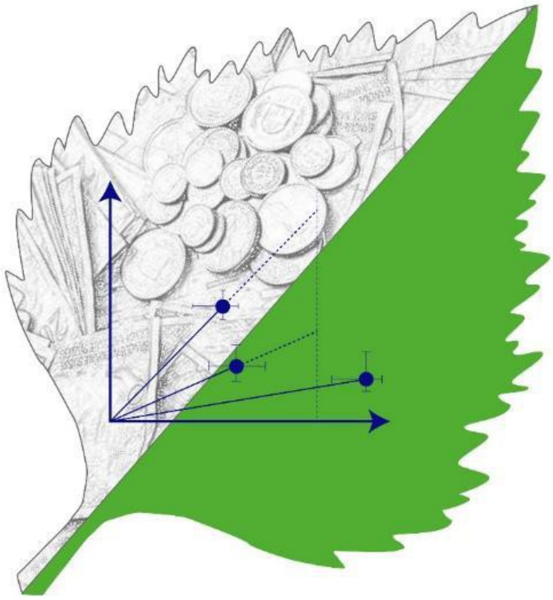
HSR University of Applied Sciences Rapperswil

EconEcol

Cost-Benefit Analysis of Recycling Systems



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Project partners:

- Federal Office for the Environment, FOEN
- EPA of the Canton of Berne, AWA
- Industry Association of ICT providers, Swico

UMTEC INSTITUTE OF ENVIRONMENTAL AND PROCESS ENGINEERING

COMMENT

This study proposes the implementation of a specific-eco-benefit-indicator (SEBI) to serve environmental decision-makers as a decision-making aid. Against this background, the following points must be kept in mind:

1. The SEBI was introduced for assessing the efficiency of newly proposed environmental measures against the background of already implemented environmental measures.
2. **The SEBI is not suitable for the decision whether to abolish already established environmental measures.** If the already established measure with the lowest efficiency were to be abolished, the same argument could be used to eliminate the measure with the second lowest efficiency, and so on, until a single measure is left.
3. The results of this study aim to achieve an accuracy of +/- 20%. They are semi-quantitative in nature and serve as a guide. Uncertainty is caused by the following reasons:
    a. The ecological balancing method we use weights environmental-relevant activities on the basis of political objectives that can change. Other ecological basic data may also change but are only periodically tracked in databases.
    b. The cost and financing structures of the systems under review are subject to changes, for example, the highly volatile raw material prices, adjustments of advanced recycling fees, the creation and dissolution of financial provisions of the collective associations, etc. .

1 Background

Switzerland plays a pioneering role in waste management. About half of the annual municipal waste is collected and recycled. The remaining half is disposed of in modern municipal waste incineration plants, MSWIP, where much of the energy content is recovered.

Material recycling lies in the area of conflict between economy and ecology. Materials that cannot be recycled must be substituted by primary raw materials such as ore and oil. The extraction of primary raw materials is often ecologically disastrous but economically profitable. The recycling of materials is, on the other hand, beneficial to the environment compared to the production of primary raw materials, but usually more expensive.

In recycling, we distinguish between market-driven systems and law-driven systems. An example of a market-driven system is the waste paper recycling (left upper quadrant in Fig. 1). Although ecologically better than co-incineration in a municipal solid waste incineration plant MSWIP, this recycling does not require any legal or financial support because the recycling costs are lower than those of waste incineration.

An example of the "market-driven disposal" (left lower quadrant) is the illegal refuse incineration, which causes much more environmental pollution than proper incineration in a Swiss MSWIP.

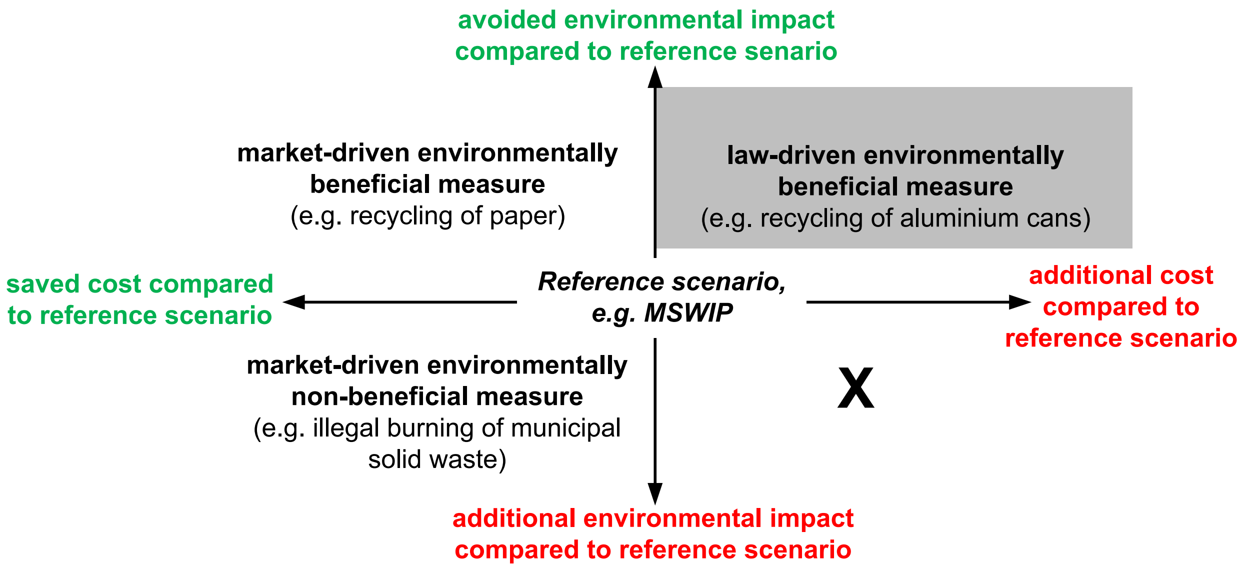

Fig. 1: Recycling systems in the area of conflict between ecology (y-axis) and economy (x-axis). Cost and benefit are compared to co-incineration in a Municipal Waste Incineration Plant (MSWIP).

An example of law-driven recycling is the material recycling of aluminum cans whereby environmental benefit is provided at additional cost against the co-incineration in the MSWIP. Another example of the upper right quadrant in Fig. 1 is the proper recycling of electronic waste. In order to avoid the electronic scrap following the market-generated suction into "recycling in emerging markets" (lower left quadrant in Fig. 1), the option "recycling according to Swiss standards" must be supported by appropriate regulations. This requires either direct legal provisions (for example, an export ban on electronic waste), or a legally regulated financial support for recycling in Switzerland, e.g. by means of a “point of purchase recycling fee” PPRF.

The EconEcol project exclusively deals with legally driven recycling systems that produce a positive environmental benefit at an additional compared to the reference scenario MSWIP, i.e. systems in the right upper quadrant in Fig. 1.

In Switzerland, stringent environmental requirements are not only anchored in laws, but these laws are also enforced. At the same time, Swiss environmental legislation is constantly changing, in particular as a result of parliamentary proposals (“green economy", “energy transition”...). Many discussions arise from the conflict between "cheap and ecologically bad" and "expensive but ecologically good" (Fig. 2). Here, reality is often determined along political boundaries: while some argue with the ecological advantage, the others consider the high costs. It would be desirable to support the decision on environmental policy measures by objective criteria. This also applies to Swiss waste management.

If a waste management system had unlimited financial resources available to support recycling, it would be sensible to support every sort of recycling, provided that it was ecologically better than the alternative. In reality, however, the money available for ecologically motivated measures is limited (for example revenue from taxes).

This means that newly proposed environmental measures are subject to competition, not only with other environmental measures, but also with other sectors of the economy (education, health, internal security, etc.). So far, this competition is decided "politically", while strongly influenced by recent environmental events (Fukushima ...). Above all, the decision depends on which side is able to mobilize the more powerful lobbies (e.g. economic associations, environmental associations ...).

In order to provide an objective base for the decision to implement a new recycling system, we propose to prioritize the eligibility using cost-benefit efficiency indicators. An introduction to this approach is shown in Fig. 2 (left), which gives a more detailed description of the upper right quadrant in Fig. 1.

Measures in the "red area" which are absurdly expensive, with only a marginal ecological benefit, are usually not even considered, e.g. the recycling of separately collected ballpoint pens or tooth brushes. Measures in the "green" area are cost-effective and at the same time bring a great ecological yield, such as aluminum can recycling. These measures are generally implemented without much discussion. It is the "yellow area" along the vector "ecological worse but cheaper" to "ecologically better but more expensive" that gives rise to objections.

The cost/benefit efficiency of the four environmental measures A, B, C, D is compared in Fig. 2 (right). The measures were initially evaluated for ecological benefits with "saved environmental burden points per ton" sEBP/ton (further explanations on this method are given in section 2). Then the additional costs for the implementation of the measures were calculated (in CHF/ton). The measures thus assessed were then entered into the diagram in Fig. 2 (right). To illustrate the cost/benefit efficiency, the points are linked with vectors from the zero point. In this way, the number of environmental “saved burden points” sEBP per additionally spent CHF can be determined for each of the four measures. The sEBP against the reference scenario per additional Swiss franc are read off on the y-axis. Clearly, measure C is the most efficient, because it brings the highest environmental benefit per Swiss Franc. Then follow A and B, both of which have the same cost-benefit efficiency, and finally measure D with the lowest efficiency.

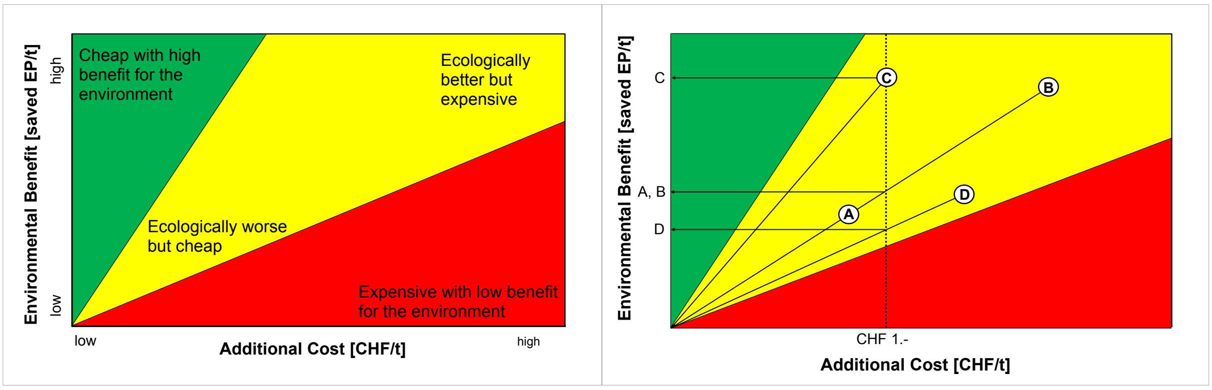

Fig. 2: Left: Example - Waste management measures that are cheap and have a high ecological benefit are carried out without much discussion. Measures that are expensive and bring little ecological benefit are generally rejected. In between is the field of conflict from "cheap but ecologically bad" to "expensive but ecologically good". Right: Cost-benefit-efficiency of the measures A...D in "saved environmental burden points" sEBP per additional issued franc (sEBP/1CHF). In terms of eco-efficiency, the following ranking follows: C>A=B>D.

2 Objective and content

The objective of the EconEcol project was the creation of cost-benefit-based foundations for environmental policy decisions.

EconEcol's central building block is a list that displays the ecological and economic efficiency of environmental measures. Life cycle assessment methods are used to determine the ecological aspects, e.g. the "method of ecological scarcity". In this way, the environmental benefit of a measure is quantified against the reference scenario (e.g., MSWI) by "saved environmental burden points (sEBP)". The ratio sEBP/CHF is the "specific-eco-benefit-indicator", SEBI for short. A high SEBI thus stands for a particularly eco-efficient recycling system, i.e. a large environmental benefit per Swiss franc spent.

Example Laptop Recycling: For laptops the buyers pay a "point of purchase recycling fee" PPRF of 1,150 CHF/t. This fee is used for the separate collection of laptops, followed by proper processing by Swiss recycling companies. This cost against the reference scenario "Incineration after disposal into the garbage bag" (cost per ton approx. CHF 310) is an additional 840 CHF/ton, but also 7.7 million EBP are saved. For reference: 7.7 million EBP corresponds to the environmental burden, which is triggered, for example, by a 20,000 km journey with the average car or by the extraction of 50 g of gold from ore.

After the calculation of the SEBI of a number of environmental measures in this manner, a picture of the cost-benefit efficiency of environmental measures already introduced in Switzerland emerges.

In the case of newly proposed measures, it is now possible to determine how these compare with respect to the measures adopted so far. This comparison serves as a decision aid. Against the background of Fig. 6, the range of recycling systems in Switzerland is in the range of 1,000-15,000 sEBP/CHF. It will therefore be much more difficult to introduce a new recycling system X with only 500 sEBP/CHF as compared to a measure Y, which brings 20,000 sEBP/CHF. For the implementation of measure X, further supporting arguments would need to be found, e.g. "strategic measure with investment character" (costs are currently high, but worthwhile in the long term), "harmonization with international obligations" (e.g. CO2-reduction commitments), "resource considerations" (creation of a raw material basis by recycling), "political will", etc.

The SEBI thus proves to be an instrument which provides a quantitative framework. This makes it possible, to carry out the political discussion based on facts and rationality.

3 Materials and Methods

3.1 Definition of scenarios

In order to determine the ecological efficiency, an ecologically superior "alternative scenario" is compared with a cheaper "reference scenario". The reference scenario is generally the scenario that would be applied if the considered alternative was not implemented, i.e. the "status quo". In order to assess environmental measures that were introduced, the reference scenario is usually the scenario, which would be applied if the measure to be investigated had not been introduced or was to be abolished.

The standard reference scenario for the assessment of the eco-efficiency of systems for the recycling of municipal waste in Switzerland is the incineration of the waste in an average MSWIP. A reasonable reference scenario for the assessment of the recycling of mineral construction waste would be the deposition on a Type B landfill.

The alternative scenario would, for example, be the recycling of PET-bottles, instead of incineration (thermal use). Another example of an appropriate alternative scenario would be the processing of mixed demolition waste rather than landfilling.

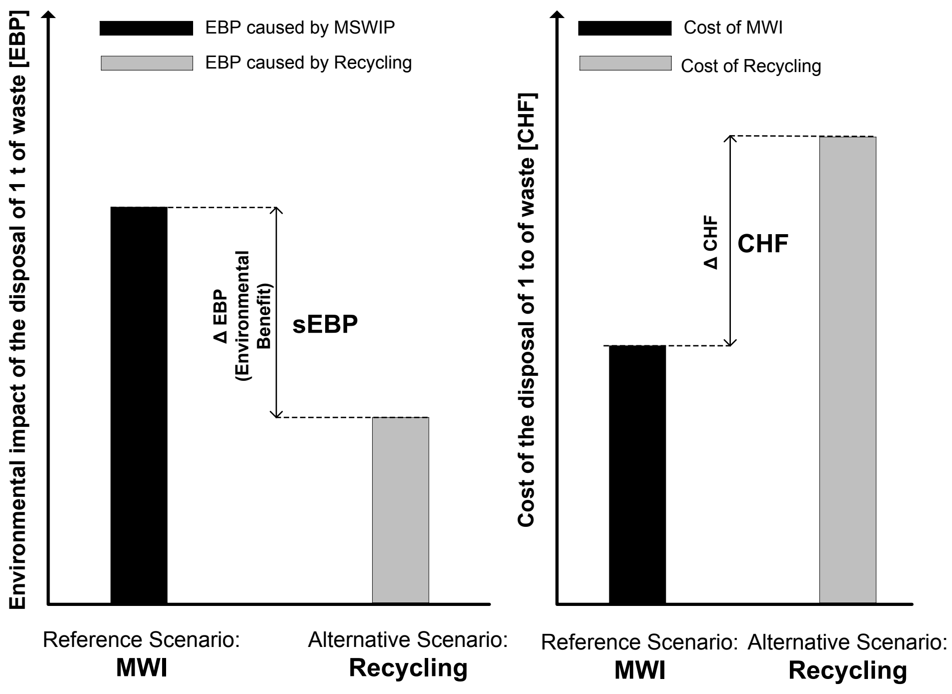

Fig. 3: *"Reference Scenario" municipal solid waste incineration MSWI vs. "Alternative Scenario" recycling. Left: Quantification of environmental burden by environmental burden points leads to △ EBP. Right: In the same way, the costs (△ CHF) which are additionally incurred against a reference scenario are determined. These two differences (△ EBP and △ CHF) are divided to determine the SEBI: SEBI=△EBP/△CHF=sEBP/CHF.*

3.2 SEBI - Specific-Eco-Benefit-Indicator)

Measures with a high ecological efficiency (“eco-efficiency") cause a high environmental benefit with little financial expenditure. Ecological efficiency is defined in the SEBI model:

$$SEBI = \frac{environmental\ benefit\ compared\ to\ reference\ scenario}{costs\ compared\ to\ reference\ scenario}$$

$$= \frac{saved\ environmental\ impact}{additional\ costs}$$

$$= \frac{EBP_{reference\ scenario} - EBP_{alternative\ scenario}}{Costs_{alternative\ scenario} - Costs_{reference\ scenario}} \left[\frac{\mathrm{sEBP}}{CHF}\right]$$

Fig. 3 shows how the SEBI is determined from the saved environmental burden points sEBP and the additional costs of an environmental measure in CHF.

3.3 Quantification of the environmental burden

The determination of environmental burden points EBP by the EconEcol-project was compliant with ISO 14044:2006 and derived by means of a life cycle assessment (LCA) based on the databases Ecoinvent 2.2 and 3.1. The applied "method of ecological scarcity" weighs the environmental burdens according to environmental policy objectives of Switzerland. Alternatively, other methods of eco-balancing could also be used, e.g. the quantification of environmental burdens using CO_2-equivalents.

The functional unit is the disposal of a ton of waste. The system boundaries have been set as follows: from "handover to the disposal system" (for example, "picked up from the roadside" or "delivered to municipal collecting containers") to "recyclable material recovery" or "landfilling of the waste incineration slag".

The substitution principle was applied for the quantification of the environmental benefit triggered by "recycled material". A credit is given for the recycling process, which results from the difference between the EBP caused by the production of the new material and the EBP caused by the recycling of the material. For example, by the recycling of metals the production from primary ore is prevented.

3.4 Calculation of costs

In order to determine the costs of a recycling system in comparison to incineration in a waste incineration plant, the total costs are considered (Fig. 4).

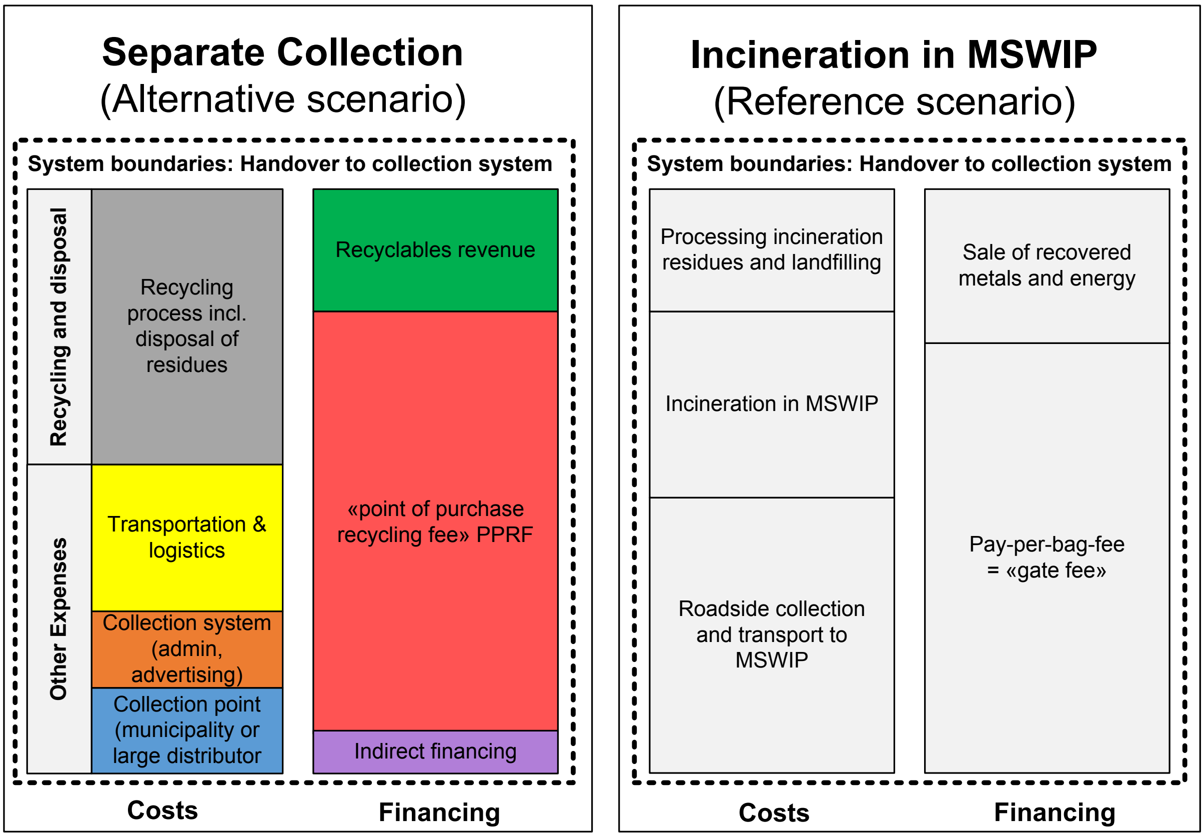

Fig. 4: The costs of the alternative scenario within the system boundaries "handover to the disposal system" are divided into "recovery costs" (recycling by recyclers including disposal fees for residues) and "other expenses" (collection and logistics expenses, etc.). In the reference scenario MSWI, the collection, combustion, processing and landfilling costs are considered. While these costs are covered by a gate fee and the sale of energy and metals, recycling systems are financed through the sale of value, the PPRF and through any "indirect financing", e.g. by means of taxes or collection costs incurred by the large distributors.

Both disposal systems, separate collection and recycling as well as municipal waste incineration MSWI, cause costs, which are financed through revenues. We assume that costs and revenues are just levelled. In the alternative scenario (left side in Fig. 4), the total cost is as follows (from bottom to top in Fig. 4):

- Collection point: The expenses for the maintenance of a collection point, e.g. provided by a municipality.
- Collection system: The expenses listed by the collective associations, e.g. administration and marketing expenses, etc.
- Transport & logistics: All transports and storage from the collecting point to the recycler.
- Processing: The cost for the recycling process and the proper disposal of the residues.

The financing is provided as follows (from bottom to top in Fig. 4):

- Indirect financing: Expenses, which are generally not explicitly stated. Example 1: Support for collection centers by municipalities (covered by tax). Example 2: Support for the collection centers by the provision of logistics by the major distributors (financed by surcharges on the products).

- Advanced recycling fees, which are usually paid at the point of purchase.
- Recyclables revenue: The revenue generated by the sale of recovered and recycled materials.

The bulk of the fees collected at the point of purchase is used to pay for the collection and recycling processes (red box in Fig. 4). The rest of the treatment and disposal costs are covered by revenue from the recyclables revenue (green box in Fig. 4).

The reference scenario (see right figure in Fig. 4) comprises the costs of the waste collection from the roadside, the incineration in the MSWIP, and the subsequent treatment of the incineration residues including landfilling of the residues. These expenses are financed mostly through the proceeds of the “pay-per-bag-fee” (collection&gate fee). A minor fraction of the revenue is generated by the sale of energy (electricity and heat) and recovered metals.

4 Results and discussion

4.1 Calculation of costs

Over the last few years, Swiss communities are increasingly confronted with a "waste collection rage" of their citizens. As a result of the idea that recycling is "intrinsically good", ecologically committed citizens are continuously requesting new separate collections, such as for credit cards, DVDs, wine bottle corks and the like. However, the following point needs to be considered: The costs for separate collections strongly depend on the total amount of material collected. The logistics costs increase massively with diminishing amounts of material collected and, as a rule, exceed all other costs including the actual processing costs (Fig. 5).

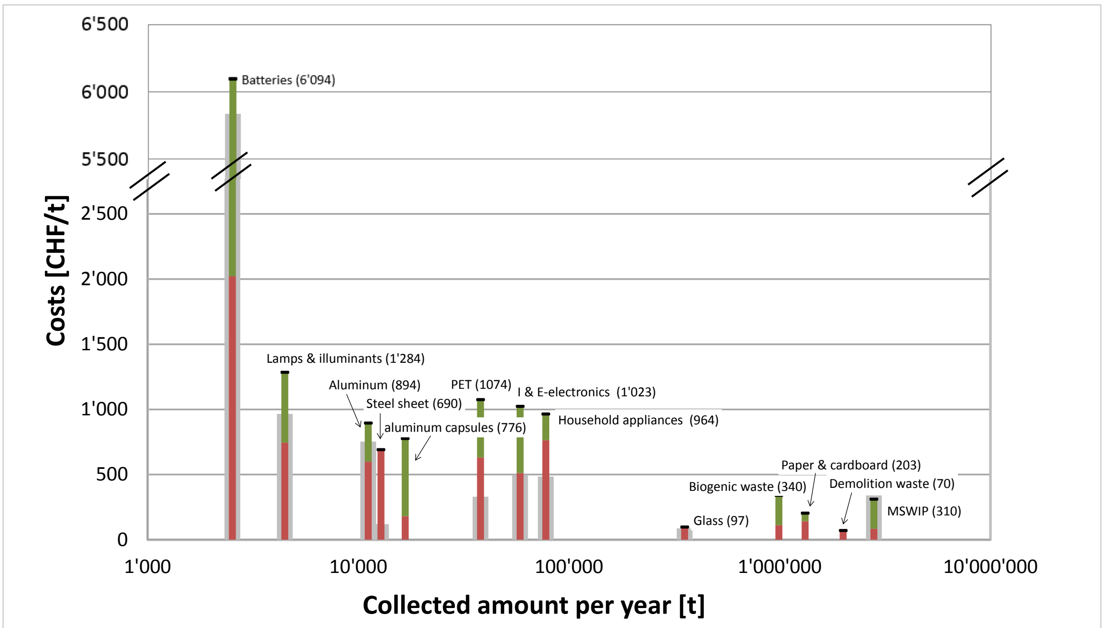

Fig. 5: Total costs per ton in relation to the quantities collected. The revenue covered by the prepaid fees is marked red, the revenue generated by the sale of recyclables is green. The data used are based on the years 2012 through 2014. "I & E electronics" are computer science and entertainment electronics, which are recycled by SWICO.

From Fig. 5 it becomes clear that there is an inverse correlation between the quantities of materials collected for recycling and costs: the larger the quantity, the lower the cost.

4.2 SEBI of recycling systems

With the model described in Chapter 3, the SEBIs were calculated for Swiss recycling systems. These are shown in Fig. 6 divided into two material groups:

- Packaging materials
- Electronic devices

A high eco-efficiency (= large SEBI) is achieved by the metallic packaging materials aluminum and tinplated steel as well as the electrical scrap recycling (SENS) (Fig. 6). The recycling of electronics (SWICO), "lamps & illuminants" and PET is located in the middle of the spectrum. At the bottom of SEBI, there is the recycling of household batteries, beverage cartons and aluminum coffee capsules.

Although the recycling of household batteries has a high specific environmental benefit of 7.8 million sEBP/t, it also has the highest specific costs (5,921 CHF/t). Historically, the separate collection of batteries was mainly initiated because of their mercury content. This poisonous metal was inititally contained in large quantities in the earlier batteries, and only incompletely filtered by the flue gas purification of the former MSWIP. In the meantime, however, the ban of the use of mercury in household batteries and much improved offgas cleaning processes in MSWIP have led to an almost complete elimination in mercury emissions by MSWIP. Thus, at about constant costs, the environmental benefit of battery recycling vs. co-incineration in MSWIPs is dramatically lower and consequently the SEBI is also now much lower now than previously (in 1990).

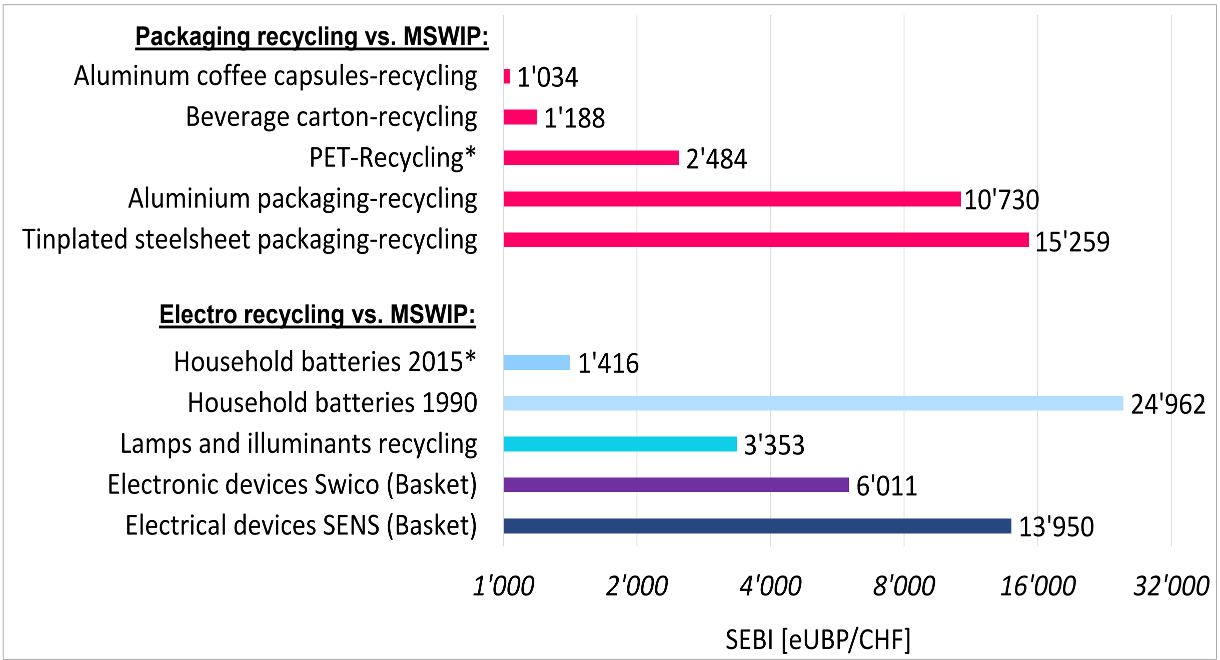

*Fig. 6: SEBI of different recycling systems, shown as a bar chart. The costs of the recycling systems were determined at UMTEC. The asterisk * behind individual recycling systems in the legend indicates that the data for determining the environmental burden were derived from an external study (Carbotech).*

According to our estimates, the recycling of separately collected beverage cartons would have a similarly low SEBI as battery recycling. In contrast to battery recycling, the recycling of beverage cartons has not yet been introduced in Switzerland. If our estimates of the rather low cost-benefit efficiency of the beverage carton collection are correct, special arguments must be given to support the introduction of legislation promoting a separate collection of beverage cartons.

The recycling system for aluminum coffee capsules also has a comparatively low SEBI. However, a criticism of this system would be misguided in that the recycling of the capsules is carried out and financed privately, i.e. does not require support by legal requirements. While the costs of capsule recycling are high and the environmental yield is low, these costs are being passed on directly from the producers to the customers through an increased product price (and not to the general public).

The recycling of PET considered in this study is cost-efficient in the lower midfield. The reason for this is that the reference scenario "thermal utilization in MSWI" performs surprisingly well in environmental terms, thanks to the credit for heat and power generation in modern MSWIP. This decreases the difference between the environmentally more beneficial material recycling of PET and its thermal utilization. Consequently, the cost/benefit efficiency also decreases.

It is to be expected that the recycling of other plastics will have an even poorer cost-benefit efficiency than PET recycling. However, from the relatively low eco-efficiency of the plastic recycling it must not be inferred that plastic packaging is fundamentally ecologically poorer than, for example, packaging made from metals, glass or paper. The SEBI indicator simply says that compared to the reference scenario "incineration in the MSWI", the material recycling of plastic packaging has only a relatively small advantage. Plastic packaging, on the other hand, can be significantly better than alternative packaging materials when the ecological added value of plastic packaging in the areas of "avoidance of food waste" and "low transport weight" prevails over the ecological disadvantage of recycling packaging.

Table 1: List of recycling systems considered.

Recycling system		**recyclable material**
IGORA	Aluminum packaging recycling association	Aluminum packages (incl. cans)
Ferro	Ferro Recycling	Tinplated steel sheet cans
INOBAT	Battery Disposal Organization	Household batteries
SENS	Foundation SENS eRecycling	Electrical and electronic household appliances, toys, construction, garden and hobby equipment
SWICO	Association of ICT providers in Switzerland	Informatics and entertainment electronics
PRS	PET Recycling Switzerland	PET beverage bottles
SLRS	Light Recycling Foundation Switzerland	Light bulbs, lamps & illuminants

It should also be pointed out that some recycling systems in the Swiss waste management sector were excluded from our considerations, e.g. the recycling of paper and cardboard. Disposal of paper and cardboard costs an average of 203 CHF/t, which means that it is not only ecologically better, but also cheaper than incineration in the MSWI with 310. -/t. This system is thus located in the upper left quadrant of Fig. 1 and is therefore beyond the scope of the project EconEcol, which is limited to the right upper quadrant.

Fig. 7 (left graphic) represents the "effect", i.e. the effectiveness, of the recycling systems discussed so far with respect to avoided environmental burden. On the x-axis, the cost per ton and the y-axis the EBP per ton are mapped. In addition, the ecological benefits are represented by the size of the individual bubbles (relative to the ecological overall benefit of all recycling systems). Table 1 provides an overview of the recycling systems in Switzerland considered in this study.

The two systems SENS (electronic scrap) and SWICO (electronic scrap) represent the largest share of the ecological benefits (largest bubbles). The IGORA and PET systems also make a considerable contribution to the overall environmental burden avoided.

In contrast, the recycling of household batteries, beverage cartons and aluminum coffee capsules makes a comparatively small contribution to the overall ecological benefit. These systems are both: neither are they particularly effective (contribution to the overall benefit) nor are they particularly efficient (lower SEBI). In comparison, the separate collection of tinplated steel sheet cans is also not very effective, but at least very efficient.

In Fig. 7 (right chart) it is shown that cumulatively over 90% of the total environmental benefits of all Swiss recycling systems are provided by only four recycling systems, namely SENS, SWICO, IGORA and PET Recycling. Interestingly, these trigger only 75% of the total costs.

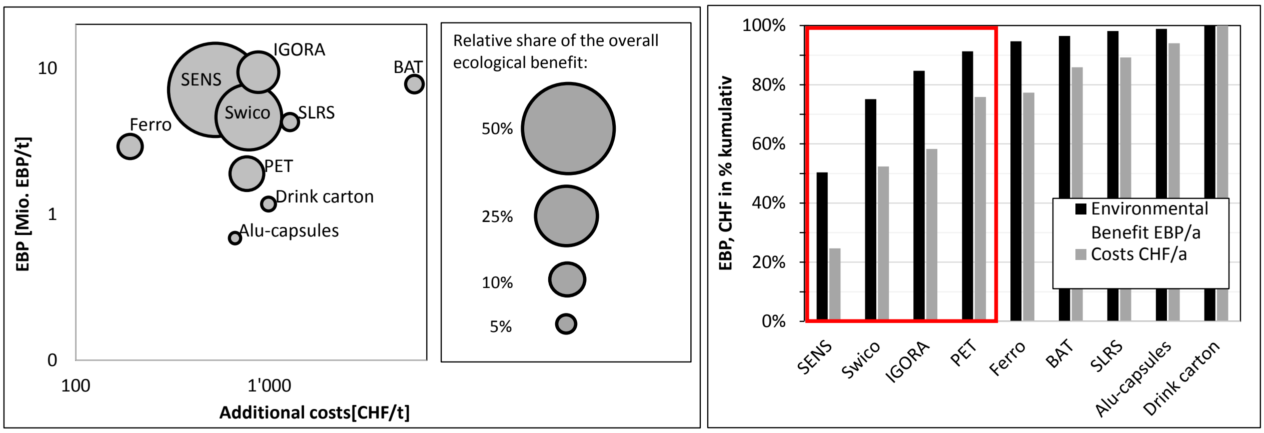

Fig. 7: Left: The size of the respective bubbles is used to illustrate how much environmental benefits the individual systems produce with respect to the overall environmental benefits of all recycling systems. Right: Cumulative presentation of the environmental benefits and the costs of the recycled systems considered. Over 90% of the total environmental benefit is produced by only four collection systems with merely 75% of the total cost.