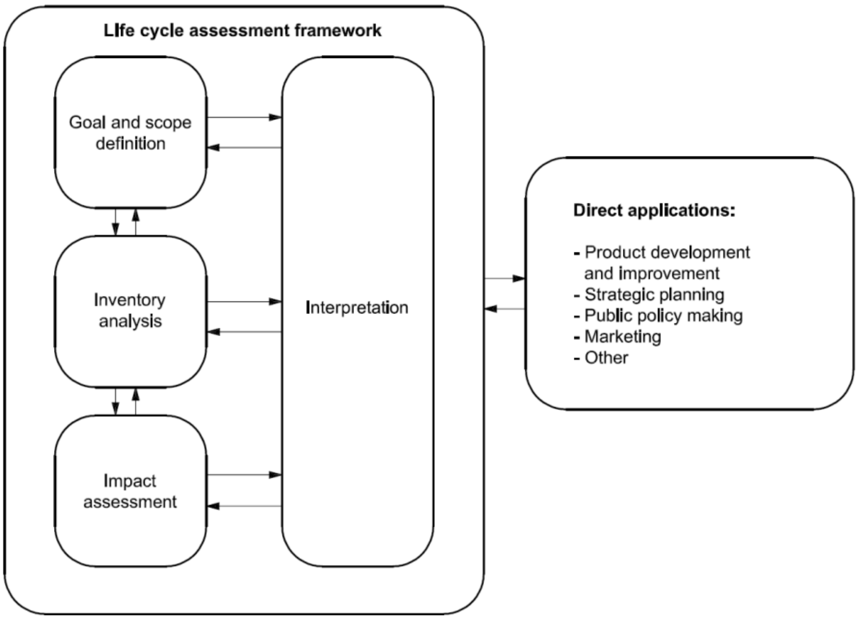

Figure 1 — Stages of an LCA

Figure 2. Stages of LCA[11].

The following steps must be taken:

1. Defining the purpose of the LCA study, ending with the definition of the functional unit, which is the quantitative reference for the study.
2. Defining the scope of the study, which includes the drawing up of a flowchart of the unit processes that constitute the product system under study, taking into account a first estimation of their inputs from and outputs to the environment (the elementary flows or burdens to the environment).
3. Defining the data required, which includes a specification of the data required both for the Inventory Analysis and for the subsequent Impact Assessment phase. [11, 12].

The Inventory Analysis collects all data of the unit processes of the product system and relates them to the functional unit of the study. The following steps must be taken:

1. Data collection,
2. Normalization to the functional unit,
3. Allocation,.
4. Data evaluation,.

The Impact Assessment phase aims to make the results from the Inventory Analysis more understandable and more manageable in relation to human health, the availability of resources, and the natural environment. To accomplish this, the inventory table will be converted into a smaller number of indicators. The mandatory steps to be taken are:

1. Selection and definition of impact categories, which are classes of a selected number of environmental such as global warming or acidification.
2. Classification, comprising the assignment of the results from the Inventory Analysis to the relevant impact categories.
3. Characterization, which means the aggregation of the inventory results in terms of adequate factors, so-called characterization factors, of different types of substances in the impact categories, therefore a common unit is to be defined for each category, the results of the characterization step are entitled the environmental profile of the product system.

Once inventories are established, the environmental impact is evaluated using the following methods: Ecoindicator 99, Impact 2002+, or similar methods [11].

The Interpretation phase aims to evaluate the results from either Inventory Analysis or Impact Assessment and to compare them with the goal of the study defined in the first phase. The following steps can be distinguished:

1. Identification of the most important results of the Inventory Analysis .
2. Evaluation of the study's outcomes
3. Conclusions, recommendations and reporting, final reporting of the results.

At present, LCA is primarily used by companies (company internal use) to support their environmental decision making . The most frequent applications are related to:

1. design, research and development,
2. comparison of existing products with planned alternatives, and
3. providing information and education to consumers and stakeholders

The interpretation step allows interpretation of the results obtained in each of the steps or sub-steps above. The environmental impact analysis is completed by a social weighting of damage which gives a relative importance of different damage and effect classes. Some methods introduce an intermediary step called normalization which relates the contribution of each category to the global effect.
This last interpretation step may be completed by linking environmental aspects to economic and social aspects.

5. MFA vs. LCA

Several advantages result from combination MFA and LCA . First of all, it is possible to know what happens at each geographical level, regional and national. This is not covered by traditional LCA, the geographical component generally being implicitly included in calculation. Knowing this, the interactions through the regional boundaries may be analyzed which is of great importance for regional MFA. It is also possible to separate the processes taking place inside the national boundaries, especially concerning the extraction and production of raw materials and energy [4].

- MFA is a method to establish an inventory for an LCA
- LCA can be an impact assessment of MFA results
- LCA strives for completeness – As many substances as possible , while MFA is directed towards reducing the number of substances of study as much as possible to maintain transparency and manageability
- MFA strives for transparency and manageability – Limited number of substances

5.1 Are Industrial Ecology Tools Appropriate Tools for Policy Making?

This development raises the question, if political measures can be developed and evaluated based on LCA and MFA. For this being the case, the instruments must be able to capture the complex consequences caused by regulatory action. [5,7].

LCA and MFA as independent tools do not consider these effects adequately.

LCA is able to include some of the results of environmental regulation, especially when they are directly connected to the product. Effects that only occur on the economy-wide level, however, are captured insufficiently.

The MFA does measure all material flows in tonnes. The connection between weight and environmental effects remains unclear. Specific regulatory acts cannot be developed using MFA.

LCA alone as a tool to evaluate environmental policy is not sufficient. At the same time, the approach to assess the impacts of products throughout the whole life cycle appears to be promising. Therefore, different models are available as well.

MFA on the other hand is a macro level tool that quantifies physical inputs and outputs of an economy at a highly aggregated level. MFA is advocated to be introduced as an information tool for policy making. MFA also treats the economy itself as a black box. This implies that nothing can be said about the economic consequences of regulatory intervention. As a consequence, MFA can only be used as an instrument to measure the physical size of the economy, but not as a tool for policy making.

MFA refers to accounting in physical units (usually in tons) the extraction, production, transformation, consumption, recycling and deposition of materials in a given location (i.e., substances; raw materials; products; wastes; emissions into the air, water or soil). Within the range of the present work, MFA encompasses methods such as Substance Flow Analysis (SFA) and other types of material balance calculations for a given region.

At present the main role of LCA in policy development is in environmental labelling and the formulation of regulations on product policy and waste management. The significance of LCA will increase when it is a part of a standard decision-making procedure. The public sector is undertaking LCAs in relation to policy development, for example in product and waste policy (UK and Germany); in directives for waste management (EU waste directive) and cleaner production (EU IPPC- Integrated Pollution Prevention and Control). The use of a well-developed LCA framework will allow governments to address social and economic sustainability indicators on a product level.

LCA is already used in policy making, mainly as a tool to detect products with major environmental impacts, i.e. for setting priorities in policy making. LCA can provide a comprehensive and holistic overview of impacts associated with a product over its life cycle. LCA is a product based instrument and it is therefore natural to use it in product based regulation.

A combination between LCA and economic models seems interesting in order to overcome the problems of limitation in application for both tools. Several ways to construct such a combination are imaginable.

5.2 **MFA ; LCA and waste management**

The Environment Action Programme to 2020 'Living well, within the limits of our planet' of the European Commission aims to support 'the shift towards an economy that is efficient in the way it uses all resources, decouples absolutely economic growth from resource and energy use and its environmental impacts, reduces GHG emissions, enhances competitiveness through efficiency and innovation and promotes greater energy security'.

Integrated waste management contributes to sustainable development as it reduces environmental pollution by treatment of waste and waste disposal on sanitary landfills. Moreover public health and living conditions of the local community can be improved. Integrated waste management also contributes to sustainable development by economizing use of natural resources though recycling and energy recovery

The choice of appropriate surveying and treatment methods of waste is currently one of the main tasks in waste management. Due to increasing circuitry and anthropogenic accumulations into the environment material aspects are reasonable more important than ever. The material flow analyzing became one of the most reliable methods in quantitative detection and is applied as a basic utility in rating waste management systems.

During the last couple of years the complexity of certain disposal systems continuously rose, resulting into more dependency between the processes. Due to the link and increasing re-feeds of waste flows into certain disposal connections more complex disposal connections arise.(Figure 3)

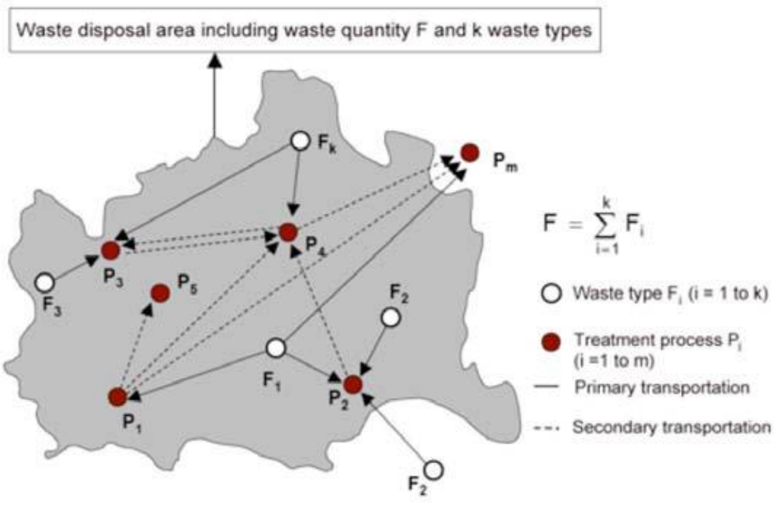

Figure 3 Complexity of waste management [14].

Material or substance flow analysis (MFA/SFA) and life cycle assessment (LCA) represent two well-established methodologies to support decision making related to waste management. MFA offers valuable insights into the material efficiency of a system, e.g. whether critical materials like potential resources or pollutants are concentrated or diluted throughout the system. It also enables capacity constraints and system dynamics to be considered, but typically does not provide any information on the environmental relevance of the different flows. LCA is a powerful tool for comparing waste treatment options from a comprehensive environmental perspective. LCA studies are commonly performed on a single functional unit basis and poorly reflect the constraints posed by, for example, the total treatment capacity of the waste management system under study. In both MFA and LCA, the improvement potential is typically identified through comparison of predefined scenarios, which may lead to suboptimal decisions. Hence, both methodologies lack a systematic approach to identify the optimal system configuration [15].

The method of MFA can be applied to a waste management system with the following targets[15].:

- Illustration of material flows and processes, including different detail grades
- Considering altered frameworks
- Accounting and analyzing the regarding system in terms of the material and energy efficiency
- Supporting the material flow management by analyzing the opportunity to distribute waste flows to various constructions, considering technical, economic and ecological framework conditions
- Analysis of critical points, development of measures for optimisation,
- Definition of a base line scenario to assess future development

For the system, the principle of mass balancing, founded on the first law of thermodynamics, is applied. The principle, also called the law of conservation of matter states that matter, i.e. mass and energy, is neither created nor destroyed by any process. Since Input and Output of complex waste treatment processes can differ, the term of stock is invented in order to describe this variation: The basics for a material flow analysis are the definition of spatial and temporary boundaries.

Generally the specific period of time for a waste management material flow model is set with one year. The spatial boundary depends on the definition, for instance within a region or a catchments area of a private company.

In general the definition of local boundaries is deduced from the scope of the analysis. If, for example, the a waste management plan for a region is developed and therefore the structure of the waste management sector in this region is looked at, the system boundary will be defined by the political boundary of the region (Figure 4).

For the environmental assessment of a waste management system the live-cycle-approach is used to define the system boundaries: the way of the waste defines the system boundaries (Figure 4). Thus, the life-cycle methodology qualifies to assess the environmental burdens of waste management from the point at which a material is collected to the point at which recyclable material, usable compost or recovered energy is produced.

When comparing different systems, e.g. for assessment of two different process alternatives, it is important to choose similar and well-defined system boundaries. The results of the analysis are set in relation to a reference (functional unit) for direct comparability.

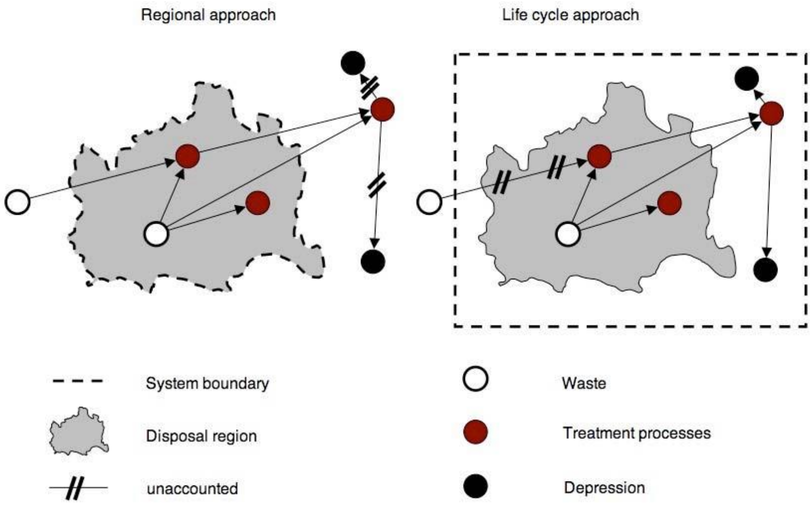

Figure 4: System boundaries: distinction between regional system boundaries and LCA-system boundaries [14].

5.2.1.Software applications

Several types of software is available for modelling waste management systems, ranging from ready-to-use software to software that supports individual solutions [11,14,15].

The applicability of a software for modelling of waste management systems depends on several aspects: apart from user friendliness and well managed data bases, the possibilities to visualize the waste management system, i.e. the treatment processes and material flows, is of importance.

Table 1 : International software solutins for modelling of waste management systems [14].

Software / developed by	Description
GaBi PE International in co-operation with LBP, University of Stuttgart www.pe-international.com	• Application of material flow analysis (MFA) and Life cycle analysis (LCA) • Environmental management systems in companies
UMBERTO Ifu Hamburg www.umberto.de	• Modelling on the basis of material flow networks • Level-based structure for visualisation of system • Variety in application, high flexibility, • Management of comprehensive data bases • Different valuation systems for impact assessment • Company-related (Process optimisation, Material efficiency) and product-related (LCA, LC Costing)
STAN Technical University of Vienna, Austria www.iwa.tuwien.ac.at	• freeware, developed for of MFA in waste mng. • import from/export from EXCEL data base possible • Pre-designed components to visualize processes • Presentation of results in form of Sankey Diagrams
IWM 2 (Integrated Waste Management, Version 2), Procter & Gamble	• Minimum of data input required due to pre-designed management systems • Ready-to-use-design for application in companies • Inventory possible but no assessment, e.g. LCA

The applicability of model software depends on the scope of the system modelling. Ready-to-use software is suitable for indicative analysis because less work and cost intensive. If complex systems and effects of variation within the system are determined, advanced modelling software is required.

6. Conclusion

On the basis of evaluation of analyzed tools and implementation in waste management decision making ., it can concluded [2,3,15].:

- that each of the tools serves its own purposes and therefore has its own strong points as well as its own limitations.
- Tools are in most cases complementary rather than contradictory. SFA/MFA can be used to assess whether certain options, as technical measures, could solve the problem in principle. LCA can be used to assess whether certain technical solutions do not lead to other, also serious environmental problems..
- SFA and LCA models usually handle much larger systems, even in theoretical applications. SFA mostly operates at a macro-level, encompassing all economic sectors insofar as they handle the substance involved. LCA is primarily a micro-level tool; the LCA system is large because of the inclusion of processes in a detailed manner and the allocation of tiny parts of macro-level sectors such as energy or transport. Large systems are possible because the modeling equations used for LCA and SFA are all simple linear equations.
- Both tools are more the physical models and the economic model rather obtain their strength from the observing of mechanisms than from describing “the real world”.
- The SFA model identifies problem-causing mechanisms based on mass conservation, such as stock-building, creating cycles, poisoning of cycles and connections.
- The LCA model identifies the main problematical parts of functional chains, options to improve chains, and problem shifting between environmental problems.
- This leads to some considerations regarding the use of these models. A first and rather straightforward recommendation is not to use the models for purposes they were not designed for.
    - Material flow analysis (MFA) is a method of analyzing flow of a material in a well-defined system which is an important tool of industrial ecology and is used to produce a better understanding of the flow of materials through an industry and connected ecosystems, to calculate indicators, and to develop strategies for improving the material flow system . MFA’s data can be used for life cycle assessment (LCA) and material flow cost accounting (MFCA).
    - LCA is a tool to assess the environmental consequences of a product from cradle to grave which can produce results at the level of the interventions (emissions, extraction of natural resources), at the level of impact categories (global warming, toxicity), at the level of damage to endpoints (human health, material welfare), or at the level of one single indicator .

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