Separate Collection of Waste Fractions: Economic Opportunities and Problems

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Abstract Separate collection of valuables from waste is of growing importance for the conservation of resources and the mitigation of greenhouse gas emissions from landfills. Moreover, the separation of certain waste fractions, such as food waste, is necessary to ensure that landfills and – more importantly – incinerators are managed properly. It is therefore necessary to examine the reasons and motivations for separating waste. Separation and recycling of waste fractions should decrease the overall cost of waste disposal for citizens and public bodies. This can only happen if the authorities take into consideration some important "stumbling blocks," i.e. physical and socioeconomic indicators and prerequisites, when introducing a recycling system. Four examples (landfill tax as an incentive for separate collection, recycling of used paper and cardboard, collection of bio-waste, recycling of mixed packaging waste) have been investigated in order to evaluate the reasons for successful and unsuccessful attempts at resource recovery. Economic incentives for waste segregation are very important and should be tested in pilot studies or through simulation games, because major differences between opportunity costs and costs for alternative treatment options may lead to unwanted behavior by waste producers and/or citizens. Furthermore, citizens' behavior regarding the separation of valuables, their cultural background with respect to waste management, and social norms must be taken into account when planning collection schemes. Obviously, convenient access to collection systems is essential. Citizens must become accustomed to these systems; long-term awareness raising helps to optimize the successful collection of recyclables.

Keywords Economic incentives, Extended producer responsibility, Informal collection, Separate collection, Stumbling blocks for recycling

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1 Scope and Introduction

Waste management is part of the public duty to prevent hygienic and environmental risks. Incorrect and inadequate waste management often leads to health problems and damage to the environment [1]. That is why national, regional, or local governments are in charge of organizing the collection and disposal of waste. These activities are financed from taxes and/or charges paid by waste producers. In many developing countries, funding for waste management is insufficient, which might result in a far higher burden on the national economy, as can be seen in the case of large dumpsites [2]:

- Emission-related diseases suffered by people living near large-scale dumpsites
- Contamination of groundwater by leachates and/or rivers by effluents from landfills

If public expenditure for waste collection and disposal could be decreased by revenues from resources recovered from waste, the financial burden for the public bodies concerned could be mitigated.

Early recycling programs caused, in some cases, higher overall expenditure than disposal. At present, waste management systems in many countries include separate collection of recyclable materials. The advantages to be gained from carefully considered recycling programs are widely accepted in scientific literature as well (see, for example, [3–6]), but they depend on a number of prerequisites and a reliable framework for the relevant stakeholders (see, for example, [7]). Waste management should be regarded as a multidimensional scientific framework which incorporates technical, social, economic, environmental, and other aspects. Especially in the case of recycling, several aspects are interlinked and interdependent. Though technical solutions and equipment can be transferred from one country to another, the answers to challenges for resource recovery may differ considerably depending on the level of development as well as varying social and economic conditions.

1.1 Guiding Questions

In the following section, three questions are investigated:

- Separate collection of waste fractions – when does it pay off?
- Can public waste management save financial resources through separate collection?
- How can separate collection be supported by economic incentives?

These questions will be discussed against the backdrop of experience and examples from Europe, especially from Germany, where the separate collection of waste fractions by public bodies and private companies has developed over about 40 years. These developments were fostered by national regulations (Germany, Austria, The Netherlands, Switzerland, Denmark, etc., see, for example, Dornack [8]) which prohibited the disposal of degradable waste on landfills and set recycling targets for specific waste streams at the European level, e.g. WEEE [9] among others. The introduction of what is referred to as the "waste hierarchy" by European law [10] encouraged the Member States and the municipal authorities to look for further possibilities for material recovery.

1.2 Basic Conditions for the Recovery of Valuables from Waste

Collection and recycling are subject to a number of physicochemical and socio-economic conditions which can be generalized in the form of seven "stumbling blocks" [11, 12], which represent the most significant types of obstacles. In the following section, only those stumbling blocks are described which are relevant for answering the questions listed above:

- *Entropy (ΔS)*: All recycling processes are confronted with the entropy dilemma. Following statistical thermodynamics, entropy can be used as a yardstick for the disorder of a closed system [13]. To achieve greater order in the system, external energy has to be fed into the system. It is therefore impossible to close recycling loops completely as was already published by Stumm and Davis in 1974, cf. [14]. It is very difficult to recover valuable materials encased in products, and energy is needed for their separation. According to a model based on information theory [15], the profitability of a recycling operation can be derived from just a few economic and physical figures, including the absolute measure of material mixture within a used product.
- *Dissipative use (D!)*: Consumption of goods means a dissipative dispersion of products. Waste management companies collect dissipated goods after use. The

higher the dissipation rate, the less devices can be collected separately in relation to the number of devices sold.[1]

- *Dual character of waste and resource ($H \leftrightarrow R$)*: Waste is Janus-faced: it is either a resource or a peril. The more the material or product in question is mixed up with potentially hazardous substances, the more difficult the recovery of valuables is. This is also limited due to the danger of transferring critical substances into new products made from secondary materials [17–19].
- *Socioeconomic situation (ΔE)*: From an economic point of view, waste is a good with a negative price, i.e. for waste disposal, a price has to be paid depending on the quality and the amount of waste. If waste contains valuable components, the waste owner might decide to keep this waste fraction separate in order to decrease the price to be paid for the residual waste. He might also decide to collect valuable parts of the waste from other waste owners and seek to generate additional income. For this decision, the individual socioeconomic situation is of utmost importance. High income disparities are an enormous incentive for informal collection activities triggered by the market price of the waste fraction in question, as can be seen in the relationship between formal and informal collection in large cities (see, for example, Rodic et al. [20], and the analysis of the Beijing informal waste management published by Steuer et al. [21]).
- *Role of time (Δt)*: Time is a crucial challenge for waste management for several reasons: Firstly, consumption habits change with time and thus lead to unforeseen changes in the volume and/or the composition of waste. Secondly, valuable resources cannot be substituted with secondary raw materials as long as they are in use. This sounds very simple, but the consequences can be dramatic in the case of societies threatened by the absence of already scarce resources in the near future. Thirdly, chemicals banned for use in new products are present in the waste and thus disrupt recycling processes (see above: $H \leftrightarrow R$).

2 Economic Basis of Separate Collection

2.1 Economic Efficiency of Collection and Recycling

With regard to the economic efficiency of the collection and recycling of separated waste fractions, it is necessary to differentiate between two perspectives:

[1] The dissipation dilemma can be demonstrated using platinum (Pt) as an example: Pt is used in the chemical industry (catalysts, laboratory equipment) and for the production of glass (fiber glass nozzles). The recycling rates are >80% and >95%, respectively. As to Pt from automobile catalysts, the recycling rate is <<50% [16], though the loss of Pt from car catalysts during the use phase has been minimized. The recovery of Pt from smaller devices used by consumers is far less.

- The perspective of the waste management administration responsible (e.g., city, region)
- The perspective of the waste producer, waste owner, or waste trader

As indicated in Table 1, there are several potential motivations for administrative bodies to collect waste fractions separately.

If separate collection is driven by strategic or ecological reasons, even higher expenses might be accepted by administrative bodies in order to reach the goals in question (e.g., rapidly declining landfill capacity). This mostly also leads to lower costs in the long term.

The waste producer's perspective is primarily determined by the opportunity costs for waste disposal [22], as indicated in Fig. 1. The difference between the disposal costs and the costs (or even revenues) for separation and recycling is an economic incentive for the waste producer to separate certain fractions for recycling, like waste owner and waste trader as well. Economic advantages or disadvantages are an important factor which influences the behavior of waste producers. As has been proven empirically, there is a close relationship between the percentage of recycling investments (as compared to the total budget) and the price for waste disposal: Japanese and German companies invest more money in recycling activities when the price level for waste disposal increases [23]. However, regulations, convenience as well as cultural and ethical attitudes are also important (see, for example, [24–26]).

From the perspective of the administrative body responsible or from that of a company commissioned with waste collection, several prerequisites have to be fulfilled in order for a collection scheme to be successful. First of all, the financial background of investments in waste treatment facilities differs from other sectors.

Table 1 Potential motivations for separate waste collection from the standpoint of a public body responsible for waste management

	Potential motivations for separate collection	Economic consequences
Strategy	Extending the operational life of a landfill Incineration capacity insufficient	Saves money in the long run, not driven by short-term revenues
Ecology	Safe depositing of hazardous waste Decreasing GHG emissions Saving resources	Minimizes costs; action not driven by revenues
Social issues	Help for unemployed or poor inhabitants	Saving costs for unemployment; action not driven by short-term revenues
Economy	Revenues for the municipal budget Policy pressure to decrease waste charges	Short-term and long-term revenues from recycling necessary

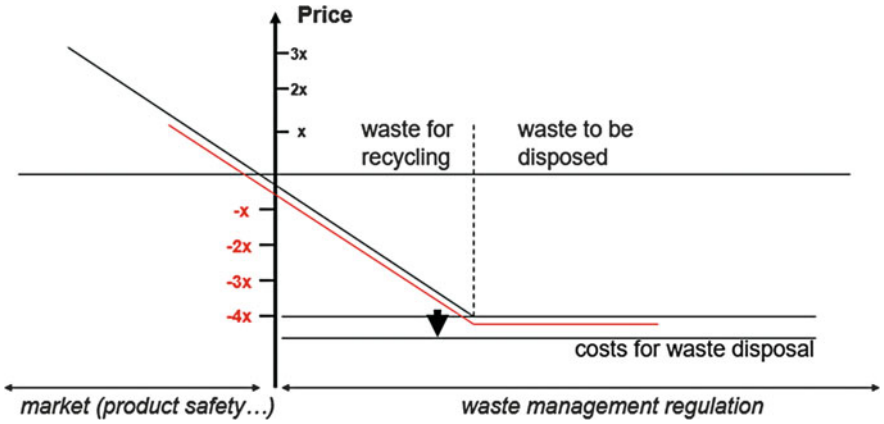

Fig. 1 Opportunity costs for waste disposal (*black line*) and the decision pathway of the waste owner (*red line*). They describe the growing incentive in the case of higher costs for waste disposal (*black arrow*) or decreasing costs down to small revenues for separated waste (simplified presentation following [22])

Waste management assets are characterized by their irreversibility and by their subadditivity [27]:

- An "irreversible" asset cannot be transferred to other markets when the investment turns out to be unprofitable. This holds true for nearly all investments in waste management with some exceptions, e.g. trucks designed for container transport.
- The specific costs for waste treatment in landfills, incinerators or advanced sorting facilities strongly depend on capital expenditures rather than on operating expenses. Capital costs as well as overall costs are therefore "subadditive": Larger installations have lower specific costs (money invested vs. capacity) than smaller ones, e.g. boilers and grates for incineration, volume needed for landfilling. This is not the case for waste logistics.

These specific features of assets in the waste sector lead to severe losses ("stranded investments"), if return on investment is not flanked by long-term agreements on the volume of waste to be treated and on prices. A number of assets are presented in Fig. 2 with respect to irreversibility and subadditivity ([27] and literature cited therein). Due to the high subadditivity and irreversibility of investments in landfills, WtE plants, and advanced sorting plants, investments of this type are undertaken by either public bodies or companies which reign over a monopolistic market.

There is not only a need to finance suitable logistics systems for collection, but also to invest in sorting and disposal facilities in order to arrive at a complete and sustainable waste management system. Expenditures for collection and disposal on the one hand and revenues from recycling on the other hand are connected with

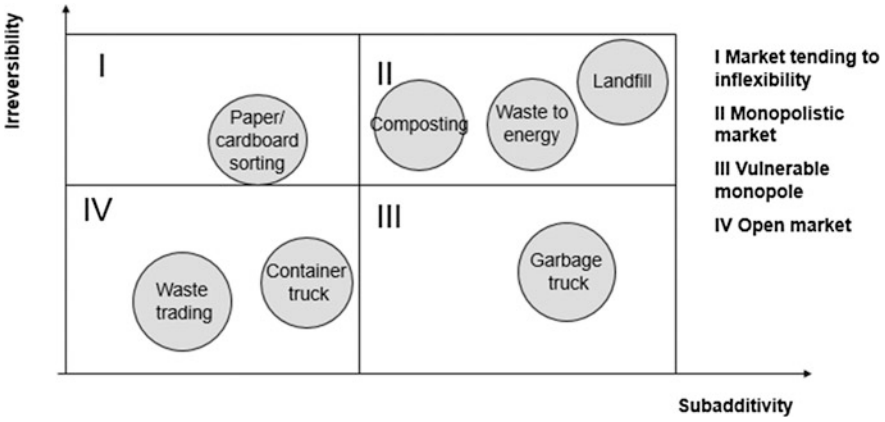

Fig. 2 Specific features of assets for waste management and their influence on market conditions (adapted from Cantner [27])

respect to budget. Economic efficiency means sufficient liquid funds for the current fiscal period and timely return on investment. Depreciation takes about 20 years for sorting plants or WtE facilities, and for landfills even longer. This minimizes capital expenditures and ensures continuous but acceptable overall costs funded either by taxes or by charges paid by citizens. Obviously, economic efficiency also depends on the revenues from energy or material gained from waste. Thus the revenues from separately collected fractions depend on

- capital and operational costs for collection,
- amount and quality of the input material,
- price to be paid for the waste,
- capital and operational costs of the facilities, and
- market prices for the recovered material.

The easiest way to achieve profitability is a continuous delivery of waste at a fixed price, but this is a rare case. Volume and quality of the input material links financial considerations to the waste collection system. If the quality of the collected material is poor, operational costs for sorting will increase as well as costs for the disposal of residues from sorting. If the quality of the input material is rather low, sorting will ultimately not pay even if considerable effort is made. In such cases, the additional costs for separate collection, capital expenditures for the sorting facility, etc. are a burden on the budget. For economic efficiency, correct separation of valuables by citizens is essential in order to achieve surplus revenues from recycling. The effort necessary to reach this goal is often underestimated [28].

2.2 Design of Waste Management Systems for Successful Collection

"Success in separate collection" means reaching the specific goals of the region or city as presented in Table 1. It is therefore worthwhile examining some examples.

Strategic Motivation In many developing countries, household waste exhibits very low calorific value due to a high concentration of organic fractions, "which are significantly higher in middle- and low-income countries (averaging 46–53%) than in high-income countries (averaging 34%)" ([1], p. 56, see also [20]). The water content originates from a high percentage of fruit and vegetables in daily nutrition and also from steamed rice and vegetables. Physical and chemical properties of this waste hamper not only incineration but also landfilling. In the case of incineration, additional energy is needed to dry the waste on the grate before it is burned. This means less energy recovery or even a negative energy balance. In cases like this, "waste to energy" becomes meaningless; anticipated revenues from energy are lost. As for landfills, the high percentage of water

- impedes the construction of higher waste piles,
- leads to the solution and transport of contaminants which endanger groundwater and rivers nearby, and
- accelerates degradation processes and therefore the emission of methane.

In the latter case, more space for landfilling is required compared to waste with low moisture content. Additional costs may also be incurred through the purification of raw water to ensure a safe drinking water supply in the area surrounding the landfill. To reduce the moisture content in residual waste significantly, separate collection of food waste from households as well as organic waste from markets and the food industry seems to be the easiest solution. The yardstick for the economic efficiency of this separate collection is defined by saved expenditures for additional fuel and operational costs due to lower throughput (incinerator) or treatment of high leachate volume, purification of raw water, or additional land use (landfill), respectively.

Ecological Motivation Residual waste often contains hazardous waste from craftsmen's workshops or small-scale industry, sometimes also from hospitals. This waste

- is a hazard to garbage collectors,
- may lead to accidents at the landfill or in the incinerator bunker (self-ignition, explosion), and
- contaminates leachate from the landfill.

On the other hand, these types of waste sometimes include valuables such as sludge from plating or residues from the plastics industry. Recovery of valuables from commercial waste therefore already helps to recuperate collection costs.

Additional costs for the continuous cleaning either of leachates or – far worse – of drinking water can be saved.

Social Motivation Many underprivileged people, especially in developing countries, work as garbage collectors. They concentrate on those items and waste fractions which can be re-used or recycled and promise a small profit when sold. The working conditions of informal collectors and recyclers are normally poor and cause health problems, as well as prevent children from attending school (for an overview, see Wilson et al. [29]). From an economic point of view, the consequences of these poor working conditions cost public money in the long run. Moreover, the activities of the informal sector can sometimes severely disrupt waste management activities undertaken by public authorities. "The challenge for authorities is to support and promote the entrepreneurship, flexibility and productivity that characterize the informal sector, while striving to reduce the sector's negative aspects. . . Such an approach would imply giving a mandate to the informal service providers, integrating them to work alongside the formal sector and thus incorporating them in the system." ([1], p. 178). Saved costs for social welfare and optimized collection and recycling of valuables on the one hand and the expense of integrating the informal sector alongside the companies responsible for waste management on the other (for further considerations see Cavé [30] and Velis et al. [31]) can also lead to a profitable result from a holistic perspective.

Economic Motivation In this case, either the tax income required for waste management or charges paid by households are decreased. In both instances, the background is usually a policy decision (e.g., by the city council) driven by budget needs or prompted by dissatisfaction amongst the electorate. This goal can be achieved by collecting potentially valuable waste fractions which are separated at the source and sale of these separated materials. The goal is met if revenues from the separated waste fractions continuously exceed the costs for a second collection system (e.g. trucks, waste bins, etc.), for sorting waste from the separated fractions, and the disposal of materials which cannot be recovered properly.

In all the cases described above, citizens' co-operation in separating their waste into fractions is a crucial prerequisite for a successful collection scheme. Apart from people's (possibly changing) attitudes towards the task of waste separation, informal activities can endanger new collection systems for valuable fractions. It might therefore make sense to combine the economic and the social motivation (Table 1) for recycling in order to integrate the informal sector into the public system [32], thus providing economic benefits for both. "Increasing segregation at the source is a critical component of any programme to include the informal sector into mainstream waste management and would both improve their working conditions and improve their livelihoods by improving the quality of the recycled materials." ([1], p. 80). If a high percentage of the collected material is exported, revenues from recycled waste depend on global market conditions. If collection is only possible at the regional level, then prices are determined by regional forces. Most secondary resources are subject to price volatility on international markets, and this is especially the case with some non-ferrous metals. "Secondary materials

have traditionally been used to 'top up' a relatively stable supply of primary materials... in response to short-term variations in market demand, so their prices have tended to be even more volatile than those of the related primary commodities." ([1], p. 80). Market development since about 2005 indicates increasing price volatility for most raw materials, both primary and secondary.

3 Experience Gained with Economic Incentives for the Separation of Waste Fractions

Economic incentives for waste prevention and/or waste recycling can be based on

- deposits for products,
- charges for waste volume.

Deposits have been widely introduced in European countries (Germany, Switzerland, Norway, Sweden, Estonia, Finland, Croatia, etc), in the United States (which are known as "bottle bills" found in about 50% of all states), and in Japan for the packaging of consumer goods and some other short-lived products. In Germany, deposit legislation was greatly extended in 2006 for beverages sold in returnable bottles in order to avoid the breakdown of the market. The deposit for one-way bottles and cans for beverages is about double that of returnable items and is an incentive to

- buy beverages in returnable bottles,
- prompt the consumer to bring one-way bottles back to the retailer.

In 2012, the return ratio of one-way bottles and cans was 95.9% [33]. In the area of commercial goods, deposits are used to guarantee the return of transport pallets, safety containers for chemicals, etc. These systems are restricted to items with a short lifetime or – in the case of commercial contracts – to items which are frequently exchanged with different customers. Deposits normally do not work very well with products for long-term use.[2]

In many European countries, private households and commercial companies pay charges for waste services provided by local or regional authorities. These charges recover the expenses incurred by the bodies responsible. In the following section, the considerations and results of some economic incentives are described in order to gain an impression of the successful or sometimes "risky" design of systems for segregated collection.

[2]The economic restraints for deposits in the case of products with a long usage period cannot be described here in detail. It should be noted that the value of a complex product after operational life cannot be estimated reliably. Moreover, high deposits for products which are in use for a long time extract considerable liquidity from the capital markets.

1. *Landfill tax*: Taxes for landfilling waste have been introduced in a number of countries (e.g., Belgium, The Netherlands, United Kingdom, Switzerland, some US states – see, for example, [34]) with the aim of accelerating the construction of sorting and incineration plants. This tax is not paid directly by the consumer but by the municipal and commercial waste owners. In general, the level of the landfill tax is increased yearly, thus doubling or trebling the price for disposal. In Belgium, the landfill tax resulted in a switch to material and energy recovery from waste within about 10 years. In Great Britain, changes in the waste collection system are now underway, triggered by the landfill tax which has been raised to 80 GBP and therefore now exceeds landfill prices by about 100–200%. When the additional costs are transferred to the citizens, political pressure for alternative waste management options, i.e. recycling and incineration, increases. In this way, waste owners are incentivized to keep valuable fractions separate in order to save money, because waste charges increase as a result of the landfill tax.
2. *Saving costs for residual waste disposal by collecting used paper*: In most European countries, used paper and cardboard are separated from residual waste. In Germany, the current recycling rate is about 74% (specific amount 186 kg inh^{-1} $year^{-1}$) in comparison to the volume of material put on the market [35]. Higher collection rates can hardly be achieved due to the proportion of paper from sanitary use. At least in Germany, the quality of the collected paper is very good and yields 75% (±6%) graphic paper and 23% (±6%) packaging paper and cardboard with an average proportion of 2% (±1%) residual waste [36]. The incentive for citizens to collect used paper and cardboard stems from:

   (a) Regulation: Waste owners are obliged to keep paper and other materials separate from residual waste and deliver it to the municipality responsible.
   (b) Convenience: "Blue bin" or other curbside collection is available for ~80% of all households; deposit containers are available in densely populated areas.
   (c) Economy: Less residual waste to be disposed d saves money, even if a small amount of money has to be paid for the collection of the "blue bin."

   As the share of waste paper and cardboard in household waste increases from 6% in low-income countries to 24% in high-income countries [37], there is a good opportunity, especially for middle- and high-income countries, to decrease the waste charges imposed on citizens. On the other hand, cities can generate revenues from sales of used paper. For an average German municipality (own calculation), this pays off as follows:

   - Costs for separate collection of used paper/cardboard ~45 €/t
   - Costs for sorting and bundling of sorted material ~20 €/t
   - Revenues from sale of sorted material ~100 €/t

   With respect to the 186 kg (volume collected, see above), net earnings are about €6.50/inhabitant, which represents between 5 and 15% of the normal expenditure for waste disposal. It should be noted that the separate collection

of waste fractions such as used paper and cardboard, used glass or textiles takes place continuously, even if market prices for secondary materials are low, so that people become accustomed to separating waste on a daily basis.

Obviously, commercial and informal waste collectors are motivated to interfere in municipal waste collection if prices are high. As such activities impede the continuous collection of paper and cardboard by the cities, the German Waste Law was amended to regulate competition between commercial and public waste management [38]: Commercial companies and charities are now obliged to register any intended collection campaigns. The authority responsible may prohibit such collection for several reasons, e.g. if the budget covered by waste service charges is affected to a certain extent. As can be seen from studying a 2-year period after the amendment, 3% of all prior registrations by private companies for separate paper collection were rejected [39].

3. *Saving costs for residual waste disposal by collecting biowaste*: European law obliges Member States to collect biowaste (waste from kitchens and gardens) separately in order to keep this degradable material away from landfills [10]. In Germany, the volume of separately collected biowaste is in the range of about 100 kg inh^{-1} $year^{-1}$ ([40] and literature cited therein).

   The incentive for citizens to collect biowaste separately stems from:

   (a) Regulation: Waste owners are obliged to keep food and garden waste separate from residual waste.
   (b) Convenience: "Brown bin" door-to-door collection is offered in nearly all cities.
   (c) Economy: Less residual waste to be deposited saves money, even if a small amount of money has to be paid for the collection of the "brown bin."

   Biowaste is usually treated aerobically to produce compost. Anaerobic treatment yielding biogas and organic fertilizer is increasingly important. Apart from alleviating the problems caused by organic waste on landfills, separate treatment of biowaste also increases the calorific value of residual waste for incineration thus yielding higher revenues from energy sales. Contamination of biowaste with residual waste, plastics, etc. hampers both treatment options. Farmers will not accept compost or fertilizer containing plastics. The degree of contamination varies from 0.9 to 12% w/w. High contamination very often corresponds to high population density ([41] and literature cited therein).

4. *Extended producer responsibility (EPR) systems for packaging*: In the case of EPR, the producer assumes responsibility for his product again after its usage period. When the product goes into the waste bin, the physical and/or economic ownership for the waste shifts from the consumer to the producer. The idea behind this instrument is "the provision of incentives to producers to take into account environmental considerations when designing their products" [42]. For packaging waste, individual take-back systems would be far too expensive. Collective solutions are therefore provided by producer responsibility organizations (PRO), which bundle the take-back obligations of various producers of packaging material and collect this waste fraction. In most cases, the result of

EPR was the financing and creation of infrastructure for post-consumer recycling. However, there is no concurring opinion on the cost-effectiveness of this strategy [43]. The economic consequences are twofold: The producer pays for collection and recycling and in this way comes under pressure to design and create products suitable for recycling. This is, however, only of minor importance in the case of collective product responsibility systems, "which may distort competition and allow free-riding on design for recycling efforts to reduce product recovery costs" [44]. The municipality saves part of its budget money for some of the waste generated by citizens.

Implementation of the EC packaging directive differs considerably in the individual Member States (see Cahill and Grimes [45] for an overview).

In Germany, collective systems ("Duale Systeme") sell licenses for packaging material to the producers who undertake to collect and recycle an equivalent amount of packaging waste. The collective systems then finance the collection, sorting, and cleaning of recovered material. The operational work is carried out by tendered contractors, i.e. private or public companies. The incentive for citizens to separate packaging materials stems from:

(a) Regulation: Waste owners are obliged to keep these materials separate from residual waste and to deliver it to the producer responsibility systems.
(b) Convenience: Curbside collection ("yellow bin," "yellow bag") for all lightweight packaging (plastics, cans, etc.) is common. For used glass and paper, containers are available in the streets (besides the blue bins for used paper and cardboard already mentioned above).
(c) Economy: Citizens save money with the disposal of residual waste.

As packaging waste (lightweight packaging material, glass, and cardboard used for packaging) represents about 20% (w/w) of household waste [46], municipalities save an equivalent amount of money with the disposal of residual waste. Used glass and cardboard from packaging are often collected in containers which induce relatively low costs. There is door-to-door collection for lightweight packaging waste (plastics, cans, composite materials, etc.). The average full cost (sum of expenditures and revenues) for the management of packaging waste is €553 Mg^{-1} with respect to the volume of licensed materials and €281 Mg^{-1} for the separately collected waste [47]. This means far higher costs compared to residual waste. The high costs for the management of lightweight packaging waste are due to

- complicated sorting aimed at separating different packaging materials, i.e. polyethylene, polypropylene, polystyrene, PET, aluminum, tinplate, cardboard/plastic compounds,
- poor quality of the material collected, which includes 35% (on average) of other waste fractions [48].

4 Discussion

From a cost-accounting perspective, setting the charges due for a specific waste fraction should reflect the percentage of the costs incurred by the municipality or the producer (in the case of EPR systems) for this fraction. However, this is only part of the solution because the following question still needs to be answered: Which economic incentive prompts the waste owner to bring back used items or sort his waste correctly? As presented in Fig. 1, waste charges should be in relation to the waste owner's opportunity costs for disposal. This also means that an individual fee for waste disposal is crucial for further incentives which support separate collection of waste fractions.

With respect to the disposal of short-lived products, it is clear that the economic incentive must be high enough to prompt the waste owner to bring back used items to a retailer or a take-back machine despite the additional effort. The economic incentive must therefore be selected not only under consideration of the specific costs for a waste fraction, but also of the desired behavior. This may lead to incentives which do not mirror the costs for the waste fraction in question, but optimize the collection result with respect to quality and quantity. In the case of packaging, the deposit value is mostly higher than the market value of a plastic bottle or a tin can. On the other hand, such a high economic incentive may lead to unwanted effects, e.g. shipment of empty bottles from regions without a deposit into areas where deposit charges are implemented. Deposit regulations should therefore be harmonized between adjacent regions or countries to avoid windfall profits in the case of no (or low) deposits in one region and high deposits in other regions, as has been observed between Germany and the Netherlands.

The positive experience gathered with landfill taxes (example No. 1) shows that economic incentives work especially well in cases where a limited number of stakeholders are involved, invoicing schemes are simple, and there is the possibility of transferring the costs to the waste producers. The cities and regions involved are in a position to enforce material and energy recycling. In so doing, they reduce their own costs by decreasing the amount of residual waste. Landfill taxes proved to be a major incentive [34] to invest in waste-to-energy and recycling plants. In view of large differences in landfill prices in adjacent countries, the cross-border transport of waste must be strictly controlled (e.g., compulsory notification within the EU).

Example No. 2 shows successful sorting efforts by citizens which lead to high quality of the separately collected fractions. This is not only due to the economic incentive but also thanks to convenient collection systems and long-term awareness raising amongst waste producers. Although prices on the paper market are volatile, there is reasonable surplus income for municipalities over time. Increasing revenues may lead to a situation where collection also pays off for private companies, even if they have to invest in new bins and trucks. As outlined above, these assets have relatively short depreciation periods compared to sorting facilities. To avoid disruption between private and municipal collection, regulations in European

countries in general distinguish clearly between household waste and other parts of the waste market.

It can be concluded from example No. 3 that a similar system to example No. 2 leads to worse results with respect to quality. In a detailed questionnaire distributed among the citizens of a small town [49], the following reasons for contamination were identified:

- Use of plastic bags for collection at home which are deposited in the "brown bin"
- Misconception about "degradable" plastic bags
- Incorrect sorting of sanitary organic waste, e.g. diapers
- Saving money for residual waste disposal

Some of these misconceptions and types of behavior can be remedied through information campaigns. To fight intentional misuse stimulated by price advantages (unwanted effect caused by a high economic incentive), many municipalities monitor biowaste bins in areas where high contamination is observed with the aim of penalizing the owners.

Example No. 4 displays unsatisfactory results. The differences between the second and the fourth example can be linked to two of the stumbling blocks described in Chap. 1.2: Used paper and cardboard are a uniform waste fraction which can easily be identified by citizens; sorting is only necessary to eliminate a few contaminants and adds value through the output of various grades of paper. Used packaging comprises a high number of different materials, of which only some are intended for collection in the "yellow bin." Others are excluded, e.g. glass, cardboard, and wood. The entropy factor ($\mathbf{\Delta S}$) is considerably higher for the yellow bin compared to the cases mentioned before. In contrast to the previous examples, where the charges for waste management are determined by the municipality, the costs for waste management of packaging are integrated in the price of the product. This changes the perspective of the citizen who is confronted with charges for his residual waste, whereas the disposal of packaging waste is free of charge. This difference is a powerful economic incentive for the waste owner ($\mathbf{\Delta E}$) and can lead to misuse of the collection system for the disposal of other waste fractions, especially residual waste. This behavior is rarely penalized due to the different responsibilities of municipalities and PROs: Local governments save money if citizens dispose of part of their residual waste in a system financed by a PRO. On the other hand, the PROs are reimbursed by a great number of producers, who include these costs when calculating the price of their products.

5 Conclusions

The economic efficiency of waste management can be significantly enhanced by the bodies responsible if separate collection is properly planned and also takes into account strategic, social, and ecological goals. Prior to planning, motivation, which is strongly dependent on the intended waste management system, must be clear.

Changes in waste streams may occur over time, such as the current increase in used cardboard and the corresponding decrease of used paper due to changing consumer behavior. Although waste management facilities have to be planned for a long operational lifetime, partial refurbishment might be necessary and should be integrated into the budget. Extrapolation of future waste streams from today's waste should be complemented by an assessment of future output based on current streams of products put onto the market (input). In order to plan long-term investments, a sensitivity analysis of the relevant economic parameters is strongly recommended.

Economic incentives for the separation of waste fractions or for waste prevention are very helpful and should be regarded as measures to accompany suitable regulations as has been concluded by Zhang et al. [50] with respect to the situation in China. Waste management systems can be severely disrupted by unforeseen conflicting economic interests. This is especially important for all activities involving high investments with long depreciation periods. In the case of waste fractions which yield low earnings due to the difference between expenditures for collection and revenues from material sales, commitment on the part of municipalities can be very successful. Earnings might be optimized by simple rules and long-term awareness-raising as well as convenient collection systems. This is also true for fractions which could be separated simply to avoid expenditure for residual waste treatment, such as biowaste.

When planning a collection scheme, citizens' attitudes towards the separation of valuables, their cultural background with respect to waste management (i.e., hygiene standards), social norms [24], and convenient access to waste bins or deposit container systems near their homes [26] must be taken into account. If economic incentives have already been introduced or will be in future, their impact should be tested in pilot studies or by simulation games. Major differences between opportunity costs and costs for alternative treatment options may lead to unwanted behavior, i.e. the contamination of separately collected waste fractions by individuals, as well as the disruption of municipal waste collection by private companies or scavengers. To overcome such problems, a bundle of regulatory as well as participative instruments can be introduced. Good governance is key to successful implementation of these instruments. Public acceptance for recycling systems can be obtained by intensive public involvement in the planning phase [51]. It is difficult to identify and integrate all relevant stakeholders, which means that risks still remain even after such a process. A general dilemma for citizens' participation stems from common misconceptions about recycling, e.g. naïve assumptions about the economic and ecological value of "closing loops" [28]. This may lead to misguided political decisions on the one hand and disappointment amongst citizens on the other, when people become aware of the long time period required to implement the system and of only slowly increasing revenues.

Prior to the installation of a recycling system, the stumbling blocks presented in Chap. 1.2 can serve as a simple tool to assess opportunities and risks: The greater the influence of one or more stumbling blocks for a specific waste fraction, the more problems have to be anticipated in further planning [11, 12].

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