Indicators for Eco-efficiency in Recycling Systems

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The concept of eco-efficiency was introduced by the World Business Councils on Sustainable Development (WBCSD) in 1992. Since then it has been widely adopted among companies to measure and improve the value added while progressively reducing the environmental influence per product or service to the market. However, emphasise has until now mainly been put on the creation stage and to some extent the user stage of products or services, not on the end-of-life stage. In this paper, which is one part of the research project "Eco-efficiency in recycling systems" within the Norwegian research program Productivity 2005-Industrial ecology, we have, by using WBCSDs eco-efficiency as a starting point, developed three categories of indicators that should be used to evaluate and improve the eco-efficiency of recycling systems. The general applicable indicators should be used to measure the eco-efficiency of all kinds of recycling systems. Additionally, If needed, the system specific indicators should be developed for the particularly recycling system analysed. These indicators are the eco-efficiency indicators to be used to evaluate the performance of the whole recycling system. However, in order to change/improve the eco-efficiency an existing recycling system, the company specific indicators should be developed for each of the most contributing company/activity/actor/stage of the life cycle chain for the analysed material or product

Introduction

Intuitively we all use indicators to monitor complex systems we generally are interested in or need to control. Indicators condense its enormous complexity to a manageable amount of meaningful information, to a small set of observations informing our decisions and directing our actions (Bossel 1999). We measure for instance the temperature in Celsius, give the economic activity in the US by the Dow Jones Index and present emissions of climate gases by CO_2-equivalents. According to Meadows (1998) indicators both arise from values (we measure what we care about) and create values (we care about what we measure). Some values are place- or culture-specific others may be common to all humanity. According to Hertwich and Hammitt (2000) there exist no such things as value-free objective indicators. They state that an indicator is good if it supports the purpose of the analysis carried out and at the same time gives desired information for decision-making.

Several indicators have been applied to evaluate recycling systems and there are no scientific agreements on what the best analysis method and indicators for such

systems are. Should the set of indicators applied to evaluate recycling systems involve environmental, economical or social issues and what conditions within these issues should be indicated are examples on answer that must be answered before developing indicators? The selection of indicators to apply are undoubtedly decisive for the outcome of an analysis and thus for the decision-making. The many studies carried out regarding recycling of plastic packaging illustrate this: Several studies have concluded that due to high *economic costs* in the collecting and sorting phase, high *degree of recycling* are not necessarily a better solution then energy recovery, incineration and landfill, see for instance Bruvoll (1999), GUA (1999) and Eggels et al (2000). On the other hand, other studies have concluded differently, quantification of *environmental indicators* has shown that high recycling rate is desirable (Raadal et al 1999, Wollny and Schmied 2000). Another problem emerges when it comes to the use of indicators. Since indicators only are useful if they are able to influence decision-making, the indicators must off course be relevant for the current decision-maker. This means for instance that governmental institutions will probably be concerned about other conditions and thus indicators than a recycling company will be. The company may be concerned about how many recycled products it produce or the sales price of the product, while the government may need information on the overall recycling rate for a nation or a region an what the socio-economic cost for this recycling rate is.

In this paper we will present a framework for development of indicators for environmental- and economic efficiency (eco-efficiency) in recycling systems. We are applying the World Business Councils for Sustainable Developments (WBCSD) definition and work on eco-efficiency indicators as a starting point (Verfaillie and Bidwell 2000, WBCSD 2000). This work will be extended to be useful for evaluation of the eco-efficiency in the recycling systems. We will develop an indicator framework with eco-efficiency indicators for the recycling systems as a whole and connected company specific indicator for the actors/activities/companies within the recycling system.

Presentation and extension of the eco-efficiency concept

Eco-efficiency was popularised in 1992 in Stephan Schmidheiny's book "Changing course" (Schmidheiny 1992). Since then the concept has been further developed and applied by among others WBCSD (Verfaillie and Bidwell 2000, WBCSD 2000), Fussler (1996), Organisation for Economic Co-operation and Development (OECD 1998), Global Reporting Initiative (1998) and the Norwegian Research Council (2000). Eco-efficiency offers an open and flexible approach, focusing on giving needed information for decision making by taking both economic- and environmental issues into account (Verfaillie and Bidwell 2000, WBSCD 2000). Eco-efficiency can be understood as (i) a *concept or strategy* to improve the environmental- and economic performance of a company or a nation and (ii) as a way of measuring the performance by use of *indicators* (Norwegian Research Council 2000).

WBCSD has developed a set of eco-efficiency indicators to help measure progress towards economic- and environmental sustainability in business. Eco-efficiency indicators primarily serve as a decision-making tool for internal management to evaluate performance, set targets and initiate improvement measures (Verfaillie and Bidwell 2000). The intent of eco-efficiency is, according to WBCSD, to maximize economic value while minimizing adverse environmental impact, i.e.use of resources and impacts from emissions.

In order to calculate eco-efficiency the WBCSD has developed the following equation, which merges value and ecological aspects into an efficiency ratio:

Eco-efficiency = product or service value/environmental influence

The WBCSD have trough testing developed the following "generally applicable indicators", which they argue are "applicable to virtually all businesses" (Verfaillie and Bidwell 2000):

Product or service value
- Quantity of product/service produced or sold
- Net sales

Environmental influence
- Energy consumption
- Water consumption
- Material consumption
- Greenhouse gas emissions
- Ozone depleting substance emissions

In addition to the "generally applicable indicators", WBCSD are suggesting that "business specific indicators" should be developed if more information on environmental- and/or economic performance is needed. These indicators should be developed in order to describe all relevant and meaningful aspects for a business, and will be dependent on sector and type of business (Verfaillie and Bidwell 2000)

How should then eco-efficiency be calculated, by stand-alone indicators or by combinations of indicators for products/service value and environmental influence? In contrast to their prescription of describing *all* relevant aspects, WBCSD claims that the companies should be aware of producing excessive information. Only the most meaningful combinations, providing the most useful information for decision- making, should be used to measure eco-efficiency ratios (Verfaillie and Bidwell 2000). It is therefore not obvious how the businesses should perform their reporting. A prescription easier to live with is to report the environmental and economic profile separately because this will often provide a better basis of information for decision-making.

WBCSD have developed "generally applicable" indicators to measure what is "under direct management control" of a company. The question we are going to examine later on is to what extent these indicators are appropriate for evaluations of recycling systems as well, and to what extent more indicators is needed for this purpose.

A method for development and use of indicators

As mentioned several times, efforts within the concept of eco-efficiency are often focusing on improving environmental- and economical performance on the production site, or what is under "direct management control" of a company. Less emphasize is put on the life-cycle stages of extraction of raw materials, use,- and -end-of-life. The end-of-life cycle stages may often include activities as source separation, collection, central sorting, transport, and recycling/energy recovery/disposal.

A recycling chain consists of many individual companies and actors (in transport, processing, recycling, and production), and to analyze this we need to focus on the end-of-life cycle of the material, i.e. we analyze each of the companies in the recycling chain. Hence economic and environmental considerations should be taken into account, and hereby increasing the "value added" and reducing the "environmental influence", of both the sorting, transportation, recycling process. Additionally, the fact that use of recycled material often saves an equivalent amount of virgin material should be included in such an analysis. An important obstacle, however, is that there are normally many independent actors involved in a recycling chain, which are mainly concerned about their own business, and to a less extent the life cycle faith of the material or product. On the other hand there is undoubtedly a link between the system- and company level since each activity in a recycling chain have influence on the overall eco-efficiency performance of the system, and since each activity is dependent and limited of the other activities in the recycling system and the system as a whole. To obtain changes on the system level, changes must therefore occur at the technical and organizational level in the various ed-of-life cycle stages. In our method we therefore suggest to first use a simplified economic- and environmental life cycle assessment to evaluate existing or possible future recycling systems. This analysis should serve as a basis for development of indicators on the company level that work as a decision support tool to improve the companies' performance in such a way that it also improves the eco-efficiency of the overall recycling system.

We are suggesting a six steps method for development and use of indicators to evaluate and improve eco-efficiency of recycling systems. Before going more detailed into each step of analysis method we will briefly present the steps we suggest should be carried out in an eco-efficiency analysis. The first 4 steps are dealing with *evaluation* of the recycling system, while the last 2 steps focus on development and implementation of company specific indicators to *release the potential for improvement* of the eco-efficiency in the recycling system.

1. Definition of the recycling system
2. Development of *generally applicable indicators* for recycling system
3. Development of *system specific indicators* for the recycling system
4. Use of the indicators to quantify the eco-efficiency of the recycling system
5. Development of *company specific indicators* as a basis for improvement of the eco-efficiency in the recycling system
6. Testing, implementation, measurement, reporting and action within the companies

The economic- and environmental performance (eco-efficiency) should be evaluated for the recycling system as a whole. In evaluation of the recycling system we suggest to apply *generally applicable indicators,* that are valid for all recycling systems (step 2), and *system specific indicators* that should be developed for the actual recycling systems evaluated (step 3). These two sets of indicators are used to quantify the eco-efficiency of the recycling system analyzed (step 4). Thereafter these indicators should be transferred into company specific indicators for each of the most contributing activities (step 5) in the recycling chain. In the final step 6 these indicators should be implemented in the relevant companies.

Figure 1 shows an example on how a recycling eco-efficiency indicator is connected to company specific indicators through a cause-effect chain. In this way the value of eco-efficiency indicators for the recycling system is the effect of the value of the company specific indicators. The eco-efficiency indicator % recycled plastic packaging is measured (step 4) and thereafter the company specific sorting

indicators are developed from this indicator, because they are identified to be the most relevant to improve the recycling rate. External influences on the defined recycling system and effects on other systems are also indicated in the figure.

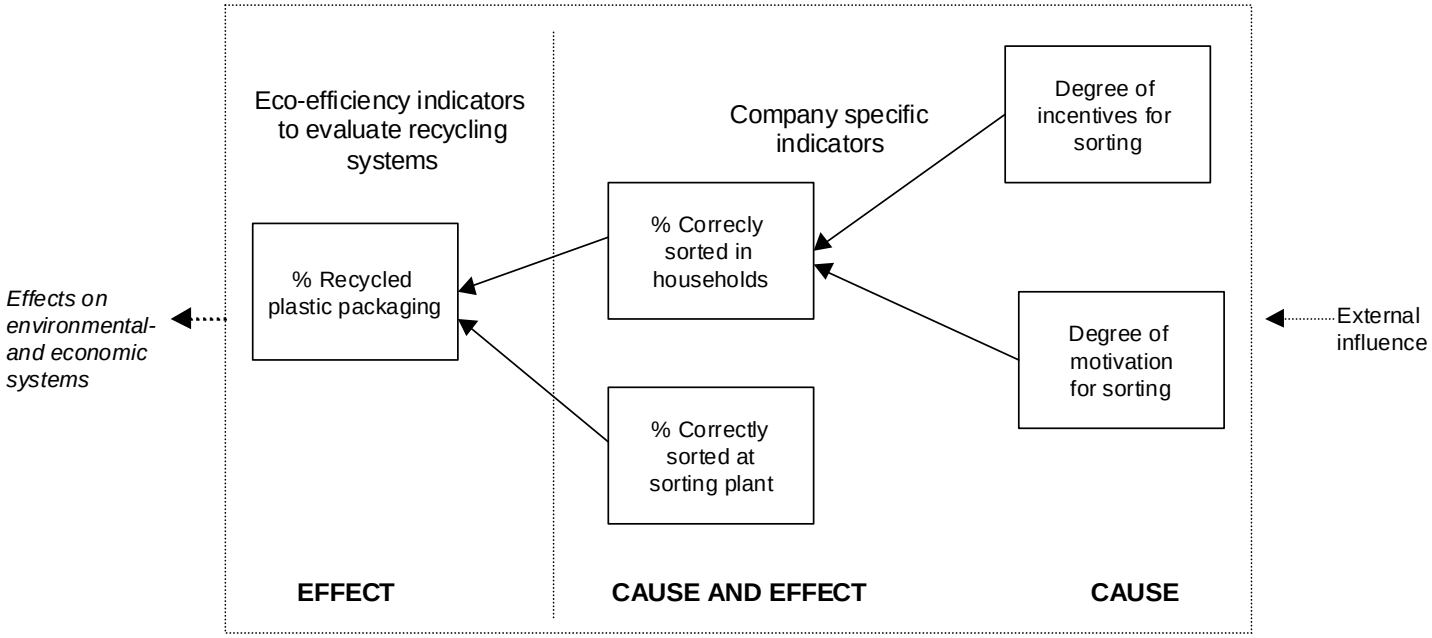

Figure 1: Examples on eco-efficiency indicator and company specific indicators, connected in a cause-effect chain

For more information on how eco-efficiency and company specific indicators are developed and used for a recycling plastic packaging system in Trondheim, Norway, se Eik et al (2001)

Applicability of the method and indicators

Normally evaluations of existing or possible new recycling system do not lead to any actions in itself. There might be many reasons for that, one reason may be that the people carrying out the study is not involving the various decision-makers in the recycling system to a large enough extent, and therefore the outcome is often that recommendation from a system analysis is not followed in practice. In our method we are recommending that the most important actors and stakeholders (public, authorities, companies, employees etc.) in the recycling system are included throughout the whole analysis, from defining the recycling challenge to use of the indicators in the various companies' organization. The method of stakeholder assessment (Økstad and Grøm 2000) may be a systematic way of carrying out this work.

When applying the six steps method to evaluate the eco-efficiency of recycling systems it is important to ensure that the indicator and analysis provide the different actors in the recycling system with sufficient information for decision-making. To initiate and steer the analysis method an "expert" on recycling issues on system- and company level as well as on life cycle assessment and eco-efficiency is needed. This expert, who may be a researcher, consultant or a skilled representative from the government, must also ensure that communication- and information system between the actors in the system are well established throughout the whole analysis. Additionally every activity/company in the system must have at least one person that

are contributing to development, implementation and reporting of the company specific indicators. Local and national authorities and other system-oriented actors are concerned about the eco-efficiency of the whole recycling systems, while actors such as transporters and recyclers are important for development, use and implementation of company specific indicators. In this manner the actors that are representing the whole recycling chain are mainly contributing to *evaluate* the recycling system. However, since the changes must occur within each of the life cycle stages of the product chain, each of the companies are a crucial factor for *improving* the performance of the company and hence the system.

Step 1: Definition of the recycling system

In order to analyse an existing or possible future recycling system the recycling system must be clearly defined. In the same way as in the methodology of life cycle assessment, appropriate system borders and functional unit must be defined (ISO 14041, 1999). This should be done by among others discussing and taking into account:

- What is or should be he function and performance of the recycling system?
- The relation between the system levels for material, product, activities and recycling chain analysed
- How different product-, material- and recycling chains are connected to each other in the society?
- Whether the whole product chain or only the recycling phase should be included in the analysis?
- Whether the functional unit should be based on waste management or production of new material (or energy) and whether it should be based on recycling, recovery or other technical options?
- Whether allocation between material- and money flows should be carried on the basis of mass, volume, monetary value or others?
- If and how avoided emissions and costs due to production of recycled material (and energy) should be included?

Step 2: Development of generally applicable indicators

We are suggesting that the generally applicable indicators should be applied to quantify the eco-efficiency of all kinds of recycling systems, included all kinds of materials and products. We have extended WBCSDs principles for generally applicable indicators (for what is under “direct management control”) (Verfaillie and Bidwell 2000) with experiences from studies on recycling issues (Wollrad and Scmied 2000, Eggels et al 2000, Raadal et al 1998), literature on LCA and recycling (Finnveden 1999, Ekvall and Tillmann 1997, Ekvall and Finnveden 2001), indicators (Meadows1998 and Bassel 1999) and industrial ecology (Graedel and Allenby 1995, Ehrenfeld 1995). Based on this we are suggesting that the *generally applicable indicators* for recycling system should as far as possible be based on the following characteristics:

1. Indicators should reflect the industrial ecological ambition of closing material- and energy loops.
2. Indicators should reflect the function and the performance of the system.
3. Indicators should be based on the most important environmental and/or economic impacts (eco-efficiency) in the whole life cycle of the recycle chain, from end-of-life product or material to new recycled material

4. Indicators should reflect global environmental concern or business value
5. Indicators should be relevant, understandable, meaningful and useful for decision-makers
6. Indicators should support system-oriented decision-makers (e.q local, national and regional authorities, pro-active firms, ”material companies”)
7. Definitions, data and methods for measurement must be established and accepted globally as scientifically valid

To develop the generally applicable indicators for recycling systems we will examine to what extent each of WBCSDs generally applicable indicators also can be applied to evaluate eco-efficiency of recycling systems.

Product or service value (economic indicators)

Quantity of product/service sold

WBCSD are expressing and measuring this indicator as a physical measure or count of product or service produced, delivered or sold to producer (Verfaillie and Bidwell 2000). In recycling system, which in principal can be defined as a production system, only what is actually sold should be included. Since one of the objectives of a recycling system is to move as much as possible of a end-of-life fraction through the recycling systems, the quantity of recycled and sold product from a given start fraction, given as % recycled. It should be mentioned that each defined recycling system has its limitation where a further growth in amount of recycled material is not preferable from an environmental- and/or economic point of view. Therefore there is a need for more than this indicator to evaluate eco-efficiency in recycling systems.

We recommend to use % recycled , instead of quantity of product/service sold as a generally applicable indicator for recycling systems

Net sales

According to the definition from WBCSD the net sales are the total recorded sales less sales discounts and sales returns and allowance (Verfaillie and Bidwell 2000). This indicator is not appropriate as generally applicable indicator for recycling systems since the focus in such systems should be on the life cycle stages from end-of-life fraction into a new product, not the net sale from for instance one recycling factory. However, the net sales in a recycling system, given as average sales price of the recycled products multiplied with kg recycled and sold material, are giving important information on the overall economic efficiency of the recycling system. It also reflects the quality of the material and what the market is willing to pay for the recycled material, even though the sales price for recycled products will depend on the market price on virgin material or alternative products as well. However, rather then having one specified indicator for the net sales or the sales price, it is more appropriate to include the incomes from the sale of recycled material in a net costs indicators, see below.

We do not recommend to use net sales as a generally applicable indicator for recycling systems.

Net costs in the system

WBCSD has not proposed costs as one of the generally applicable indicators for companies. However, they have given it as an example of a possible additional

indicator for product or service value (Verfaillie and Bidwell 2000). The costs of recycling is a very much analysed and debated issue within recycling systems and should be included as an important parameter to be able to justify or disqualify recycling as a reasonable option (Bruvoll et al 1998, GUA 1999, Eggels et al 2000).

Wollny and Schmied (2000) are mentioning cost-benefit analysis and prevention costs as possible approaches to estimate costs in recycling systems. Eggels et al (2000), are using an eco-efficiency model developed by BASF, to calculate the *cost balance*. Credits achieved through substituting virgin material with recycled material are included in this cost balance. The cost methodology in Weitz et al (1999) calculates annualised *construction and equipment capital costs and operating costs* per ton processed at the facilities in the recycling chain. In a value chain analysis to evaluate recycling costs and benefits ERRA (2000) evaluates the cost of each activity according to generally accepted accounting principles to establish *net costs* where the sales price of recycled material are included.

We recommend applying the net costs as it is given by ERRA (2000) as a generally applicable indicator for recycling systems.

Environmental influence

Net energy consumption

Energy consumption is a global environmental issue and relevant to all businesses across sectors (Verfaillie and Bidwell 2000). WBCSD expresses this generally applicable indicator as the total sum of energy consumed (equals energy purchased minus energy sold to others for their use). It includes electricity and district heat, fossil fuels, other fuel-based energy (e.g. biomass, waste fuel) and non-fuel base energy (e.g. solar, wind), calculated for instance in joule (Verfaillie and Bidwell 2000). Energy consumption is a very important parameter when evaluating recycling system since large amounts of energy often are involved in processes as transport, sorting and recycling. Additionally, a large amount of energy is saved when the recycled material from the defined system substitute alternative use of virgin material (in other systems), which are normally very energy demanding to extract. Correspondingly if incineration with energy recovery is a part of the treatment, the energy produced can substitute other energy sources.

We recommend to use net energy consumption as a generally applicable indicator for recycling systems.

Material consumption

In the framework of WBCSD material consumption is total weight of all materials the company purchases or obtains from other sources, including raw materials for conversion, other process material and pre- or semi-manufactured goods and parts (Verfaillie and Bidwell 2000). For a production site, this may very well be a relevant indicator even though such an indicator does not distinguish between the use of different kinds of material. For a recycling system, however, such an indicator would not be very useful since the end-of-life fraction is the raw material to be converted into a new product. This fraction is normally not a limited factor that should be saved. The aim is rather to use as much as possible of the end-of-life fraction, and this use is already included in the % Recycled indicator.

We do not recommend to use material consumption as a generally applicable indicator for recycling systems

Water consumption

This generally applicable indicator quantifies the sum of all water purchased from public supply, or obtained from surface or ground water sources (Verfaillie and Bidwell 2000). Use of water may be a problem in recycling processes that are water consuming and in area where there is a scarcity of water to use for such purposes. However, this is probably not a problem in general and in those cases it is, water consumption may rather be chosen as a system specific indicator.

We do not recommend to use water consumption as a generally applicable indicator for recycling systems

Ozone depleting substance (ODS) emissions

ODS are a global concern, defined in the Montreal Protocol which lists the group of gases to air from processes and losses/replacement from contaminants. Even though the effect of earlier emissions of ODS have lead to ozone depletion and will be visible in the stratospheric ozone layer over many decades, the indicator is less important since the emissions of ODS have been reduced strongly due to the possibility of using other materials. For treatment of end-of-life products as white goods this may still be a problem, but in general emissions of ODS are probably not a problem in recycling systems.

We do not recommend to use ozone depleting substance emissions as a generally applicable indicator for recycling systems

Greenhouse gas (GHG) emissions

This generally applicable indicator from WBCSD includes the amount of GHG emissions to air from fuel combustion, process reactions and treatment processes. It includes CO_2, CH_4, N_2O, HFCs, PFCs and SF_6, and are given in metric tons of CO_2-equivalents (Verfaillie and Bidwell 2000). The climate changes related to increasing concentrations of greenhouse gases are a very important and are maybe the most discussed environmental issues these days. Due to the possibly ratification of the Kyoto-protocol on reduction of climate gases, these will be very much in focus in the next decade. In recycling systems there will be GHG-emissions, particularly from the transport and the recycling process. However, as for the case of net energy, consumption of GHG-emissions will be reduced when substituting virgin materials, other products or energy resources. GHG-emissions are dependent on the use of fossil fuels, which also will be an important contribution to the net energy consumption. The reason why we suggest to include both these indicators among the generally applicable indicators is because energy consumption reflects the total energy account, while GHG-emissions indicates the use on non-renewable fossil fuels. To make a recycling system more sustainable it is both important to reduce the use of energy in total as well as shifting from fossil fuels to renewable energy sources, which will give a reduction in the emissions of greenhouse gases. Additionally, a large amount of GHG-emissions is saved when the recycled material from the current recycling system substitutes alternative use of virgin material (in other systems), which are normally very greenhouse gas demanding to extract. Correspondingly, if incineration with energy recovery is a part of the defined system,

the energy produced can substitute use of other energy sources, which in many gases give GHG-emissions.

We recommend to use greenhouse emissions, expressed as emission of CO_2-equivalents, as a generally applicable eco-efficiency indicator for recycling systems.

To summarise, we suggest that the following indicators should be applied to quantify the eco-efficiency of recycling systems in general:

Value added

- Net costs

Environmental influence

- % Recycled product or material
- Net energy consumption
- Net emission of CO2-equivalents

Step 3: Development of system specific indicators

In some cases more information about environmental and economic challenges than the generally applicable indicators can give is needed for an identified system. In this case *system specific indicators* for the particularly recycling chain should be developed. To identify these indicators it should be taken basis in both the economic (value added)- and environmental (influence) condition of the system. The system specific indicators for recycling systems should be relevant, understandable, meaningful and useful for system-oriented decision-makers.

System specific indicators may be needed to evaluate the *economic conditions* of a recycling system:

- If the net cost indicator is not giving full justification to the economic efficiency of the system (e.g. if alternative treatment cost is higher)
- If a decision-maker need an alternative overview of the economical picture in the system (e.g. subsidies to the system, net profit from all the companies in the system, net turnover for all the companies)

Additional indicators on *environmental influence* may be needed:

- If there is other significant local, regional or global emissions to air, water and ground from processes in the recycling chain (e.g. particles from transport)
- If the decision maker need information on controversial or much debated aspects (e.g. emission of dioxin from incineration plant)

To develop the system specific indicators a thoroughly study of the defined recycling system is needed. Important flows and emissions must be identified and analysed and conversations and research interviews with the actors in the recycling should be carried out.

Example

Examination of the material flows and the actors and stakeholder opinions have shown that there is a concern on toxic emissions from transport and particularly from the incineration plant in a recovery system. In this case one or several indicator on these aspects should be developed, and the Human Toxicity Potential (HTP) indicator (Hertwich et al 2000), which among others include emission of heavy metals and dioxin could for instance be chosen.

Step 4: Use of the indicators to quantify the eco-efficiency of the recycling system

In this step the generally applicable and system specific indicators should be used to quantify the eco-efficiency of existing or possible future recycling system.

As discussed earlier eco-efficiency indicators can both be quantified as stand-alone economic- and environmental indicators or as combination ratios of some of these indicators. In any case some kind of valuation between the indicators may have to be carried out in order to be able to make a decision based on the analysis. There is a debate going on the LCA community to what extent valuation between impact categories (indicators) should be included in the analysis (Hertwich 2000). The same problem emerges when quantifying the eco-efficiency of recycling chain by use of the indicators developed. How should total net costs be valuated compared to emissions of CO2-equivalents? Or % recycling compared to emission of toxic emissions (HTP)? However, as a general rule we propose that valuation between indicators into one single indicator should be avoided when carrying out eco-efficiency analysis. By developing stand-alone- or eco-efficiency ratio indicators the various eco-efficiency aspects are transparent for the decision maker and she can hence make her own valuation dependent on what she consider as the most important issue in each case. However, every indicator calculated should be taken into account.
It should also be notified that the way results are summarised and presented may be crucial for the final decision. Results or figures from the eco-efficiency analysis of a recycling system can be presented in many ways, among others in tables, diagrams, or as compasses, see chapter 5.

If the aim with the analysis is to *compare or give an overview* of existing or possible future recycling systems, in order to choose the most preferable option it is enough to carry out step 1 to 4. An example could be to carry out an analysis to agree upon future recycling rate for plastic packaging within the European Union or within a municipality. If the goal, however, is to look detailed into an existing system that it is desirable to *improve* the it is highly advisable to carry out the next steps.

Step 5: Development of *company specific indicators*

In step 1-4 we have defined the recycling system and developed and applied indicators to evaluate the eco-efficiency of the whole recycling chain. Such an evaluation is important to give information to system-oriented decision-makers such as authorities and companies that are responsible for or are concerned about larger parts of a recycling chain. Usually, however, a recycling chain consists of several actors/companies with various interests that do not necessarily have a system perspective. Since these actors, as well as actors upstream of the recycling system (designers, producers, users etc.), are the major drivers of change in the recycling

system it is necessary to transfer results from the eco-efficiency evaluation to understandable *company specific indicators* at the actor/activity/company level. These indicators should be:

- Related to activities in the recycling chain that have the highest *contributions* to the overall eco-efficiency of the recycling system, and at the same time
- have potential for a significant improvement

Similarly to the ISO 14031 standard for environmental performance evaluation (ISO 1998), we suggest that the company specific indicators could be both operational- and management indicators.

To make the indicators as appropriate as possible for supporting decision-making by actors/companies as designers, municipalities, sorting plant and recycling companies we see it as an absolutely necessity that the indicators are developed and tested in close collaboration with the current actors. Change potentials on both a short term- and a long term perspective will work as a basis for developing the indicators. The following characteristics of the company specific in indicators is desired:

- Based on a technical, organisational or economic aspects within the activities
- Connected to one or more of the eco-efficiency indicators, see the previous cause-effect figure
- Understandable, relevant and meaningful for various decision-makers in the activities or organisations
- Appropriate for both internal communication, decision-making and external reporting
- Based as far as possible on information which are easily available

Examples

Examples on company specific indicators in a recycling chain may for instance be:

- % Material or product designed for recycling
- % Material and product properly source separated
- Degree of motivation for source separation
- Sales price recycled material
- Transport efficiency in collection

Step 6: Testing, implementation, measurement, reporting and action within the companies

To be used in practice a company specific indicator must be implemented and applied within each relevant company in the recycling chain

Testing of the initial set of indicators is intended to reveal (NORDEPE 2001):

- How the indicators have been perceived and understood
- Whether they have been useful for intended purposes
- If they have provided the necessary information to the selected decision-makers

To test the indicators a company internal workshop or meeting with the relevant decision-makers is suggested.

To collect results and experience from the testing period, formalised interviews may be used. Based on the original set of company indicators and experience gathered, a final set of indicator is defined for use in the relevant decision and communication situations. Note that a set of indicators may not be defined once and for all, but should be revised according to changing needs from strategic decision makers and external stakeholders or according to changing situations.

Finally, the project group should establish a plan for implementation and modification procedures. Full implementation should then be left to internal decision-makers and personnel responsible for reporting/communication.

Summary of indicators

In the table below we have summarized the various kinds of indicator that should be developed and applied when carrying out the eco-efficiency method.

Evaluation level	**Indicator category**	**Measures/ Indicates**	**Decision makers**	**Characteristics of a good indicator**	**Indicator**
Recycling-system	Generally applicable eco-efficiency indicators for recycling system	Useful to measure eco-efficiency of all kinds of recycling systems	System oriented decision makers: local-, national- and regional governments, "material companies", pro-active companies	Based on industrial ecology and eco-efficiency, scientifically valid, relevant, understandable and meaningful for decision makers	Total net costs, Emission of CO_2-equival., Energy consumption, % Recycled product or material.
	System specific eco-efficiency indicators for recycling systems	Eco-efficiency of the particular recycling system analyzed	System oriented decision makers: local-, national- and regional governments, pro-active companies	Give additional system information, understandable and meaningful for decision makers	Example: Human toxicity potential (HTP)
Actor Company Activity Life cycle-stage/step	Company specific indicators	Operational- and management conditions within companies in the product- or material system	Company- and/or system oriented decision-makers: Activities, companies, actors within the particularly recycling system analyzed	Related to the eco-efficiency indicators, understandable and relevant for decision-making	Examples: % designed for recycling, % satisfied with source separation facilities, degree of motivation at sorting plant etc.

Table 1: Summary of eco-efficiency indicators for recycling system and company specific indicators

Summary

The concept of eco-efficiency was introduced by the World Business Councils on Sustainable Development (WBCSD) in 1992. Since then it has been widely adopted among companies to measure and improve the value added while progressively reducing the environmental influence per product or service to the market. However, emphasise has until now mainly been put on the creation stage and to some extent the user stage of products or services, not on the end-of-life stage. In this paper, which is one part of the research project "Eco-efficiency in recycling systems" within the Norwegian research program Productivity 2005-Industrial ecology, we have, by using WBCSDs eco-efficiency as a starting point, developed three categories of indicators that should be used to evaluate and improve the eco-efficiency of recycling systems. The *general applicable indicators* should be used to measure the eco-efficiency of all kinds of recycling systems. These indicators are *net costs, % recycled, net CO_2-equivalent emissions, net energy consumption*. Additionally, if needed, the *system specific indicators* should be developed for the particularly recycling system analysed. Human Toxicity Potential is an example of such an indicator. These indicators are the eco-efficiency indicators to be used to evaluate the performance of the whole recycling system. However, in order to change/improve the eco-efficiency an existing recycling system, the *company specific indicators* should be developed for each of the most contributing company/activity/actor/stage of the life cycle chain for the analysed material or product. Examples of such indicators could be: % material designed for recycling, % properly source separated, kg recycled material produced, Sales price recycled material.

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